Aircraft Metallurgy

(According to the Syllabus Prescribed by Director General of Civil Aviation, Govt. of India)

FIRST EDITION

AIRCRAFT METALLURGY

Prepared by

L.N.V.M. Society Group of Institutes
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  (Approved by Director General of Civil Aviation, Govt. of India)

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Dedicated To

Shri. Laxmi Narain Verma
[Who Lived An Honest Life]

Preface

Material" is the word which is associated with every object existing in the universe. The knowledge of material enhances our understanding of physical world.

The aircraft design is based on the suitability of material considering the various factors such as weight, strength, cost, reliability and easy availability. The knowledge of aircraft material is essential for aspirant of Aircraft maintenance engineering to get through their DGCA Licence papers and translate this knowledge on their day to day work in aviation field.

This book is prepared by L.N.V.M. Society Group of Institute, with the dedicated efforts by it's experienced faculty and staff with the view to sumup the vast material details under single cover to impart the essential knowledge to AME trainees to succeed in their aspired carrier.

My thanks are due to those who helped me to bring out this valuable edition.

I would very much appreciate criticism, suggestions and detection of errors from the readers which will be grate fully acknowledged.

Arjun Singh

Senior Instructor

L.N.V.M. Society Group of Institutes   Dated : Aug. 2006

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CHAPTER-1
TERMS AND DEFINITIONS

VARIOUS PHYSICAL TERMS USED IN WORKSHOP TECHNOLOGY
Terms used in describing the properties of materials should be clearly understood by the reader. Many of these terms have acquired popular meanings which are not necessarily corrects, while others are very hazy in the minds of a majority of people. It is the author's intention to define these terms in the following pages so that a firm foundation may be established from the equation point of view.

Hardness
Hardness is the property of resisting penetration or permanent distortion. The hardness of a piece of metal can usually be increased by hammering, rolling, or otherwise working on it. In the case of steel, some aluminium alloys, and a few other metals, hardness can also be increased by a heat treatment. A modified heat treatment known as annealing will soften metals. Increased hardness and strength go hand by hand. Testing apparatus has been developed for testing hardness rapidly by without destroying or harming the tested metal or part. The principle usually employed in this type of apparatus is to sink a hardened steel ball under a definite load into the material being tested. The impression made by the ball is to be measured and recorded; the smaller the impression, the harder the material. For each type of material there is a fairly definite relationship between the depth of penetration (which is represented by a Hardness Number for convenience) and the ultimate strength of the material. Tables have been worked up for different materials based on this relationship. By means of a simple hardness test and the use of such a table, the approximate tensile strength of a piece of material or finished part can be obtained without cutting out tensile test specimens or mutilating the part.

Brittleness
Brittleness is the property of resisting a change in the relative position of molecules, or the tendency to fracture without change of shape. Brittleness and hardness are very closely associated. Hard material is invariably more brittle than soft material. In aircraft construction the use of too brittle material must be avoided or failure will be caused by the shock loads to which it will be subjected.

Malleability
Malleability is the property of metals which allows them to be bent or permanently distorted without rupture. It is this property that permits the manufacture of sheets, bar stock, forging, and fabrication by bending and hammering. It is obviously the direct opposite of brittleness.

Ductility
Ductility is the property of metals which allows them to be drawn out without breaking. This property is essential in the manufacture of wire and tubing by drawing. It is very similar to malleability and, in fact, is generally used in place of that term to describe any material that can be easily deformed without breaking. Thus in aircraft work a material is usually referred to as soft or hard, or else is ductile or brittle. Ductile material is greatly preferred because of its ease of forming and its resistance to failure under shock loads. In order to obtain the required strength it is often necessary, however, to use a hard material.

Elasticity
Elasticity is the property of returning to the original shape when the force causing the change of shape is removed. All aircraft structural design is based on this property since it would not be desirable to have any member remain permanently distorted after it had been subjected to a load. Each material has a point known as the elastic limit beyond which it cannot be loaded without causing permanent distortion. In aircraft construction, members and parts are so designed that the maximum applied loads to which the airplane may be subjected will bear stress above their elastic limit.

Density
Density is the weight of a unit volume of the material. In aircraft work the actual weight of a material per cubic inch is preferred since this figure can be used in calculating the weight of a part before actual manufacture. The density of a material is an important consideration in deciding which material to use in the design of a part.

Fusibility
Fusibility is the property of being liquefied by heat. Metals are fused in welding. Steels fuse around 2500^0 F, aluminium alloys around 1100^0 F.

Conductivity

Conductivity is the property of transmitting heat or electricity. The conductivity of metals is of interest to the welder as it affects the amount of heat he must use and, to a certain extent, the design of his welding jig. Electrical conductivity is also important in connection with the bonding of airplanes to eliminate radio interference.

Contraction and Expansion

Contraction and expansion are caused by the cooling or heating of metals. These properties affect the design of welding jigs, castings, and the tolerances necessary for hot rolled material.

HEAT-TREATMENT TERMS

Critical Range

Critical range , applied to steel, refer to the range of temperature between 1300^0 F. and 1600^0F. When steel passes through this temperature range, its internal structure is altered. Rapid cooling of the metal through this range of temperature will prevent the normal change of the structure, and unusual properties will be possessed by the material so treated. The heat treatment of steel is based on this phenomenon.

Annealing

Annealing is the process of heating steel above the critical range, holding it at that temperature until it is uniformly heated and the grain is refined, and then cooling it very slowly. Other materials do not possess critical ranges, but all are annealed by a similar heating process which permits rearrangement of the internal structure, followed by cooling (either slowly or quickly), depending on the material. The annealing process invariably softens the metal and relieves internal strains.

Normalizing

Normalizing is similar to annealing, but the steel is allowed to cool in still air - a method that is somewhat faster than annealing cooling. Normalizing applies only to steel. It relieves internal strains, softens the metal somewhat less than annealing, and at the same time increases the strength of the steel by about 20% above that of annealed material.

Heat Treatment

Heat treatment consists of a series of operations which have as their aim to improvement of the physical properties of a material. In the case of steel these operations are hardening (which is composed of heating and quenching) and tempering.

Hardening

Hardening of steel is done by heating the metal to a temperature above the critical range and then quenching it. Aluminium alloys are hardened by heating to a temperature above 900^0F and quenching.

Quenching

Quenching is the immersion of the heated metal in a liquid, usually either oil or water, to accelerate its cooling.

Tempering

Tempering is the reheating of hardened steel to a temperature below the critical range, followed by cooling as desired. Tempering is sometimes referred to as "drawing".

Carburizing

Carburizing is the addition of carbon to steel by heating it at a high temperature while in contact with a carbonaceous material in either solid or liquid, or gaseous form. Carburizing is best performed on steels containing less than .25% carbon content.

Case-hardening

Case-hardening consists of carburizing, followed by suitable heat treatment to harden the metal.

PHYSICAL-TEST TERMS

Strain

Strain is the deformation of material caused by an applied load.

Stress

Stress is the load acting on a material. Internal stresses are the loads present in a material that has been strained by cold working.

Tensile Strength

This is often referred to as the ultimate tensile strength (U.T.S.). It is the maximum tensile load per square inch which a material can withstand. It is computed by dividing the maximum load obtained in a tensile test by the original cross - sectional area of the test specimen. In this country it is usually recorded as pounds per square inch.

Elastic Limit

The elastic limit is the greatest load per square inch of original cross- sectional area which a material can withstand without a permanent deformation remaining upon complete release of the load. As stated under " elasticity", the aim in aircraft design is to keep the stress below this point.

Proportional Limit

The proportional limit is the load per square inch beyond which the increases in strain cease to be directly proportional to the increases in stress. The law of proportionality between stress and strain is known as Hooke's Law. The determination of the proportional limit can be more readily accomplished than that if the elastic limit, and since they are very nearly equivalent, the proportional limit is usually accepted in place of the elastic limit in test work.

Proof Stress

The proof stress is the load per square inch a material can withstand without resulting in a permanent elongation of more than 0.0001 inch per inch of gage length after complete release of stress. With the standard 2- inch gage length the limit permissible elongation would be 0.0002 inch.

Yield Strength

Yield Strength is the load per square inch at which a material exhibits a specified limiting permanent set or a specified elongation under load. This load is fairly easily determined and is commonly used.

Yield Point

The yield point is the load per square inch at which there occurs a marked increase in deformation without an increase in load. Only a few materials have a definite yield point. Steel is one of these materials.

Elongation (Percentage)

The percentage elongation is the difference in gage length before being subjected to any stress and after rupture, expressed in percentage of the original gage length. The length after rupture is obtained by removing the two pieces from the machine and piecing them together on a flat surface. The distance between the gage marks is then accurately measured.

Reduction of Area (Percentage)

The percentage reduction of area is the difference between the original cross-sectional area and the least cross sectional area after rupture, expressed as a percentage of the original cross-sectional area. This information is seldom used other than as an indication of ductility.

Modulus of Elasticity

The modulus of elasticity of a material is the ratio of stress to strain with in the elastic limit.

Thus

E = unit stress / unit strain.

CHAPTER-2
FERROUS METAL: PRODUCTION OF IRONS AND THEIR PROPERTIES

INTRODUCTION
The readers have come across the names of several metals like iron, steel, aluminium, copper, nickel, lead, zinc, etc., in connection with their metallurgical structures and properties. These metals and their alloys are extensively used in the manufacture of various tools, equipment, instruments, machinery, etc. It is, therefore, necessary to discuss in details their production, composition, specific properties, etc., in order to enable the readers to have a clear insight into these metals which they are supposed to use in their every day work. The discussions in this chapter will mainly confine to ferrous metals and their alloys while the nonferrous metals and alloy will be described in the next chapter.

CLASSIFICATION OF METALS
All the metals used in engineering work can be classified into two categories : Ferrous and Nonferrous. Ferrous metals are those in which the chief constituent is iron, although other constituents like carbon, sulphur, manganese and phosphorus, etc. also exist in varying proportions. Iron, steel and their alloys fall under this category. Nonferrous metals are those which do not contain iron. Metals like lead, copper, zinc and tin, etc. and their alloys fall under this category of non-ferrous metal classification. Nonferrous metals are more costly as compared to ferrous metals, but their use in many cases is unavoidable because of some special qualities they possess; like good conductivity of heat and electricity, lightness in weight, good machinability, high resistance to corrosion and the property of being antimagnetic.

PIG IRON
Various stages, through which the raw material passes from the mined ore state to the finished product state in the production of ferrous products, it will be seen that the first usable ferrous product obtained by smelting the mined ores in a blast furnace is Pig iron. Before studying the actual production of pig iron it would be worthwhile to discuss the raw materials used in the production of pig iron. The common raw materials required are :
1.   Iron ore.
2.   Fuel.
3.   Flux.

Iron ores in our country are available in abundance in Bihar, Orissa, Madhya Pradesh, Mysore, Andhra Pradesh, Tamilnadu, and in small quantities in some other states also. The following are the common varieties of iron ores. They are normally found to occur in the forms (see Table2.2):

TABLE 2.1. MAIN IRON ORES AND THEIR CHARACTERISTICS

Ore	Composition	Form	Percent yield of metal
Red hematite	Fe_2O_3	Oxide	60 ----- 70
Magnetite	Fe_3O_4	Oxide	62 ----- 72
Limonite	$Fe_2O_3H_2O$	Oxide	40 ----- 60
Iron pyrite	F_eS_2	Sulphide	30 ----- 40
Siderite	$FeCO_3$	Carbonate	35 ----- 50

Of all the ores, magnetite is the richest in iron content but its reduction is very difficult and, hence, it is not favored for extraction. Iron obtained from iron pyrite is of very low quality due to high sulphur content. Of the remaining three, hematite is the richest in iron (about 70 percent), is free from sulphur, can be reduced easily and is the most widely used ore.

Fuel
Hard coke is commonly used as a fuel in blast furnace. This coke has two functions; one it provides the required heat for melting and the other to combine with the oxygen of the ore in order to reduce the same. It is desirable that the fuel used should be hard enough to withstand the heavy weight of the charge without being crushed. It should possess high calorific value, low ash content, high density and good porosity. It should be of uniform size and free from sulphur and phosphorus.

Table 2.2,Various stages in the manufacture of different standard ferrous products.

TABLE.2.3 USES OF STEEL SCRAP

STEEL SCRAP

ELECTRIC ARC FURNACE	SELECTED STEEL SCRAP	STEEL SCRAP PLUS PIG IRON
	INDUCTION FURNACES	OPEN HEARTH FURNANCE
ALLOY STEELS	HIGH GRADE ALLOY STEELS	STEEL
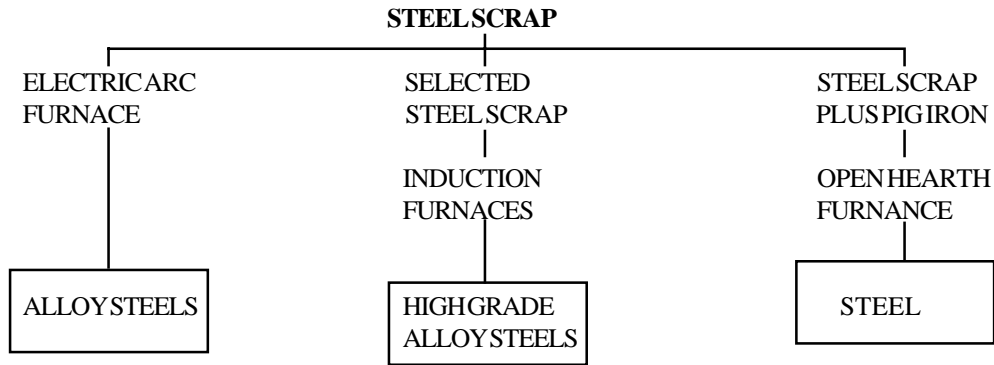
Flux

Flux is added to the charge so that it may melt and drive away the impurities with it in the form of slag. Due to the presence of silica in most Indian ores, limestone is commonly used as flux. Dolomite is also sometimes used. It is usual to add about 500 kg to 750 kg limestone for each tonne of pig iron produced.

Refractories

These are those materials which are capable of withstanding high temperatures without fusion. They are used to provide the inner lining in the blast furnace.

THE BLAST FURNACE

It consists of a tall steel structure supported on a strong foundation an heavy columns all around. A vertical cross-section through this furnace is shown in Fig. 2.1. The outer shell is made of mild steel plates and the inner surface is lined throughout by the refactory material. Its structure can be described as a combination of two frustums of right cones with their bases joining to form the maximum section. Of the two, the upper frustum is longer and is known as shaft or stack. The lower frustum is shorter and is called bosh. The upper frustum is tapered upwards and the lower one downwards.

Two tapping holes are provided, one near the bottom and the other a little above it, for removing the metal and slag respectively. Hot air is supplied to the furnace by the main circular pipe, called bustle pipe, through a number of tuyers. The topmost position of the stack is called throat, through which the charge is fed into the furnace. The double bell arrangement at the top is for prevention of the escape of gases from inside. Turbo blowers or blast furnace gas blowing engines of very high capacities are used for supplying air to the furnace. This air is preheated before entering the bustle pipe by means of special heaters called blast stoves. This preheating produces high temperature inside the furnace and enables considerable saving in fuel consumption. A water cooling system is incorporated in the brick - work all around the furnace to protect its walls against excessively high temperature. This need is more pronounced in the region around the bosh where the temperature is highest.
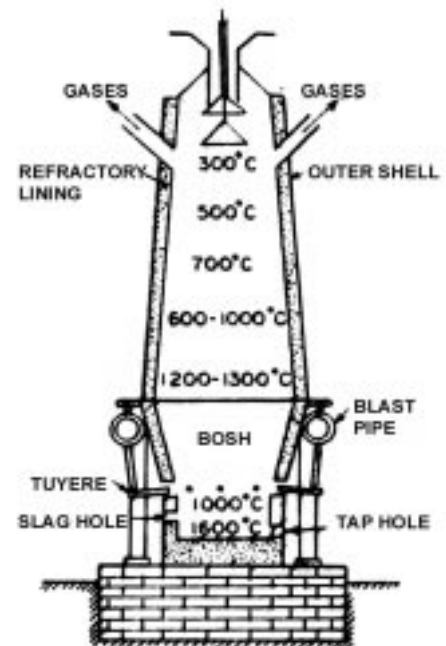
Fig2.1 The blast furnace.

CHARGING OPERATION

The mined ore carries a number of earthy impurities, and before smelting they are separated from the ore to the extent it is possible. The operation performed for doing so is calcination or roasting. In these preparatory process the mined ore is first crushed into small size and concentrated, followed by roasting it in kilns. This enables considerable reduction in moisture content and carbon dioxide and also to some extent sulphur and arsenic. Ferrous oxide (FeO) is converted into ferric oxide (Fe_2O_3) and attains enough porosity which helps in its quicker reduction to iron.

This calcined ore, along with suitable amount of coke and flux is charged in the blast furnace. These materials are lifted through a hoisting mechanism to the top of the furnace and charged through the double bell arrangement into the throat. The operation of this furnace in many respects is similar to that of the foundry cupola, described in later chapters. The

hot air blast enters the furnace through tuyeres and rises upwards through the downward moving charge. As the charge is melted, the molten metal is collected at the bottom and the slag floats over its top surface. They are then separately tapped. The normal capacity of this furnace ranges from 800 to 1200 tones of pig iron per 24 hours. This furnace, once started, can run nonstop for years together.

CHEMISTRY OF BLAST FURNACE

Different chemical reactions take place in different parts of the blast furnace according to the temperatures in those parts. The highest temperature in the furnace is at the bottom and lowest at the top. According to these temperature ranges the blast furnace can be divided into the following zones :

1. Preheating zone   -   from the top to gas outer level.
2. Reduction zone   -   from the gas outlet level to nearly the maximum cross section level.
3. Fusion zone   -   from the bottom of the reduction zone to a little below the tuyere level.

Preheating zone

It consists of only the top layers of the charge. The temperature in this zone range between 200^0C to 350^0C, which provides only a preheating effect on the charge and helps in evaporating the moisture content from it.

Reduction zone

In this zone the temperature ranges between 350^0C to 1200^0C. For convenience of explanation of the chemical reactions this zone is further subdivided into *upper reduction zone* and *lower reduction zone*. The chemical reactions taking place in these zones are as follows :

Upper reduction zone (350^0C --- 700^0C).

In this zone the iron oxide is reduced to metallic iron by reacting with the ascending carbon monoxide. For this reason this zone is also called *iron oxide reduction zone*. The reaction is as follows

$$+ \qquad \Leftrightarrow$$

In this zone limestone (flux) also starts dissociating as follows :

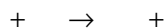$$\rightarrow \qquad +$$

$+$

Lower reduction zone (700^0C ---- 1200^0C)

In this zone the charge becomes hotter as it descends. The decomposition of $CaCO_3$ started earlier, is completed at about 850^0C. This CO_2 formed due to this decomposition reacts with the carbon of coke to reduce to CO.

$$+ \quad \rightarrow$$

Reduction of iron oxide, if remaining after the previous zone, is completed here.

$$+ \quad \rightarrow \quad +$$

The calcium oxide formed by the decomposition of limestone combines all the impurities like silica and aluminium with it to form the slag. The higher temperature of about 1200^0C also causes the reduction of other oxides in the ore, like P_2O_5, MnO_2 and SiO_2 etc., into respective free elements P, Mn and Si. They are absorbed by the metal formed (Fe) as above. As a result of all these, the melting point of iron is lowered and it starts melting at about 1200^0C instead of 1530^0C the melting point of pure iron.

Fusion zone (1200^0C --- 1600^0C).

Evidently this part carries highest temperatures and in this region the melting of charges is finally completed . The iron gets superheated here and trickles down to the bottom of the furnace. On its top floats the slag. The slag and molten metal are tapped separately from the furnace. The molten metal is poured into the moulds, where it solidifies to form what is known as Pig iron. This iron contains 2 to 5% C, upto 3% Si, upto 0.1% P, upto 0.3% S and upto1% MN, the remainder being iron.

Hot gases

The hot gases passing out of the blast furnace carry a temperature between 800^0C to 1200^0C. If they are allowed to escape as such into the atmosphere, a lot of heat will be wasted., This heat is, therefore, utilized in many ways. However, before using these gases they are passed through dust catchers and gas washers to remove any dust or coke particles present in them. After that a part of their heat is utilized in driving the gas blowing engines supplying the air blast. Some of the heat is utilized in blast stoves for preheating the air blast before sending it to the furnace. Waste gases may also be utilized in gas turbines for electric power generation.

New Developments

Substantial research work in the past years has lead to a number of new developments which affect in saving of fuel, use of low grade iron ores, better yields, etc. For example, electric furnaces are widely used for preheating the iron ore, followed by its reduction by coke. Thus, a saving of the order of about 50 percent is affected in the consumption of coke. This partial replacement of coke by electricity in the smelting process is of great significance in those areas where electricity is cheap and coke is not available in sufficient quantity. Similarly, modifications in blast furnaces and increased use of oxygen to help the reactions.

Another significant modern development, specially in the context of a country like ours where substantial quantities of low grade iron ores were going unutilised, is for sponge iron process. This process enables direct treatment and reduction of low grade iron ores without using a blast furnace. A few such plants are now being established in our country in private sector.

WROUGHT IRON

Wrought iron is produced by remelting pig iron in a puddling furnace, which is of reverberatory type, as shown in Fig.2.2
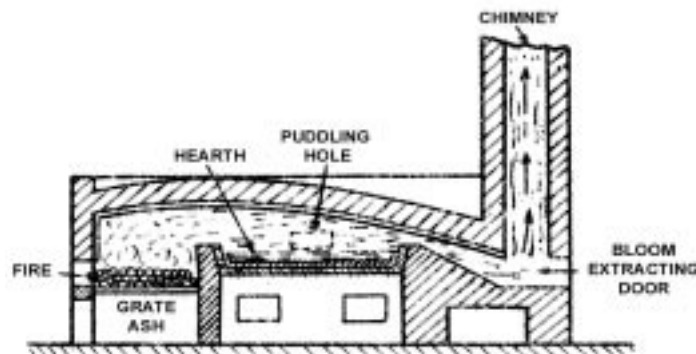

Fig-2.2 Cross-section through a puddling furnace

Use of white iron in place of pig iron yields still better results. Wrought iron is collected from the furnace in a spongy form known as puddled ball and is given further treatments like shingling and rolling, etc. to impart it the desired properties. It is the purest form of iron available, so much so that it may contain iron upto the extent of above 99.8 percent, remainder being the other constituents like carbon, silicon, manganese, sulphur and phosphorus, etc. It does not fuse like cast iron at elevated temperatures and, as such, is not suitable for casting . On the contrary at white heat it acquires considerable plasticity and its two separate pieces, if hammered together at this heat, can be welded to a homo-geneous joint. Owing to the lack of carbon content, it cannot be hardened by heating and then quenching in water. It is very

ductile and malleable and is, therefore, quite suitable for wire drawing and making sheets. This metal may have defects like cold shortness or Red shortness which are due to the presence of phosphorus and sulphur respectively. Cold shortness renders the metal brittle and weak, making it unsuitable for cold working. Contrary to this the Red shortness renders the metal unworkable (due to brittleness) at red heat, thus making it quite unsuitable for forging work. These two constituents should therefore be properly controlled. The maximum use of this metal is in forged articles, those which are made by forge welding and parts likely to be subjected to conditions which may lead to rusting of these parts. It is commonly used in ship building, agricultural implements, steam, oil and water-pipes, nuts and bolts, crane hooks, chains and railway draw gear, etc.

The Aston process

Another useful method of *wrought iron* production is the **Aston Process**. It is also known as **Byers Process**. In this process a *Bessemer converter* is used along with a *cupola furnace*. The *pig iron* is first melted in cupola and then refined in Bessemer converter. An *open hearth furnace* is used to prepare *iron silicate* separately and the same is collected in fluid form in a *ladle*. The liquid iron collected from the Bessemer converter is also poured into the same ladle at a specific rate. *Excess slag* floating on the top of the liquid metal is poured out of the ladle., leaving behind the pure metal and slag. This mass is then fed on to a press where it is squeezed. In this process the metallic mass takes the shape of a rectangular block, called *bloom*, and more slag is squeezed during the process. The bloom formed in the press is still very hot and the same is fed into the *rolling mills* to produce wrought iron rolled products of different shapes and sizes.

CAST IRON

It is the product of a cupola or any other suitable type of furnace used for remelting pig iron billets made from molten pig iron received from the blast furnace. As already described earlier, pig iron is not capable of being cast directly to give suitable castings for engineering use. For making it useful for engineering purposes it is remelted in a cupola or

any other type of suitable furnace for this purpose, together with a definite amount of limestone (flux), steel scrap and spoiled castings, etc. This remelting of pig iron along with the above additions enables it to be cast into moulds to give suitable castings. It is then known as cast iron. The cast iron produced as above consists of iron, carbon, silicon, sulphur, phosphorus and manganese in varying proportions. Out of all these constituents carbon plays a very significant role and its proportion in the metal varies from 2 to 4.5 percent. Average cast irons, in general use, possess carbon from 3 to 4 percent. Other percent, phosphorus upto 1.0 percent and manganese 0.5 to 1.0 percent. This metal is very brittle and has a low resistance to tension but is good in compression. It is sufficiently hard and cannot be worked with a hand file. It has no plasticity and hence is unsuitable for forging work. Cast iron is also available in different forms such as grey iron and white iron which are described in the following articles.

GREY CAST IRON

It is the iron which is most commonly used in Foundry work. If a piece of this iron is broken, its fractured section shows the greyish colour, after which it is named as *Grey Iron*, Most of the carbon present in it is in the form of free graphite which is seen in the form of the small flakes in the fractured section. It is this free carbon which imparts the grey colour to the iron, The carbon content in the combined form may vary form 0.3 percent to 0.9 percent. It has a low resistance to tension but a fairly high resistance to compression. The ultimate tensile and compressive strengths of it are nearly 1250kg per square cm. and 6.50 kgs per sq. cm. respectively. It has good machinability and fusibility. It is very brittle and possesses no ductility and plasticity. As such, it is quite unsuitable for forging work. The presence of free graphite in it provides a sort of natural lubricant. With the result it is very suitable for such parts where sliding action is desired. Its high compressive strength mainly to compressive stresses such as legs, bases and supports for heavy machinery. Its extensive brittleness renders it unsuitable for such parts which are to withstand severe shocks. The total carbon , its main constituent, varies from 3 to 3.5 percent and other constituents may vary as silicon 1.0 to 2.75 percent, phosphorus 0.15 tp 1.0 percent, sulphur 0.02 to 0.15 percent and manganese 0.4 tp 1.0 percent.

WHITE CAST IRON

It is called so because of the whitish colour shown by its fracture. Most of the carbon present in it is in the combined form which mixes with iron to form carbide. It is the formation of this carbride which renders the colours of the structure white. Cementite is the name given to this carbide. This cementite is a very hard and brittle substance and renders the iron unsuitable for machining. Cemetite is formed due to rapid cooling of iron after melting. It is due to this fact that all the chilled parts of a casting are hard and possess white structure as the cooling rate of the chilled portion is comparatively faster than the rest of the casting. The extreme hardness of this iron, due to formation of cemetite, renders it wear resistant. Its melting point is lower than that of the grey iron. The various constituents present in it are carbon 1.75 tp 2.4 percent (most of it combined state), silicon 0.85 to 1.2 percent, phosphorus upto 0.2 percent, sulphur upto 0.12 percent and manganese upto 0.5 percent. Its fluidity is not upto the mark in the molten state and, as such, it is not suitable for general foundry work. But, it is used as the raw material in the production of malleable cast iron.

MOTTLED CAST IRON

It can be best described as a compromise production between grey and white cast iron. Its structure, on being fractured, shows greyish white colour. The carbon content is present in both free and combined states and is divided almost equally in these two forms.

MALLEABLE CAST IRON

It is mainly produced through Duplex Process in which two furnaces, a melting furnace (usually cupola) and an annealing furnace, are used together. White cast iron is widely used for producing malleable cast iron. The object in producing malleable cast iron is to precipitate the combined carbon gradually into free graphite and then drive it out so as to limit the presence of total carbon content to about 1.0 percent . This renders it more or less similar in composition to that of wrought iron. For achieving this, white cast iron is melted in cupola and cast in sand moulds. These castings are packed in iron boxes, containing a material rich in oxygen, and fed into the annealing furnace. They are allowed to remain there for about 4days or so at a temperature of 815^0C to 1010^0C, and then allowed to cool slowly. The oxygen of the material, contained in the boxes, combines with the carbon of the casting to reduce its proportion. The castings so obtained are quite tough, have fairly good resistance to shock and good in machining. Their tensile and compressive strengths are almost equal. Ductility of these castings is very low Malleable cast iron parts are mainly used in place of forged steel or wrought iron parts where the intricate shape of these parts creates difficulty in forgoing. Similar parts made of grey cast iron will be unsuitable for this purpose due to their brittle nature and low tensile strength.

NODULAR CAST IRON

This iron is also known as **Spheroidal Graphite** (or simply **S.G.**) cast iron, **ductile** cast iron or **high strength** cast iron. The production of this iron consists of changing the graphite of cast iron from flake form to spheroidal or nodular form by the addition of magnesium to the molten cast iron just after tapping. This metal, when cast into moulds, gives S.G. iron castings directly. The magnesium process for making S.G. iron offers no difficulties. Any castings made in grey cast iron can be made equally well in S.G. iron. As a result of the change in graphite form the mechanical properties of the metal are considerably improved.

This iron is normally produced in two forms for commercial purposes. In 'as cast' form, its strength is double that of flake graphite cast iron. In 'annealed' form its toughness is increased from 4 to 12 times, brittleness eliminated, ductility increased considerably and the strength is slightly reduced but is still much higher than flake graphite iron. Its yield point is much higher than even the malleable cast iron, rendering it capable of sustaining higher loads without permanent deformation. This rare combination of various properties like high yield strength, high modulus of elasticity (17,600kg/mm^2) and good elongation makes this iron highly ductile and at the same time sufficiently stiff and rigid. Its damping capacity lies between those of flake-graphite iron and steel.

This iron has a very high castability, in that, a large variety of section thickness from 2 mm to 1 meter and castings weighing from a few grams to 60 tons have been produced. It can be cast easily through all normal casting methods like sand and centrifugal casting. With the application of proper foundry techniques, pressure tight castings can easily be produced in this iron for which steel proves unsuitable due to casting difficulties and flake-graphite iron due to its extreme weakness. It has high machinability and takes a high surface finish. It can also be cold and hot worked to a limited extent. It can be readily welded using normal techniques. It readily takes surface coatings of tin, copper, nickel or chromium etc. for improving the properties on the surface. It can also be galvanized easily.

This iron is gradually replacing to a great extent both malleable iron and steel. A few examples of the application of this iron are marine castings such as engine frames, bed plates and brackets etc., locomotives and railway rolling stocks, tractor parts such as frames, wheel hubs, support brackets, plough parts, cultivator blades, worm wheels, gears, pinion, cams, clutches, gear boxes and housings, various types of levers, hydraulic cylinders and drums, jack bodies, pumps and valves, parts and bodies of electric motors, circuit breakers, cylinder heads and liners of I.C. engines, flywheels, pneumatic tool bodies and hand tool like spanners and clamps, heat-resisting parts of hearths and furnaces, various parts and bodies of heavy machinery and machine tool etc.

MEEHANITE CAST IRON

Meehanite is a trade name which covers a fairly wide range of *high duty* cast irons, which are nothing but specially treated grey cast irons. The process involves the use of *calcium silicide* as a graphitiser. The basic grey iron selected for graphitisation is one that contains low silicon content and carbon content in the range of 2.5% to 3%. Usual grey iron containing this carbon percentage if cast through normal process will lead to the production of white cast iron. But the use of calcium silicon enables production of fine graphitic structure which leads to the production of a metal which possessed excellent mechanical properties. This results, however, is not entirely due to the use of calcium silicide alone but an effective control of several other parameters during melting and moulding also plays a vital role.

This metal has high machinability and can be easily machined with HSS or cabide tipped tools. It responds well to heat treatment and carries high strength. It is quite tough and ductile, unlike usual cast irons, It can be gas or electric arc welded without much problem . It carries almost similar electrical and magnetic properties as of a normal cast iron, but its vibration damping capacity is superior to that of cast iron. It has good creep resistance too. It is on account of these useful characteristics that this metal is now gradually replacing several other ferrous metals like malleable iron, cast irons, steel castings and even some nonferrous alloys. Machine tool castings are now largely made from this metal.

Although a large number of varieties of meehanite metal are available they can be broadly put under the following five categories :
1. General engineering
2. Abrasion resisting
3. Heat resisting
4. Nodulat 'S' type
5. Corrosion resisting

CHILLED CAST IRON

The term *Chilled Cast Iron* is used to denote the metal of that iron casting which has been rapidly cooled to convert its metal structure into white cast iron. In fact, the whole casting is never required to be *Chilled* like this. The outer surface of every iron casting always gets chilled to a limited depth during pouring and solidification due to its coming in contact with the cool sand of the mould. This is a natural side effect of normal method of casting. But, if required, selected portions of the casting can also be got chilled deliberately. This is done to make those selected portions harder than the rest of the casting. For this, *metal chills* (metal pieces) are placed suitably in the mould to form the inner surface of the mould on those spots where chilling effect is desired. When the molten metal poured in the mould comes in contact with these metallic chills a very rapid heat transfer takes place on those portions as compared to the rest of the casting. Since those portions get cooled at a faster rate they become harder than the remaining part of the casting and the iron of those portions is known as *Chilled cast iron.*

EFFECT OF DIFFERENT ALLOYING ELEMENTS ON CAST IRON

1. **Carbon.**

   It generally varies from 2 to 4 percent in cast iron, and its presence is due to the carbon present in pig iron scrap and coke. All these materials contribute in adding this content to iron, and more the amount of carbon present in these, materials the higher will be the percentage of this constituent in the composite of cast iron. It may be present either in free state or combined form. The form in which this element is present, greatly effects the properties of cast iron. Its presence in free state renders the iron weak and increases machinability and brittleness. Presence of carbon in combined form makes the iron hard and strong.

2. **Silicon.**

   It acts as a softener as it promotes the formation of free graphite by combining with iron and forming silicates. If this content is, however, allowed to increase beyond a definite limit (*approximately 3.2%*), it acts as a hardener. Its proportion should be kept lower for big castings and higher for small ones. It normally ranges between 2.5 to 3.0 percent.

3. **Sulphur.**

   It renders the iron hard by promoting the formation or combined carbon. With the result the iron loses its due fluidity and it leads to the production of blow holes in the casting. To minimize its effect manganese should be added.

4. **Manganese.**

   It is added to cast iron mainly with a view to mitigate the ill effects of sulphur by the formation of manganese sulphides. The normal range of manganese in cast irons is between 0.5 to 0.8. percent. Its presence below 0.5 percent has no significant influence.

5. **Phosphorus.**

   It improves the fluidity and castability of molten metal into thin sections, and promotes graphite formation. Its higher percentage increases hardness and brittleness and decreases toughness.

6. **Nickel.**

   It acts as a graphitizer in cast iron. With its addition, therefore, machinability of cast iron is improved. For common engineering applications it varies in cast iron between 0.25 to 2.0 percentage. Higher proportions are, however used in alloy cast irons.

7. **Chromium.**

   It forms its own stable carbides in cast iron and, thus, acts as a carbide stabilizer. Its proportion normally varies from 0.15 to 0.9 percent. Its addition increases wear resistance, tensile strength and hardness and aids chilling. Higher proportions of chromium are used in alloy cast irons.

8. **Molybdenum.**

   Its proportion normally varies between 0.25 to 1.5 percent. It may be added either as free molybdenum or combined with other elements. It improves tensile strength, increases hardness and resistance to shock, improves toughness and machinability.

9. **Vanadium.**

   It forms carbides and reduces graphitization. It is normally used in proportions varying between 0.1 to 0.5 percent. It increase strength, hardness and machinability of cast iron.

10. **Copper.**

    It promotes graphite formation and improves strength. Its proportion normally varies between 0.25 to 2.5 percent.

SPECIAL OR ALLOY CAST IRONS

A fairly large variety of special and alloy cast irons have been developed by suitable additions in varying proportions of different alloying elements. Their development has largely overcome the inherent drawbacks in cast iron. The principal alloying element in most of these alloy irons is nickel. Other elements are also added to impart certain specific properties to them. The most commonly used special and alloy cast iron are the following :

Low nickel cast irons

They carry nickel 2 percent. These alloys have a high machinability. The common machining difficulty experienced, when the casting has thin sections which are chilled very quickly, is eliminated in these alloy irons. Moreover the use

of nickel enables the refinement of iron matrix and improves general physical properties. Low nickel cast irons can, therefore, be safely used for pressure castings. They carry their Brinell hardness numbers from 210 to 230. A few typical compositions of these alloy irons are given below :

1.   Ni-   Cast iron ;   C -   3.2 %,   Si-   1.4 %,   Ni-   1.0.%,   remainder iron.
2.   Ni.   Cr cast iron ;   C-   3.2%,   Si-   1.7,   Ni-   1.0%,   Cr-   0.5 %   remainder iron
3.   Ni-   Mo cast iron;   C-   3.2%,   Si-   1.8 %,   Ni-   1.0 %,   Mo-   0.3%,   remainder iron
4.   Acircular cast iron ;   C -   3.0 %,   Si-   2.0 %,   Ni-   2.5 %,   Mo-   0.8 %,   remainder iron.

Hard and heat treatable Ni cast irons

The proportion of nickel in them varies from 2 to 6 percent. The hardness value of these irons goes at high 300 - 400 B.H.N. They are highly wear-resistance and respond well to heat treatment. A few of their uses are in gear wheels, cams, dies, valve guides and automobile cylinder liners, etc. a few useful compositions of these irons are given below :

Hard grey iron :   C-   3.2 %,   Si-   1.2 %,   Ni-   2.5 %,   remainder iron.
Martensitic grey iron :   C-   3.2 %,   Si-   1.2%,   Ni-   5.0 %   remainder iron; difficult to machine.
Heat treatable C.I. :   C-   3.2%,   Si-   1.4%,   Ni-   2.5%,   remainder iron.

Ni-hard and Ni-white irons

They are high abrasion resistance and hard alloy cast irons. Of these, the Ni-hard is harder having its hardness from 550 to 800 B.H.N. Although Ni-white C.I. Also offers difficulty in machining, but machining of Ni-hard through conventional methods is not at all possible. The useful compositions of these alloy irons are as follows :

Ni-white iron :   C-   3 %,   Si-   0.5%,   Ni-1.8%,   Cr-0.8%,   remainder iron.
Ni-hard :   C-   3%,   Si-   0.5%,   Ni-4.5%,   Cr-1.5%,   remainder iron.

These alloy irons contains nickle upto 5 percent as maximum. The lower percentages is used in NI-white iron and the higher percentage in Ni-hard. A few typical uses of these irons can be seen in various parts and equipment used in cement industry, glass and ceramic industries, coke industries, coal and coke foundry machines, material handling equipment and sintering plants.

Austenitic cast irons

They carry nickle from 10 to 40 percent. The most common commercial forms of these irons are Nomag, Ni-resist, Nicrosilal hard, Nicrosilal soft and low expansion Ni-resist. Of all these only Nicrosilal hard is difficult to machine and all others have good machinability. The hardness of Nicrosilal hard varies from 320 to 350 B.H.N and of others between 110 to 210. Their compositions are given below :

Nomag :   C-   2.8%,   Si-   1.5%,   Ni-   11%,   Mn-   6%,   remainder iron.
Ni-resist :   C-   2.8%,   Si-   1.5%,   Ni-   14%,   Cr-   2%,   Cu 6%,
                                                                                                      remainder iron.
Low expansion NI-resist :   C-   2.8%,   Si-   1.5%,   Ni-   30%,   Cr-   2%,   remainder iron.
Nicrosilal hard :   C-   1.9%,   Si-   5%,   Ni-   18%,   Cr-   5%,   remainder iron.
Nicrosilal soft :   C-   1.9 %,   Si-   5%,   Ni-   18%,   Cr-   2%,   remainder iron.

All these cast irons are nonmagnetic. Ni-resist has a high resistance to heat. They all possess a good electrical resistance.

CHAPTER-3
FERROUS METAL: PRODUCTION OF STEELS AND ALLOYS STEELS

STEEL

Steel basically differs from cast iron in the amount of carbon content contained by it. It is not only the quantity of carbon which makes the difference but also the form in which it is present. In steel the amount of carbon present is upto 1.5 percent and it is completely in the combined form. Higher the percentage of this carbon, harder and tougher is the steel. Carbon content cannot be increased in the metal in chemically combined form beyond 1.5 percent. If this proportion is increased beyond this limit it moves the metal into the category of cast iron. Thus, steel can be said to be an alloy of iron and carbon with the carbon content to a maximum of 1.5 percent. These steels are called plain carbon steels because they owe their properties mainly to the percentage of carbon present in them. These steels are classified into different groups as follows:

Dead mild steel	-	having carbon below 0.15 percent.
Mildsteel	-	having carbon from 0.15 to 0.3 percent.
Medium carbon steels	-	having carbon from 0.3 to 0.8 percent.

High carbon steels- having carbon from 0.8 to 1.5 percent.

It should, however, be noted that the carbon percentages in the above four types of plain carbon steels are not very rigid. Some sort of overlapping from one to another is always there. A particular range of high carbon steels having more than 1.0 percent carbon is known as *carbon tool steel* or *cast steel.*

Applications

The above four classes of plain carbon steels have various applications in engineering and other requirements and their selection for a particular purpose depends upon several factors like suitability for fabrication process, wear resistance, machinability, nature and extent of the stresses to which it is likely to be subjected and similar other factors. A few typical uses of these steels are given in Table 3.1.

TABLE 3.1. APPLICATIONS OF PLAIN CARBON STEELS

Types of steel	*Applications*
Dead mild steel.	Welded and solid drawn tubes, thin sheets and wire rods.
Mild steel.	Forgings, stampings, structural sections such as angles and channels, plates for boilers and ships, bars and rods, wire, tubes and castings.
Medium carbon steel.	Drop forgings, boiler drums, marine shafts and axles, rotors and discs, agricultural tools and implements, aero engine cylinders, high tensile tubes and wires, bright drawn bars, castings for automobile engine components, laminated springs for automobiles, helical springs, locomotive types, wire ropes, steel spokes, clutch plates. Large forging dies, hammers and snaps for pneumatic riverters etc.
High carbon steel having	Springs, shear blades, wood chisels, cold sets, hammers,
0.8 % carbon.	small forging dies, boiler maker's tools.
0.9 % carbon.	Cold chisels, cold working dies, punches and dies.
1.0 % carbon.	Springs, broaches, drifts, reamers.
1.1 % carbon	Press dies, punches, milling cutters, anvils, taps, wood working tools.
1.2 % carbon	Taps, drills, screwing dies.
1.3 % carbon	Files, razors, metal cutting tools for lathe, planer and slotter, mandrels and drawing dies.
1.4 - 1.5 % carbon	Lathe tools for machining harder metals, gauges, engraving tools.

CLASSIFICATION BASED ON THE DEGREE OF DEOXIDATION

Yet another basis of classification of steels is the degree of deoxidation occuring during its production. On this basis the steels are classified as :

1.   **Killed steel**

This steel is very severely deoxidised. Therefore, there is no evolution of gases during solidification and the solidified metal is free of usual casting defects like blow holes, pin holes, porosity, segregation, etc. It, therefore, carries a very sound composition and exhibits uniformity in its properties. Most of the steels having more than 0.25 percent carbon are killed, especially the forging steels. These steels are denoted by the symbol '*K*'.

2.   **Semi-killed steel**

It is also known as *balanced steel*. Almost 90 percent of the total steel produced falls in this category. Its degree of deoxidation falls between that of the *killed steel,* which is completely deoxidized, and the *rimmed steel,* which is only partially deoxidized. Obviously, this steel will not show the same level of uniformity of properties as the killed steel. Most of the structural steels, carrying carbon content between 0.15 percent to 0.25 percent, fall in this *semi-killed* category. This class of steels meets the main requirements of structural steels, i.e., having a sound outer surface, free of blow holes. No symbol has been standardized to represent this class of steel.

3.   **Rimmed steel**

As already stated above, this steel is only partially deoxidized. The basic objective of *rimming* the steel is to produce a clean surface carrying low carbon content. For this very reason *dead mild steel, i.e*., the plain carbon steel with carbon content below 0.15 percent, is usually rimmed. The rimmed steel is widely preferred for such manufacturing processes through which the out coming products are desired to have good surface finish and which need the steel having good formability, viz., rolling, deep drawing, spinning, etc. '**R**' is the standard symbol used to denote this class of steel.

STEEL PRODUCTION METHODS

In accordance with the requirements associated with various types of applications of steel a number of methods of manufacture of steel have been developed. They will not be dealt with in detail.

1.   **Cementation process**

It is the oldest steel making process. In this process the wrought iron bars are embedded in charcoal inside the cementation furnace. The temperature of the furnaces gradually raised to full redness, at which it is maintained for about 7 to 10 days. During this period iron bars absorb carbon from the charcoal, the outer skin absorbing more carbon and the inner core less. Due to some air leakage into the furnace carbon mono-oxide is formed which forms **blisters** on the surface of the metal making it very rough. The produced metal structure lacks considerably in homogeneity and uniformity. This metal is called **blister steel.** Quality of this metal can, however, be improved to some extent by reheating, hammering, rolling etc.

2.   **Crucible process**

The poor qualities of blister steel produced through cementation process cannot be improved to the required extent through hammering and rolling etc. For refining this steel the *crucible* process is used in order to impart greater homogeneity and uniformity of structure to it. The furnace consist of a number of small pit furnaces arranged together. Each of these carries two small crucibles, each holding about 20 to 25 kg metal. The crucibles are first heated to white heat and then charged. The charge usually consists of suitable proportions of cut or broken small pieces of swedish iron, blister steel bars, pig iron and alloying elements. After the metal is fully melted it is 'killed' *i.e*., heated for a sufficient length of time after fusion, so as to eliminate the gases from it. Small amounts of magnesium or aluminium may be added to the molten metal during 'killing' process to accelerate the gas elimination. After this, the crucibles are pulled out of the furnace, slag removed from the surface of the metal and the latter poured into cast iron ingot moulds. This is then known as *crucible cast steel* or simply *crucible steel*. These steels are of very high quality but the process is very expensive. However, its use becomes almost unavoidable when production in small quantities of high grade alloy steels is desired.

3.   **Open hearth process**

It is also known as **Siemen's process** after the name of its originator Mr. Siemen, a German engineer, who was the first to introduced the idea of using a regenerator for preheating the sir for combustion before entering the open hearth furnace. Two types of open hearth furnaces are in use in this process. The selection of a particular type will depend upon the composition of the raw material used for steel making. *Basic* lined furnaces are used for making steel from such raw material which contains high percentage of phosphorus and sulphur. Against this, the *acid* lined furnace is not capable to remove these element. Hence, the raw material required for this furnace should have very low proportions of these elements.

Basic Furnace It is a reverberatory type rectangular furnace having mostly the brickwork structure. Its sides and ends are properly supported on channels and slabs etc
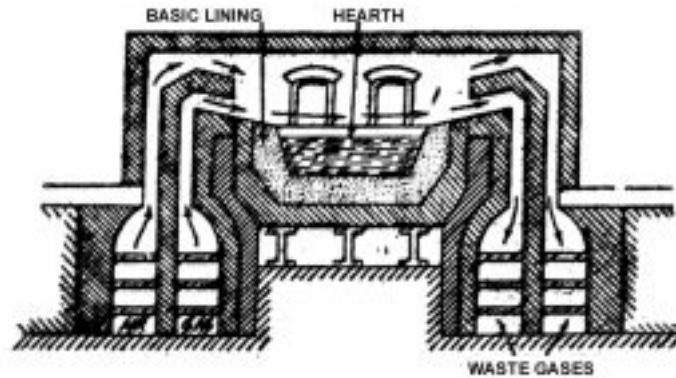
Fig.3.1 An open hearth furnace.

Although its size varies with the desired melting capacity, 10 to 25 meters length and 4 to 6 meters width are very common. Attached to the furnace are regenerative chambers for preheating the combustion air in case of a coke fired furnace and the air-gas mixture in case of a gas fired furnace. A sectional view of an open hearth furnace is shown in Fig.3.1 The lining of this furnace is of either magnesite or dolomite, both being basic refractories. Limestone can be used as flux in this furnace. The charge consist of pig iron and steel scrap. The pig iron may be either cold or molten. The latter can be directly transferred from the blast furnace. To control the composition of the produced metal some iron ore (pure hematite) is also added in required proportion.

During the process the various constituents of the charge viz., iron, silicon, manganese, sulphur and carbon are oxidised due to being exposed to furnace gases. Oxides and carbon and sulphur go out in the form of gases. Oxides of phosphorus and silicon combine with calcium oxides of the limestone to form calcium phosphate and silicate. They go out as slag. Manganese oxide combines with silica to form manganese silicate. This is also removed as slag. On account of the large scale oxidation taking place in the melt there are chances of entrapment of oxygen and the same is removed by adding strong deoxidisers like ferro silicon, manganese or aluminium etc., to the molten metal prior to pouring, otherwise blowholes will be produced in the castings.

Acid furnace

It is usually a little smaller than the basic furnace of the same capacity. Other constructional features are similar to a basic furnace. The inside lining is fully acidic, usually of silica. It reacts less with the metal and, therefore, only such pig iron, scrap and ore can be used as charge in it which is too low in phosphorus and sulphur. Due to these limitations its use is also not as popular as that of basic type open hearth furnace.

4.　　The Bessemer Process

It is known so after the name of its inventor. It consists of melting the charge in a special type of vessel (Fig-3.2) known as **Bessemer converter.** This vessel has an outer shell of steel having refractory lining inside. It is mounted on two trunnions, about which it can be rotated to a nearly horizontal position to receive the molten metal. One of the trunnions is hollow through which air blast is sent to the bottom of the converter. According to the nature of the refractory lining inside the converter used in the process is classified as basic or acid. As usual, acid lining is provided by silica and dolomite is used for basic lining. Acid lined converter is used when pig iron used contains no or negligible phosphorus. When phosphorus is present in pig iron basic lining is used, since it cannot be removed with the acid lining.
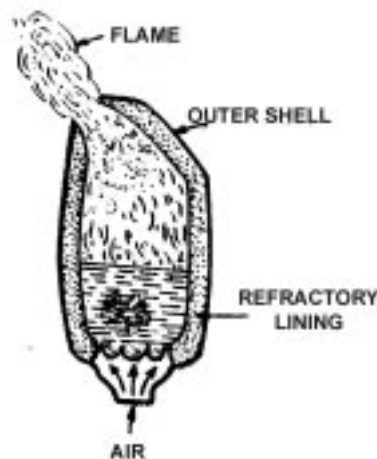

Fig.3.2 A Bessemer Converter

Molten pig iron from blast furnace is brought in ladles and transferred to the converter in 'tipping-in' position. The converter is than roated and brought in nearly vertical position. The air entering at the bottom bubbles up through the molten iron, whereby it burns carbon, silicon and manganese. The heat evolved due to their burning helps in maintaining the necessary bath temperature.

At the end of the blow the metal usually lacks in various constituents, particularly carbon. Therefore, the required amount of carbon and other elements are added back to the metal in the form of ferro alloys, coal and coke dust etc. Also the metal contains iron oxide and gases in large quantity. Therefore, suitable amounts of deoxidisers are also added during pouring into ladle in order to nullify these defects.

5.   The Linz-Donawitz Process

In short, it is popularly known as *L.D. process. It* is actually a modified form of Bessemer process. In this process no air blast is used. Instead of that, pure oxygen at a pressure of 8 to 12 kg per cm^2 is injected through a water cooled nozzle, called lance, vertically downwards. This oxygen strikes on the surface of the molten charge and a temperature of about 25,00^{0}C is produced and the elements like carbon, iron, silicon and manganese oxidised. There is a substantial reduction in sulphur and phosphorus also. The steel produced through this process is superior to that produced by bessemer or open hearth process. The operation is also simpler and quicker.

6.   The Electric Process

Electric furnaces are now widely used in steel making, but owing to the high cost of electric power their use is generally confined to the production of alloy and tool steels only. Two types of electric furnaces are commonly used in steelmaking. They are :

1.   The direct arc furnace.
2.   High frequency induction furnace.

Direct arc furnace :

It consists of a steel shell having a spherical bottom, as shown in Fig.2.5. The complete furnace is mounted on rollers, so that it can be titled for pouring the melt into the ladle. The hearth inside has a bowl shape and is provided with a basic lining with mangesite or dolomite. Two spours are provided on opposite sides, one for the slag and the other for the molten metal. The roof is of detachable type and the charge is fed through it. Three vertical electrodes are suspended through the top through which a 3-phase current is led into the furnace. These electrodes can be raised up or lowered as desired.
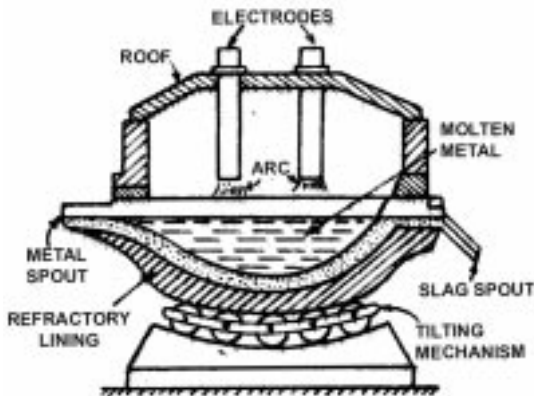

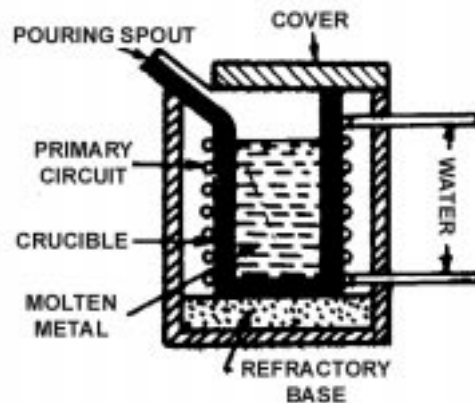Fig. 3.3. A direct arc furnace   Fig.3.4. A direct arc furnace.

After charging, the furnace top is closed and the electrodes lowered. The current is switched on to generate the arc, thereby producing a high temperature of about 2000^{0}C or above. This intense heat melts the charge. As the level of the molten metal rises, the electrodes are also raised automatically. The charge usually consists of light and heavy steel scrap together with suitable amount of flux. Alloy additions are usually made later on for controlling the final composition.

High frequency electric furnace

This furnace consists of a crucible surrounded by a water-cooled coil of copper tubing. This coil also conducts the high frequency current and acts as the primary winding. The metal charge in the crucible serves as the secondary winding. Thus, the furnace works on the principle of a transformer. As the high frequency current is passed into the primary winding, eddy currents are produced in the metal charge (secondary winding) through induction. Thus, the

charge is rapidly melted and agitated. The furnace is usually of tilting type mounted on two trunnions. The refractory lining is of basic type.

The duplex processes

In several steel plants two different methods of producing steel are combined together to produce steels. Such a combination of two different methods to form a common process is called duplex process. The following combinations of steel making methods are in common use :

1. A basic steel hearth process and an acid open hearth process.
2. A basic open hearth process and a Bessemer converter process.
3. A basic open hearth process and an Electric furnace process.

INFLUENCE OF OTHER ELEMENTS ON PLAIN CARBON STEELS.

Although plain carbon steels mainly owe their properties to the amount of carbon present in them still there are many other elements present and they do influence these properties to a certain extent. The common other elements present and their influences on the properties of steel are as follows :

1. **Manganese**

   It is usually a ladle addition and works as a deoxidiser and purifier. The oxide formed due to this addition precipitates out in the form of slag. The manganese content present in steel ranges from 0.2 percent to 1.0 percent. It reacts chemically with sulphur and decreases the latter's harmful effect on hot rolling properties of steel. Due to its addition the tensile strength and hardness are marginally increased. When used in low proportion in low carbon steels the ductility and bending ability are increased but a higher manganese content will reduce the ductility.

2. **Silicon**

   It also acts as a deoxidier and removes oxides and gases. Thus, it prevents the formation of blow holes and gas cavities and makes the metal sound, tough and hard. It also prevents the occurance of porosity in the metal. However, its effect on the mechanical properties of the metal is not as appreciable as that of manganese. Normally, its proportion in steel ranges from 0.05 percent to 0.4 percent.

3. **Sulphur**

   This element is usually present in steel as ferrous sulphide and sometimes as manganese sulphide also. Its main disadvantages are that it promotes ' *hot shortness'* and reduces ductility. Consequently, the metal exhibits increased brittleness at high temperatures and does not suit to deep deformation processes, like deep stamping or deep drawing, and develops cracks when forged or hot rolled. As such, its proportion is always kept below 0.03 percent. Another important point to be noted here is that all these ill effects are mainly due to the presence of ferrous sulphide whereas the manganese sulphide does not produce any appreciable ill effect and, therefore, its presence in acceptable. Several properties of steel, like yield point, tensile strength, corrosion resistance, fatigue limit, are quite adversely effected if sulphur is present in it in higher proportions than what is permissible. However, the ill effect of promoting brittleness is advantageously used in *free cutting steels*, where higher proportions of sulphur (upto 0.25%) enable the brittle chips to break quickly.

4. **Phosphorus**

   It is usually considered as one of the most injurious elements present in steel because it produces *'cold shortness, i.e.,* very high brittleness at low temperatures. With the results, the impact strength and ductility of the metal are reduced although the tensile strength is increased. For these reasons the endeavour always is to keep its proportion in steel as low as possible. For example, in sheets and strips, which are to be subjected to impact loads in operations like deep drawing and stamping, its proportion is always kept below 0.04 percent.

BRIGHT STEEL

It is the name given to a cold worked steel having a very clean and smooth surface and possessing close dimensional accuracy. Such steels are available in various standard sections in varying sizes, such as round, hexagonal and square bars, flats and special sections. Because of superior surface finish and high dimensional accuracy parts cut out of these sections can either be directly used in assemblies or machined to required sizes and shapes, if needed, easily.

FREE CUTTING STEELS

They are also known as *free machining steels*. Mass production of relatively smaller and lighter items through machining processes calls for the use of such stock material for the manufacture of these components which has high machinability and can be provided a high class surface finish through the process. This requirements is even more pronounced when higher speeds are to be used. For example, we can take the case of manufacture of small screwed components like bolts, nuts, screws, etc. on multi-spindle automatic machines or automatic screw machines. This demand of proper material for this purpose is met by *free cutting steels.*

The main characteristics of these steels are their high machinability and their capability to acquire a superior surface finish after machining. These two qualities of free cutting steels are mainly due to higher proportion of sulphur and phosphorus in them. Small addition of lead also helps in increasing the machinability.

Most of the sulphur present in these steels is in the form of manganese sulphide, which is distributed throughout the structure in the form of brittle flakes. During machining the chips formed out of this material disintegrate very quickly due to brittleness and a fairly good surface finish is obtained on the surface of the component after the operation. Presence of phosphorus further helps in promoting brittleness in the material and, in turn, ease in machining. As compared to the normal carbon steels these steels possess better tensile strength and better hardness but lower ductility and poor corrosion resistance. A few typical compositions of free cutting steels with their machinability ratings are given in Table 3.2.

Table 3.2. Typical chemical compositions and machinability ratings of some free cutting steels

| *Elements* | *Chemical composition (percent)* | | | |
	I	*II*	*III*	*IV*
Carbon	0.10 to 0.16	0.10 to 0.16	0.13 to 0.20	0.17 to 0.25
Manganese	0.65 to 0.85	0.65 to 0.85	1.25 to 1.50	0.65 to 0.85
Sulphur	0.12 to 0.20	0.17 to 0.20	0.09 to 0.15	0.09 to 0.15
Phosphorus	0.08 to 0.12	0.08 to 0.12	0.05	0.05
Lead	0.25	----	------	----
Machinability rating (%)	140	100	90	80

ALLOY STEELS

All steels, in addition to iron and carbon, contain other elements like silicon, manganese, sulphur and phosphorus in varying amounts. In carbon steels manganese normally varies upto 1 percent and silicon upto 0.3 percent. Against this, there is another variety of steel in which manganese is more than one percent and silicon more than 0.3 percent. Also, in addition to iron and carbon, they carry sulphur, phosphorus, nickel, chromium, molybdenum and vanadium etc. in varying proportions. Such steels are called 'Alloy steels', and they owe their different properties mainly to these alloying elements. They are normally named after the principal alloying elements. These elements are alloying with steel for one or more of the following reasons :

1.   To improve tensile strength without adversely affecting the ductility.
2.   To improve hardenability.
3.   To improve toughness.
4.   To improve corrosion resistance.
5.   To improve wear resistance.
6.   To impact capability to retain physical properties at high temperatures.
7.   To improve cutting ability and ability to retain shape and resist distortion at elevated temperatures.
8.   To promote fine grain size.
9.   To improve case hardening properties.

EFFECTS OF ALLOYING ELEMENTS

The various alloying elements affect the properties of steels as follows:

Nickel

It improves toughness, tensile strength, ductility and corrosion resistance.

Chromium

It is added in varying proportions upto 18%. Below 1.5% addition increase tensile strength and 12% addition imparts high corrosion resistance. In general, chromium addition improves hardenability and toughness simultaneously.

Cobalt

It improves hardness, toughness, tensile strength, thermal resistance and magnetic properties. It also acts as a grain refiner.

Manganese

In lower proportions, say from 1.0 to 1.5 percent, its addition increases strength and toughness. Higher proportions upto 5 percent impact hardness accompanied by brittleness. Still higher proportions, say between 11 to 14 percent, provide very high degree of hardness.

Silicon
It acts as a ferrite strengthened and improves elastic limit. It improves magnetic permeability and decreases hysterisis losses. Higher percentage of silicon gives rise to corrosion resistance.

Molybdenum
Its addition increases wear resistance, thermal resistance, hardness, ability to retain mechanical properties at elevated temperatures and helps to inhibit temper brittleness. When added with nickel, it also improves corrosion resistance.

Tungsten
It increases hardness, toughness, wear resistance, shock resistance, magnetic reluctance and ability to retain mechanical properties at elevated temperatures.

Vanadium
It improves tensile strength, elastic limit, ductility, shock resistance and also acts as a degaser when added to molten steel.

Boron
It increases hardenability and is, therefore, very useful when alloyed with low carbon steels.

Aluminium
It is basically used as a deoxidiser. It promotes the growth of fine grains helps in providing a high degree of hardness through nitriding by forming aluminium nitrides.

Titanium
It is a fairly good deoxidation and promotes grain growth. Also, it readily form titanium carbides but has no marked effect on the hardenability of the material.

Copper
It increases strength and improves resistance to corrosion. Its proportion normally varies from 0.2 percent to 0.5 percent.

Niobium
It improves ductility, decreases hardenability and substantially increases the impact strength. Also,it promotes fine growth. It is also known as *'columbium'*.

CLASSIFICATION OF ALLOY STEELS
Alloy steels are classified into various categories on the basis of several different considerations. Some common criteria are given below :

1. **According to the number of alloying elements**
   The basis of this classification is the number of alloying elements other than iron and carbon. If there is only one additional alloying element the steel is known as a *three-component* steel and if two additional alloying elements it is called a *four-component* steel, and so on.

2. **According to the type of internal structure**
   Based on this criterion the alloy steels are classified as *pearlitic steels, austenitic steels, martensitic steels, ferritic steels, carbide steels,* etc.

3. **According to the purpose and applications**
   Based on this criterion the alloy steels are classified as *structural steels, tool steels, special alloy steels,* etc.

4. **According to the principal alloying elements**
   Alloy steels are quite often named after the principal alloying element, which is largely responsible for the specific properties present in that type of steel. A few common examples include *nickel steel, chromium steel, manganese steel, tungsten steel, cobalt steel,* etc.

   Some very commonly and important types of alloy steels will now be discussed in details in the following articles.

STRUCTURAL STEELS
In accordance with Indian Standard (IS : 7598 --- 1974) these steels are further classified as :
1. *Low alloy steels, i.e.,* those steels which posses alloying elements upto a maximum of 5 percent.
2. *Medium alloy steels, i.e.,* those in which the total content of alloying elements varies from 5 percent to 10 percent.
3. *High alloy steels, i.e.,* those in which the content of alloying elements is more than 10 percent.

These steels carry nickel, chromium and manganese as principal alloying elements. Small proportion of tungsten, molybdenum, titanium, vanadium, etc., can also be mixed with the above principal alloying elements, but they are not added as independent elements. Ferrite is the main constituent and forms the bulk of these steels. The main function of the principal alloying elements is to strengthen this main constituent, i.e., ferrite. Other elements, in conjunction with the principal alloying elements, help in increasing hardenability and resistance against softening when heated to moderate temperatures.

These steels find wide applications in the manufacture and fabrication of various engineering components and structures which are likely to be subjected to static and dynamic loading use. Some symbolic examples of such applications are bridge construction, overhead structures of industrial buildings, transportation requirements, etc.

ALLOY TOOL STEELS

These alloy steels have special applications in the manufacture of cutting tools used in various cutting and machining operations where the tools made from carbon steels will either fail to perform or will have a very short life. There are two common varieties of *alloy tool steels* :

1. **Low** *alloy steels*

   Which contain silicon, chromium, manganese and tungsten as alloying elements and are capable of hardness upto a temperature of 250^0C.

2. **High** *alloy steels*

   Which mainly contain higher proportions of the carbide forming elements like tungsten, chromium, vanadium, etc. The presence of these carbides makes these alloys capable of retaining a high degree of hardness at elevated temperatures upto 620^0C. They respond very well to various heat-treatments and obtain superior cutting qualities through these treatments only. The most commonly used variety of this class of alloy steels is *High Speed Steel (HSS)* in which the main constituents are carbon, tungsten, chromium, vanadium and molybdenum. This steel has excellent wear resistance, high abrasion resistance and high red hardness.

SPECIAL ALLOY STEELS

These steels form a very important group of alloy steels which have been developed to meet specific requirements in respect of properties under specific situations and special applications. The most common varieties of these steels are described below :

1. **Stainless steels**

They are also known as *corrosion resistant steels.* Their principal alloying element is *chromium* while some other elements like nickel, managnese, etc. can also be present in small amounts. Since substantial amount of chromium is present in them they can not be considered as low alloy steels. While it is seen that an addition of just 4 to 6 percent chromium to low carbon steels render them fairly good corrosion resistant for most of the common uses, but if they are required to be highly corrosion resistant with very superior appearance a very high percentage of chromium (usually > 12%) is added. The chromium reacts with the oxygen to form a strong layer of chromium oxide on the surface of the metal which is responsible for offering the resistance to corrosion. Stainless steels carrying more than 12% chromium are known as *true stainless steels.* Classification of stainless steels is generally done on the basis of their structures as follows :

   a. **Ferritic stainless steels**

   By now it is well known that chromium is an effective ferrite stabilizer. Its addition, therefore, widens the temperature range through which ferrite will be a stable structure. As such, with the addition of sufficient amount of chromium to a low carbon steel an alloy is produced which carries a stable ferritic structure at all temperatures below its solidification temperature. Such alloys are called *ferritic stainless steels.* This group of stainless steels carries chromium content in the range of 11 to 27 percent, usually without any other alloying element. Sometimes, of course, manganese (1 to1.5%) and silicon (upto 1%) are added. They possess BCC crystal structure and, therefore, their ductility and formability are poor. However, they possess good weldability. They can be made good heat resistant by the addition of about 3% silicon. They exhibit fairly good strength even at elevated temperatures, can be hot worked, but can not be hardened through heat treatment. These steels are widely used in dairy equipments, food processing plants, chemical industries, heat exchangers, various types of household utensils, cutlery, surgical instruments, nuclear plants, etc.

   b. **Martensitic stainless steels**

   This group of stainless steels carries chromium between 12 to 18 percent but contains a higher percentage of carbon usually (0.15 to 1.2%). The carbon dissolves in austenite which, when quenched, provides a martensitic structure to the alloy. Hence, the name. Due to formation of chromium carbides the corrosion resistance of this alloys is decreased. Different amounts of carbon are used to vary the strengths of these alloys. They are costlier than ferritic stainless steels and can be hardened by heat treatment. Their main applications are in the manufacture of items like springs, bolts, nuts, screws, valves, cutlery, etc.

c. Austenitic stainless steels

Indeed the most important, and at the same time costliest, is this group of stainless steels. The main idea behind the development of this alloy steel is to stabilize the austenite structure, for which nickel is added in sufficient quantity in addition to chromium. This provides a stable austenite structure at room temperature. Manganese and nitrogen are sometimes added to reduce the cost, but the results in slight deterioration in quality as well. This group of stainless steels may contain 0.03 to 0.25% carbon, 16 to 26 percent chromium, 3.5 to 22% nickel, 2% manganese, 1 to 2% silicon and in some cases small amounts of molybdenum, titanium, etc. A very widely used variety of this type of steel, called 18-8 stainless steel, carries 18% chromium and 8% nickel. It responds well to cold working and its strength and hardness can be increased through cold working. It can also be cold drawn into wires.

These steels are nonmagnetic and higher corrosion resistant. However, they may be corroded in salt media and halide acids surroundings. They possess excellent formability and good weldability. They offer the best corrosion resistance out of all the three classes of stainless steels. They however, can not be hardened by heat treatment. Titanium or niobium is sometimes added to these alloys to stabilise carbon and molybdenum to improve corrosion resistance. These steels have wide applications where high corrosion resistance and attractive appearance are vital requirements.

2.   Magnetic steels

These steels are rich in cobalt and tungsten contents and carry varying percentages of other elements like carbon, chromium, nickel, etc. A typical *magnetic steel* composition shows 15 to 40% cobalt, upto 10% tungsten, 1.5 to 9% chromium and upto 1.0% carbon. These steels are mainly used to make permanent magnets for electrical measuring instruments, loud speakers, magnetos, etc.

3.   Heat resistance steels

With alround developments in high-technologies in modern era a continued need has been to develop such metals which can resist the influence of such parameters that can lead to the failures of common metals at elevated temperatures. Such conditions commonly arise in the operations of nuclear power plants, structure and parts of high temperature furnaces, supersonic aircraft, missiles, etc. The metals required for use in such equipments should have high corrosion resistance, good strength and good creep resistance at high temperatures. These requirements are satisfactorily met by heat resisting alloy steels, although nonferrous alloys have also been developed which meet these requirements equally successfully.

Some typical compositions of such ferrous alloys are given below :

	I	II
Carbon (%)	0.4 - 0.5	upto 0.3
Chromium (%)	13 - 15	23 - 27
Nickel (%)	13 - 15	18 - 21
Silicon (%)	--	2.0 - 3.0
Tungsten (%)	2.0 - 2.5	--
Molybdenum (%)	0.25 - 0.4	--
Iron	Reminder	Remainder

4.   Maraging steels

These are ferrous alloys developed by adding 15 to 25 percent nickel, fairly high proportions of cobalt and molybdenum and small quantities of other elements to lower grades of steel, like dead mild steels. Such a chemical composition leads to the development of an alloy of which the structure will be changed to martensite when air cooled from a temperature of 815^{0}C. Its yield strength and elongation properties can be substantially enhanced by age-hardening at 480^{0}C. Such alloys are known as *maraging steels* and are widely favoured when extremely high strength and good toughness are the main requirements.

These steels have good machinability and respond well to both hot and cold working. They can also be welded, but ageing is necessary after welding.

5.   High Speed Steels (HSS)

These steels are meant for the manufacture of cutting tools, specially those used in metal machining, and other similar applications where the amount of heat developed during the operation is very high and the tools used are required to retain their hardness at elevated temperatures. The factors responsible for high heat generation are the application of higher cutting speeds, heavy cuts, hardness of material being machined, high friction at tool and job interface, etc. All such factors contribute to heat generation and raising the temperatures to such an extent that the cutting edge of the

tool may become red hot. If the tool material is unable to retain its hardness at that time it will fail to perform the cutting operation. A high carbon steel tool fails to meet this requirement and that necessitated the development of these alloys (*H.S.S*). It is reckoned that tools made of these alloys can safely operate at 2-3 times higher speed than those possible with high-carbon steel tools and retain their hardness upto a temperature of 620^0C.

The most commonly used form of these alloys is the (18-4-1 high speed steel), which carries 18% tungsten, 4% chromium, 1% vanadium, 0.7% carbon and the rest iron. It carries a balanced combination of good red hardness, wear resistance and shock resistance and is, therefore, widely used for making cutting tools for lathes, shapers, planers, slotters, milling cutter, drill bits, broaches, etc.

Another popular variety of *high-speed* is cobalt **high-speed steel.** Addition of cobalt improves red hardness and wear resistance. A typical composition of cobalt high speed steel contains 12% cobalt, 20% tungsten, 4% chromium, 2% vanadium, 0.8% carbon and the rest iron. This ensures better red hardness and can safely operate upto 620C. These steels are also known as super high-**speed steels.**

Another variety of high-speed steels, called **vanadium high-speed steel, carry** higher proportions of vanadium and shows better abrasive resistance than 18-4-1 HSS. It is, therefore, preferred for machining *difficult- to machine* materials.

Yet another variety of this category of alloys, called **molybdnum high-speed steels,** having 6% molybdnum, 4% chromium, 6% tungsten, 2% vanadium and higher percentage of carbon possess very high toughness and excellent cutting properties. It is now a very widely used high-speed steel.

CLASSIFICATION OF ALLOY STEELS ACCORDING TO THE PRINCIPAL ALLOYING ELEMENTS

1.   **Nickel Steel**
        It is the most commonly used alloy steel in which nickel, the principal alloying element, varies between 0.5 percent and 2.0 percent. The amount is determined by the purpose for which this steel is to be used. The purpose of adding nickel is to provide additional strength and hardness to the steel without losing its ductility. The carbon content present in these steels varies from 0.2 percent to 0.5 percent. With varying percentages of nickel and carbon, within the specified limits, this steel can be used for a large number of engineering components like rivets, sheets, pipe, axles, shafts, I.C. Engine parts, electric wires, precision measuring instruments and structural work of bridges, etc. The nickel-steel having about 0.3 percent carbon and 3.5 percent nickel is most commonly used.

2.   **Chromium Steel**
        This is another useful steel alloy having a number of uses. With the addition of chromium, upto 2 percent, the strength and hardness of steel is considerably increased but with a slight reduction in ductility. Where ductility is also important factor as the other two, nickel is added to the steel along with chromium. It is then known as Ni-chrome steel. A typical composition of NI-chrome steel, suitable for gears and tools shown as analysis as ; carbon 0.2% chromium 0.8 percent and nickel 3.2 percent. In general, the chromium steels are extensively used for ball and roller bearings as they respond very well to the case hardening operation. In addition, this steel has a number of other uses such as in the manufactures of gears, springs, pneumatic tools, twist drills, hammers, files, engraving tools, wrenches, hacksaw blades, surgical instruments and items used for structural work.

3.   **Manganese Steel**
        It's useful composition carries 12 to 15 percent manganese with about 1 percent carbon. Another composition, which is also in general use, contains below 2 percent manganese and about 0.15 percent carbon. Presence of manganese between 2 to 12 percent renders the alloy extremely brittle and reduces ductility. On the whole, if manganese is added within the specified higher limits (from 12 to 15 percent), this steel is a very hard and abrasion resistant alloy having sufficient ductility. It can be cast without any appreciable difficulty but cannot be easily forged. Its machinability is very low. It is mainly used for making such parts which are to withstand heavy wear or abrasion; such as cranks and connecting rods of locomotive engines. If this steel is quenched in water from proper temperature (approx. 955^0C) it gets the property of being nonmagnetic.

4.   **Tungsten Steel**
        This may contain Tungsten up to 20 percent but 14 percent to 18 percent is the most commonly used proportion, which gives us the most widely used steel known as High Speed Steel. This may contain 0.6 to 0.7 percent carbon and upto 4 percent chromium. The addition of tungsten enables this alloy to withstand high temperatures without losing its hardness. This is a very significant property due to which this steel is best suited for making various cutting tools which are required to retain their point or cutting edge during machining at very high cutting speeds. This is why the name High Speed Steel is given to this alloy.

Molybdenum can quite suitably replace tungsten up to about 60 percent without any appreciable effect on the properties of the high-speed steel. This element has a similar effect on the steel as tungsten.

CUTTING ALLOYS

These alloys are specially developed with such constituents which will enable them to retain their strengths at extremely high temperatures of the order of 1000^0C to 1100^0C. This properties enables the use of these alloys for manufacturing of cutting tools used in metal machining at very high cutting speeds. Solid tools are not made from these alloys because, if made, they are bound to break due to high brittleness and also because it is difficult to machine them. For these reasons, small bits are made of these alloys which are either brazed to the tool shanks or held mechanically. According to the method of production these alloys can be grouped as :

     1.   Cast cutting alloys
     2.   Cemented carbides.

1.   Cast cutting alloys

These alloys are rich in cobalt content and contain tungsten, chromium, niobium, boron, nickel, tantalum, etc., also in varying proportions. As cutting tool materials they perform better than H.S.S. but are inferior than cemented carbides. They retain their hardness to much higher temperatures then HSS. With the result, they can be safely operated at 50% or more higher speeds than HSS tools. They can not be heat treated but possess high hardness in 'as cast' condition itself. These alloys are popularly known as **Satellites.** They are neither forged nor machined to shape. Usually they are cast shape and then finished by grinding. They are effectively used for machining of several hard materials like cast irons, alloy steels, plain carbon steels and nonferrous alloys. They are costlier than HSS.

2.   Cemented carbides

These are, in fact, *nonferrous alloys*, consisting mainly of the carbides of tungsten (as major constituent), titanium and tantalum with cobalt as a binder. They are called **cemented** or **sintered** carbides because they are produced by sintering process of power metallurgy. The process consists of two main stages. In the first stage the powered carbides are compacted with cobalt binder (3 percent to 15 percent) to shape. In the second stage they are sintered.

Due to high brittleness they are used only as *bits.* These bits are available in many standard shapes like triangular, square, diamond, round, etc., and different sizes. These bits can either be brazed or held mechanically on the tool shanks. Brazed bits provide better stability and accuracy but the mechanically held bits (inserts) enable longer tool life because when their one edge becomes blunt it can be turned over or rotated to bring another edge in front of cutting.

These tool materials are extremely hard, possess better hot hardness, exhibit better stiffness and less friction and are chemically more stable. They can retain their hardness wear upto 1200^0C and, therefore, very high cutting speed can be used. Their higher wear resistance makes them suitable material for making drawing dies and similar other tools.

CODING OF IRON AND STEEL

As per B.I.S. Code (IS :4843 --- 1968) *plain castings* shall be designated in the following order :
1.   Symbols indicating the type of casting.
2.   Symbols indicating mechanical properties.
           O*r*
1.   Symbols indicating the type of casting.
2.   Symbols indicating the chemical composition.

The code designation of alloy castings shall follow the following order :
1.   Symbols indicating the type of castings.
2.   Average carbon content in hundredths of a percent.
3.   Symbols for significant chemical elements in descending order.
4.   Alloy index numbers for average percentages of alloying elements.

The symbol CS stand for *steel castings* and FG for *grey iron castings.* The following examples will make the designation system clear :

     FG 150   -   Grey iron castings with minimum tensile strength of 150 N/mm^2
     FG 35 Si 15   -   Grey iron castings with 3.5% carbon and 1.5% silicon.

CS 1250	-	Unalloyed steel castings with minimum tensile strength of 1250 N/mm^2.
CSM 350	-	Unalloyed special steel castings with minimum tensile strength of 350 N/mm^2.
CS 50 Cr 1 V 20	-	Alloy steel castings with 0.50% carbon, 1.0 % chromium and 2.0% vanadium.

Coding of steels

As per BIS code No. IS : 1962(part 1) --- 1974 various types of steels are designated :
1.   On the basis of mechanical properties.
2.   On the basis of chemical compositions.

Designation of steels on the basis of mechanical properties

Plain carbon and low alloy steels are designated on the basis of their mechanical properties like *tensile strength* and *yield stress.* These steels will have code designation in the following order :

(a)   The code will be preceded by either letter Fe or FeE. Letter Fe will be used if the classification is based on minimum tensile strength and FeE if it is based on minimum yield stress.

(b)   It will be followed by a figure indicating the minimum tensile strength or yield stress in N/mm^2.

(c)   It will be followed by chemical symbols representing the elements which signify the steel.

(d)   In the end the designation will carry the symbol (s) which will indicate the special characteristics like method of deoxidation, quality of steel, surface condition, formability, weldability, surface finish, treatment, etc.

Some examples

Fe 470 W	-	Semi killed steel with S and P upto a maximum of 0.035% and minimum tensilestrength of 470 N/mm^2, of fusion welding quality.
Fe E 300 P 35	-	Semi killed steel, with S and P upto a maximum of 0.035%, with minimum yield stress of 300 N/mm^2.
Fe 410 Cu K	-	Killed steel with Cu as main alloying element, S and P upto 0.035 max., with minmum tensile strength of 410 N/mm^2.

Designation of steel on the basis of chemical composition

(i)   Unalloyed steels

The code designation will comprise the following in the given order as per (IS : 7598-1974)

a. Figure indicating 100 times the average carbon percentage.
b. C --- stands for carbon.
c. Figure indicating 10 times the average manganese percentage.
d. Symbol indicating special characteristics, if any.

For example :

| 50 C 5 G | - | Carbon steel with 0.5% carbon, 0.5% Mn and with guaranteed hardenability. |
| 25 C 5 W | - | Carbon steel with 0.25% carbon, 0.5% Mn, fusion weldable. |

(ii)   Unalloyed tool steel It will be designated in the following order :

a. Figure representing 100 times the average carbon percentage.
b. Alphabet 'T' standing for tool steel.
c. Figure representing 10 times the average Mn percentage.

Example :

| 100 T 5 | - | Unalloyed tool steel with 1.0% carbon and 0.5% manganese. |

(iii)   Unalloyed free cutting steels

a. Figure indicating 100 times the average (%) carbon.
b. Alphabet *'C'* for carbon
c. Figure indicating 10 times the average (%) manganese
d. Element responsible for rendering the steel free cutting
e. Figure indicating 100 times the percentage of the element mentioned at (*d*).
f. Symbol indicating special characteristics.

Example :

15 C 8 pb 25 T 14 - A free cutting steel with 0.15% carbon, 0.8% Mn, 0.25% Pb, hardened and tempered (indicated by treatment grade T 14).

(iv) **Alloy steels**
Low and medium alloy steels in which total alloying elements do not exceed 10 percent
As per (IS : 7598 -1974) these steels will be designated in the following order :
a. Figure indicating 100 times the average (%) of carbon .
b. Symbols for alloying elements, each symbol being followed by a figure representing its average percentage multiplied by a standard multiplying factor, given below :

Alloying Element	Multiplying factor
Cr, Co, Ni, Mn, Si and W	4
A1, Be, V, Pb, Cu, Nb, Ti, Ta, Zr and Mo	10
P, S and N	100

c. Symbol indicating special characteristics.

Example:
25 Cr 4 Mo 2 G - Alloy steel containing 0.25% average C, 1.0% average Cr, 0.2% average Mo, with guaranteed hardenability.

Note : *The symbol for manganese will be included only if its average percentage is* $\geq$ *1.0%.*

High alloy steels in which the total alloying elements are above 10 percent
These steels will be designated in the following order :
a. Alphabet 'X' representing high alloy steels.
b. Figure indicating 100 times the average (%) of carbon.
c. Chemical symbols for alloying elements, each followed by the figure indicating its average percentage.
d. Symbol indicating surface condition.

Example:
X 15 Cr 18 Ni 9 S 6 - bright drawn high alloy steel containing average 0.15% C, average 18% Cr and 9% Ni.

Alloy tool steels
The order of designation of these steels is the same as for other alloy steels described above, but with a difference that the letter T or *XT* are added in the beginning of the designation depending upon weather the alloy is a low or medium one or a high alloy respectively.

Examples:
T 35 Cr 5 Mo 1 V 3   -   A medium alloy tool steel with average 0.35% C, 5% Cr, 1.0% Mo and 3.0% V.
CT 70 W 18 Cr 4 V 1   -   A high alloy steel with average 0.7% C, 18% W, 4% Cr and 1.0% V.

American Standards
The designation systems for steels have been standardised in U.S.A. by the *Society of automotive Engineers* and the *American Iron and steel Institute* and their standards are represented by corresponding abbreviations SAE and AISI. The common feature of the designation is that a 2 or 3 digit number identifies the range of composition of alloying elements and it is followed by a 2 digit number which identifies the average content of carbon in 100ths of a percent. Parallel standards have been developed by most of the industrialized counters. The Bureau of Indian Standard (BIS) has compiled a comparison of Indian Standards with foreign standards and the same can be referred to, if needed.

SUGGESTED BIS CODES FOR FURTHER REFERENCE

IS 432 (Pt & 2) : 1982	IS 1030 : 1989	IS 1812 : 1982	IS 3748 : 1990
IS 280 : 1978	IS 1079 : 1988	IS 1875 : 1978	IS 3749 : 1978
IS 513 : 1986	IS 1148 : 1982	IS 1977 : 1975	IS 3930 : 1979
SP 14 : 1976	IS 1149 : 1982	IS 1870 : 1975	IS 3945 : 1966
IS 226 : 1975	IS 1570 : 1961	IS 1956 (Pt 1) : 1976	IS 4030 : 1973
IS 961 : 1975	IS 1673 : 1984	IS 2049 : 1978	IS 4367 : 1991
	IS 1730 : 1989	IS 2611 : 1964	IS 4431 : 1978
IS 1871 (Pt 1,2,3,) : 1987	IS 1732 : 1989	IS 3747 : 1982	IS 4432 : 1988
IS 7226 : 1975	IS 5517 : 1978	IS 5518 : 1979	IS 4898 : 1989
IS 9516 : 1980	IS 5651 : 1987	IS 9516 : 1980	IS 9550 : 1980

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CHAPTER - 4
NON FERROUS METALS & IT'S ALLOYS

INTRODUCTION

Non-ferrous metals are those which do not contain iron as the base material. The most commonly used non-ferrous metals in wokshop are aluminium, copper, lead, tin, nickel and zinc. They also form very useful alloys amongst themselves, known as *non-ferrous alloys,* which possess very significant characteristics like high resistance to corrosion, conductivity of heat and electricity, lightness in weight and of being non-magnetic. These properties enable these metals and alloys to be preferred over iron, steel and their alloys where these characteristics stand as the primary considerations. Non- ferrous metals and alloys can also be cast and machined without any appreciable amount of difficulty, but they are more expensive as compared to the ferrous products. However, apart from the cost factor, there are some inherent disadvantages associated with non-ferrous metals, when compared with ferrous metals, such as high shrinkage, hot shortness and lower strength at elevated temperatures.

Use of non-ferrous metals in engineering offers the following advantages :
1. Very good electrical and magnetic properties.
2. Good castability.
3. Good formability
4. Ability to be easily cold worked.
5. High resistance to corrosion.
6. Attractive appearance.
7. Lower density.

ALUMINIUM

Aluminium ore is found as a hydrated aluminium oxide, called *bauxite.* The impurities present in it are oxide of iron, silicon and titanium. The first process, therefore, is to separate aluminium oxide from these impurities. For this purpose, bauxite is fused in an electric furnace and carbon is added to reduce the impurities, which form a *sludge* and can be removed. As a result of this refining, pure aluminium oxide is separated from the impurities. Then an electrolytic bath is used to reduce aluminium from its oxide. As the electrolytic process proceeds the oxygen escapes through the bath and molten aluminium collects at the bottom (cathode), from where it is periodically tapped off. This mineral is mainly available in our country in Bihar, Maharashtra, Madhya Pradesh, Karnataka and Tamil Nadu.

Properties and uses
1. *High electrical couductivity.* Used for heavy conducators and busbar work.
2. *High heat conductivity.* Used in various domestic tensile and other heat conducting appliances.
3. *Good resistance to corrosion.* Used in manufacture of containers for chemical industry and window frames etc.
4. It can be readily worked, extruded, rolled, drawn and forged.
5. *It has high ductility and is extremely light in weight.* Widely used in aircraft industry.
6. Its corrosion resistance can be considerably increased by anodising.
7. It becomes hard by cold working and ,therefore, needs frequent annealing.
8. Its low tensile strength can be sufficient improved by adding 3 to 4 percent copper.

COPPER

It is not available in pure form under the earth. It is extracted from its ores through a series of processes. A couple of locations where copper ores are found in India are *Khetri* in Rajasthan and Ghatsila in Bihar. *Copper pyrites* are the main ores used for extracting copper.

The copper ore is first roasted to drive out water, CO_2 and sulphur. It is followed by melting in a reverberatory furnace of the type used for wrought iron . Silica is added to the charge to form slag with impurities like iron and alumina, etc. The molten metal is tapped and transferred to a converter where air is blown through it to burn the impurities. This results in the production of a crude form of copper, known as *blister coper,* containing 68% purity. Final refining is done by an electrolytic process, pure copper depositing on the cathode. This gives a highly pure (99.9%) copper which is remelted and cast into suitable shapes.

Properties and uses
1. *High electrical conductivity.*
   Used as electrical conductor in various shapes and forms *viz*., sheet and contacts etc.

2.   *High heat conductivity.*
    Used in heat exchangers and heating vassels and appliances.

3.   *Good corrosion resistance.*
    Used for providing base coating on steel prior to nickel and chromium plating.

4.   *High ductility.*
    Can be easily cold worked, ruled, drawn and spun. Loses ductility in cold working, requiring annealing.

5.   *Light in weight.*
    Used in various appliances where light weight with good corrosion resistance is desired.

MAGNESIUM

Principal sources for obtaining magnesium are natural salt brines, sea water, water liquors obtained from potash industry and ores. The principal ores are magnesite, dolomite and carnallite. Various processes have been developed for its extraction, but the most popular and widely used one is the electrolytic process.

Properties and uses
1.   It is the lightest of all metals, weighing about two-third of aluminium.
2.   It may be sand, gravity and pressure die-cast.
3.   Its castings are pressure tight and obtain good surface finish. A few examples of magnesium castings include motor car gear box differential housing and portable tools.
4.   It may be easily formed, spun, drawn, forged and machined with high accuracy.
5.   Additions of 10% aluminium and small amounts of zinc and manganese improve its strength and casting characteristics.
6.   Additions of 2% Mn helps in its easy forming into plates and sheets and extrusion work.
7.   In finely divided form it is likely to burn, and adequate fire protection measures should be strictly observed.

ZINC

The zinc ore is first concentrated through a suitable process. This concentrate is fed into a retort with a suitable amount of carbonaceous material (say coal). Several retorts are housed in one furnace and their temperature raised to 1100^0C. Zinc emerges as vapor and is passed through a condenser, where it is collected as a liquid. The impurities are given out as gases and burn at the mouth of the condenser. By rapid cooling the zinc vapour may be quickly converted into powered zinc.

Properties and uses
1.   *High corrosion resistance.*
    Widely used as protective coating on iron and steel. It may be coated either by dip galvanising, electroplating or sheradising. The coating can also be provided through painting or hot spraying.

2.   **Low** *melting point and high fluidity.*
    Make it the most suitable metal for pressure die-casting, generally in the alloy form.

LEAD

Lead ores are generally found as oxides or sulphides. Other impurities present in the ores are iron, copper and zinc etc. The prepared ore concentrate, together with the flux (lime and silica), is fed into a small blast furnace where the temperature is raised to about 1010^0C. The lead is melted and a liquid slag formed of the impurities. Both slag and molten lead are tapped at intervals. Further refining is carried out in a reverberatory furnace, where an oxidising atmosphere is maintained to burn out the impurities.

Properties and uses
1.   **Good** *corrosion resistance.*
    Used for water pipes and roof protection.
2.   *Good resistance to chemical action.*
    Used for acid baths and containers in chemical industry.
3.   It is soft, heavy and malleable, can be easily worked and shaped.
4.   It is used as an alloying element in making soft solders and plumber's solders.
5.   It is also alloyed with brass and steel to impart them free cutting properties.

TIN

The most prominent tin ore is *cassiterite*. It also carries compounds of copper, iron, lead, antimony, bismuth and zinc

etc. As usual an ore concentrate is prepared. This concentrate is roasted to drive off excess arsenic and sulphur. The roasted ore is transferred to a reverberatory furnace, where it is heated. Anthracite is added to the charge which reacts chemically to separate tin, the latter sinking to the bottom of the furnace. From there it is tapped at intervals. This crude tin is remelted and refined further. For obtaining high purity tin the electro-deposition method is used.

Properties and uses
1.   ***Good resistance to acid corrosion***
     Used as coating on steel containers for food.
2.   It is soft, has good plasticity and can be easily worked.
3.   It can be easily rolled into thin foils, but cannot be drawn due to low strength.
4.   It is used as an alloying element in soft solders, bronzes bearing metals.

NICKEL
Its extraction process consists of first roasting the ore, followed by smelting in a small blast furnace. Limenstone and quartz are added as flux. They form slag with impurities. Coke is used as fuel. Crude molten nickel is tapped off periodically from the bottom of the furnace. This crude metal is further refined in a bessemer converter followed by treating with sulphuric acid to extract pure nickel. Copper is separated as copper sulphate.

Properties and uses
1.   It has a good resistance to both acid and alkali corrosion. It is, therefore, widely used in food processing equipment.
2.   It has high tensile strength and can be easily worked cold and hot.
3.   It is plated on steel to provide a corrosion-resistance surface.
4.   It is an important alloying element with steel. Its higher proportions are advantageously used in the production of stainless steel like *monel* and *inconel.*

NON-FERROUS ALLOYS
Due to poor physical and mechanical properties and high costs the nonferrous metals are seldom used in their pure state. But their alloys carry very good physical and mechanical properties and are widely used. In general they have lower strength, hardness and modulus of elasticity than irons and steels. However, they carry their own importantance due to some exceptional properties they possess, like lightness, ease in fabrication, good machinability, high resistance to corrosion, attractive appearance and good castability etc. Some commonly used nonferrous alloys are described in the following articles.

BRASSES
All brasses are basically alloys of copper and zinc. There are two main varieties of brasses :
1.   Alpha brass (upto 37% Zn)   -   for cold working.
2.   Alpha Beta brass (33% to 46% Zn)   -   for hot working.

Alpha brasses are very ductile and can be reality cold worked without any chances of fracture. They can be cold rolled into sheets, drawn into wires, deep drawn and drawn into tubes. In these brasses, as the proportion of zinc increases, their strength increases but ductility decreases.

They are work hardened when subjected to intensive cold working, but ductility can be regained by annealing them at 600^0C. Slow cooling provides maximum ductility, but for common uses they may be water quenched. Deep drawing of this brass requires periodical annealing during the process.

An alpha-beta brass loses strength at high temperatures but becomes very plastic. It, therefore, responds very well to hot rolling, hot extrusion, hot stamping and casting, etc. When cold worked, fractures are always likely to develop.

Common types of brasses in engineering use are the following :
Cartridge brass
It has 70% Cu and 30% Zn. It is very strong and ductile. It is used for a wide range of drawn components like cartridge cases, head lamp reflectors, radiator shells and drawn tubes.

Muntz metal
It contains 60% Cu and 40% Zn and can be cast, rolled, extruded and stamped. It is a sort of general purpose alloy having good resistance to corrosion. It is used for casting pump parts, valves, tapes and other similar items.

Naval brass
It contains 60% Cu, 39% Zn 1% tin. It is more or less similar in composition to Muntz metal except that 1% Zn is replaced

by 1% tin. As a result of this change the resistance to sea water corrosion is vastly improved. This alloy is, therefore, widely used for cast and forged fittings for ships.

Admiralty brass
It contains 70% Cu, 29% Zn and 1% tin. It is similar to cartridge brass in composition except that 1% Zn is replaced by 1% tin. It can be cold worked and has good resistance to sea water corrosion. It is cold drawn into tubes and rolled into sheets and bars. It is widely used in ship fittings, bolts, nuts, washers and the other items subjected to sea-water corrosion. It is also used in condenser plant.

Gilding brass
It contains upto 15% Zn and the rest Cu. It is a very good cold working alloy and is used for jewellery, decorative and ornamental work. It is commercially available as cold rolled strip, wire or sheet. Its colour, according to the percentage of Zn. Varies from red to bright yellow. It is also called *Gilding metal.*

Delta brass
Also known as *Delta metal*, it consists of 60% Cu, 37% Zn and 3% iron. It can be easily hot worked, forged, rolled extruded and cast. It has a fairly good tensile strength after hot working and casting. It also has a good corrosion resistance. It can suitably replace steel castings.

Free cutting brass
It contains 60% Cu, 37% Zn and 3% Pb. It is specially used in machining work, such as producing components from bar stock on turret and automatic lathes. It is also used for making cast, forged or stamped blanks to be used for further machining. With this metal very high speeds and feeds can be employed in machining.

Beta brass
It contains 50% Cu and 50% Zn. Higher percentage of zinc renders it hard and brittle, but it softens quickly when heated and melts at 870^0C. Its main application is as a brazing solder (*spelter*).

Colouring brass
Various brass components can be imparted different colours by chemical treatment. A few examples are giving of golden colour and black colour, the former being used in decorative and ornamental work and the latter in optical instruments parts. For golden colour the finished brass components are boiled in a solution consisting of water 24 parts, saltpeter 2 parts, alum 1 part and HCl 1 part, all by weight. Similarly the solution for boiling the parts for giving black colour, consists of 4.5 litre water, 0.16 kg potassium cyanide and 0.06 kg white arsenic.

Silicon brass
It contains 80% Cu, 16% Zn and 4% Si. It responds well to welding and is widely used for refrigerators and fire-extinguisher shells. It can also be easily sand or gravity die cast, hot stamped and extruded. It can be used as a cheaper substitute for phosphor bronze.

Clock brass
It contains 65% Cu, 34% Zn and 1% Pb. The lead content improves its bearing qualities and machinability. It is mostly available in strip form and is widely used in making small gears and pinions for clock work.

High tensile brass
It is similar to Naval brass but carries small additions of A1, Mn, iron, Ni and Pb. Its tensile strength is 69 tonnes/mm^2. It is used where high tensile strength and toughness along with good resistance to corrosion are required. It may be sand or die cast and forged. It is mainly used for large marine components, such as pump bodies and ship propellers.

Precipitation hardening brass It contains about 70% Cu, 30% Zn and small additions of Ni and A1. It can be hardened by usual heat treatment. It can be annealed by quenching from 850^0C and can be hardened by reheating to 500^0C. It is widely used for gears, pinions, formed and pressed parts where ability to harden after working is an advantage.

BRONZES
Bronze is basically an alloy of copper and tin. In general, it possesses superior mechanical properties and corrosion resistance than brass. Those containing upto 8% tin are called *working bronzes*. They can be easily cold worked, rolled, formed and drawn. They are available in various forms, as strip, wire and sheet etc.

With the increase in tin content, its strength and corrosion resistance increase. It is then known as *hot working bronze*. Small addition of phosphorus further improves its strength, ductility and bearing properties. The amount of phosphorus added is 0.5%. This is then known as *phosphor bronze.*

Phosphor bronze

Various compositions of this alloy are available for different uses. That having about 0.5% P is widely used for different types of springs in electrical instruments. Its drawn tubes are used in fuel systems and instruments. Cast phosphor bronze is used for bearings and gears. *Bearing bronze* contains 10% tin and small addition of lead. *Gear bronze* contains 13% tin for greater strength. Phosphor bronze can be sand cast, centrifugally cast, or cast through lost wax process. It carries good load bearing capacity, enough plasticity and good wear resistance, which make it an ideal bearing metal.

Gun metal

It is a phosphor bronze having 2 to 5% Zn. Small amount of lead is also added to improve castability and machinability. It is used for bearing bushes, glands, pumps and valves etc.

Bell metal

It is a straight bronze having 20 to 25% tin. It can be readily cast and is generally used for casting of bells.

Speculum metal

Another straight bronze containing 30% tin. It is a hard alloy and takes good polish. It is largely used for decorative work and vacuum plating.

Aluminium bronze

It contains upto 14% Al and the rest Cu, with sometimes a little addition of iron. It possesses good strength, high corrosion resistance and good heat resistance.

One variety, containing upto 8% Al, is known as *cold working Al-bronze.* It is available in the form of tubes for condensers, heat exchanges and steam and chemical plants. It is also used for springs.

Although variety, called *hot working Al-bronze,* contains 8% to 14% Al. It can be readily forged, extruded, stamped, sand and gravity die-cast and otherwise hot worked. It is used for a large range of cast and forged parts, such as gears, pinions, valve seats, guides in I.C. engines, cams and roller, etc.

Silicon bronze

It contains 1 to 4% Si, 0.25 to 1.25% Mn, 0.5 to 1% iron (if added) and the rest copper. Small addition of upto 0.5% Pb will improve machinability. It has high strength, toughness and corrosion resistance. It can be readily hot worked. With low silicon content it can be safely cold worked also. It is widely used for boiler parts, tanks, marine hardware and similar other items.

Manganese bronze

It contains 55 to 60% Cu, 38 to 42% Zn, upto 1.5% tin, upto 2% iron, upto 1.5% Al and upto 3.5% Mn. It has superior mechanical properties and high corrosion resistance. It has poor response to cold working, but can be readily hot worked. It is used for such parts where high strength and corrosion resistance are desired, such as in ship propellers and rudders, etc.

ALUMINIUM ALLOYS
Duralumin.

It contains 4% Cu, 0.5% Mg, 0.5% Mn and the rest aluminium. It has high tensile strength, comparable with mild steel, combined with the characteristic lightness of aluminium. It, however, possesses a low corrosion resistance. To improve upon the same, a thin film of Al is rolled on the duralumin sheets. These sheets are known by their trade name *Alclad*, and are widely used in aircraft industry. It is available in various forms like bars, tubes and sheets. In its wrought form it can be cast, forged and stamped easily. It can also be age hardened.

Aluminium casting alloys

A general purpose casting alloy contains 90% Al, 8% Cu, 1% Si. It has good strength, hardness and machinability. It may be sand, gravity or pressure die cast.

Another general purpose aluminium casting alloy consists of 13.5% Zn, 3% Cu and the remainder Al. Similarly, a large number of aluminium casting and forging alloys have been developed in the recent past which possess fairly high strengths.

Al-Si alloy contain 5 to 15% Si and the rest Al. They have good castability, low shrinkage, and the castings made from them are quite sound. A more refined structure of casting is obtained by adding a small amount of sodium.

Y-Alloy

It contains 93% Al, 4% Cu, 2% Ni and 1% Mg. Its principal use is as a casting alloy. It maintains its strength at elevated

temperatures, and is used for pistons of I.C. engines. A heat treatment of Y-alloy castings, consisting of quenching in boiling water from a temperature of 510^0C and then aging for 5 days, develops very good mechanical properties in them. It is also used in strip and sheet forms.

NICKEL ALLOYS
German Silver
It is also known as *Ni-silver*. It contains 60% Cu, 30% Ni and 10% Zn. It is very ductile and malleable and displays silvery appearance. It is used for electrical contacts, resistance wires, casting of high quality valves and taps and jewellery.

Constantant
It contains 45% Ni and 55% Cu. It has high specific resistance, which is unaffected by temperature variation. It is used for accurate resistors, thermocouples, wheat stone bridge, low temperature heaters and resistances.

Monel metal
It contains 68% Ni, 30% Cu, 1% iron and small additions of Mn and other elements. It has good mechanical properties and can maintain them at elevated temperatures. It has high corrosion resistance, can be cold and hot worked, cast, forged and welded. It is widely used for marine parts pump impellers, propellers, evaporators and heat exchangers in chemical works.

Inconel
It contains 80% Ni, 14% Cr and 6% iron. It has high resistance to corrosion and oxidation at elevated temperatures. It can be readily cold and hot worked, but does not respond to heat treatment. It is widely used in processing uranium and for heating for high temperature heating elements.

Nichrome
Like Inconel it is also a nickel-chromium alloy which is extensively used in electrical appliances as a resistance wire.

Incoloy It is also a Ni-based alloy which is widely used as a *high temperature alloy.* It consists of 42% Ni,13 % Cr, 6% Mo, 2.4% Ti, 0.04% C and the rest iron.

K-monel
 It possesses composition as monel, but about 3 to 4% Al is added to it. It carries similar applications as monel, but has better mechanical properties than that.

Nimonic alloy
It contains 80% Ni and 20% Cr. It has high strength and ability to operate under intermittent heating and cooling conditions. It is widely used in gas-turbine engines.

BEARING METALS
A *Bearing metal* should possess the following important characteristics :
1.   It should have enough compressive strength to possess adequate load carrying capacity.
2.   It should have good plasticity to allow for small variations in alignment and fitting.
3.   It should have good wear resistance to maintain a specified fit.
4.   It should have low coefficient of friction to avoid excessive heating. Some important bearing metals are following :

Babbit metal
It is a white metal containing 85% tin, 10% Sb and 5% Cu. It is used for heavy duty bearings.

Lead alloy
 It contains 40% lead and 60% Cu. It may be cast in position or fused as a tin shell to a bronze or steel reinforcing shell outside.

Phosphor bronze
With 10% tin is used for light load low speed bearings. It can be sand and centrifugally cast.

Cadmium alloy
It contains 95% cadmium, 5% silver and a very small amount of iridium. It is used for medium loaded bearings subjected to high temperature.

Cintered metal
Bearings suitable for light and medium loads are made by sintering metallic powders. A popular composition consist

of 90% Cu, 10% tin and a small addition of graphite. Cintering is done at 700^0C. Oil retaining bearings can be made through this process.

OTHER ALLOYS
Dow metal
It is a magnesium-base alloy, containing 90% Mg, 10% Al and a small addition of Mn. Small additions of cadmium and copper increase its thermal conductivity considerably. It offers difficulty in cold working, blanking and drawing, but can be readily cast, forged and rolled. It has good weldability and can be machined. It is used in automobile and aircraft industries.

Beryllium copper
It is an alloy of copper and beryllium. The most popular alloy contains 2% beryllium. It has superior mechanical properties, comparable to steel, can be cold worked and heat treated. It has high corrosion resistance, high heat and electrical conductivity and is nonmagnetic. It can be sand or investment cast to produce castings requiring high strength, high electrical and thermal conductivity and greater stability. It is mainly used for springs, bellows, bordon tubes, diaphragms, and electrical contacts.

Hastelloy
It consists of 57% Ni, 20% molybdenum and 23% iron. It can be readily cold and hot worked and can be welded through usual methods. It has high resistance to acids and salts.

Another composition of *hastelloy* shows 45% Ni, 22% Cr, 1.5% Co, 0.5% W, 0.15% C, 9% Mo and the rest iron. It possesses high hardness and high yield strength. It is used as a *high temperature alloy*, such as for components in nuclear plants, aeroengines, rockets, etc.

Vitallium
It is another high temperature alloy with 62% cobalt as the main constituent. Other elements present include 28% Cr, 5.5% Mo, 2.5% Ni, 1.7% Fe and 0.28% C.

Aluminium brass
It is a special alloy containing 76% Cu, 22% Zn and 2% Al which finds its exclusive use in marine applications.

METALS USED IN NUCLEAR ENERGY
The requirements of nuclear plants, where nuclear energy is generated, have given impetus to the demand of such rare metals which were neither given any commercial importance nor were in wide use before World War II. These metals include Uranium, Thorium, Plutonium, Zirconium, Beryllium and Niobium. These metals are widely used as raw materials, fuels, moderators, reflectors, fuel canning materials, materials for making pressure vessels, and similar other requirements of generation and control of nuclear energy. These metals will now be described in the following articles.

URANIUM
It is a very widely used nuclear fuel. It is found to be very radioactive and can be easily oxidised. Pure uranium possesses poor corrosion resistance and is weak. Therefore, it is shielded through cladding process before being used as a fuel. *Cladding* involves covering it all around by a thin foil of aluminium through rolling process. However, its oxide has a high corrosion resistance, high refractioness and good strength. Also, its density is fairly high. The natural uranium deposits are known to carry two types of isotopes, called *uranium 238* and *uranium 235*. It can exist in three allotropic forms, but its oxide does not exhibit any change in phase in an inert atmosphere. Due to the above shortcomings it is used in nuclear industries in alloyed form. The common elements alloyed with it are molybdnum, zirconium, chromium, plutonium, etc. On account of its high density, the depleted uranium can be used with advantage in such applications where maximum weight is required to be put in a limited space, viz., in counter weights.

PLUTONIUM
It is not a natural element, but produced from uranium 238. Its melting point is 640^0C. It is highly toxic and chemically very reactive. It can be easily oxidised. It possesses natural fissionability and, therefore, high energy alpha and gamma rays and similar other radiations emit from it at a very fast rate. It exists in six allotropic forms. It is mainly used in fast breeding atomic reactors and in making atomic bombs. Radiation hazards are always possible while using plutonium compounds and alloys. As such, perfect health protection is essential while using these compounds and alloys.

THORIUM
It is also a radioactive and carries F.C.C. structure. Below 1480^0C no phase changes take place in it. With the help of neutron absorption and beta decay processes it can be converted into uranium 233. In its pure form it is soft and weak, but its mechanical properties can be substantially changed by adding small amounts of other elements. For examples,

addition of just 0.2% carbon increases its tensile strength substantially. Its strength is also increased with the addition of uranium. But, its strength and hardness decrease if titanium, zirconium or niobium are added to it while being processed it also emits alpha rays and releases a lot of radio- active material in the same manner as uranium. But, it is less susceptible to irradiation damages.

ZIRCONIUM

In its natural mineral form it may contain upto 2.0% *hafium,* due to which it exhibits high neutron absorption characteristics. It possesses a HCP/BCC structure, a melting point of 1852^{0}C and if fairly hard. When alloyed with certain other elements it offers excellent corrosion resistance to most of the acids and chlorides, good strength, good weedability and fatigue resistance. When alloyed with copper, it shows high electrical conductivity.

Because of its natural poor resistance to Co_2 at elevated temperature it can be made suitable for use in gas cooled reactors by adding 0.5% copper and 0.5% molybdnum. With these additions its tensile strength is also increased with a simultaneous increase in its creep resistance at 450^{0}C. Similarly, its popular alloy with 1.5% zinc, 0.1% chromium, 0.1% iron and 0.05% nickel, called *zircaloy-2*, offers high corrosion resistance and finds wide applications in water cooled reactors. Of course, as already stated above, it is widely used for cladding of fuel elements.

BERYLLIUM

It is a light metal with HCP structure and a melting point of 1283^{0}C. During its melting it is essential to have an inert gas atmosphere or vacuum because it is a very reactive metal and can readily form compounds by chemically reacting with the atmosphere inside the furnace or the refractories present inside. Beryllium in cast condition is brittle and carries coarse grains. Therefore, powder metallurgy techniques are employed for making its billets. In its pure form it quickly oxidises at temperatures above 760^{0}C. Its main applications are as a reflector, moderator and source of neutron.

NIOBIUM

It carries a BCC structure with a melting point of 2470^{0}C. It has very good compatibility with uranium. It offers very good corrosion resistance, specially to liquid sodium coolants. It is added to many base metals to produce high heat resistance alloys. However, it is quite expensive.

SUGGESTED BIS CODES FOR FURTHER REFERENCE.

IS 20 : 1977	IS 304 : 1981	IS 410 : 1977	IS 739 : 1977
IS 21 : 1975	IS 305 : 1981	IS 422 : 1981	IS 778 : 1984
IS 25 : 1979	IS 306 : 1983	IS 531 : 1981	IS 782 : 1979
IS 26 : 1979	IS 404 (Pt. 1) : 1977	IS 613 : 1984	IS 1028 : 1987
IS 28 : 1985	(Pt. 2) : 1979	IS 617 : 1975	IS 1284 : 1975
IS 191 : 1980	IS 405 (Pt.1) : 1977	IS 713 : 1981	IS 1550 : 1967
IS 202 : 1981	(Pt.2) : 1977	IS 733 : 1983	IS 1655 : 1968
IS 288 : 1981	IS 318 : 1981	IS 734 : 1975	IS 1972 : 1989
IS 291 : 1989	IS 319 : 1989	IS 737 : 1986	IS 2258 : 1981
IS 292 : 1983	IS 320 : 1980	IS 742 : 1981	IS 2479 : 1981
IS 2676 : 1981	IS 407 : 1981	IS 737 : 1986	IS 2590 : 1979
IS 4170 : 1967	IS 3168 : 1981	IS 6751 : 1972	IS 6912 : 1985
IS 6051 : 1970	IS 11804 : 1986		

CHAPTER - 5
NICKEL ALLOYS

Nickel is the chief constituent of a number of nonferrous alloys which are used in special applications in aircraft work. The main feature common to all of these alloys is their exceptionally good corrosion resistance. IN this respect they are equal to or better than corrosion-resistance steel. These nickel alloys work fairly and are obtainable commercially in most of the standard forms. Their use is gradually increasing in aircraft construction, as more designers realize how well fulfill specialized needs.

Three nickel alloys are of special interest to the aircraft designer : Inconel, Monel, and K Monel. *Inconel* is a nickel-chromium alloy with good corrosion resistance and strength at normal and elevated temperatures. These properties are ideal for airplane-engines exhaust collectors, which are frequently constructed of Inconel. *Monel* is a nickel-copper alloy with high corrosion resistance, reasonably good strength, and good working properties. *K Monel* is a nickel-copper-aluminium alloy with high corrosion resistance, exceptionally good strength (inherent as well as developed by heat treatment), and the property of being nonmagnetic. This latter property create a use for this material as structural members in the vicinity of compasses.

The following pages describe these three alloys in as much detail as the aircraft designer is likely to require. There may be some occasional gaps in the data, due to the fact that two of these alloys are recent discoveries and have not yet been exhaustively tested.

INCONEL
Inconel is a nickel-chromium alloy classified as nonferrous because the iron content is negligible. The relatively small amount of contained iron and carbon do not impart any of the characteristics of steel, such as transformation ranges and hardening by heat treatment. Inconel is a corrosion and heat-resisting metal. In aircraft work it is used more especially for exhaust collector but is rapidly acquiring new uses.

Chemical Properties The approximate composition of Inconel is :

Nickel	-	79.5%	Carbon	-	0.08%
Chromium	-	13.0%	Copper	-	0.20
Iron	-	6.5%	Silicon	-	0.25
Manganese	-	0.25%			

Chromium is added in the form of ferrochrome, which also accounts for the iron present. The high nickel content gives the metal good work ability and corrosion resistance, while the chromium contributes strength and a "stainless" or tarnish-resistant surface. An increase of iron up to approximately 20% has little effect on the properties, but above that percentage rusting occurs and the welding properties change. Inconel was selected from a series of experimental alloys (in which the constituent ranges had been varied and the properties investigated) as the alloy combining the best corrosion resistance, strength, and working properties.

Physical Properties

Density (grams per cubic centimeter)	8.51
Weight per cubic foot	533.5 pounds.
Weight per cubic inch	0.309 pounds.
Melting point	2540^0F, (1395^0C)
Modulus of elasticity (p.s.i)	31,000,000 to 32,000,000
Modulus of torsion (p.s.i)	10,000,000 to 11,000,000

STRENGTH PROPERTIES

Form and condition	Yield strength (0.20% offset) (1000 p.s.i)	Tensile strength (1000 p.s.i)	Elongation in 2 in (%)
Rod and bar -cold-drawn			
Annealed	25-50	80-100	50-35
As drawn	70-125	95-150	30-15
Rod and bar- hot-rolled			
As rolled	35-90	85-120	45-30
Annealed	25-50	80-100	50-35
Rod and bar-- forged	35-90	85-120	45-20
Wire-cold-drawn :			
Annealed	25-50	80-105	50-25
Regular temper	115-165	130-175	12-3
Spring.	150-175	165-185	10-2
Plate--hot-rolled			
Annealed	30-60	80-110	50-35
As rolled.	45-95	100-140	40-20
Sheet and strip -- standard cold-drawn			
Annealed	30-45	80-100	50-35
Hard sheet	90-125	125-150	15-2
Full-hard strip	120-160	145-170	10-2
Tubing-- cold-drawn			
Annealed	30-50	80-100	50-35
Drawn	65-140	110-160	20-2

Inconel has the property of retaining high strength at elevated temperatures. This property is particularly important when the metal is used in heating systems or for exhaust collectors. The tensile properties of annealed Inconel at elevated temperatures are shown in Figure 5.1.
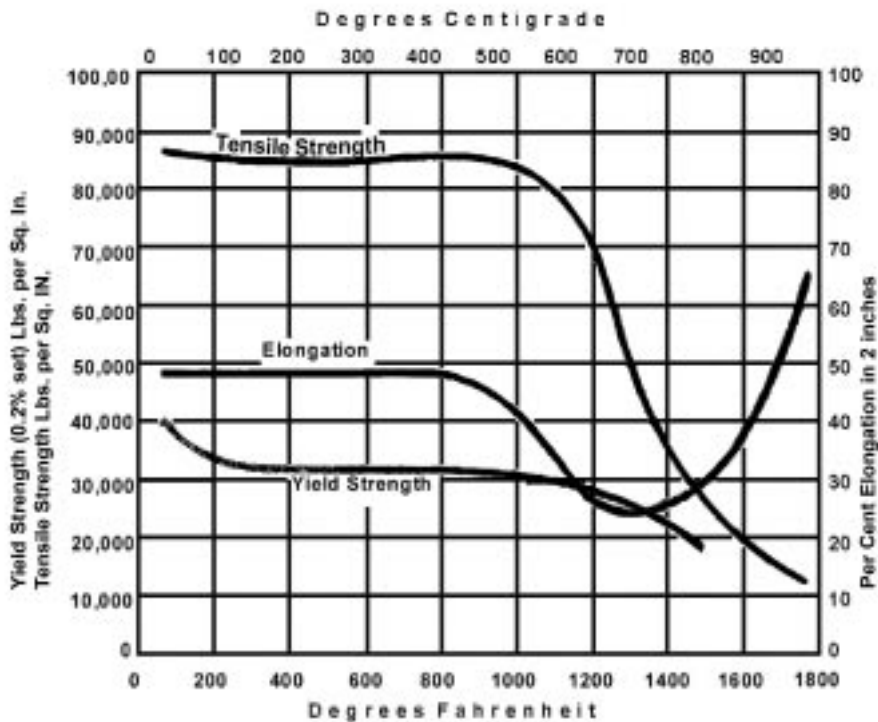
Fig.5.1.High-temperature Properties of Inconel

Impact toughness tests on a Charpy testing machines give an average reading of 200 foot-pounds without fracture of the specimen. Excellent toughness is indicated with a much higher value than steel and nonferrous alloys.

Wire up to 5/8-inch diameter can be cold drawn and given spring temper. After coiling the springs should be treated at 800^0F to release coiling strains, a necessary treatment if springs are to operate at elevated temperature up to 750^0F. The torsional elastic limit of Inconel spring wire is 100,000 p.s.i.

Annealing and Stress Relieving

The heat treatment of Inconel consists only of annealing processes which will relieve internal stresses due to cold working and for the purpose of softening the metal. Inconel cannot be hardened by heat treatment; it is only hardened by cold working.

Internal stresses set up during cold rolling or during fabrication may be relieved without appreciable softening by heating the metal for 1 hour at 800-900^{0}F. Cooling may be effected either by furnace cooling or quenching in air, water, or very dilute alcohol-water solution without changing the physical properties. Water or alcohol quench is preferable to reduce the amount of surface oxidation. Inconel springs should be given this stress-relieving treatment after cooling.

Softening of Inconel is obtained by heating the metal at 1800^{0}F for 10 to 15 minutes and quenching by any of the above methods. This softening treatment would be employed, for example, between draws where an excessive amount of cold work is to be done in the making of deep drawn articles.

In heating Inconel to temperatures above 700^{0}F the furnace atmosphere should be free from sulphur and active oxygen to avoid surface scaling. The chromium oxide which forms is removable with difficulty, only, by grinding or pickling.

Working Properties

As indicated by the elongation values gives under Strength Properties, Inconel is very ductile and can be readily formed in the annealed state. It hardens from cold working, not as rapidly as 18-8 corrosion-resisting steel but more rapidly than copper, aluminium, or Monel.

Forging must be done between 2300^{0}F and 1850^{0}F. As mentioned under heat treatment, all heating should take place in sulphur-free or very low sulphur nonoxidizing atmospheres. Shapes similar to those forged in steel may be readily produced.

Hot and cold rolling of sheets and strips is accomplished in a manner similar to that employed for steel. Rods are also hot rolled or cold drawn, and tubing---either welded or seamless---is cold drawn. Steel practice is in general followed in these operations.

Inconel castings can be made but suffer from high shrinkage. The metal must be poured fast and at as low a temperature as will permit free running, and still completely fill the mold.

Machining of Inconel is difficult and must be done at low speeds with carefully treated and sharpened tools. Considerable heat is generated in machining. Inconel machines uniformly with sulphur base oils, and does not drag or stick badly.

Inconel bends readily. Government specifications require that test pieces must withstand cold bending, any direction of the sheet, without cracking, through an angle of 180^0 on a diameter equal to the thickness of the test specimen. For shop work it would be advisable to call for bend radii equal to one thickness of the material.

Welding

Inconel welds readily and gives a strong , sound, ductile weld which resists corrosion. Welding may be done by electric arc, electric spot or seam (resistance welding), or with the oxyacetylene flame.

Oxyacetylene welding is used exclusively on engine exhaust manifolds and collectors because of the lightness of the gage. In this type of welding an Inconel rod coated with Inconel Gas-Welding Flux is recommended. The joint is also coated with a water paste of this flux on both surfaces to prevent oxidation. When a slightly reducing flame is used to avoid oxidation a uniform weld with excellent penetration is easily obtained. It is advisable when finishing off an Inconel gas weld to withdraw the flame slowly, as this procedure permits slower freezing of the crater and so avoids any porosity at the finish of the well.

Welded joints in the annealed metal develop the strength of the base metal. As evidence of ductility, welded sheet may be bent flat on itself, at right angles to the weld or along the welded seam, without the cracking of the weld.

There is no limitation on the thinness of sheet which can be welded with oxyacetylene other than the skill of the welder. It is also permissible to touch-up an imperfection in a weld without affecting the general soundness.

Electric arc welding of material heavier than 18 gage (0.050 inch) is practical

Welded tubing is produced from strip Inconel by automatic oxyacetylene and automatic atomic-hydrogen welding. This type of tubing approaches the soundness of seamless tubing (which is much more expensive) and can be annealed, drawn, swaged, and bent without failure. Welded tubing is superior to seamless tubing in uniformity of wall thickness, surface finish, and freedom from die scratches.

Welded joints in Inconel are not subject to intergranular deterioration nor do they suffer any metallurgical change other than a normal very slight softening. They do not require heat treatment to improve their corrosion resistance.
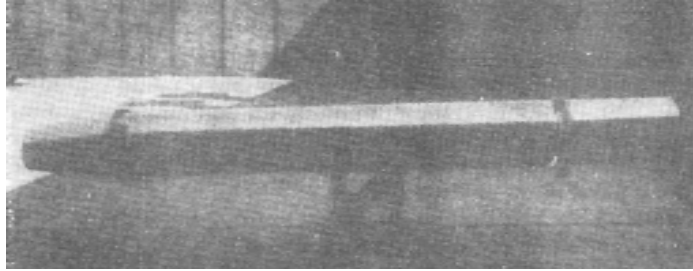
Fig.5.2. Jet Tail Pipe: Inconel.

Soldering and Brazing

Silver soldering and brazing are used where the strength of a welded joint is not required or the heat of welding would cause buckling. Both operations are performed with the oxyacetylene torch, but because of the low flow points of silver solders (1175^0F), naturally a much smaller flame is required than for welding. In silver soldering Handy Flux and Handy & Harman's Easy-Flo Brazing Alloy are recommended. Silver solders must have a low flow point to avoid cracking of the Inconel, which is hot short around 1400^0F. The recommended silver solder is of sufficiently low melting point to clear this range by an ample margin.

Soft soldering on Inconel is also possible, but care must be taken to insure a thorough bond with the metal. "Tinning" with an iron and the use of an active flux is recommended.
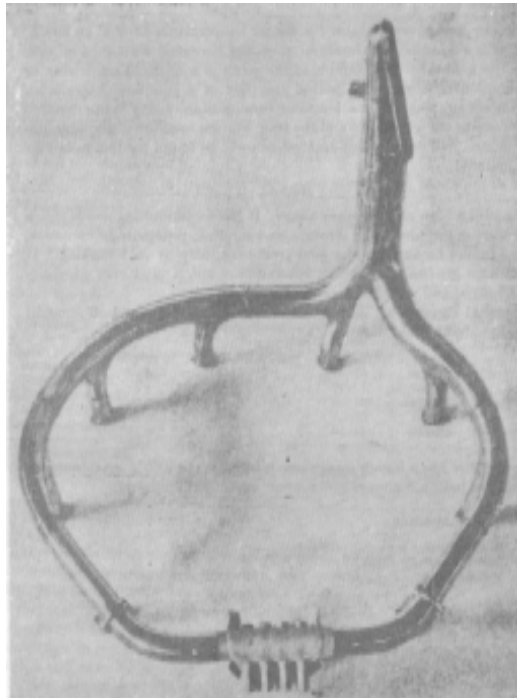
Fig.5.3. Exhaust Collector and Hot Spot ; Inconel

Corrosion Resistance

Inconel is practically corrosion resistant in normal atmosphere or in the presence of salt water. It is believed to be some what better than corrosion-resistant steel in this respect, but sufficient evidence is not at hand for a definite comparison.

Inconel welds are slightly more corrosion resistant than the parent metal . Due to the small amount of iron in Inconel, there is no trouble with carbide precipitation or intercrystalline corrosion as experienced with 18-8 corrosion-resistant steel after welding. Inconel welds should be cleaned after fabrication by immersing in a 50% (by weight) cold nitric acid solution for 5 to 10 minutes. This should be followed by a thorough water rinse.

Electrolytic corrosion or pitting of Inconel is almost negligible because of the high nickel content. Inconel is rated galvanically as a passive metal.

When heated above 700^0F in an oxidizing atmosphere chromium oxide is produced on the surface. This oxide can be removed only by grinding or picking. For exhaust collectors there is no point in removing this surface oxide, as it will simply reform as soon as the engine is run and the exhaust gets hot.

Available Shapes
Inconel is available commercially in the following forms :
    Sheet; Strip; Rod-hot rolled or cold drawn
    Tube-cold drawn seamless; welded
    Wire-cold drawn
    Castings

Uses
Inconel is ideally suited for use in the construction of heat exchanges, jet tail pipes, exhaust manifolds, and collectors. Its ease of forming and welding, combined with its strength at high temperatures and corrosion resistance, make a perfect combination of properties for this purpose. It's slightly greater weight, compare to corrosion-resistant steel, is one disadvantage, but this is compensated by the use of lighter material. Inconel exhaust collectors are usually made of 0.042- inch sheet and steel collectors 0.049-inch sheet, which makes the weights about equal.
A combined Inconel-asbestos packing is used for the scaling of exhaust joints.

Inconel springs are suitable for use at temperatures of 600^0 to 700^0 F. Inconel is also suited for locations requiring corrosion resistance or nonmagnetic qualities. An example of the latter is windshield framework or ammunition chutes located within two feet of a compass. Aluminium alloy is not suitable for these locations because of the bulky joints required in the case of the windshield and the poor wearing qualities of the ammunition chute. No doubt other applications will be found for this relatively new material.

MONEL
Monel is a high nickel-copper alloy. It has an interesting combination of properties including high strength and excellent resistance to corrosion. Monel cannot be hardened by heat treatment, only by cold working. It is not used generally in aircraft construction but is used very generally for industries and chemical applications.

Chemical Properties
The chemical composition for standard wrought Monel products is as follows :

Nickel	67%
Copper	30
Iron	1.4
Manganese	1.0
Silicon	0.1
Carbon	0.15

Spring wire has a higher manganese content up to 2.50% maximum. Castings have a higher silicon content up to 2.0% maximum.

Physical Properties

Density (grams per cubic centimeter)-cast	8.80
Density --- rolled	8.90
Melting point	2370-2460^{0}F.
	(1300-1350^{0}C.)
Modulus of elasticity tension	25,000,000-26,000,000
Modulus in torsion	9,000,000-9,500,000
Weight per cubic inch-cast	0.318 pound
Weight per cubic inch-rolled	0.323 pound

The magnetic transformation point of Monel is affected considerably by slight variations in composition and by mechanical and thermal treatment. Ordinarily a horseshoe magnet will attract Monel, but the pull of the magnet varies with temperatures and with the metal itself.

Annealing

Annealing for softening and the relief of cold-working strains is the only treatment for Monel metal. Hardening cannot be done by heat treatment, only by cold working.

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STRENGTH PROPERTIES

</div>

Form and condition	Yield strength (0.01% offset)* (1000 p.s.i.)	Yield strength (0.20% offset) (1000 p.s.i)	Tensile strength (1000 p.s.i)	Elongation in 2 in (%)
Rod and bar -- cold-drawn				
Annealed	20-30	25-40	70-85	50-35
As drawn	45-95	55-120	85-125	35-10
Rod and bar -- hot-rolled	30-55	40-65	80-95	45-30
Rod and bar-forged	25-65	40-85	75-110	40-20
Wire -- cold-drawn				
Annealed		25-40	70-85	50-30
Number 1 temper		50-85	85-110	20-5
Regular temper		85-130	110-140	15-4
Spring		130-160	140-170	10-2
Plate -- hot - rolled				
Annealed	20-30	25-45	70-85	50-30
As rolled	25-70	40-90	80-110	45-20
Sheet and strip --special cold-rolled				
Annealed		25-45	70-85	50-30
Hard sheet		90-110	100-120	15-2
Full-hard strip		90-130	100-140	15-2
Number 35 sheet		45-65	78-85	40-20
Sheet - standard cold-rolled		25-45	70-85	50-30
Tubing---cold- drawn				
Annealed		25-45	70-85	50-30
As drawn		60-120	90-125	20-10

* Proof Stress.

Stress-equalizing annealing is accomplished by heating to 525-650^{0}F., holding for one hour at temperature, and quenching in water containing 2% denatured alcohol. This alcohol-water quench will reduce the surface oxidation that takes place when the work is removed from the furnace. A silver white surface results. A pink color after the quench indicates oxidation in the furnace, improper heating conditions, or delay in quenching which permits excessive oxidation.

Soft annealing of material is done by heating to 1700^{0}F, holding for 3 to 7 minutes, depending on the severity of cold work that is to be performed, and quenching in alcohol-water solution.

Working Properties

Monel is similar to mild steel in its cold-working properties, such as cupping, drawing, bending and forming. Due to the higher elastic limit, greater power is required than for steel ; and for excessive working it is necessary to anneal frequently.

Hot working, such as forging and hot rolling, must be done between 2150^{0}F and 1850^{0}F. Heating for all high-nickel alloys should be done in sulphur-free atmospheres. These are obtainable by using gas or oil fuels, the latter carrying a specification on 0.5% (maximum) sulphur content. Coke or coal are not recommended because of their offending sulphur content. The combustion of the gases should be complete before these gases reach the surface of the metal. For that reason, combustion spaces must be large. Reducing atmospheres should be maintained. Cold-rolled or cold-drawn material is obtained by cold working hot-rolled material after pickling and annealing.

Sheet can be bent about a radius equal to one thickness of the material. The cold ductility of the metal is demonstrated in its ability to make sylphon type bellows and corrugated flexible tubing.

Machining of Monel can be done without difficulty. For automatic screw-machine work a machining-quality rod is available. Because of the great toughness of the metal, cutting speeds are slower and cuts are lighter than for mild steel. Tools should be of tough high-speed steel, ground with sharper angels that for steel, and honed. Sulphurized oil should be used abundantly as a lubricant for boring, drilling and so on. It is preferred for all work, though water-soluble oils suffice for lathe work. R Monel is available for automatic machine work where high cutting speeds must be maintained.

Welding

Monel can be readily welded by any of the methods commonly used for steel, among them oxyacetylene, carbon-arc and metallic-arc, spot, seam, butt, and flash welding. The method to use depends on the gage of material to be joined and the type of equipment to be made. Sound, strong, ductile welds are regularly made.

When oxyacetylene welding Monel, a slightly reducing flame neither harsh nor mild is maintained. A flux (Inco Gas-Welding & Brazing Flux) in the form of water paste is painted on parts to be welded and on the welding rod. The pool of weld metal should not be puddled or boiled, but kept quite ; otherwise the "life" of the metal may be burned out.

The metallic-arc welding of Monel is carried out by using a flux-coated Monel wire of the shielded-arc type capable of producing X-ray-perfect welds. Reversed polarity is used. Welds are made with single and multiple beads, but, of course, in the latter case the flux and slag must be removed before laying down subsequent beads.

Carbon-arc welding is similar to acetylene welding in that a source of heat in the form of an arc flame is used instead

of an oxyacetylene flame. Small-diameter pointed carbons (/ / inch) are used, together with a lightly fluxed Monel

filler wire.

Soldering

Soft soldering is a convenient easy means of joining where corrosion and contamination are not troublesome and where strength is not required. Soft solder is inherently weak and must not be used where finished equipment will be subjected to vibration or high stresses. Pre-tinning of the edges prior to forming is desirable. Either high- or- low- tin solders are satisfactory ; the 50-50 lead-tin is the more widely used with zinc chloride base fluxes.

Silver solders are also used for joining Monel, the procedure outlined under Inconel being applicable.

Uses

Monel has been used in the manufacture of oil coolers, stainers, and rivers for use with stainless steel.

KMONEL

K Monel is a nonferrous alloy composed mainly of nickel, copper, and aluminium. It is produced by the addition of a small amount of aluminium to Monel. It is corrosion resistant and can be hardened by heat treatment - two properties which are very important. K Monel has been successfully used for gears, chains, and structural members in aircraft subject to corrosion attack, K Monel being nonmagnetic is sometimes used for structural members in the vicinity of a compass.

Chemical Properties The approximate composition of K Monel is :

Nickel	66%
Copper	29
Aluminium	2.75
Carbon	0.15
Iron	0.90
Manganese	0.85
Silicon	0.50

Physical Properties

Density (grams per cubic centimeter)	8.47
Melting point	2400-2460⁰F.
	(1315-1350⁰C.)
Modulus of elasticity (tension) (p.s.i)	25,000,000-26,000,000
Modulus of torsion (p.s.i)	9,000,000-9,500,000
Weight per cubic inch	0.31 pound.

Cold-rolled, soft material is obtained by a softening heat treatment. It should be specified where great softness is necessary for fabricating operations. Structural parts made from this material should normally be hardened by heat treatment after fabrication. Secondary parts are often left in the soft state. It should be noted that the strength values given for the soft material are maximum values.

Cold-drawn material is the strongest grade that can be machined reasonably well. For this reason it is usually specified for machined parts that are to be used without further heat treatment.

The heat-treated materials are cold worked and the given full heat treatment, which makes them hardest and strongest. These grades can be machined only with difficulty. They should be specified only for parts that can be purchased finished or can be finished by grinding.

STRENGTHPROPERTIES

Form and condition	Yield strength (0.01% offset)* (1000 p.s.i.)	Yield strength (0.20% offset) (1000 p.s.i)	Tensile strength (1000 p.s.i)	Elongation in 2 in (%)
Rod and bar				
Cold-drawn				
Annealed		40-60	90-110	45-35
Annealed, age-hardened	70-100	90-110	130-150	30-20
As drawn		70-100	100-135	35-13
As drawn, age-hardened	80-125	100-130	140-170	30-15
Hot-rolled				
As rolled		40-90	90-120	45-25
As rolled, age-hardened	80-110	100-120	140-160	30-20
Forged				
As forged		40-90	90-120	40-25
As forged, age-hardened	80-115	100-125	40-165	30-20
Wire -- cold-drawn				
Annealed		40-60	90-110	45-30
Annealed, age-hardened		90-110	130-150	30-15
Spring		130-155	145-175	4-2
Spring, age-hardened		150-175	160-200	8-3
Strip -- cold-rolled				
Soft		50-65	90-105	45-25
Soft, age-hardened		90-110	130-150	25-10
Half-hard		85-105	125-145	20-5
Half-hard, age-hardened		110-130	150-180	15-3
Full-hard		105-120	145-165	8-2
Full-hard, age-hardened		125-145	170-200	10-2

* Proof Stress

Wire up to ¼ inch can be cold drawn and heat treated to above 175,000 p.s.i. for use as springs. This is full-hard material. The wire must be in the cold-drawn condition when coiled if maximum strength is desired after heat treatment. If the spring is made from soft wire or formed hot, subsequent heat treatment will only develop intermediate properties. The reason for this action is explained under Heat Treatment, below.

K Monel is nonmagnetic at all normal temperatures. Its magnetic permeability is 1.0, which is the same as air. This property is extremely important for parts located in the vicinity of a compass.

Heat Treatment

Annealing or softening of K Monel is obtained by soaking at one of the following temperatures for the time specified :

    1600°F.   5 to 10 min.
    1800°F.   1 to 4 min.

Quenching must be done in water for sections over ½- inch thick, or in oil for smaller sections. K Monel will not soften, if cooled in air, as it requires a rapid quench.

The maximum hardness that can be attained by heat treatment alone, starting with soft K Monel, is equivalent to about

300 Brinell. How ever, if the hardness of soft material is increased by cold working and then heat treated, the additional hardness developed by the heat treatment is superimposed on the cold-working hardness. Thus, cold-worked metal with a Brinell hardness of about 250 can be further hardened by heat treatment to 350-400 Brinell.

Hardening by heat treatment is obtained by following the procedure outlined below, depending on the initial hardness of material :

Material condition	Treatment (^{0}F.)	Time at temperature
Soft : 140 to 180 Brinell	1200-1250 or 1080-1100	1 hr. 16 hrs.
Moderately cold worked : 175 to 250 Brinell	1080-1100	8 to 16 hrs.
Fully cold worked : over 250 Brinell	980-1000	6 to 10 hrs.

The longest time should be used for the softest material. For best possible hardness, the material should be cooled not faster than 15^{0}F. per hour down to 900^{0}F. Furnace cooling is essential.

K Monel can be stress-relief annealed after cold working by heating to 525^{0}F. and quenching. No softening occurs due to this treatment.

In heating K Monel the fuel should be free from sulphur and a reducing atmosphere maintained in the furnace to avoid excessive oxidation. K Monel should bot be placed in a cold furnace and heated gradually, but should be charged into the hot furnace.

Working Properties

K Monel can be worked quite readily in the shop in the annealed form. Working above this grade is difficult, due to the greater hardness.

Hot working of K Monel should only be done between 2175^{0}F. and 1700^{0}F. The metal should be quenched in water from the finishing temperature above 1700^{0}F. Annealed soft material will then be obtained.

Cold-drawn rod is produced from hot-rolled rod that is annealed, pickled, and cold drawn to size in two or more operations through chromium-plated hardened steel dies.

Cold-rolled strip or sheet is produced from hot-rolled material by annealing, pickling, and cold rolling to the desired hardness. The maximum hardness obtainable by cold rolling without subsequent heat treatment is known as the full-hard condition.

Wire is cold drawn in the same manner as rod but the percentage of cold reduction is greater. Spring wire is cold drawn to 25% of the original cross-sectional area. As noted under heat treatment, in order not to anneal out any of the effect of cold working this grade material is not heated as high as the softer materials. Heat treatment at 980-1000^{0}F. will give a tensile strength of 175,000 to 200,000 p.s.i.

Hot-rolled or cold-drawn rod can be machined satisfactorily. Heat-treated material can only be machined with difficulty. A special free-machining grade, known as KR Monel, is available for high-production parts on screw machines, turrets, etc. The mechanical properties are slightly lower than for K Monel.

Welding

K Monel sheet has been successfully welded by oxyacetylene. A rod of the same material and a flux composed of half sodium fluoride and half Inco (a welding and brazing flux prepared by the International Nickel Company) mixed with water to form a paste can be used. Another satisfactory flux consists of 5 to 6 parts of chromalloy flux mixed with 1 part of fluorspar powder. A slightly reducing flame should be used. The weld obtained is ductile and can be bent flat on itself without cracking. The weld will respond to heat treatment.

Electric arc welding of K Monel is readily accomplished. Spot, seam, and flash welding can also be used.

Brazing

 K Monel can be brazed readily and with good results by the use of Handy & Harman's Easy-Flo Brazing Alloy and Handy Flux. Care should be taken to have the edges of the sheets perfectly smooth or cracking will result because of hardness of the metal. The minimum amount of heat necessary to completely flow out the silver solder should be supplied to the joint.

Corrosion

K Monel is naturally corrosion resistant and does not rely upon a protective film, such as oxide formed on the surface. It is resistant to corrosion in normal atmospheres or in salt water.

Electrolytic corrosion does not affect K Monel since it is high in the galvanic series, but if coupled with steel or aluminium, it may cause corrosion of these metals.

As purchased, K Monel will usually be received in a nontarnished condition. If subsequent heat treatment is performed, the metal surface will oxidize. This oxide can be removed by pickling. The manufacturer will gladly furnish the proper pickling solution that should be used for any given set of conditions.

Available Shapes

 K Monel is commercially available as strip, wire, rod and forgings. Forged stock can be obtained to suit any possible requirements in aircraft work.

Uses

K Monel is used for instrument parts and for structural parts in the vicinity of compasses because of its nonmagnetic quality. The corrosion resistance and excellent strength qualities of this material make it practical for machined parts that are subject to corrosion. Specific examples of this use are gears and chains for operating retractable landing gears on amphibian airplanes.

SPECIFICATIONS

Inconel :

AN-N-4	Wire and welding rod
AN-QQ-N-268	Bars, forgings and rods.
AN-QQ-N-271	Sheet and strip
AN-WW-T-831	Tubing, seamless, round
An-WW-T-833	Tubing, welded, round

Monel :

Federal QQ-N-281	Forgings, rods, sheet, wire
Navy 46 M7	Forgings, rods, sheet, wire
Navy 44 T38	Tubing

K Monel :

Federal QQ-N-286	Forgings, rods, strip, wire
Navy 46N5	Forgings, rods, strip, wire

CHAPTER - 6
COPPER AND ITS ALLOYS

Copper, brass, and bronze have a limited use in aircraft construction. They do have important specialized applications, however, such as bearings and fuel and oil lines. Copper wire is used throughout the electrical system. In general these metals are corrosion resistant, nonmagnetic, fairly strong, and good conductors of electricity.

COPPER
Copper Tubing
Copper tubing is very generally used for fuel and oil lines. The copper used in the manufacture of this tubing must contain at least 99.90% copper. The tubing is purchased in the soft annealed condition and it is seamless drawn. In the purchased condition or after annealing it has the following physical properties.

Ultimate tensile strength (p.s.i)	32,000
Yield point (p.s.i)	6,000
Elongation (%)	52%
Rockwell hardness	63 (B- / -100)

This tubing can be annealed by heating it in an air furnace at 1100-1200^{0}F. and quenching it in water. To obtain the maximum softness and ductility the tubing should be held at temperature longer than 5 minutes.

Copper tubing is available in sizes ranging from / to 1 / inches outside diameter. A wall thickness of 0.035 inch is used up to / -inch diameter and 0.049 inch for larger diameters. These sizes cover the standard requirements for aircraft fuel, oil, and water lines. For high-pressure oxygen lines a special high-pressure copper tubing is used.

Copper-Silicon-Bronze Tubing
This tubing is considerably stronger than pure copper tubing and has largely superseded it for fuel, oil, water and air lines.

CHEMICAL COMPOSITION (%)

Silicon	1.00-5.00	Iron (max.)	2.50
Manganese (max.)	1.50	Impurities (max.)	0.50
Zinc (max.)	2.50	Copper	remainder

This tubing has a tensile strength of 50,000 p.s.i. and an elongation of 35%. It is used in the following standard sizes: 1/8×0.035, 3/16×0.035, 1/4×0.035, 5/16×0.035, 3/8×0.035, 7/16×0.035, 1/2×0.035, 5/8×0.035, 3/4×0.049, 7/8×0.049, 1×0.049, 1 1/8×0.049.

This tubing can be annealed at a temperature of 1000-1100^{0}F. if required after severe forming and bending.

Copper Wire
A soft copper wire is used as a locking wire in aircraft construction. It is drawn from pure copper and has a tensile strength approaching 40,000 p.s.i. and an elongation of 25%.

Beryllium Copper
This material is a high-strength, heat-treatable, nonmagnetic alloy available as bar, rod, sheet, strip and wire. Its density is 0.298 lb./cu. in.

CHEMICAL COMPOSITIONS (%)

Beryllium	2.00 - 2.25
Elements added to obtained special properties	0.50 max.
Metals (impurities) other than above .	0.50 max
Copper	remainder

PHYSICAL PROPERTIES

	U.t.s. (p.s.i.)	Yield point (p.s.i.)	Elongation (%)
Bars, rods, forgings			
Annealed (over ⁄ ")	80,000 max.		35
Cold-drawn (over ⁄ ")	80,000 min.		5
Annealed (⁄ to ⁄ ")	80,000 max		35
Cold-drawn (⁄ to ⁄ ")	95,000 min.		5
Annealed, heat-treated	150,000 min.	85,000	10
Cold-drawn, heat-treated	175,000 min.	88,000	3.5
Sheet and Strip (cold-rolled)			
Soft annealed	80,000 max.		35
Soft annealed, heat-treated	150,000	90,000	7.5
⁄ hard	80,000		10
⁄ hard, heat-treated	160,000	92,000	5
⁄ hard	90,000		5
⁄ hard, heat-treated	170,000	93,000	2.5
Full hard	100,000		2
Full-hard, heat-treated	180,000	95,000	2
Wire			
Soft annealed	80,000 max		35
Soft annealed, heat-treated	150,000		5
⁄ hard	90,000		5
⁄ hard, heat-treated	160,000		3
⁄ hard	100,000		2
⁄ hard, heat-treated	180,000		1.5

This material is annealed by heating at 1440^0F for ⁄ to 3 hours and quenching . Hardening is accomplished by holding at 525-575^{0}F up to 3 hours, depending on the properties required. Heat-treated material is considered to have more stable and uniform properties and is preferred for aircraft work.

BRASS

Brass is a copper alloy consisting of a solid solution of zinc in copper. In addition to zinc and copper, brasses sometimes contain a small amount of aluminium, iron, lead, manganese, magnesium, nickel, phosphorus, or tin. Brass with a zinc content of 30% to 35% is very ductile, and with 45% zinc content it has a relatively high strength. Brasses with a zinc content up to 37% are in so-called "alpha solution," while above that percentage a "beta solution" condition exists. It is the difference between these two conditions that accounts for the ductility of the low-zinc brass and the strength of the high-zinc brass. Alpha-solution brass can only be annealed, but beta-solution brass can be increased in strength by heat treatment.

Muntz Metal

Muntz metal is a brass composed of 60% copper and 45% zinc. It has excellent corrosion-resisting qualities in contact with salt water. It can be increased in strength by heat treatment. When heated to 1500⁰F. the beta solution absorbs the alpha solution. If quenched in water from this temperature, the homogeneous beta condition is retained and the strength increased about 50%. If the heated metal is cooled slowly as in air, the absorbed alpha is reprecipitated and the properties of annealed material are obtained.

PHYSICAL PROPERTIES

	Heat treated	Anneale
Ultimate tensile strength (p.s.i)	80,000	57,000
Yield point	60,000	20,000
Elongation (%)	9.5	48
Hardness (Brinell 10mm, 500 kg)	158	80
Weight (lb./cu. in.)	0.303	0.303

As cast this metal has an ultimate tensile strength of 50,000 p.s.i. and an elongation of 18%. It is used in the manufacture of bolts and nuts, as well as parts in contact with salt water.

Manganese Bronze (Brass)

Manganese bronze is really a high-zinc brass. It is exceptionally strong, tough, and corrosion resistant.

CHEMICAL COMPOSITION (%)

Copper	57-60	Manganese (max)	0.50
Tin	0.5-1.5	Aluminium (max.)	0.25
Iron	0.8-2.0	Lead (max)	0.20
Zinc	remainder	Impurities (max).	0.10

PHYSICAL PROPERTIES OF WROUGHT MANGANESE BRONZE

	U.t.s.(p.s.i)	Yield point (p.s.i)	Elongation (%)
Rods and bars, half-hard	72,000	36,000	20
Rods and bars, hard	85,000	60,000	5
Shapes, soft	55,000	22,000	25
Plates, soft	57,000	22,000	20
Plates, half-hard	60,000	24,000	18

This metal can be forged, extruded, drawn, or rolled to any desired shape. It is generally used in rod form for machined parts when used at all in aircraft construction.

A casting variation of this alloy known as manganese-aluminium bronze has the following chemical composition :

CHEMICAL COMPOSITION (%)

Copper	60-68	Manganese (max)	2.5-5.0
Tin	0.50	Aluminium (max.)	3.0-7.5
Iron	2.0-4.0	Lead (max)	0.20
Zinc	remainder		

This type of casting has an ultimate tensile strength of 110,000 p.s.i., a yield strength of 60,000 p.s.i., and an elongation of 12%. This material can be sand cast or centrifugally cast in permanent molds.

Hy-Ten-Sl-Bronze

This is the trade name of a very high strength copper alloy resembling manganese bronze in chemical composition.

PHYSICAL PROPERTIES

	Sand cast	Forged, rolled, extruded
Ultimate tensile strength (p.s.i)	115,000	120,000
Yield point (p.s.i)	70,000	73,000
Elongation (%)	10	8
Weight (lb./cu. in.)	0.280	0.280

With lower strength but higher elongation this alloy is also available in four other grades. It is reputed to be extremely hard, wear-resistance, noncorrosive, and readily machinable, and is recommended for bearings or bushings subject to heavy loads.

Naval Brass (Tobin Bronze)

Naval brass is often called Tobin bronze. It is not as strong as manganese bronze but has greater strength, toughness, and corrosion resistance than commercial brass. It is used for turnbuckle barrels, bolts, studs, nuts and parts in contact with salt water.

CHEMICAL COMPOSITION (%)

Copper	59.0-62.0	Iron (max.)	0.10
Tin	0.5-1.5	Lead (max)	0.20
Zinc	remainder	Impurities (max.)	0.10

PHYSICAL PROPERTIES

	U.t.s.(p.s.i)	Yield point (p.s.i)	Elongation (%)
Rods and bars, soft	54,000	20,000	30
Rods and bars, half-hard	60,000	27,000	25
Rods and bars, hard	67,000	45,000	22
Shapes, soft	56,000	22,000	30
Plates, soft	52,000	20,000	30
Plates, half-hard	56,000	28,000	25
Sheets and Strips, soft	50,000	20,000	20
Sheets and strips, half-hard	60,000	25,000	15
Castings	30,000		15
Tubing	67,000	45,000	15

Naval brass has excellent machining qualities and is used for screw machine parts. Turnbuckle barrels are made of this material, using either hard rod or tubing. The rod is in accordance with specification An-QQ-B-646 and the tubing with specification AN-T-20.

Red Brass Red Brass is sometimes classified as a bronze because of its tin content. Castings made from red brass are used in the manufacture of fuel- and oil-line fittings. It has good casting and finishing properties and machines freely.

CHEMICAL COMPOSITION (%)

Copper	84.0-86.0	Iron (max.)	0.25
Tin	4.0-6.0	Phosphorus (max)	0.75
Lead (max)	4.0- 6.0	Antimony (max.)	0.25
Zinc	4.0-6.0	Impurities (max.)	0.15

BRONZE

Bronzes are copper alloys containing tin. Lead, zinc, and phosphorus are also present in some bronze but do not total more than 15%. There is also an aluminium bronze in which aluminium is the major alloying element. The true bronzes have up to 25% tin, but those containing below 11% tin are the most useful. Bronzes have excellent bearing qualities due to the fact that the tin is in a hard delta solid solution in the copper. This hard delta solution distributed through the alpha metal gives ideal bearing properties. Delta solution is only present in bronze with over 9% tin content. When less tin is present it is in alpha solution. It is possible to improve the strength of copper-tin bronzes through heat treatment. The exact response to heat treatment depends upon the state of solution of tin . The bearing qualities are impaired if the delta solution is removed or changed by heat treatment.

Gun Metal

Gun metal is a hard bronze casting material. Its shrinkage is not great and it has fair machinability. It is recommended for use under severe working conditions and heavy pressure as in gears and bearings.

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CHEMICAL COMPOSITION (%)

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Copper	86.0-89.0	Lead (max)	0.20
Tin	9.0-11.0	Iron (max.)	0.60
Zinc	1.0-3.0		

Gunmetal castings have an ultimate tensile strength of 30,000 p.s.i. a yield point of 15,000 p.s.i., and an elongation of 14%. It should not be used where the temperature will exceed 500^0F. When used for bearings, it should not be annealed, or the hard delta eutectoid will be removed.

Phosphor Bronze

Phosphor Bronze can be obtained in the following forms : rod, bar, sheet, strip, plate, and spring wire. It is used for the manufacture of bolts, valve disks, electric contacts, and small springs.

<div align="center">

CHEMICAL COMPOSITION (%)

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Copper (min.)	94.0	Lead (max)	0.20
Tin (min.)	3..5	Iron (max.)	0.10
Phosphorus	0.05-0.50		

PHYSICAL PROPERTIES

	U.t.s.(p.s.i)	Yield point (p.s.i)	Elongation (%)
Rods and bars			
Up to ⁄ inch	80,000	60,000	12
Over ⁄ to 1 in	60,000	40,000	20
Over 1 to 3 in	55,000	30,000	25
Over 3 in	50,000	25,000	25
Sheet and Strips			
Spring temper, 0-8 in. wide	90,000	45,000	1
Spring temper, 8-12 in. wide	80,000	40,000	1
Half-hard, all sizes	50,000	25,000	25
Spring wire			
Up to .025 in	150,000		
Over .025 to .0625 in	135,000		1.5
Over .0625 to .125 in	130,000		2
Over .125 to .250 in	125,000		3.5
Over .250 to .375 in	120,000		5
Over .375 to .500 in	105,000		9

Phosphor Bronze Casting Alloy

They casting alloy is sometimes called a leaded phosphor bronze or leaded gun metal. It machines more easily than gun metal. It is used for bearings, bushings, gears, and other applications requiring good strength and resistance to saltwater corrosion.

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CHEMICAL COMPOSITION (%)

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Copper	86.89	Phosphorus (max)	0.05
Tin	7.5-11.0	Iron (max.)	0.10
Zinc	1.5-4.5	Nickel (max.)	0.75
Lead	0-0.3		

This alloy has an ultimate tensile strength of 40,000 p.s.i. and an elongation of 20%.

Aluminium Bronze

Aluminium bronze possesses greater resistance to corrosion than manganese bronze, and hence may be used where greater strength and corrosion resistance is required. It has good bearing qualities as well as great strength. It may be readily forged. It is available commercially in the form of bars, rods, shapes, plates, and sheets.

Bar and rod can be purchased to specification AN-B-16. This material is frequently used for fluid connection fittings and coupling sleeves.

CHEMICAL COMPOSITION (%)

Aluminium	6.5-11.0	iron (max.)	4.0
Manganese (max)	2.0	*Nickel (max)	5.5
Tin (max)	0.60	*Silicon (max)	2.25
Copper	remainder		

*If large amounts of either nickel or silicon are present the other element may not exceed 0.25% maximum.

PHYSICAL PROPERTIES

	U.t.s.(p.s.i)	Yield point (p.s.i)	Elongation (%)
Rods and bars			
Up to ⁄ in	90,000	45,000	15
Over ⁄ to 1 in	88,000	44,000	15
Over 1 in	85,000	42,000	20
Shapes (all sizes)	75,000	35,000	20
Plates, Sheets, Strips			
Up to ⁄ in, under 30 in wide	60,000	24,000	25
Up to ⁄ in, over 30 in. wide	55,000	22,000	25
Over ⁄ in, all widths	50,000	20,000	30

Aluminium Bronze casting Alloy

This alloy is as hard as manganese bronze, and has great strength and resistance to corrosion, shock, and fatigue. It is used for worm gears, valve seats, bearings, and propeller hub cones.

Specification AN-QQ-B-672 described this material.

CHEMICAL COMPOSITION (%)

Copper(min)	78.0	Manganese (max.)	5.0
Aluminium	10.5 - 12.0	Nickel (max.)	5.0
Iron	2.0 - 5.0	Tin (max.)	0.20

This material after heat treatment has an ultimate tensile strength of 85,000 p.s.i. minimum, and a minimum elongation of 3%.

Bronze Cable

Extra-flexible bronze cable, 7 by 19 stands, is manufactured for aircraft use. The weight and breaking strength for each size of cable is as follows :

Diameter (inch)	Weight 100ft. (pounds)	Breaking strength (pounds)
⁄	72.0	14,000
⁄	60.4	11,350

/	48.8	8,900
/	38.4	6,800
/	29.9	5,100
/	20.0	3,500
/	13.5	2,500
/	10.7	2,000
/	7.3	1,500
/	5.0	1,000
/	3.3	700

Many of the brasses and bronzes are subjected to a phenomenon called season cracking. These metals crack spontaneously after being in services for a period of time. It is believed this cracking is due to internal stresses left in the metal by cold working. A low-temperature anneal is usually sufficient to relieve these stresses and avoid season cracking.

Specifications generally require the following test for material subject to season cracking : the sample is thoroughly cleaned with nitric acid and then dipped into a mercurous nitrate solution for 15 minutes. This solution consists of 100 grams of mercurous nitrate and 13 cubic centimeters of nitric acid (specific gravity 1.42) dissolved in a liter of water. After removal from the solution, the sample is washed with water and then alcohol. The sample will crack visibly within 24 hours after this treatment if the material is subject to season cracking. This treatment is sometimes called a *strain test*.

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CHAPTER -7
WROUGHT ALLUMINIUM ALLOYS

At the present time aluminum alloys are used almost exclusively in the construction of aircraft. Aside from fittings carrying high concentrated loads, or parts subject to severe wear, or special forms of corrosion for which special steel alloys are used- the general structure of the airplane as built today is aluminium alloy. The ascendancy of this material

is due to its light weight, high strength, ease of fabrication, and its availability in all standard forms. It is about ╱ as

heavy as steel and can be obtained with a minimum ultimate tensile strength as high as 78,000 p.s.i. It is available in many tempers and forms, so that just the proper material may be selected for any particular application. These applications vary from formed cowling requiring a very ductile material to highly stressed wing beams requiring great strength.

Aluminium is found in most clays, soils and rocks, but the principal commercial source is the ore *bauxite.* Bauxite is largely aluminium oxide mixed with impurities. These impurities are removed by a chemical process leaving the pure aluminium oxide, *alumina.* An electrolytic process is used to obtain aluminium from the oxide. It was not until 1886 that a practical process was discovered to effect this separation on a commercial scale. In that year, Charles M. Hall in this country and P.L.T. Heroult in France, working independently, each discovered a practical process. The industries development of aliminum began shortly ofter these discoveries.

The metallic aluminum obtained by the electrolytic process is cast into pig form. These pigs are later remelted to form the commercial ingots used in rolling, forging, extruding, and other fabricating processes. By the addition of other constituents during the remelting operations, many alloys of aluminum are obtained with varying properties. A great many structural shapes are wrought from the ingots by rolling, drawing, extruding, or forging. The common shapes used in aircraft construction are : sheet, tubing, wire, bar, angles, channels, Z-section, U-section, and so on. A number of the aluminum alloys are especially adapted for casting. Castings are regularly made in sand molds, permanaent molds, or dies. As with other materials, castings do not have as great a strength as wrought material, but find numerous applications in aircraft.

In order to identify the various aluminum alloys, they are designated by a number. If this number is followed by the letter S it indicates a wrought alloy. Casting alloys are designated by a number without the S. Thus 3S, 13S, 17S, 24S, 52S, 61S are all wrought alloys, differing from each other in chemical composition and physical properties. Commonly used castings alloys are 43, 142, 195. The exception to this rule is wrought material produced by the Reynolds Metals Company and designated as R303, R353, and R 361 without an S.

Fig.7.1Grumman Navy Fighter; Aluminum-alloy Construction

In a few cases a letter precedes the alloy number, as A17S. This letter indicates that this alloy has a slightly different chemical composition from the normal 17S alloy.

The wrought alloys can be manufactyred in a number of different tempers. To distinguish these tempers another letter or symbol is added to the S. Hence the temper of a wrought alloy that is strain-hardened by cold work is designated

by $\diagup$ H, $\diagup$ H, $\diagup$ H, H ; H stands for "hard" and the fractions indicate the relative hardness. When the material is in the soft, annealed state, the letter O is appended to the S. For instance, 3S material is available in five tempers, which bear the following designations 3SO, 3S $\diagup$ H, 3S $\diagup$ H, 3SH.

Wrought alloys that are hardened by heat treatment are indicated by the addition of a T. Thus we have 14ST, 17ST, 24ST, 25ST, 53St, 75ST, R301-T.

These heat-treatable alloys in the soft, annealed state are designated by the letter O as 14SO, 17SO, 24SO, 25SO, 53SO, 75SO, R301-O.

Alloys in the heat-treated temper may be strain-hardened to improve their physical properties. When this is done the alloy is designated by the insertion of an R between the S and T, as in 17SRT, 24SRT. Some of the heat-treatable alloys are subject to an intermediate heat treatment, and do not develop their full strength until given a second heat treatment, and do not develop their full strength until given a second heat treatment called a "precipitation heat treatment." After this latter heat treatment, they are identified by the letter T following the S, as described above. When only subjected to the intermediate heat treatment, these alloys are identified by adding a W. Thus we have 25SW, 53SW, 61SW, R301-W.

In some instances an alloy may be heat treated in more than one way to obtain special physical properties. If a modified heat treatment is used the aloy is identified by a number after the normal heat-treatment designation. Thus we have 53ST, 53S-T5, 53S-T61.

Some casting alloys require a heat treatment in order to develop their best properties. These alloys are denoted by their number, followed by a symbol designating the heat treatment. We have, therefore, 195-T4, T4 indicating the heat treatment. This particular alloy is very generally used in aircraft construction.

CLASSIFICATION OF WROUGHT ALLOYS

As indicated above under Nomenclature, the wrought aluminum alloys may be broadly classified under one of two groups as either *strain-hardened alloys* or *heat-treatable alloys*. In the first group the physical properties are improved solely by cold working, whereas in the heat-treatable group the properties are improved by heat treatment. Further improvement of the heat-treated group is obtainable by cold working slightly after heat treatment. The strain-hardened alloys do not respond to any heat treatment other than a softening, annealing treatment.

The two extreme tempers in which all strain-hardened alloys can be obtained are the soft annealed temper and the full-hard temper. The latter temper is produced by cold working the metal the maximum amount that is commercially practical. The intermediate tempers such as ¼ H, ½ H, and 3/4 H are produced by varying the amounts of cold work after annealing. In the manufacture of sheet, tubing, or wire the cast alloy ingot is broken down while hot into slabs, tube blooms, or rods. The amount of reduction in area of these sections by cold working can be closely controlled by the

setting of the rolls, or by the mandrel can be closely controlled by the setting of the rolls, or by the mandrel and die sizes selected. To obtained the intermediate tempers, it is only necessary to anneal the material at the proper size from which remaining cold-finishing operations will give the desired temper.

The heat-treatable alloys can be obtained in the soft annealed condition, the heat-treated conditions, or the heat-treated and cold-worked conditions. A few of the alloys also have an intermediate heat-treated condition. Greater strength is obtainable in the heat-treatable alloys than in the strain-hardened alloys. Consequently, they are used for structural purposes in aircraft in preference to the strain-hardened alloys.

CORROSION

Pure aluminum (2S) is very resistant to atmospheric corrosion but when alloying elements are added, the corrosion reisistance is decreased. One strain-hardened alloy (3S) and two heat-hardened alloys (53S and 61S) are as corrosion-resistant as commercially pure aluminum, but all the other alloys are somewhat inferior. 52S is more resistant to salt-water corrosion than 2S but not to atmospheric corrosion. It is customary in Naval aircraft work to protect all aluminum alloys with a protective coating of paint. A good protective coating is particularly important when the airplane will be subjected to severe corrosion conditions, as in the case of a seaplane.
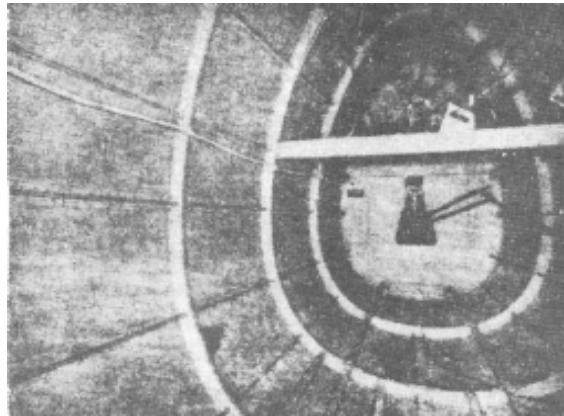
Fig.7.2.Grumman Monocoque Fuselage; R301 and 14ST Clad Aluminum Alloy

One type of corrosion of aluminum alloys is the pitting of the surface, which is analogous to the rusting of iron. This eating away of the surface is accelerated in the presence of moisture, particularly salt water. If a dissimilar metal or impurities are also present, an electrical action is set up that eats away the aluminum alloy. All other metals used in aircraft except magnesium are above aluminum in the galvanic series, so that in any action set up the aluminum is the anode and will be attacked. Experience has shown that this type of corrosion occurs most often in parts of the structure that are poorly ventilated, and in inaccessible corners of internal joints.

Intercrystalline corrosion is a much serious type of corrosion, since it greatly reduces the strength and destroys the ductility of the metal. This type of corrosion is apparently limited to aluminum alloys containing copper, such as 17S and 24 S. The resistance of these materials to this type of corrosion is lowered by incorrect heat treatment or by slow or delayed quenching. It is imperative that quenching of this type of material be done immediately in cold water, to avoid intercrystalline corrosion (clad 75ST may be given a slower quench without affecting corrosion). This type of corrosion gives practically no surface indication, but spreads through the interior of the metal along the grain boundaries. All type os corrosion must be guarded against in aircraft construction due to the light gage of material used.

ALCLAD ALUMINUM ALLOYS

"Alclad" is the name given to standard alloys, such as 17S and 24 S, when they have been coated with a thin layer of aluminum or another aluminum alloy which is alloyed to and integral with the base metal core. The name Alclad, a registered trade-mark, usually refers to products of the Aluminum Company of America. "Pureclad" is the equivalent name for material mmanufactured by the Reynolds Metals Company. Due to the fact that pure aluminum is highly resistant to corrosion, it protects the alloy sandwiched in between the two surface layers. The aluminum covering is electropositive to the underlying alloy and, consequently, also protects it by means of electrolytic action. This fact is important, becuase the soft aluminum covering is easily scratched and the edges of the sheet are not coated with aluminum, so that corrosion might occur in these places if it were not for the electropositive aluminum coating. No painting of Alclad is necessary to protect it from corrosion unless it is subject to very severe service conditions such as underwater or bilge locations in seaplane float construction. In such cases it is deirable to anodically treat the alloy before painting, in order to provide a good bond for the paint.

At the present time only sheet and wire are obtainable as Alclad materials. The aluminum coating is put on the alloy by a rolling process which makes it an integral part of the metal. In the case of wire, which is more likely than sheet to be subject to abrasion, an aluminum alloy coating is used in place of the soft, pure aluminum. This alloy coating is also electropositive to the underlying alloy and protects it from corrosion.

14S clad, R301 and 75S clad are relatevily new materials which are coated with corrosion-resistant aluminum alloy that is electropositive (anodic) to the base alloy. The cladding on 14S and R301 is a magnesium silicide of 53S composition ; the coating on 75S is of a different composition, containing zinc, as shown later in the table of chemical compositions. The average casting thickness per side for the various clad materials is as follows :
Alclad 17S and 24S-5% under 0.064 inch thick; 2½ % 0.064 inch and over.
R301-10% under 0.025 inch; 7 ½ % 0.025 to 0.039 inch; 5% 0.040 to 0.101 inch; 2 ½ % over 0.101 inch.
Clad 14S- 10% under 0.040 inch; 5% 0.040 inch and over.
Clad 75S- 4% for all thicknesses.
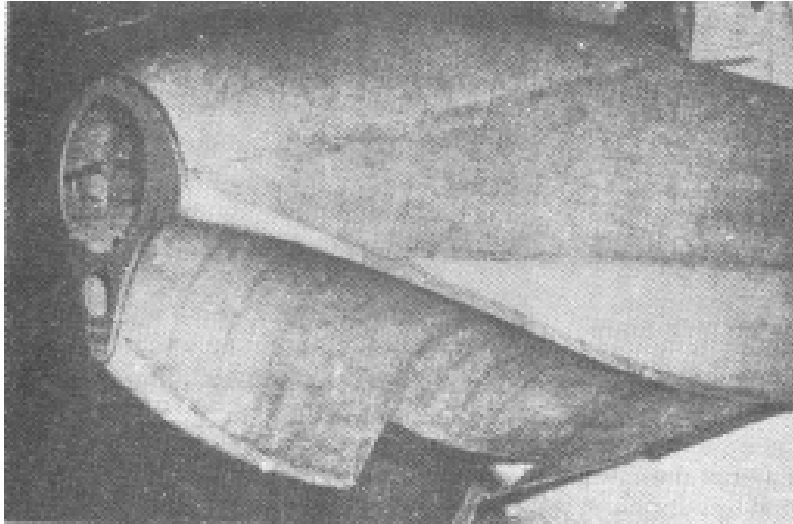
Fig.7.3.Bow of Mallard Hull;1ST (R301) Clad ALuminum Alloy

A given thickness of clad material will not be as strong as the same thickness of the standard alloy. This reduction in strength is due to the strength of the coating being less than that of the base or core material. the exact strengths of clad and standard alloys are tabulated later in this chapter. Clad material has one great advantage, however, as regards strength, and that is the fact that after years of services it still retain most of its original strength. The standard alloys, even though protected by paint, may lose a great deal of their strength and nearly all of their ductility, due to corrosion. Corrosion in modern airplanes is usually locafized to poorly drained spots but may have serious effects on the strength of the airplane. This retention of strength is particularly important in this thin sections used in aircraft construction.

As explained later under Heat Treatment, it is important that Alclad be held only the minimum time at the soaking temperature. These precautions are necessary to prevent the diffusion of alloying constituent from the core to the cladding, thus reducing corrosion resistance.

EXTRUSIONS
In aircraft construction channels, angles, T-sections, Z-sections, and many other special structural shapes are required.

These shapes are all obtainable in aluminum alloy by an extruding process. In this process a cylinder of aluminum alloy is heated between 750^0 and 850^0F, and is then forced by a hydraulic ram through an aperture in a die. The aperture is

Fig.7.4. Edo Seaplane Float;Alclad

the shape desired for the cross section of the finished extrusion. The extrusion is then straightened by stretching it under tension. Extruded material has performed satisfactorily but it does not have so fine a grain, nor is it homogeneous as rolled or forged material.

Extruded shapes may be purchased in 14 ST, 17ST, 24ST, 53ST, 61ST, and 75ST material for aircraft purposes. The manufacturers have on hand a great many dies covering most of the commonly used sections. When a great many dies covering most of the commonly used sections. When a designer desires to use a new section, the manufactureer will make a new die for a very moderate cost and produce the necessary section. An extrusion pool has been established

by a number of aircraft manufacturers and members are free to use any extrusion die in the pool by securing written permission from the aircraft manufacturer who purchased the die originally.

FORGINGS

Aluminium alloys may be forged to close limits to provide light, strong fittings, or other structural parts. These forgings have a uniform structure and are free from blowholes, hardsports, or cavities. Only a few thousandths of an inch need be allowed for finish machining. In forging, the metal is heated to the proper forging temperature for the part in question and then hammered, pressed, drop forged, or upset to shape. Pressed forgings have a fine finish and can be held to close tolerances. The present limit on size is approximately 18 inches in length but this will be greatly increased when the new 18,000-ton press at Wyman-Gordon, which is also mentioned in the chapter on Magnesium Alloys, is operating. At present pressed forgings are available in circular shapes up to 6 ½ inches in diameter. At the temperatures used, the metal is not hot enough to flow easily, so tremendous power is required to form it. A higher temperature cannot be used because the metal becomes hot-short and crumbly, and is ruined for further heat treatment. The power needed exceeds that used in forging steel. In laying out forgings a draft of 7^0 should be provided. The shrinkage allowance varies. The manufacturer should be advised of the finished dimensions desired. It is also important in forging design to avoid abrupt changes in section and to specify liberal fillets.
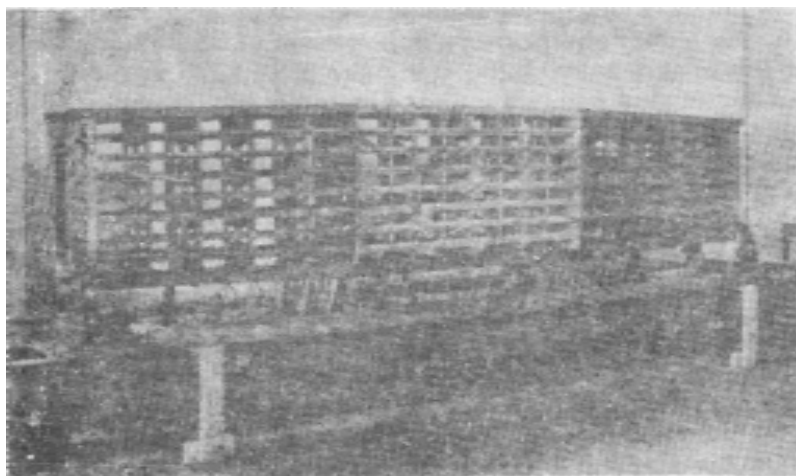
Fig.7.5. Wing Box Beam

The aluminum alloys commonly used for aircraft forgings are 14ST, 17ST, 18ST, 25ST, 32ST, A51ST, 53ST, and 75ST. The most easily worked and the cheapest is A51ST but it has the lowest mechanical properties, and is used mostly for complicated engine forgings. 53ST has low mechanical properties but is very corrosion-resistant. 25ST works fairly easily and has properties similar to 17ST, which is hard to work but has somewhat better corrosion-resistant qualities. Forgings made from 25ST are used for aluminum-alloy propeller blades. Good mechanical properties are found in 14ST, and it is generally used in aircraft construction in applications where high strength is required. 75ST has the highest physical properties and is ideal for highly loaded structural parts.

Because of their superior resistance to corrosion 14ST, 17ST, and 75ST are used in airplane structures. For engine parts A51ST and 25ST are used because the sections are heavy and frequently oily. Propellers made from 25ST have performed satisfactorily in service for years. 53ST press forgings are ideal for tank flanges which are welded in place.

SPOT-WELDING ALUMINUM ALLOYS

Electric spot and seam welding of aluminum alloy has been generally adopted for joining nonstructural and semistructural parts. Spot welding has displaced riveting in many applications, due to its speed, lower cost, and elimination of projecting rivet heads. It has already been used sucessfully in welding fuel tanks. Other common uses are the attachment of stiffeners to cowling, stringers to fuselage and wing skins, and in the assembly of brackets and shelves. Spot welding is generally used in the fabrication of primary structural parts of airplane.

Spot-welding machines must have very accurate current, time, and pressure control. Machines in services at the present time have an amperage output of between 30,000 to 40,000 amperes and are capable of welding two 1/8- inch sheets.

The throat of the machine may be as great as 72 inches. All four surfaces of the material to be welded must be absolutely clean. A wire brush hooked up to an air drill is one satisfactory method of cleaning such surfaces. The brush must not be so stiff, however, that it will remove the aluminum coating from Alclad. A fine grade of abrasive cloth, or fine steel wool may also be used. A hydrofluoric acid etching solution can also be prepered for this purpose.

Clad alloys and 52S material are most satisfactory for spot welding. When resistance to corrosion is important and an extruded shape must be used, 53ST material should be selected if its physical properties are satisfactory. Clad material spot welded to 14ST, 24ST, or 75ST extrusions has satisfactory corrosion resistance for aircraft use. Anodically treated material cannot be spot welded. For this reason 17ST and 24ST material must be spot welded first and the assembly anodically treated. Adequate protection against corrosion cannot be obtained on the faying surfaces if this is done. For this reason clad material is preferred, particularly for forming structural assemblies that are to be spot welded. More reliable welds are also obtained with clad materials.

It is possible to spot weld through wet zinc chromate primer. When maximum corrosion resistance is necessary between the faying surfaces of 17ST or 24ST they should be coated with zinc chromate primer just prior to spot welding.

Spot welds should be put in shear only, since they are relatively weak in tension. They are usually spaced apart about 8 times the minimum sheet thickness and 4 times this thickness from the edge of the sheet. For maximum efficiency three rows of welds are necessary. With this arrangement it is believed an efficiency of 70% is obtainable with clad sheet and 100% with 52S material. In either the soft or ½ hard temper, 52S has been used for fuel tanks.

HEATTREATMENT

There are two types of heat treatment applicable to aluminum alloys. One is called solution heat treatment, and the other is known as precipitation heat treatment. Some alloys, such as 17S and 24S, develop their full properties as a result of solution heat treatment followed by about 4 days aging at room temperature. Other alloys, such as 14S, 75S, and R301, require both heat treatments.

Solution heat treatment is so named because during this treatment the alloying constituents enter into solid solution in the aluminum. It has been found that these alloying elements which increase the strength and hardness are more soluble in soild aluminum at high temperatures than at low. After the metal is held at a high temperature for a sufficient time to complete the solution, it is quenched rapidly in cold water to retain this condition.

Precipitation heat treatment consists of aging material previously subject to solution heat treatment by holding it at an elevated temperature for quite a long period of time. During this temperature a portion of the aloying constituents in solid solution precipitate out. This precipitation occurs at ordinary room temperatures in the case of 17S and 24S material. The precipitate is in the form of extremely fine particles which, due to their "keying" action, greatly increase the strength. The "natural aging" of 17S and 24S material at room temperatures is 90% to 98% complete after 24hours, and fully complete after four days. 24S develops greater strength than 17S immediately after quenching, ages more rapidly, and is considerably less workable.
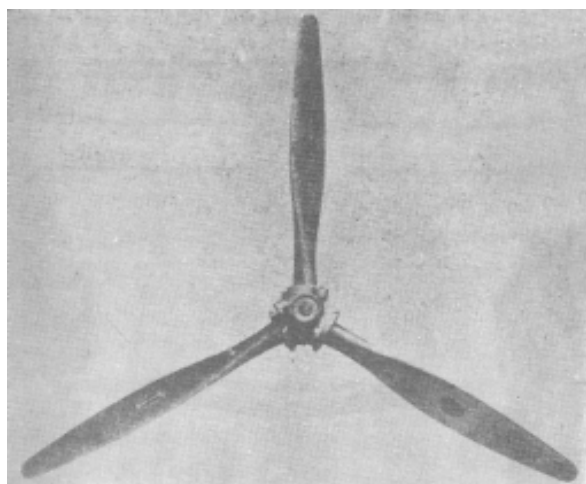
Fig-7.6. Controllable-pitch Propeller;25ST Aluminum-alloy Blades

It has been found advisable to form aluminum alloys within one hour after solution heat treatment, before the aging has progressed too far. During this period the metal may be worked with ease and without danger of cracking, especially 17S, 24S, and 75S alloy. It has been found that the aging of a heat-treatable alloy may be ratarded for as much as 24 hours if it is kept at or below a temperature of 32^0F. Aging can be retarded for longer periods if a lower temperature is maintained. In practice, an icebox containing dry ice or a refrigerating unit is used to hold rivets or small pieces of sheet until the shop is ready to work them.

In the solution heat treatment of aluminum alloys it is extremely important to hold the temperature within narrow limits These limits are usually about 20^0F., as in the case of 14S material, when the heat-treatment range is 930-950F. The heat-

treatment range of 24S material is 910-930⁰F. Exceeding the upper temperature limit may cause incipient melting of the eutectic and result in serious blistering. Clad 14S and R301 are exceptions to this restriction and can be heat treated 20-30⁰F above their normal heat-treatment range of 930-950⁰F. without damage. Too high a temperature, however, may cause eutectic melting. If the temperature is too low, complete solution will not take place, and the full properties of the material may not be developed. Sloution heat treatment is usually done in a salt bath heated by gas, oil, or electricity, or in an electric air furnace.
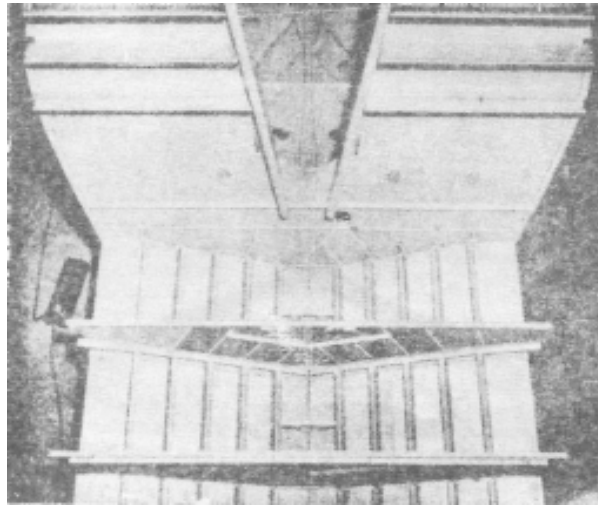
Fig.7.7.Hull Bulkhead and Bottom.

The salt bath is composed of fused sodium nitrate, or a mixture of 50% sodium nitrate and 50% potassium nitrate. The 50-50 solution must be used if the bath is also going to be used for annealing. The most important point in connection with the furnace selected is that it must maintain an even temperature throughout its interior. All parts of the work being treated must be subjected to the same temperature. It is common practice to raise and lower the load, always keeping it submerged in the salt bath, to obtain circulation of the liquid and assure a uniform temperature. In the electric air furnace, provision should be incorporated for circulating the air.

The length of time that material must be soaked at the proper temperature depends upon the nature of the material, the prior heat treatment of the material, the thickness of the material, and the type of heat-treating equipment. Heavier material requires a longer soaking period. When various thicknesses are treated at one time, the soaking time necessary for the heaviest material should be used. The lighter material will not be injured by a moderately long soaking. This is not true of clad material which must be heated as rapidly as possible and soaked for the shortest possible time; otherwise, the alloying elements of the base material will diffuse through the cladding and destroy the corrosion resistance. For this reason clad material should not be reheat treated in thicknesses up to 0.049 inch, and not more than twice in thicknesses up to 1/8 inch. The standard alloys can be reheat treated any number of times without affecting them.

Table7.1 gives the time recommended for soaking wrought material, but these periods may vary slighty for different heating equipment. Soaking time beigns when the temperature of the bath or furnace has reached the minimum heat-treatment temperature after inserting the load.

TABLE7.1.SOAKING TIME FOR SOLUTION TREATMENT - WROUGHT ALUMINUM ALLOYS
A : WROUGHT MATERIALS EXCEPT FORGINGS.

Alloy	Time after load reaches minimum temperature (minutes)			
	Up to 0.032inch	0.033-0.125 inch	0.126-0.250 inch	Over0.250 inch
14S			30	60
14S clad	7	15	25	45
17S	20	20	30	60
24S	30	30	40	60
24S clad	20	30	40	60
53S	20	30	40	60
61S	20	30	40	60
75S	25	30	40	60
75S clad	20	30	40	60
R301	7	15	25	45

B.FORGINGS

Alloy	Time (hours) Up to 2 inches thick	Over 2 inches thick
14S	0.5 - 6.0	2 - 12
17S	0.5 - 6.0	2 - 12
25S	3.0 - 6.0	4 - 12
32S	0.5 - 6.0	2 - 12
A51S	0.5 - 6.0	2 - 12
53S	0.5 - 6.0	2 - 12
75S	6.0	6

After soaking, the work is removed from the bath or furnace and quickly quenched in cold water. It is extremly important that not more than a few seconds elapse before quenching the hot material, or the corrosion resistance and strength will be seriously affected. In many plants a hood is placed over the work while transferring it from the furnace to the quenching bath, to prevent cooling. It is also important that the quenching bath be at a temperature below 85^0F. When the hot work is immersed. The bath must be large enough tp prevent the water temperature from rising above 100^0F. While the work is cooling. If these conditions are met in the quenching bath, the corrosion resistance of the material will not be destroyed. It is advisable in the design of the quenching bath to provide for continuous running water and draining. These will aid in keeping the temperature of the bath low and will prevent the salting up of the bath caused by quenching material heat treated in a salt bath.
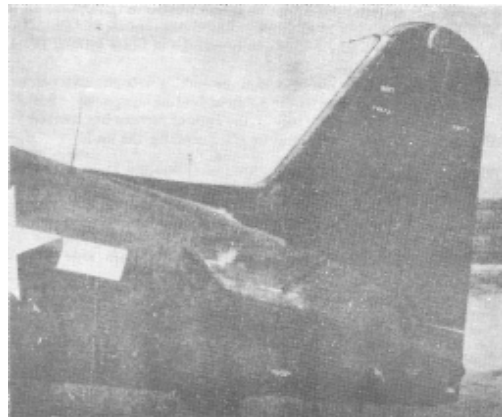
Fig.7.8. Tail Surfaces; Aluminum Alloy

Quenching may also be accomplished by the use of high-velocity and high-volume jets of cold water for thoroughly flushing the material. This method is particularly good for quenching massive objects in that it prevents the adherence of steam pockets.

When quenching in cold water, will badly distort a finished part and it will not be subjected to severe corrosion in service,it can be given a mild quench in oil or hot water, or quenched by water spray or air blast. This method should only be used for clad material and with the knowledge that the full physical properties will probably not be developed by the milder quench.

Forgings and castinfgs are normally quenched by immersion in water at $150\text{-}212^0F$., unlesss their shape is such that cold-water quenching will not cause cracking or excessive warpage.

Rivets must be quenched by dumping in cold water. Other small parts, such as spacers and washers, may be quenched in a tray or container designed to permit a free flow of quenching water.

Material heat treated in salt baths must be rinsed after quenching to ensure the removal of all the salt. Warm water is used for rinsing, but it must not exceed 150^0F. The use of hot water for rinsing adversely affects the corrosion resistance and accelerates aging of the material. This latter point is particularly important when it is desired to work and form material immediately after heat treatment. In case where severe forming must be done, it might be advisable to do it right after quenching, and then rinse the material later. By this means it would be possible to work the material in the period before age-hardening sets in.

TABLE 7.2, HEAT TREATMENT OF ALUMINUM ALLOYS

Alloy	Solution heat treatment			Precipitation heat treatment		
	Temperature (^{0}F)	Quench	Temper	Temperature (^{0}F)	Aging Time	Temper
14S	925-950	Cold water	14Sw	– –		14ST
17S	925-950	Cold water	----	Room	4 days	17ST
24S	910-930	Cold water	----	Room	4 days	24ST
25S	950-970	Cold water	25SW	335-345	8 hrs.	25ST
32S	940-970	Cold water	32SW	335-345	8 hrs.	32ST
A51S	950-1010	Cold water	A51SW	345-355	8 hrs.	A51ST
53S	960-1010	Cold water	53SW	– –		53ST
61S	960-1010	Cold water	61SW	– –		61ST
75S	860-880	Cold water	75SW	245-255*	24 hrs.	75 ST
75S clad	860-930	Cold water	75SW	245-255*	24 hrs.	75ST
	925-950	Cold water		310-330	18 hrs.	

*Other aging treatments known as interrupted and progressive aging treatments may be used. Interrupted aging consists of heating at 212^{0}F for 4 hours, cooling to room temperature, and then heating at 315^{0}F. for 8 hours. Progressively aging consists of heating at 212^{0}F. for 4 hours, increasing the temperature to 315^{0}F., and holding it for 8 hours. Some of these treatments are patented.

Precipitation heat treatment of aluminum alloys consists in heating the material for from 8 to 24 hours at a tempertaure around 300^{0}F. In practice an oven heated by steam coils or an electric furnace is used for heating.
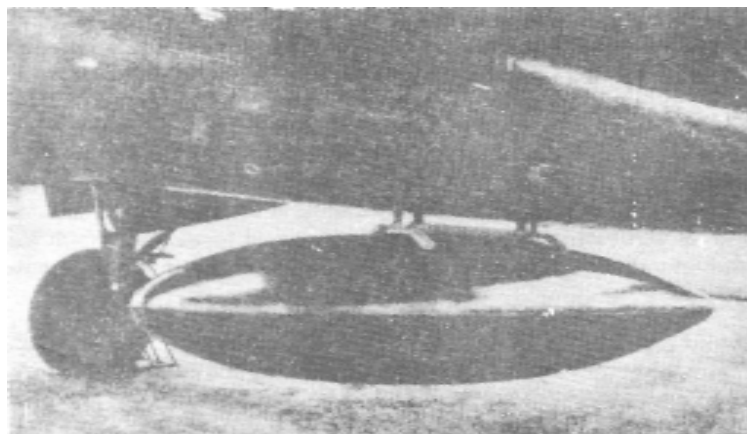
Fig.7.9.Fuel Tank- Droppable; 61SW Aluminum Alloy

The heat treatments required to develop the full physical properties of various types of aluminum alloys used in aircraft construction are summarized in Table 7.2.

HEAT TREATMENT OF ALUMINUM-ALLOY RIVETS
Rivets made from 17S material are very commonly used in aircraft construction. These high-strength riverts may be identified by a small tit left on the head of the rivet. This identification is necessary to prevent substitution of worker rivets made from 2S or 3S material. From the strength viewpoint it is necessary that the 17S riverts develop the full strength of the material in the 17ST temper. It is difficult in diameters over 1/8 inch to drive a 17ST rivet without cracking

the head due to the hardness of the metal in this temper. But it has been found practical to heat treat 17ST rivets and then drive them within one hour before they have age-hardened. 24ST riverts age harden within one hour 20 minutes. It is necessary either to heat treat small batches of rivets at frequent intervals to stay within the time limitation or to keep the riverts in an icebox to retard the aging. This latter method will keep the riverts soft for 48 hours and is very generally employed in the aircraft industry.

The actual heat-treatment operation for rivets is similar to that described above for structural material, but the technique employed is quite different because of the small size of rivets and the large quantities that must be treated. It is customary to use a steel tube (from 1 to 2 inches in diameter) with a closed bottom and a loose fitting cap. A quantity of rivets is placed in this tube, the cap is placed on it, and the tube is immersed vertically in a salt bath. There it is held soaking at the heat treating temperature for 40 minutes. The top layer of rivets should be at least 4 inches below the surface of the salt bath, and the cap should be tight enough to exclude the entrance of cold air. The cap must be removed while the tube is still submerged and the rivets poured into the quenching bath to facilitate their removal. No rinsing of the rivets poured into the quenching bath without delay The rivets are poured into a wire basket in the quenching bath to facilitate their removal. No rinsing of the rivets is necessary since the steel tube container protects them from contact with the salt bath. As stated above, the heat-treated rivets must be used within one hour of quenching or placed in an icebox to retard aging. Rivets may be reheat treated not more than 15 times.

In order to check the heat treatment and aging of the rivets, it is customary to check the hardness of a few rivets from each batch after they have aged for 24 hours. When subjected to a Rockwell test, using a 1/16⁻ inch ball and 60-kilogram load, the shank of the rivet must show the following minimum hardness :

Rivet diameter (inch)	Rockwell hardness
/	73
/	75
/	78
/	82
/	83

As explained under Hardness Testing, this test should not be considered too reliable.

Annealing

The heat-treatable alloys may be annealed to remove the strain-hardening effects of cold working or to soften heat-treated material that must be severely formed. Oftentimes the forming is too severe or will take too long to permit its being done within ½ hour after heat treatment, and in these cases the material must be annealed, formed, and then heat treated. Annealing of heat-treatable alloys must be carried out with great care as regards the temperature and the rate of cooling. If the temperature is too high, the material will be partially heat treated and will not attain its full softness. Under these conditions it is important to cool the material slowly to destroy as much of the heat-treating effect as possible.

To anneal material which was originally in the soft state and was strain hardened by cold working, it is only necessary to heat it to a temperature of 640-670^{0}F. and cool it slowly in air. This operation would be necessary in a case where so much forming had to be done that the material would strain-harden and prevent further working before the job was done. This annealing treatment is satisfactory for all alloys except 75S, which can be strain-relieved by soaking it at ½ to 2 hours and air cooling. Normally it is better to fully anneal 75S as described in the last paragraph.

To anneal material in the heat-treated temper when maximum softness is not required, the method described in the preceding paragraph may be used. This treatment will not removed all the effects of heat treatment, but it is usually satisfactory where only a moderate amount of forming is to be done.

To fully anneal heat-treated material and remove all effects of the prior heat treatment, the material must be heated to a temperature of 750-800°F, and soaked at this temperature for two hours. It must then be cooled at a slow rate (not exceeding 50°F per hour) until it has reached 500°F., after which it may be air cooled. The rate of cooling is adjusted by leaving the material in the furnace and allowing the furnace to cool slowly. In the case of 75S alloy the work must

be held at 450°F. for at least one hour to stabilize it against age hardening, unless it will be formed within 5 hours after cooling. It is apparent that this method of annealing is costly due to the long soaking period and the tying-up of the furnace while the material is cooling. It is only necessary when severe forming is to be done. One such case is the flattening of the end of a tube. If the tube is flattened so that both faces touch each other and no radius exists at the flattened edges, it is likely that these edges will crack unless the tube has been given the full annealing treatment.
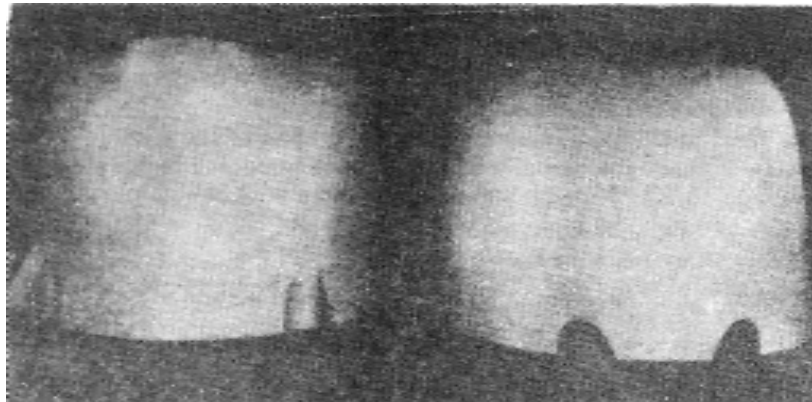
Fig-7.10. Engine ring Cowl; Aluminum Alloy.

Heat-treatable alloy are never installed in the airplane in the annealed condition because of their poor corrosion resistance and strength in this condition. After forming they must always be heat treated.

It is sometimes necessary to anneal strain-hardened alloys, such as 3S and 52S, in order to complete forming operations. The method is described in the following section, Strain-Hardened Alloys.

STRAIN-HARDENED ALLOYS

The strain-hardened alloys which are commercially available are 2S, 3S, 52S, and 56S. All of these alloys are commonly used in aircraft construction, but they are not used for primary structural purposes because their strength is not as high as other available materials. How ever, they are readily, bent, and formed, and welded and, for these reasons, are used for tanks, cowling, and fairings. In tubular form these materials are used for electrical conduit and for fuel and oil lines.

CHEMICAL COMPOSITION

	2S	3S	52S	56S
Aluminum (min.)	99.0%	97.0%	96.0%	remainder
Manganese		1.0-1.5		0.05-0.20
Magnesium			2.2-2.8	4.5-5.6
Chromium			0.15-.35	0.05-0.20
Copper (max.)		0.2	0.07	0.10

Small amounts of impurities, particularly iron and silicon, are also present. Commercially pure aliminum (2S) has up to 1% of these impurities.

PHYSICAL PROPERTIES.

	2S	3S	52S
Density (lb. / cu. in.)	098	.099	096
Elect. conductivity (% of copper)	58	4l	40
Modulus of elasticity	10,300,000 p.s.i.		

It will be noted from Table 7.3 that the tensile strength, yield strength, and fatigue strength increase with the temper or hardness of the material. There is also a distinct gradation of strength between the three materials. In selecting a material it is usually preferable to choose one that will give the required strength in the softest temper. Thus the material that can be most easily worked is obtained.

Annealing

The strain-hardened alloys cannot be heat treated to improve their properties. Higher strengths are obtainable only by cold working. In fabrication or forming, these materials will harden too much if worked severely, and it is then

necessary to soften them before further working. They can be softened by a simple annealing treatment which consists in heating the material to permit recrystallization. Softening due to recrystallization is practically instantaneous if the material is heated to a high enough temperature. For 2S and 52S material this temperature is 650°F., while for 3S material it is 750°F. The metal should not be heated too much above this temperature. Annealing may also be done by heating the metal for a longer period of time at a lower temperature. In either case the rate of cooling is not important, provided it is not so rapid as to cause warpage.

TABLE 7.3 STRAIN-HARDENED ALUMINUM ALLOY - MECHANICAL PROPERTIES.

Alloy and temper	U.t.s (p.s.i.)	Yield strength (p.s.i.)	*Elongation in 2 in (%)	Brinell hardness (500 kg 10mm)	Shearing strength (ps.i)	Fatigue+ strength(ps.i)
2SO	13,000	5,000	35	23	9,500	5,000
2S / H	15,000	13,000	12	28	10,000	6,000
2S / H	17,000	14,000	9	32	11,000	7,000
2S / H	20,000	17,000	6	38	12,000	8,000
2SH	24,000	21,000	5	44	13,000	8,500
3SO	16,000	6,000	30	28	11,000	7,000
3S / H	18,000	15,000	10	35	12,000	8,000
3S / H	21,000	18,000	8	40	14,000	9,000
3S / H	25,000	21,000	5	47	15,000	9,500
3SH	29,000	25,000	4	55	16,000	10,000
52SO	29,000	14,000	25	45	18,000	17,000
52S / H	34,000	26,000	12	62	20,000	18,000
52S / H	37,000	29,000	10,	67	21,000	19,000
52S / H	39,000	34,000	8	74	23,000	20,000
52SH	41,000	36,000	7	85	24,000	20,500
56S***					24,000	

* Elongation values are for 1/16 inch sheet. Thinner sheets have less elongation.
**Based on 500,000,000 cycles of reversed stress, using R. R. Moore type of machine and specimen.
***Cold-worked rivet stock.

It is common shop practice to anneal strain-hardened alloys locally when they become too hard by playing a welding torch on the part to bring it up to heat and then allowing it to cool. Care must be taken not to overheat or burn the metal.

WORKING PROPERTIES
When the proper temper is selected, all the strain hardened alloys can be satisfactorily worked to the desired form for their aircraft use. The easiest to form by drawing, spinning, or stamping is 2S material. Only slightly more difficult to form is 3S material, and it has better physical properties. For this reason it has superseded 2S material almost entirely in aircraft work. For spinning ring cowls 3SO or 52SO ,material is used. The material strain-hardens during the spinning and becomes equivalent to about 3S ½ H or 52S ½ H temper. 52S ¼ H is generally used for engine cowling because of its ease of forming and greater tensile and fatigue strength. Wherever its forming properties are satisfactory for the purpose 52S is rapidly displacing the other strain-hardened alloys. The high fatigue strength of this material is particularly important in reducing cowling cracks.

The following table gives the bending qualities of the strain-hardened alloys. These bend radii will vary somewhat with the tools used, the particular operation, and the technique employed.
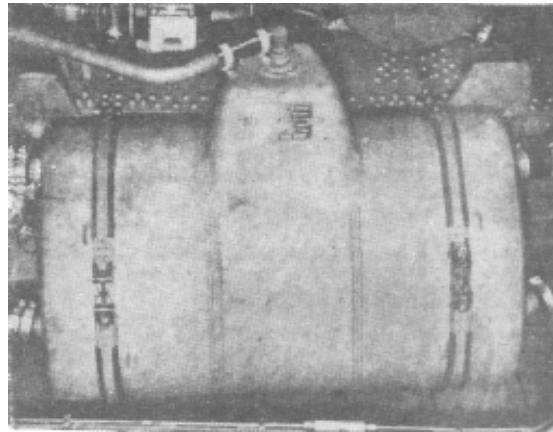
Fig-7.11. Oil Tank; 32S ½ H Aluminum Alloy

It is difficult to predict in advance just which material and temper will work best in a new application. It is recommended that several possible samples be obtained and worked under the actual shop conditions before a final selection is made. it must be borne in mind that it is always difficult for a sheet metal worker to get the most out of a new, unfamiliar material.

TABLE 7.4, APPROXIMATE RADII FOR 90° COLD BEND

Alloy	Approximate thickness (= t)				
	0.016 in.	0.032 in	0.064 in	0.128 in	0.189 in
2SO	0	0	0	0	0
2S /H	0	0	0	0	0-1t
2S /H	0	0	0	0	0-1t
2S /H	0	0	0-1t	/t-1 /t	1t-2t
2SH	0-1t	/t-1 /t	1t-2t	1 /t-3t	2t-4t
3SO	0	0	0	0	0
3S /H	0	0	0	0	0-1t
3S /H	0	0	0	0-1t	0-1t
3S /H	0-1t	0-1t	/t-1 /t	1t-2t	1 /t-3t
3SH	/t-1 /t	1t-2t	1 /t-3t	2t-4t	3t-5t
52SO	0	0	0	0	0
52S /H	0	0	0	0-1t	0-1t
52S /H	0	0	0-1t	/t-1 /t	1t-2t
52S /H	0-1t	/t-1 /t	1t-2t	1 /t-3t	2t-4t
52SH	/t-1 /t	1t-2t	1 /t-3t	2t-3t	3t-5t

Welding

The strain-hardened alloys are normally joined by gas welding in aircraft work. Electric arc welding is faster and causes less distortion, but the material must be at least ╱ inch thick. This type of welding is seldom used in aircraft construction. Welding is done by either the oxyacetylene or the oxyhydrogen flame. Skilled aircraft welders can successfully weld 0.020 inch aluminum alloy with an oxyacetylene flame.

Most of the welding on strain-hardened aluminum alloys is done in the fabrication of fuel and oil tanks. These tanks are often subjected to a 15-hour vibration test after fabrication, to check the design, the welds, and the quality of the material. Leaks caused by failure of welds or cracked material are cause for rejection. Seams to be welded are not butted directly together but are flanged slightly, the faces of the flanges butted together, and then the entire flange burnt down to the level of the sheet proper in the welding operation. By this method a continuous, sound, thorough weld is obtained.

A welding rod of pure aluminum, or of the same composition as the metal being welded, may be used. In aircraft welding a rod containing about 95% aluminum and 5% silicon is found to be best. Due to the formation of an oxide film on the surface, it is necessary to use a flux in welding aluminum alloys. It is sometimes necessary to weld two or more of the strain-hardened alloys together. This can be done satisfactorily if the 5% silicon welding rod is used.

After welding, the material on either side of the weld is in the annealed condition and the weld itself is a cast structure. The strength in the region of the weld is the same as the material in the soft temper. Unless the welds are ground down, they will develop greater strength than the adjoining metal. Welds can be hammered to flatten them without reducing their strength. In fact, the working should improve it somewhat.

Corrosion

2S aluminum is highly resistant to atmospheric corrosion. The addition of various elements to aluminum to form alloys changes the corrosion resistance characteristics.

3S is somewhat inferior to 2S material in resisting atmospheric corrosion.

52S material will resist salt-water corrosion even better than 2S. It will retain its mechanical properties better, as well as its surface appearance. 56S aluminum-alloy rivets contain 5% magnesium and no copper and have practically no corrosion action on magnesium alloys.

In aircraft work it is considered good practice to protect all aluminum alloys with paints. It is essential that the material be given a surface treatment first. This treatment forms an oxide on the surface, which aids in protecting the surface, and also provides an excellent base for the paint. painting usually consists of one coat of a good primer, followed by two coats of lacquer or enamel.

When tanks are fabricated by welding it is essential to remove all traces of the flux, which is corrosive towards aluminum alloys. This flux should be removed as soon as possible after completion of the welding. It may be removed by immersing the work in a tank containing a warm 5% sloution of sulphuric acid, followed by a thorough rinsing in clear, warm water and then drying. All accessible welds should be scrubbed with a stiff bristle brush before or during the water rinse. In the case of tanks, the rinsing water should be agitated in order to clean the interior welds that are not accessible for scrubbing.

Available Shapes

From time to time as the demand arise, the aluminum alloys are made available in new forms. At present it is posssible to obtain the strain-hardened aluminum alloys in the various forms.

Uses

As stated previously, strain-hardened alloys are commonly used in aircraft construction for cowling, fairings, tanks, electrical conduits, and fuel and oil lines. No one alloy excels the others for all purposes, but must be considered in connection with the particular application. The following alloys and tempers have been successfully used for the purposes described :

3S½H for welded fuel tanks, and for general engine cowling.

52SO and 52S ½ H for cowling and fairings subject to severe vibration in service including ring cowl spinnings.

2S½H tubing for electrical conduit.

52SO tubing for fuel and oil lines.

3 SO for ring cowls and other parts that are formed by spinning.
56S¼H rivets are used almost exclusively in magnesium-alloy assemblies.

STANDARD SHAPES-STRAIN-HARDENED ALLOYS

Shape	2S	3S	52S	56S
Sheet	*	*	*	
Plate	*	*	*	
Rod and bar	*	*	*	
Wire	*	*	*	*
Extrusions	*	*		
Tubing	*	*	*	
Rivets	*	*		*

Sheet is 0.250 inch or less in thickness; plate is over 0.250 inch. Sheet can only be obtained up to 0.162 inch thick in the 3/4 H temper and up to 0.128 inch thick in the full H temper.

Bar stock is similar to plate, but is obtainable only up to 10 inches in width.

Cold-finished rod is obtainable from 3/8 to 1 ½inches in diameter. Rolled rod is obtainable up to 8 inches in diameter.

Wire can be obtained drawn anywhere from 36 gage up to 3/8 inch diameter. On special order, wire finer than 36 gage is obtainable.

Tubing can be obtained in practically diameters and wall thicknesses.

HEAT-TREATABLE ALLOYS

The heat-treatable aluminum alloys are used for aircraft structural purposes because of their relatively high strength and light weight. They are available in many structural forms and can be worked with production tools. The alloys commonly used in the manufacture of aircraft are 14S, 14S clad, 17S, 24S, 61S, 75S and R301. All of these are available in clad forms except 61S, which is very corrosion resistant without cladding.
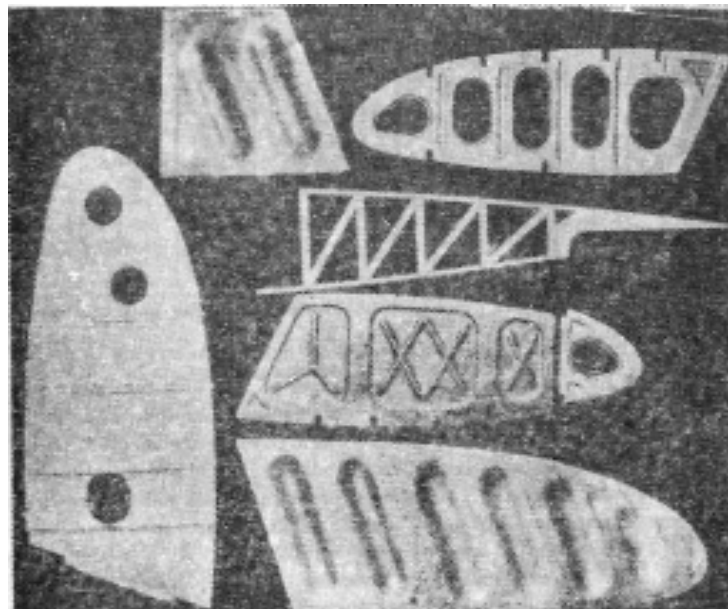
Fig.7.12.Wing Ribs

Until recently 17S and 24S, which in both the bare and clad forms were used almost exclusively. The development of high-strength alloys, such as 14S, R301, and 75S, and their commercial availability in standard forms have resulted in their widespread adoption in new designs. 14S clad and R301 are identical- the products of two manufactures who have named them differently. They are available in sheet form only in the clad condition; bare 14S is also available in many other forms but R301 is not. 75S alloy is available as clad or bare sheet, and in many other forms in the bare condition. It is the strongest of the aluminum alloys. 61S has recently been quite generally adopted for severely formed parts which do not require extremely high strength such as cowling.

Chemical composition

Table 7.5 gives the chemical composition of the heat-treatable aluminum alloys used in aircraft construction. It will be noted that 14S clad and R301 are identical. They are, in fact, covered by one Army-Navy Aeronautical Specification AN-A-22.

Physical Properties

Modulus of elasticity = 10,300,000 p.s.i.

Alloy	Weight (lb./cu. in.)
14S	0.101
17S	0.101
24S	0.100
25S	0.101
A51S	0.097
53S	0.097
61S	0.098
75S	0.101

TABLE 7.5, HEAT-TREATABLE ALUMINUM * ALLOYS-CHEMICAL COMPOSITION (%)

Alloy designation	Manganese	Magnesium	Chromium	Copper	Silicon	Zinc
14S	0.4-1.2	0.2 - 0.8	0.25	3.9 - 5.0	0.5 - 1.2	0.25
14S(cladding)	0.75	0.8 - 1.5	0.35	0.10	0.35 - 1.0	0.20
17S	0.4 - 1.0	0.2 - 0.75		3.5 - 4.5		
A17S		0.3		2.5		
24S	0.3 - 0.9	1.25 - 1.75		3.6 - 4.7		
24S (cladding)	0.05			0.1		0.1
25S	0.4 - 1.2	0.02		3.9 - 5.0	0.5 - 1.2	
32S	0.2	0.8 - 1.3	0.10	0.5 - 1.3	11.5 - 13.5	0.25
A51S	0.2	0.45 - 0.8	0.15 - 0.35	0.3	0.6 - 1.2	
53S		1.1 - 1.4	0.2 - 0.3	0.05	0.5 - 0.9	
61S		0.8 - 1.2	0.35		0.4 - 0.8	
75S	0.10 - 0.30	2.1 - 2.9	0.15 - 0.40	1.2 - 2.0	0.5	5.1 - 6.1
75S (cladding)	0.10	0.10		0.10	0.7	0.75-1.25
R301	0.4 - 1.2	0.20 - 0.8	0.25	3.9 - 5.0	0.5 - 1.2	0.25
R301(cladding)	0.75	0.8 - 1.5	0.35	0.10	0.35 - 1.0	0.20
R303	0.10	2.1 - 3.0	0.1 - 0.35	0.8 - 1.8	0.5	5.9 - 7.1

Aluminum is remainder. Small amounts of iron and other impurities are also present

*Element percentage is maximum except where indicated as a range

Table 7.6, lists the mechanical properties of the heat-treatable alloys used in aircraft constuction. It recommended that this table be used only for reference puposes; ANC-5, Army-Navy specification, or the manufacturer of the mateial be consulted when a design must be based on the allowable strength. Manufacturer of materials will always furnish a minimum guaranteed strength for mateiral in the form that is to be used.

Clad 24S is normally aged at room temperature. It has been found, however, that an artificial aging treatment at 365-380⁰F. for approximately 6 hours will greatly improve the mechanical properties. When given this treatment the material is identified as a clad 24S-T8 alloy. A second numeral is added after the 8 to indicate the percentage of cold work imposed on the material prior to the artificial aging treatment.

There are four commonly used tempers of this alloy, as follows :

Clad 24S-T80

This temper is solution heat treated, is not cold worked, and is artificially aged. It is used for parts formed from annealed sheet which cannot be stretched (cold working), after solution heat treatment because of their shape.

Clad 24S T81

This temper is solution heat treated, is straightened at the mill by stretching (cold working), and is artificially aged either at the mill or by the aircraft manufacturer. This temper is used for parts requiring moderate formability.

Clad 24S - T84
This temper is solution heat treated, is cold worked about 4% by stretching or forming, and is artificially aged. It has higher properties than the T80 to T81 tempers and is used for stiffeners and stringers.

Clad 24S- T86
This temper results from artifically aging Clad 24ST sheet or plate. It is used for wing skins and in similar locations requiring no forming.

Artificial aging is applicable to extruded 24S as well as to clad sheet stock but the corrosion resistance is slightly reduced.

Clad 24S-T8
Tempers have better corrosion resistance than bare 24ST material aged at room temperature.

Clad 24S-T81
is available from the mill in thickness up to 0.188 inch; clad 24S-T86 is available from the mill in thickness up to 0.500 inch.

TENSILE PROPERTIES

Thickness (inch)	Temper	Tensile strength (p.s.i.)	Yield strength (p.s.i)	Elongation (%)
Less than 0.064	T80	60,000	47,000	8
	T81	64,000	56,000	5
	T84	67,000	63,000	5
	T86	68,000	65,000	4
0.064	T80	62,000	49,000	8
to	T81	67,000	59,000	5
0.500	T84	70,000	66,000	5
	T86	71,000	68,000	4

Heat Treatment
As the name implies, the heat-treatable alloys can be heat treated to improve their physical properties. In aircraft work they are used only in the heat-treated state. As explained earlier in this chapter, the material is sometimes annealed to improve its forming qualities, but it is always heat treated after forming.

The structure of many airplane built now-a-days consists of both clad 14S(R301) and 24S material. In heat treating these materials it is advisable that they be done separately since their heat-treating temperatures are different. The temperature for 14S material is 930-950⁰F., for 24S material it is 910-930⁰F. If 24S material is treated above 930⁰F., there is a possibility of surface blisters from overheating and also of extensive damage due to eutectic melting. The fabricating shop should definitely identify the type of aluminum alloy when it is sent to the heat-treating shop so that no costly errors are made.

Working Properties
Heat-treatable alloy 24S, either in standard or alclad form, is commonly used in aircraft construction. 24S is slightly more difficult to form than 17S (which was the standard aircraft structural material until recent years), but has superseded 17S because of its higher yield point.

These alloys can be formed to any structural shape used in aircraft construction, or they can be bent, drawn, or rolled as necessary, provided the proper temper is selected. For severe forming operations requiring over 20 minutes for completion, it is necessary to use the material in the "SO" temper. If the forming operation can be completed quickly, it is customary to heat treat the work and form it within one hour before it has aged. The first 20 minutes of this hour is by far the best time to form the material. By this method heat treatment of the completed work is avoided. When work has been formed in the annealed state and then heat treated, it will distort badly. It must be straightened out before it can be used. The distortion is caused by the severe cold-water quench.

Table 7.6, Heat-Treatable Aluminum Alloys - Mechanical Properties

Alloy and temper	Form and thickness of material	U.t.s. (p.s.i.)	Yield strength (p.s.i.)	Elongation in2 (%)	Brinell hardenss (500 kg.- 10 min.)	Shear strength (p.s.i.)	Fatigue strength (p.s.i.)
14SO	Extrusion - ⁻ and over	35,000*		12			
14SW	Extrusion-⁻ and over	50,000	32,000	12			
14ST	Extrusion-⁻ and over	60,000	50,000	7			
14ST	Forgings	65,000	50,000	10	125	39,000	12,000
14SO	Clad sheet	30,000*		16			
14SW	Clad sheet-0.039 and under	56,000	37,000	14		38,000	
14SW	Clad sheet- 0.040 and over	57,000	37,000	15		38,000	
14SW	Same- reheat treated	55,000	34,000	15		38,000	
14ST	Clad sheet- 0.039 and under	63,000	56,000	7		40,000	12,500
14ST	Clad sheet- 0.040 and over	64,000	57,000	8		40,000	12,500
14ST	Same- reheat treated	62,000	54,000	8		40,000	12,500
17ST	Bar- 0.750 and under	53,000	30,000	16	92	32,000	15,000
17ST	Bar- 0.751 and over	50,000	28,000	16	87	30,000	15,000
17ST	Extrusion	50,000	30,000	12	87	30,000	15,000
17ST	Forgings	55,000	30,000	16	90	33,000	12,000
17ST	Rivet					30,000	
17SO	Bare sheet	35,000*		12			
17ST	Bare sheet	55,000	32,000	18	96	33,000	15,000
17ST	Clad sheet	50,000	27,000	15		30,000	
17SRT	Bare sheet	55,000	42,000	12	100	33,000	
17SRT	Clad sheet	50,000	37,000	10		30,000	
17ST	Tubing-as received	55,000	40,000		96	33,000	15,000
17ST	Tubing heat treated	55,000	30,000		96	27,000	12,000
A17ST	Rivet					25,000	
24ST	Bar-up to 3"	62,000	40,000	14	100	37,000	14,000
24ST	Extrusion- as received	57,000	42,000	12	96	34,000	14,000
24ST	Extrusion- reheat treated	57,000	38,000				
24ST	Rivet					35,000	
24SO	Bare sheet	35,000*		12			

24ST	Bare sheet	62,000	40,000	15	100	37,000	14,000
24ST	Clad sheet	56,000	37,000	15		34,000	
24SRT	Bare sheet	65,000	50,000	11	110	39,000	
24SRT	Clad sheet	58,000	46,000	9		35,000	
24ST	Tubing- as received	62,000	42,000		100	37,000	14,000
24ST	Tubing- reheat treated	62,000	10,000		100	37,000	14,000
25ST	Forging	55,000	30,000	16	90	35,000	12,000
32ST	Forging	52,000	40,000	5	115	38,000	
A51ST	Forging	44,000	34,000	12	90	32,000	
53ST	Bar-extrusions	32,000	25,000	10			
53ST	Forging	36,000	30,000	14	75	24,000	
53ST	Rivets					22,000	
53SO	Sheet or tubing	19,000*		22			
53SW	Sheet or tubing	28,000	16,000	15			
53ST	Sheet or tubing	35,000	28,000	10			
61ST	Bar	42,000	35,000	10			
61ST	Extrusions	38,000	35,000	10			
61SO	Sheet or tubing	22,000*		16			
61SW	Sheet or tubing	30,000	16,000	16			
61ST	Sheet or tubing	42,000	35,000	10			
75SO	Extrusions	40,000*		6			
75ST	Extrusions	78,000	70,000	6		46,000	22,500
75ST	Forgings	75,000	65,000	10	135		
75SO	Bare sheet	40,000*		10			
75SO	Clad sheet	36,000*		10			
75ST	Bare sheet- 0.039 and under	76,000	65,000	7		46,000	22,500
75ST	Bare sheet-0.040 and over	77,000	66,000	8		46,000	22,500
75ST	Clad sheet- 0.039 and under	70,000	60,000	7		44,000	13,000
75ST	Clad sheet- 0.040 and over	72,000	62,000	8		44,000	13,000
75SO	Tubing	40,000*		10			
75ST	Tubing	70,000	58,000	10			
R301	Clad sheet	(Identical with 14S clad sheet in physical properties and chemical composition)					
R303	Bare or clad	(Equivalent to 75S alloy)					

* All values for annealed material are maximum permissible.
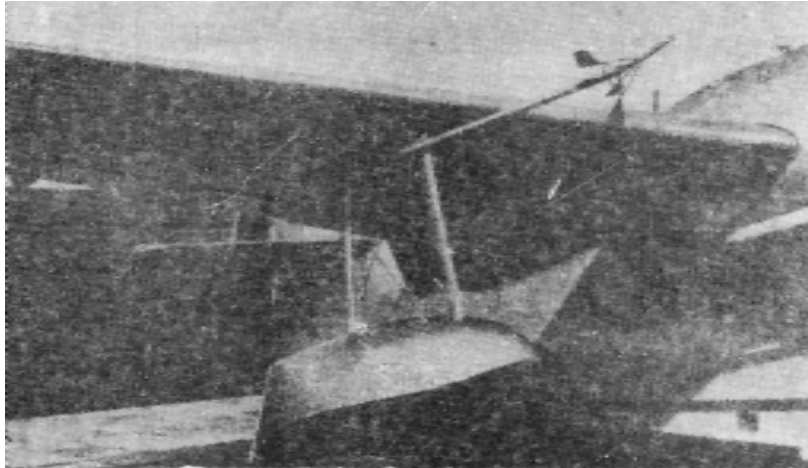
Fig7.13. Wing-tip Float and Bracing;Aluminum-alloy Sheet and Tubing

14SO clad (R301-0) sheet can be formed in the same manner as 24SO sheet. Difficult forming operations-stretching, deep drawing, etc. can be done, but the subsequent cold-water quench will distort the work and necessitate straightening. Freshly quenched 14SW clad (R301 - W) material has only slightly less formability than the annealed material .It can be stretched or drawn but must be worked within 1 hours of quenching. In the "as received" SW condition, moderate forming can be done. The use of male and female steel dies is advisable in pressing material in this condition. 14ST (R301-T) material requires large radii for forming but dimples satisfactorily. When necessary to improve its formability in this temper, it can be heated to 350^0F. for as long as 30 minutes without materially affecting its properties.

75SO material, either bare or clad, can be stretched or rubber-formed in the hydraulic press but requires high pressures. It can be dimpled satisfactorily but distorts on quenching. Severe double-curvature forming is sometimes done partially in the SO condition and finished in the freshly quenched SW condition. In this condition the material forms about as well as freshly quenched 24S. It should be worked within one hour of quenching but can be dimpled satisfactorily (using 24 ST tools) for several days after quenching. Due to its high yield strength and low plastic range, 75 ST has very poor forming characteristics and is inferior to 24ST. It has a high notch sensitivity and deep scratches and tool marks must be avoided. Cold dimpling of 75ST has had only limited success on an experimental basis. Hot dimpling has been successful. In this method an electronic timer is used to apply dimpling pressure immediately after the area is heated electrically. Hot forming at temperatures up to 325^0F. with less than a 5% loss in strength and very little effect on elongation is practicable. Use of electrically heated forming dies, and heating the work and quickly forming it before the heat dissipates, have both been successfully used.

61S in all its tempers has excellent formability. It is frequently purchased, formed, and used in the 61 SW condition. When this is done no heat treatment is involved.

The table 7.7 lists the bend radii for various thicknesses and tempers of the heat-treatable alloys. The bend radii are a good criterion of the relative forming properties.

The heat-treatable alloys machine beautifully.

Welding
The heat-treatable alloys cannot be welded with the oxyacetylene torch without destroying their mechanical properties. Even if subsequently heat treated after welding, the original mechanical properties cannot be restored. These alloys are difficult to weld in any event and are generally considered unweldable for silicon rod (43S) and is welded up into ducts and cowling.

Prior to the introduction of electric spot welding these alloys were joined only by reverting or bolting. As described earlier in this chapter, electric spot welding is rapidly displacing reverting for nonstructural parts and is being extended to structural parts.

Riveting
Aluminum alloy rivets for structural parts may be grouped in two classifications : those requiring heat treatment just before driving, and those that can be driven as received. Heat treatment is required by 17S and 24S rivets, whereas A17ST, 53SO, 53SW, and 53ST rivets can be driven as received.

On extremely important work where every pound of rivet strength is necessary 17S and 24S rivets are used. Because of their better heading qualities 17S rivets are used more often even in 24S structural assemblies. While 17S rivets can be driven within one hour of heat treatment, 24S rivets must be driven within 20 minutes of treatment. The aging of both these types of revert can be retruded by storing in an ice box. The 17S rivets are identified by a small raised tit in the centre of the head; 24S rivets have two small radial dashes at the ends of a diameter on the periphery of the load.

A17ST rivets do not have as good strength as 17S or 24S rivets, but are very generally used even in structural assemblies, such as metal-covered wings and fuselages. They are particularly good for field repairs since no heat treatment is necessary. The A17ST rivets have a small dimple at the center of the head. From an appearance standpoint 53S rivets of the appropriate temper are best for reverting 25S or Alclad material. Electrolytic corrosion will not attack these metals adjacent to 53S rivet heads even when unpainted.

TABLE 7.7, APPROXIMATE RADII FOR 90⁰ COLD BEND

Alloy	Approximate thickness (= t)				
	0.016 in.	0.032 in.	0.064 in.	0.128 in.	0.189 in.
14SO clad (R301 - 0)	0	0	0	$\frac{1}{2}t$	$\frac{1}{2}t$
14SW clad (R301 - W)	$1\frac{1}{2}t$	$2t$	$2\frac{1}{2}t$	$3t$	$3t$
14ST clad (R301 - T)	$2t$	$2t$	$3t$	$4t$	$4t$
24SO	0	0	0	0	0-1t
24ST	$1\frac{1}{2}t$ - 3t	2t-4t	3t- 5t	4t-6t	4t - 6t
24SRT	2t-4t	3t-5t	3t-5t	4t-6t	5t-7t
53SO	0	0	0	0	0
53SW	0 - 1t	$\frac{1}{2}t$-1$\frac{1}{2}t$	1t-2t	$1\frac{1}{2}t$-3t	2t-4t
53ST	$\frac{1}{2}t$-1$\frac{1}{2}t$	1t-2t	$1\frac{1}{2}t$-3t	2t-4t	3t-5t
61SO	0	0	0	0	0 - 1t
61SW	0-1t	0-1t	$\frac{1}{2}t$-1$\frac{1}{2}t$	1t-2t	$1\frac{1}{2}t$-3t
61ST	0-1t	$\frac{1}{2}t$-1$\frac{1}{2}t$	1t-2t	$1\frac{1}{2}t$-3t	2t-4t
75SO clad	0	0	0-1t	$\frac{1}{2}t$-1$\frac{1}{2}t$	2t
75SW clad	$\frac{1}{2}t$	$\frac{1}{2}t$-1t	1t-1$\frac{1}{2}t$	$1\frac{1}{2}t$-2t	2t
75ST clad	3t	3$\frac{1}{2}t$	3$\frac{1}{2}t$-4t	4$\frac{1}{2}t$-5t	5t

Alclad 24S can be bent over slightly smaller radii than the corresponding temper of the standard alloy.

Radii given for 24ST are for the fully aged condition. Much smaller radii can be used if formed immediately after quenching.

14SW clad (R301-W) radii are for material as received. When such material is freshly quenched the values for 14SO clad (R301-O) can be used.

75SW clad radii are for freshly quenched material. It is unstable in this condition and cannot be purchased.

The strength properties (in pounds per square inch) of these various rivets are as follows :

	17ST	24ST	A17ST	53S	53SW	53ST
U.t.s			55,000	62,000	38,000	18,000
25,000	35,000					
Yield strength		30,000	40,000	18,000	15,000	14,000
28,000						
Shear strength	30,000	35,000	25,000	12,000	18,000	22,000
Bearing strength	75,000	90,000	60,000	30,000	48,000	60,000

Corrosion

Clad material should be used whenever severe corrosion condition must be met in service. 53S material has excellent corrosion resistance being comparable to pure aluminum, but its mechanical properties are not as high as those of the other heat-treatable alloys. Consequently it is not practical to use 53S if great strength is a primary requisite 61S material also has excellent corrosion resistance and is considerably stronger than 53S. The other heat-treatable alloys have about equal corrosion resistance, except 25S which is somewhat inferior. Clad 14ST and R301-T have somewhat less corrosion resistance than clad 24ST. The heat-treatable alloys do not have such good corrosion resistance as the strain-hardened alloys.
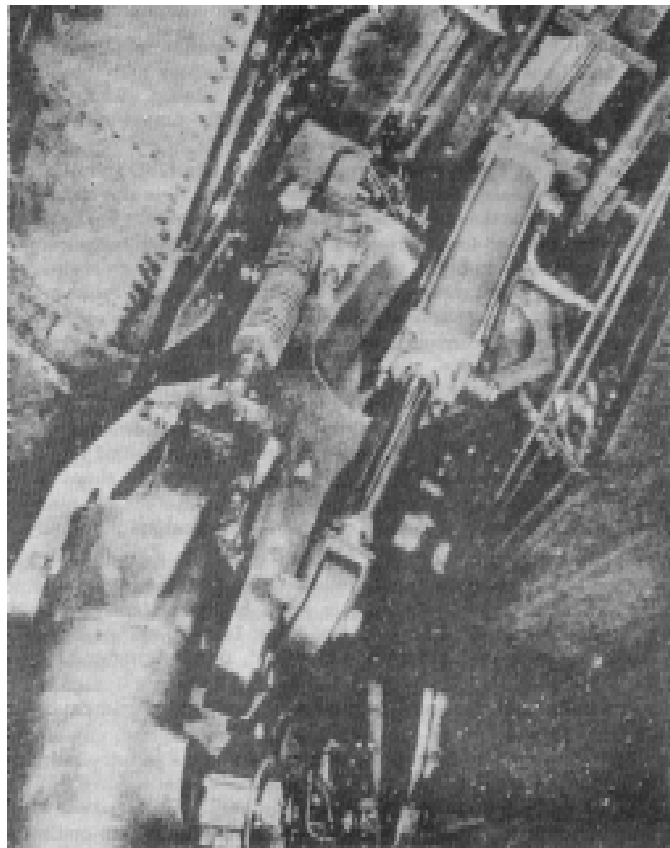
Fig.7.14. Retractable Landing Gear; 14ST Aluminum-Alloy Forging

It is standard practice in aircraft designed to operate under severe corrosive conditions to anodically treat aluminum alloys and then to apply one coat of primer and two coats of paint. Joints and fittings subject to corrosive conditions are often additionally coated with hot beeswax or paralketone as an added protection.

17ST and 24ST are much more corrosion resistant than 17SO and 24SO. If these alloys are heated above 375°F. their corrosion resistance is also lowered. Heating has the same effect on the alloys that require precipitation heat treatment, and for this reason these alloys in the ST temper are inferior to the same alloys in SW temper. However, 53ST is only slightly inferior to 53SW. Baked enamel finishes are not recommended for aluminum alloys, because it is questionable whether the added paint protection is equivalent to the basic corrosion resistance that is lost due to the baking temperature.

53S and 61S material have good corrosion resistance in all tempers.

Available Shapes

The alloy most often used in aircraft construction may be obtained in practically all standard forms. As explained in the paragraph on Extrusions, the designer may even specify the shape he wants and the manufacture will supply it. Some of the other alloys are available only as forgings. The table 7.8 summarizes the standard commercial forms of the heat-treatable alloys.

Sheet used in aircraft work usually falls between 0.014 and 0.120 inch in thickness. It is usually purchased in seven standard sizes as follows : 0.020×36''×144'', 0.025'' × 36''× 144'', 0.032'' × 36'' × 144'', 0.032''×48''×144'', 0.040'' ×48''×144'', 0.051''×48''×144'', 0.064''× 48''× 144''

Annealed-temper coiled strip is available at a considerable price saving compared to flat sheet.

Plate is purchased in much smaller pieces, usually 1 × 2 feet, since it is used for fabricating small fittings.

Rod can be obtained up to 8 inches diameter.

Bar can be rolled to a maximum cross-sectional size of 3 × 10 inches.

Bar 10 inches wide is often used in place of plate for fittings.

Tubing is available in many round and streamline sizes. A table of standard tubing sizesused in aircraft construction is given in the Appendix.

Square tubing is also available and is often used.

TABLE 7.8, STANDARD SHAPES-HEAT-TREATABLE ALLOYS

Shape	14S	14S clad	17S	Alclad 17S	A17S	24S	Alclad 24S	25S
Sheet		*				*	*	
Plate		*				*	*	
Rod and bar	*		*			*		
Wire			*	*			*	
Extrusions		*		*		*		
Tubing						*		
Rivets			*		*	*		
Forgings	*		*					*
Rolled shaped			*					

STANDARD SHAPES-HEAT-TREATABLE ALLOYS (CONTINUED)

Shape	32S	A51S	53S	61S	75S	75S clad	R301	R303
Sheet				*	*	*	*	*
Plate				*	*	*	*	
Rod and bar			*		*			
Wire			*					
Extrusions			*	*	*			*
Tubing				*				
Rivets			*					
Forgings	*	*	*		*			
Rolled shapes				*				

Uses

The heat-treatable alloys are used for practically all structural purposes in aircraft. They are used only in the heat-treated temper but they are often formed in the annealed temper and then heat treated.

14S extrusions and forgings are used for primary structure requiring high strength .

14S clad (R301) sheet is used for structural sheet-metal parts, including wing and fuselage skins, and may or may not be aged to 14ST-depending on the strength required.

17ST was the standard aircraft structural material until about ten years ago but is no longer produced in sheet, plate, or tubing form. 17 ST rivets are still commonly used.

A 17ST rivets are frequently used to avoid the necessity for heat treatment. They are particularly useful in field repairs.

24ST has completely replaced 17ST as the standard aircraft structural material but it is currently being displaced by 14ST (R301) and 75ST (R303), which have still higher physical properties. Alclad 24ST is frequently used when corrosion is important, as in covering seaplane floats and hulls. 14 ST clad (R301) has satisfactory corrosion resistance for this application also.
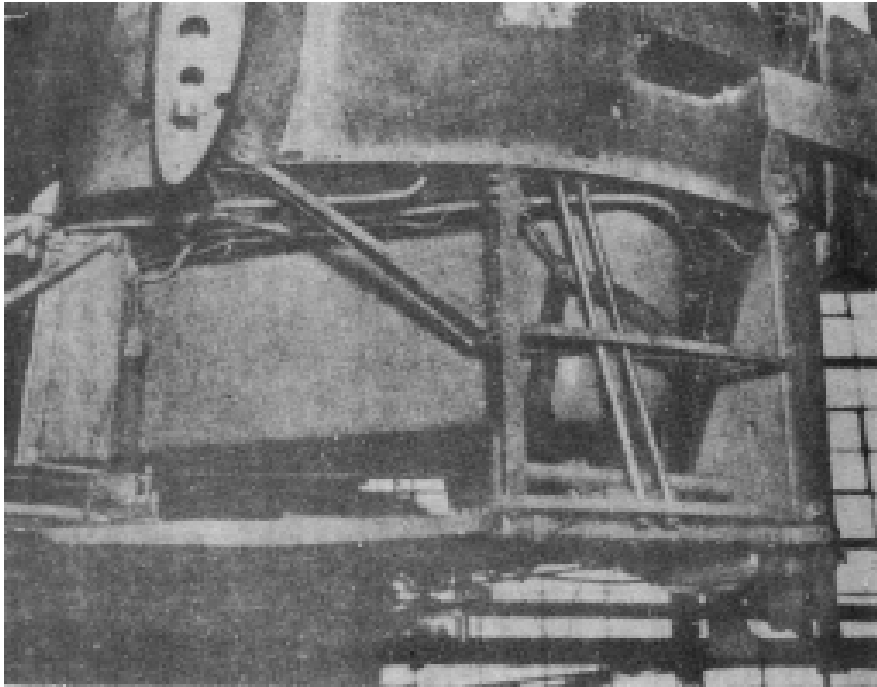
Fig.7.15.Forward End of Monocoque Fuselage Showing Tank Installation; Aluminium Alloy

TABLE 7.9, ALUMINUM ALLOY SPECIFICATIONS - WROUGHT

Alloy designation	Form	AN Aero Specification	Federal Specification
2S	Bar		QQ-A-411
	Sheet		QQ-A-561
	Tubing		WW-T-783
3S	Bar		QQ-A-356
	Sheet		QQ-A-359
	Tubing		WW-T-788
14S	Extrusion	AN-A-8	
	Forgings		QQ-A-367-C1.5
14S clad	Sheet	AN-A-22	
17S	Bar		QQ-A-351
	Forgings		QQ-A-367-C1.1
	Sheet		QQ-A-353
	Tubing		WW-T-786
Alclad 17S	Sheet		QQ-A-361
A17S	Rivets	AN-R-19	

24S	Bar		QQ-A-354
	Sheet	AN-A-12	
	Tubing	AN-T-80	
Alclad 24S	Sheet	AN-A-13	
25S	forgings		QQ-A-367-C1.2
32S	Forgings		QQ-A-367-C1.6
A51S	Forgings		QQ-A-367-C1.3
52S	Bar		QQ-A-315
	Sheet		QQ-A-318
	Tubing		WW-T-787
53S	Bar		QQ-A-331
	Forgings		QQ-A-367-C1.8
	Sheet		QQ-A-334
	Tubing		WW-T-790
56S	Rivets	AN-R-19	
61S	Extrusions		QQ-A-325
	Sheet		QQ-A-327
	Tubing		WW-T-789
75S	Extrusions	AN-A-11	
	Forgings		
	Sheet	AN-A-9	
75S clad	Sheet	AN-A-10	
R301 clad	Sheet	AN-A-22	
R303	Extrusions	AN-A-37	

25ST forgings are used for propeller blades and engine parts.

32ST forgings are used for aircraft-engine pistons and parts requiring good strength and hardness at elevated temperatures. 18ST is also used for engine pistons. It forges and machines more easily than 32ST but does not retain as high properties at elevated temperatures.

A 51ST forgings are used for complicated engine parts and for aircraft fittings, where the mechanical properties of this alloy are adequate for the purpose.

53S material is used when corrosion resistance is of primary importance.

61S is a relatively new material with good strength and excellent forming characteristics. It is rapidly finding favor for stamped and pressed sheet-metal parts. It should be fabricated in the ST condition wherever possible, to avoid the necessity for artificially aging the material from the SW temper. 61SW is frequently used for cowling panels.

R303 and 75S are the strongest aluminum alloys. They are ideal for wing-beam cap strips, fittings, and sheet parts not requiring much forming.

R301 is identical with 14S clad and is used interchangeably.

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CHAPTER-8
MAGNESIUM ALLOYS

Magnesium is the lightest of the structural metals available for aircraft construction. Pure magnesium weighs only 65% as much as aluminium. It is a silvery white metal that is relatively soft, and does not have the strength or other properties required for structural use. In its pure state magnesium has been widely used for flashlight powder, and a magnesium alloy was used for the cases of incendiary bombs. This latter use resulted in the construction and expansion of numerous magnesium plants during the war. A Peak production of 21,000 tons of magnesium per moth was reached early in 1944. This production rate was subsequently reduced when new types of bombs not using magnesium were developed. This enormous capacity was kept available in active or standby status, however, and may well be utilised in the near future as the structural applications of magnesium alloys increase.

Magnesium is commonly alloyed with aluminum, zinc, and magnesium, to create usable structural materials. Magnesium alloys have a specific gravity of 1.8, as compared to 2.7 for aluminum and 7.9 for steel. The light weight and relatively high strength of magnesium alloys results in a strength/ weight and relatively high attractive in aircraft design. There are also many places in aircraft construction, such as fairings, ducts, doors, brackets, bilkheads and partitions, and similar locations, where strength is secondary and a minimum thickness of material is all that is necessary. The use of magnesium alloys in these locations will effect an appreciable weight saving.

Magnesium alloys are non sparking and nonmagnetic; this characteristics permits their use adjacent to magnetic compasses. These alloys machine very well, can be gas, arc, or spot welded, and can be fabricated into many shapes, although special techniques are usually required.

Magnesium alloys are available as sand, permanent-mold, and die-castings; press and hammer forgings; extruded bar, rod, shapes, and tubing; and rolled sheet, plate, and strip. A number of alloys with varying characteristics are available in each form. These characteristics must be considered in choosing the best for a specific application. In the following pages the important characteristics of the commonly used alloys and their typical applications are described.

At present there are three main fabricators of magnesium alloys in the United States : Magnesium Division of the Dow Chemical company, American Magnesium Corporation, a subsidiary of the Aluminum Company of America; Magnesium-Aluminum Division of Revere Copper and Brass Incorporated. Each of these companies manufactures similar alloys but each has its own method of designation them. Army-Navy aeronautical specifications have been issued describing the commonly used alloys. Since the designation of the fabricators as well as the AN aero specifications have been listed in the tables in this chapter. Table 8.1 has been prepared to indicate the specifications and designations of magnesium alloys of similar type. For completeness S.A.E. and A.S.T.M specifications have been included.

PUREMAGNESIUM

Magnesium is never found in its native state. There are several common ore sources from which it is extracted, namely : magnesite (magnesium carbonate) which contains 500 pounds of magnesium per ton ; dolomite (magnesium calcium carbonate) which contains 240 pounds of magnesium per ton; carnallite (magnesium and potassium chloride) which contains 160 pounds of magnesium per ton. These ores are found practically all over the world. Magnesium constitutes 2.24% of the earth's crust and is fifth in abundance of the metals in the earth, following silicon, aluminum, iron, and calcium in the order named.

In addition to that in the magnesium ores, there is an infinite supply of magnesium in ocean water. Magnesium chloride makes up about 11% of the total salt content and magnesium is about 0.125% by weight of ocean water. The Great Salt lake in Utah contains 0.56% magnesium. One pound of metallic magnesium is recoverable from every 770 pounds of ocean water.

Production Methods

Magnesium was first produced in 1808 by Sir Humphrey Davy, who reduced magnesium from magnesium oxide with potassium vapor and also by the electrolysis of anhydrous magnesium chloride.

The first production of magnesium on a commercial basis began in 1914. There are three basic methods used at the present time of the reduction of magnesium from its source. These are the electrolytic process; the ferrosilicon process (Pidgeon); and carbothermic process (Hansgirg).

Table 8.1, Magnesium Alloys- Specifications and Uses

Form	AN aero	S.A.E.		A.S.T.M.		American Magnesium	Dow. Reverse	General use
		No	A.M.S	Designation	Alloy			
Sand castings	AN-QQ-M-56 (A)	50		B80-44T	AZ63	AM265	H	General casting use
	AN-QQ-M-56 (B)			B80-44T	M1	AM403	M	Weldable-tank flanges
	AN-QQ-M-56 (C)	500	4434	B80-44T	AZ92	AM260	C	Pressure-tight castings
Permanent-mold Castings		503	4484			AM260	C	Strong-good corrosion characteristics
		502				AM240	G	casts well- inferior corrosion
Die castings	AN-M-16	501	4490	B94-44%	AZ90	AM263	R	Housings.fittings,instrument parts
Extruded bar, rod, and shapes	AN-M-24	520	4350	B107-44T	AZ61X	AM-C57S	J-1	General purposes- good strength
	AN-M-25			B107-44T	AZ80X	AM-C58S	O-1	Highest strength
	AN-M-26	522		B107-44T	M1	AM3S	M	Weldable- light stresses
	AN-M-27	52		B107-44T	AZ31X	AM-C52S	FS-1	Cold forming
Extruded tubing	AN-T-71	520				AM-C57S	J-1	Best strength- high notch sensitivity
	AN-T-72	52				AM-C-52S	FS-1	Medium strength- extrudes well
	AN-T-73	522				AM3S	M	Welding-high resistance to salt water
Forgings	AN-M-20	531	4350	B91-44T	AZ61X	AM-C57S	J-1	Intricate shapes-press forged
	AN-M-21	532	4360	B91-44T	AZ80X	AM-C58S	O-1	High strength- difficult to forge
	AN-M-22	533				AM3S	M	Weldable- easily forged- low cost
	AN-M-23	53		B91-44T	AT35	AM65S	D-1	Easily forged- fair corrosion resistance
				B91-44T	AZ31X	AM-C52S	FS-1	Easily forged
Sheer and strip	AN-M-28	511	4380	B90-44T	AZ61X	AM-C54S	JS-1	High strength- welding
	AN-M-29	510		B90-44T	AZ31X	AM-C52S	FS-1	Cold forming- welding -tough
	AN-M-30	51	4370	B91-44T	M1	AM3S	M	Deep drawing- welding- low cost

AN Aero specifications must be used in Army and Navy airplanes.

S.A.E. is abbrevation for society of Automotive Engineers.

A.M.S. are S.A.E. Aeronautical Material Specifications.

A.S.T.M. is abbrevation for American Society for Testing Materials.

The electrolytic process electrolyses molten magnesium chloride which is obtained from brine, from sea water, or from one of the ores. The pure magnesium collects at the cathode. Magnesium ingot produced by this method may, if required, have a minimum purity of 99.88%.

The ferrosilicon or Pidgeon process is a thermal reduction process in which temperatures as high as 2150°F. are used. This method was adopted for many of the new plants constructed during the war because it uses a minimum of electric power. The process consists of reducing magnesium oxide in a vacuum with heat by means of ferrosilicon (an alloy of iron and silicon containing about 75% silicon). The magnesium oxide is prepared by calcining magnesium carbonate obtained from dolomite. Magnesium produced by this process may have a minimum purity of 99.99%.

The carbothermic or Hansgirg process for the reduction of magnesium is also a thermal process. It consists of heating magnesium oxide (previously reduced form dolomite and sea water) in the presence of coke at a high temperature. The product of reaction are magnesium and carbon monoxide. The magnesium vapor, at 3500-4000°F., is shock chilled by cold natural gas, causing condensation of the magnesium as a very fine dust. Magnesium produced by this process may have a minimum purity of 99.99%.

Physical Properties. Pure magnesium has the following properties :

Specific gravity	1.74
Density	0.064 lb. / cu. in.
Melting point	1204^0F
flame temperature	8760^0F.
Electrical conductivity :	
Volume basis	38 % of copper.
Mass basis	197 % of copper
Mean coefficient of thermal expansion, per inch per degree Fahrenheit	
(32^0-750^0F.)	0.0000166 inches
Modulus of elasticity	6.500.000 p.s.i.

MAGNESIUMALLOYS

The advantages of these of magnesium alloys in aircraft construction have not yet been fully realised by aircraft designers. The increased availability of these alloys in a variety of forms, their excellent strength/ weight ratio, and the improvement in protective systems against corrosion will soon result in their general use in aircraft design. These alloys have,however certain disadvantages which the designer must allow for if failures are to be avoided. These alloys are very poor as regards toughness and notch sensitivity in fatigue, and some alloys are susceptible to stress-corrosion cracking. Suitable heat treatment, good design, and the proper choice of alloy for a given application will minimise these disadvantages.

Fig-8.1. Stratosphere Gondola; Magnesium-alloy Sheet

The fabrication of wrought magnesium-alloy parts will require new shop tools and tecnique. The reason is that many forming operations can only be done at elevated temperatures from 450^0 to 700^0 F. The close-packed hexagonal crystal

structure of these alloys permits only a small amount of deformation at room temperatures. Zinc has a similar crystal structure. Copper and aluminum have what is known as face-centered cubic crystal structure and as a result are very ductile and easily worked at room temperature. As the temperatures of magnesium alloys is raised above 450⁰F. they may be more severely worked than most other metals at room temperatures. The use of heat also allows parts to be completely drawn or fabricated in one operation, where as in other metals several anneals and redraws might be required. Springback is negligible in parts formed at high temperatures. In general, magnesium-alloy parts can be formed in more intricate shapes than aluminum-alloy parts if the shop is properly equipped.

The directional properties of magnesium-alloy sheet are very pronounced. This condition is often referred to as preferred orientation. It evidences itself by a difference in properties, such as tensile strength and eleongation, in different directions. In magnesium alloys the greatest tensile strength and elongation will be found at right angles to the direction of rolling, or across the grain as it is commonly called. In general, the poorest properties are parallel to the direction of rolling, or with the grain-except the yield strength of hard rolled sheet, which is sometimes higher with the grain. The physical properties tabulated in this chapter are along the grain or the lower of the two directions. It should be noted that in magnesium alloys the maximum tensile strength and the maximum elongation always occur in the same direction, which is contrary to most other alloys. Because of the greater elongation across the grain it is possible to make sharper bends when the bend line runs parallel with the grain. As would be expected, hard rolled magnesium-alloy sheet has considerably greater differences in properties across and along the grain than annealed sheet has.

Chemical Composition

The chemical compositions of the commonly used mnagnesium alloys given in Table 8.2 . Since the same basic alloy is used in different forms such as forgings, extrusions, and sheet, all the AN aero specifications that apply have been listed opposite each alloy. Nominal percentages of each element have been listed; individuals specifications should be consulted if detailed chemical compositions are desired.

TABLE 8.2, MAGNESIUM ALLOYS-CHEMICAL COMPOSITION

Specification			Aluminum	Manganese	Zinc	Tin	Magnesium
AN aero	American Magnesium	Dow, Revere					
AN-QQ-M-56(C)	260	C	9.0	0.1	2.0		
AN-M-27,29;AN-T-72	C52S	FS-1	3.0	0.3	1.0		
	240	G	10.0	0.1			
AN-QQ-M-56(A)	265	H	6.0	0.2	3.0		
AN-M-20,24;AN-T-71	C57S	J-1	6.5	0.2	1.0		
AN-M-28		JS-1	5.0	0.2	1.0		Remainder
AN-QQ-M-56(B);							
AN-M-22,26,30; AN-T-73	403, 3S	M		1.5			
AN-M-21,25	C58S	O-1	8.5	0.2	0.5		
AN-M-16	263	R	9.0	0.2	0.6		
AN-M-23	65S	D-1	3.5	0.5		5.0	

Suffix - 1 or prefix C on alloy indicates that iron and nickel impurities are reduced to lowest concentration (0.005% maximum)

The common impurities found in magnesium alloys are iron, nickel, and coper. These impurities affect the corrosion resistance of the alloy and must be held to a minimum.

MAGNESIUM - ALLOY CASTINGS

In recent years 80% of the magnesium alloy products have been castings. The excellent mechanical properties of these castings permit their substitution for aluminum -alloy castings on an equal-volume basis, with a resultant weight reduction of about one-third. In highly stressed castings, adding of fillets and increase of section may reduce saving to one quarter. Patterns or dies designed for use with aluminum alloys can often be used for magnesium. Magnesium alloys have good casting characteristics and may be cast in intricate shapes. Practical castings have been made that weigh hundreds of pounds, while others weigh only a few ounces. Magnesium alloys are available as and, permanent-mold, and die castings. The type of casting chosen depends upon the quantity, size, intricacy, shape, strength, finish, or other requirements of the intended application. The three available types of castings are described in detail in the following pages.

Magnesium-alloy castings are used extensively in aircraft construction in such application as wheels, brake pedals, control columns, bell cranks, instrument housings, engine housings, bomb-rack supports, gear-box housings, and other miscellaneous brackets. Their satisfactory service record in these applications will result in the increased use of magnesium-alloy castings in the future.

These alloys are available in various chemical compositions and physical conditions. The choice of alloy depends upon the properties required for the intended application. The available casting alloys and their mechanical properties are listed in Table 8.4.

As mentioned above, aluminum-alloy casting patterns may generally be used for magnesium castings, since the shrinkage factors for these two metals are very similar. However, in magnesium-alloy castings subject to high stresses, larger fillets and radii should be used, stud bosses should be increased, and critical sections strengthened. Section changes should be gradual to reduce stress concentrations, and notches should be avoided. In general the notch sensitivity of the magnesium alloys to fatigue is even greater than that of aluminum, and more care must be taken to avoid stress concentrations. In magnesium castings it is also desirable to use stud lengths of the order of 2½ to 3 times the diameter, and to use inserts for bolts or studs that must be frequently removed in service.

Heat Treatment of Castings

Magnesium-alloy castings can be stabilized, solution heat treated, solution heat treated and stabilized, or solution heat treated and aged. All these heat treatments improve the properties of the casting in one way or another.

Solution heat treatment puts alloying ingredients into solid solution and increases the tensile strength and ductility.

Aging, after solution heat treatment, precipitates alloying ingredients and results in high yield strength and hardness. Aging also minimizes growth at elevated temperatures.

Stabilizing of cast material provides higher creep strength and less growth at elevated temperatures. In addition to these effects, the yield strength is increased when solution-heat-treated material is stabilized. Stabilizing is really a high-temperature aging treatment that can be done more quickly- than full aging.

The time and temperatures required for the various heat treatments are given in Table 8.3. Type II and III-aalloys require a pretreatment of not less than two hours' duration during which time the temperature of the furnace should be increased slowly from 640^{0}F to the heat-treatment temperature. Heating slowly through this range avoids fusion of the lower melting eutectics in the alloy before they are absorbed into solid solution in the heat-treatment operation. The presence of small amounts of calcium in an alloy reduces the danger of partial fusion and pretreatment is unnecessary. Type III-b in Table 8.3 is such an alloy.

TABLE 8.3, MAGNESIUM ALLOY CASTINGS-HEAT TREATMENT

Alloy designations			Types, heat-treat spec AN-H-25	Solution (hours at temperature)	Aging (hours at temperature)	Stabilizing (hours at temperature)
AN-QQ-M-56 composition	American Magnesium	Dow				
A	Am240	G	I	18 at 780^{0}F.	10 at 325^{0}F	
	AM265	H	II	(as cast--- stabilized A.C.S.)		18 at 350^{09}F
						4 at 500^{0}F.
A	AM265	H	II	10 at 730^{0}F.	14 at 420^{0}F; 18 at 350^{0}F.	4 at 500^0
C-sand cast	AM260	C	III-a	18 at 770^{0}F.	18 at 350^{0}F	4 at 500^{0}F
C-sand cast	AM 260		III-b	(as cast---stabilized A.C.S.)		8 at 325^{0}F
C-sand cast	AM260		III-b	14 at 780^{0}F.	12 at 150^{0}F.; 20 at 350^{0}F.	8 at 325^{0}F.
C-permanent mold	AM260	C	III-c	(as cast---stabilized A.C.S.)		10 at 325^{0}F. 4 at 500^{0}F
C-permanent mold	AM 260	C	III-c	18 at 770^{0}F	10 at 235^{0}F. - 350^{0}F	4 at 500^{0}F

Army-Navy aeronautical Specification AN-H-25--- process for Heat Treatment of Magnesium-Alloy Castings describes acceptable furnace equipment and heat-treatment practice. For solution heat treating an electrically heated air chamber with forced circulation is preferred. A 0.3% sulfur dioxide atmosphere should be maintained in the furnace. Aging and stabilizing furnaces may be of any type.

Fig. 8.4, Magnesium-alloy Castings-Mechanicasl Properties

Form	AN aero	Specification American Magnesium	Specification Dow	Tension U.t.s. (p.s.i.)	Tension Yield (p.s.i)	Tension Elongation (%)	Compression yield(p.s.i.)	Brinell hardness (500Kg. /10mm.)	Shear (p.s.i.)	Fatigue (p.s.i.)	Impact Izod (ft./ib)	Condition
Sand castings / Permanent-mold castings (except B-AC) — AN-QQ-M-56	A-AC	AM265-C	H-AC	24,000	10,000	4	14,000	50	18,000	11,000	3	As cast
	A-ACS	AM265-T51	H-ACs	24,000	10,000	2				11,000		As cast-stabilized
	A-HT	AM265-T4	H-HT	32,000	10,000	7	14,000	55	19,000	14,000	5	Solution heat treated
	A-HTA	AM365-T6	H-HTA	34,000	16,000	3	19,000	73	20,000	13,000	2	Heat treated-aged
	A-HTS	AM265-T7	H-HTS	34,000	13,000	4		59		13,000		Heat treated-stabilized
	B-AC	AM-403	M-AC	12,000		3	4,500	33	11,000		9	As cast
	C-AC	AM260-C	C-AC	20,000	10,000	1	14,000	65	18,000	11,000	1	As cast
	C-ACS	AM260-T51	C-ACS	20,000	11,000					11,000		As cast-stabilized
	C-HT	AM260-T4	C-HT	32,000	10,000	6	16,000	63	20,000	14,000	4	Solution heat treated
	C-HTA	AM260-T6	C-HTA	34,000	18,000	1	23,000	84	21,000	13,000	1	Heat treated-aged
	C-HTS	AM260-T7	C-HTS	34,000	16,000	1		75		13,000		Heat treated-stabilized
		AM240-C	G-AC	18,000	10,000	1	13,000	54	17,000	10,000	2	As cast
		AM240-T4	G-HT	34,000	10,000	6	12,000	52	19,000	12,000	4	solution heat treated
		AM240-T61	G-HTA	34,000	17,000		19,000	69	21,000	10,000	2	Heat treated-aged
Die casting	AN-M-16	AM263	R	30,000	20,000	2	20,000	60	20,000	14,000	2	As cast

Yield strength is defined as the stress at which the stress-strain curve deviates 0.2% from the modulus line.

Alloy C is used for both permanent-mold and sand castings.
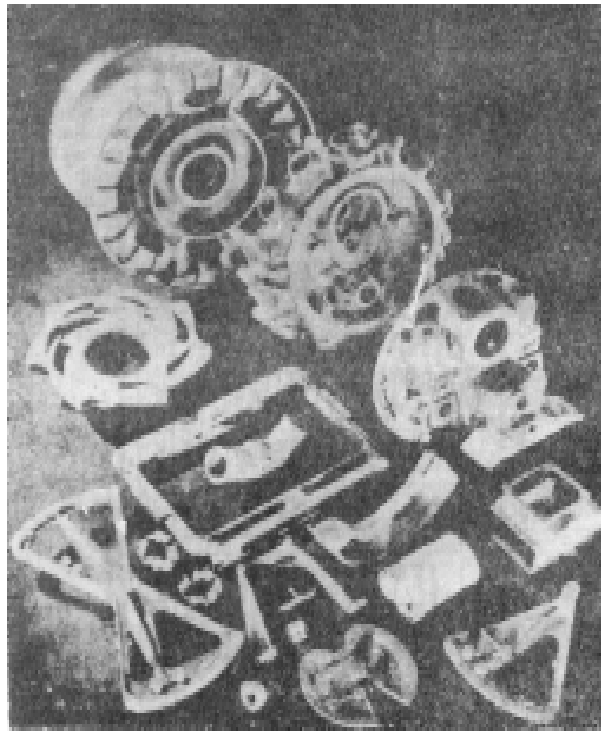
Fig.8.2. Sand-cast Magnesium Parts

Sand Castings.

The largest use of magnesium is in sand casings. The design of this type of casting is essentially the same as for aluminum castings. It is very important, however, to provide generous filleting at intersections or where sections of different thickness blend together. Adequate filleting will minimize stress concentrations and will improve metal flow during the casting process, thus avoiding shrinkage cracks and porosity. Until experience is acquired in the design and application of magnesium castings it is desirable to consult with the casting producer for advice on pattern design, choice of alloy, heat treatment, and corrosion protection.

In the manufacture of casting patterns it is necessary to use a shrink rule to allow for the contraction when the molten casting metal cools and solidifies. If the shape of the casting permits free contraction when the molten casting metal

cools and solidifies. If the shape of the casting a shrinkage factor of ⎯ inch per foot should be used for magnesium

alloy castings, if free shrinkage is restrained by bosses, gates, risers, internal core, or casting shape a shrinkage factor of inch per foot is used.

In sand casting of magnesium alloys, a minimum wall thickness of ⎯ inch is obtainable for small areas but ⎯ inch

is more practicable. A nominal tolerance of ± ⎯ inch on wall thickness or dimensions affected by core shift is

customary.

Some magnesium casting alloys are subject to "growth" when used at elevated temperatures. This growth is an increase in dimensions slowly brought about at elevated temperatures by changes in the internal structure. It occurs particularly in casting alloys in the solution heat-treated condition, which grow slightly until the amount of precipitation corresponding to the temperature is in balance. These growth values do not exceed 0.00033 inch per inch and 0.00041 inch per inch respectively for casting-alloy types A and C of specification AN-QQ-M-56. These alloys should not be used at temperatures above 200^0F. in the solution heat-treated condition. A temperature of 350^0F. is the maximum recommended when the alloys are stabilized or aged.

It is common practice in the design of magnesium castings to specify the use of steel or equivalent inserts for bushings, bearings, or threaded parts. Inserts such as these can be cast into place. Cadmium-plated steel inserts are preferred, as they minimize alloying action with the molten cast magnesium, and they do not contaminate the scrap when remelted. If brass, bronze, or other nonferrous inserts are used they should be chromium plated or sprayed with iron to reduce the alloying action.

Microporosity may occur in sections of magnesium-alloy castings. This porosity is caused by intergranular shrinkage voids. It is not visible on machined surfaces but excessive microporosity will impair strength and will permit leakage under pressure. Porous castings can be impregnated to eliminate leakage. Specification AN-QQ-M-56 permits impregnation only if specification approved and requires such castings to be stamped (IMP).

Local defects in magnesium-alloy castings can be repaired by welding if the flaw is in a nonstressed location. This type of repair should preferably be made before heat treatment. An X-ray of the defect before and after welding should be made to be sure no hidden flaws remain.

Army-Navy Aeronautical Specification AN-QQ-M-56 describes three types of magnesium-alloy sand castings, identified as compositions A, B, and C. The mechanical properties of these casting alloys and the heat-treated conditions in which they may be purchased are listed in Table 8.4.

Composition A is a general casting alloy of high strength. This alloy is used in 75% of the production in the United States.

Composition B has good welding characteristics and corrosion resistance. It has low strength and should only be used for lightly stressed parts. It cannot be heat treated to improve its strength. It is commonly used for such welded applications as tank fittings.

Compositions C has good castability and is less subject to microporosity than composition A. It is used particularly for pressure-tight castings.

Magnesium-alloy castings may be used in the as-cast (AC) condition for nonstructural parts requiring only moderate strength. For maximum ductility, elongation, and impact resistance the solution heat-treated (HT) condition should be specified. This condition should not be used if the castings are to be used at temperatures above 200^0F. or the castings will grow. The solution heat-treated and aged (HTA) condition should be specified to minimize growth and to obtain maximum strength and hardness. Growth can also be inhibited by stabilizing treatments as previously explained under Heat treatment of Castings.

Magnesium-alloy sand castings are widely used for aircraft landing wheels, instrument housings, control columns, and aircraft engine housings.

Permanent-mold castings

Permanent-mold castings are being specified more and more as their advantages become better known. In this type of castings a metal mold made of cast iron or low-alloy die steel is used. These molds have long life and are thought of as permanent when compared to sand-casting molds. As opposed to die casting, in which signifies the absence of external pressure. It is of interest to note that permanent mold casting preceded sand casting. In ancient days tools and weapons were cast in stone molds.

The manufacture of metal permanent molds is an expensive proposition and consequently a minimum production of about 500 parts is required to justify this type of casting. The size of permanent-molds castings is also limited by the problems of mold manufacture . At the present time, however, permanent mold castings up to 36 inches in length and 55 pounds in weight are being made successfully. The use of a metal mold instead of a sand mold permits closer control of dimensions and better surfaces, and the castings require less machining. The saving in machining time and cost should be considered when deciding on the type of casting to be specified.

Wall thickness of ⎯ inch for small areas nd ⎯ inch for large areas may be obtained in permanent-mold castings.

Dimensional tolerances as low as 0.01 inch can be held, but $\pm$ ⎯ inch is more commonly specified.

Permanent-mold casting is particularly adaptable to simple castings with uniform wall sections. Uniform sections allow equalisation of the rate of solidification and result in sounder castings. Undercuts on the outside face of the casting complicate the construction of the mold and are expensive. If undercuts or complicated coring are necessary it is common practice to use cores in combination with a metal mold. These are referred to as semipermanent molds.

The mechanical properties of permanent-mold castings are essentially the same as those of sand castings. These properties are listed in Table 8.4.
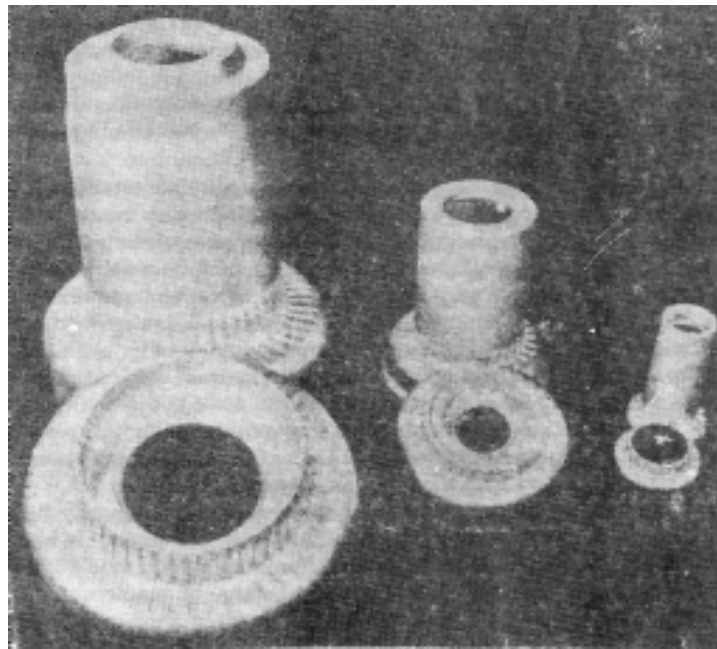
Fig.8.3. Permanent-mold Cast Magnesium Aircraft Wheels

Magnesium alloys AN-QQ-M-56 compositions A and C and Downmetal alloy G (AM240) are generally used for permanent-mold castings. Composition C is more widely used because of its good casting qualities, mechanical properties, and corrosion resistance. Downmetal G (AM240) casts better than composition C but is inferior in other characteristics. Composition A is used only for special applications, as it does not have such good foundry characteristics as the other alloys.

Permanent-mold castings are particularly adaptable for use in engine nose sections, landing wheels, wheel flanges, pistons, brackets, housings, and similar applications.

Die Castings

Magnesium alloys are well adapted to die casting. Die casting consists of forcing molten metal under high pressure into a metal mold or die. The high-pressure cold-chamber process of die casting is preferred for magnesium alloys. In this process molten metal is ladled into a receiving chamber in an injection cylinder. This receiving chamber is entirely separate from the melting pot or furnace and is referred to as a "cold chamber". The molten metal in the receiving chamber is immediately forced into the die by a hydraulically operated ram under high pressure. This pressure may run anywhere from 5000 to 35,000 p.s.i., depending on the type and size of casting and on the equipment. In this process a minimum of impurities is picked up in the molten metal since it is only momentarily in contact with the injection chamber and ram.

Dies and die-casting equipment are expensive and consequently high production of a part is necessary to reduce the cost per piece. In some cases as few as 500 pieces will justify die casting on an over-all cost basic. Machining costs are greatly reduced because of the accurate dimensions that can be held and the excellent finish. The thin walls and sections that can be cast save much material. In large quantities, die castings cost less per piece than other types of castings. The size of die castings is limited by available die-castings equipment. Parts up to 5 pounds in weight and with a projected area of 250 square inches have been successfully die cast.

Wall thickness of —— to —— inch are best from casting considerations and to obtain maximum mechanical strength.

Walls as thin as —— inch are possible for areas of 10 square inches or less. A maximum wall thickness of —— inch should not be exceeded. This limitation is necessary because heavy sections do not die cast well, owing to the fact that the die immediately chills the molten metal in contact with it, and in a heavy section shrinkage porosity would result as the interior of the section cooled more slowly. Cored holes with a diameter as small as 0.062 inch may be die cast.

Tolerances of 0.0015 inch per inch of length can be held. Normally a tolerance of $\pm$ 0.005 inch for dimensions on any portion of the casting on the same side of the parting line is specified; for dimensions that cross the parting line a tolerance of 0.010 inch is specified.

Draft allowances are very important in die-casting design to permit high production rates and to obtain a good surface finish. A minimum draft of 1^0 on outside surfaces at right angles to the parting line is necessary to allow for ejection of the casting without galling. A draft of 5^0 will greatly improve the finish of cast surfaces. The tendency of the cooling metal to shrink around internal projections necessitates a 2^0 draft on these surfaces. Cored holes require a 1^0 draft per side. These holes must subsequently be drilled or reamed to size.

Die castings should be designed as simply as possible to avoid complications in production and increased cost. Undercuts in particularly require loose die parts to permit removal of the castings. These loose parts must be replaced for each new castings, which operation reduced the production rate. Generous fillets and gradual changes in section are essential. Steel or nonferrous inserts may be cast in place, as previously described under sand casting. These inserts may serve as bearings or wear-resistant surfaces. External threads 16 per inch or coarser can be die cast if the thread axis is in the parting plane. It is described to cast such threads from 0.005 to 0.010 inch oversize on the pitch diameter in order to allow sufficient stock for chasing the thread.

Specification AN-M-16 describes the die-casting alloy that is used almost exclusively. This alloy has good casting characteristics and mechanical properties. It is used in the as-cast condition. The mechanical properties of this alloy are listed in Table 8.4.

Magnesium-alloy die castings are used for small engine parts, instrument parts and housings, small landing wheels, rudder and brake pedals, rocker-box covers, and similar applications.

WROUGHTMAGNESIUMALLOYS

Magnesium alloys are commercially available in the form of extrusions, forgings and sheet. Bars, rods, shapes, and tubing are fabricated by the extrusion process; both press and hammer forgings in a number of different alloys are available; and sheet, plate, and strip are procurable.

Magnesium alloys have the same ratio of modulus of elasticity to specific gravity as steel and aluminum. This agreement indicates there is a place in the structural field for wrought magnesium alloys. The limited applications thus far made in aircraft construction show significant weight savings are attainable by the use of magnesium alloys. Such savings will not be as great as is the case for castings in which magnesium alloy can be directly substituted for a heavier material. The mechanical properties of wrought magnesium alloys are not directly comparable with those of aluminum or steel and some additional thickness is necessary if the magnesium-alloy part is to have equal strength. The relatively low modulus of elasticity (E= 6,500,000 p.s.i.) will result in greater deflections for the magnesium-alloy member if the dimensions of the member it is replacing must be held. In such a case it would also be necessary to increase the thickness and consequently the weight. For these reasons it is not possible merely to substitute magnesium alloy for aluminum alloy and realize a full one-third saving in weight.

If a member is subject to bending stresses and its depth is not limited, the use of magnesium alloy will result in a substantial weight saving. The reason lies in the fact that in a beam the weight goes up as the first power of the depth, the bending strength increases as the square and the stiffness as the cube.

If the diameter of a tube is not limited, magnesium alloy is most efficient as compared to aluminum or steel for medium or long tubes in compression. For geometrically similar tubes of the same weight and length, the increased section of the magnesium-alloy tube will result in a much smaller slenderness ratio. This will permit a higher allowable stress (comparative), which when multiplied by the greater cross-sectional areas will give a total column load for the magnesium alloy, which exceeds that for the other materials.

In many applications a minimum thickness or bulk of material is needed for handling or for other reasons. In these cases the strength of the material is not critical. Fairings might be mentioned as one such applications. The use of magnesium alloy under these circumstances would obviously result in saving weight.

Extrusions

Magnesium alloys can be readily extruded in a variety of forms, such as bars, shapes, and tubing. Bars, structural shapes, and tubing are standard items and can be purchased from stock. Special shapes can be extruded to order but in this case the customer must bear the cost of the extraction die. The cost of a die is quite inexpensive, how ever, usually not exceeding $50 for a reasonable shape.

Bars can be obtained round, square, rectangular, or hexagonal. Structural shapes such as angles, I beams, channels, and tees are obtainable in structural sections that are standard, except for larger radii which are used to minimize stress concentrations. Tubing is obtainable as square, oval, round, or other regular hollow sections. Round tubing only is standard.

Extrusion billets vary from 2 to 16 inches in diameter and from 12 to 32 inches in length. They are heated to around 700⁰F. and forced through the extruction die by a ram pressure of 5000 p.s.i. Extrustion can be furnished up to 22 feet in length, and longer on special order.Tubing is limited to maximum ratios of diameter to wall thickness of 20/1 for AN-T-71 materials, and 30/1 for AN-T-72 and AN-T-73 materials. The tolerance on tubing wall thickness is   10% with a minimum

tolerance of 0.010 inch. The straightness of Extrusions can be held to 1 in 1000, which is equivalent to   inch in 5

feet.
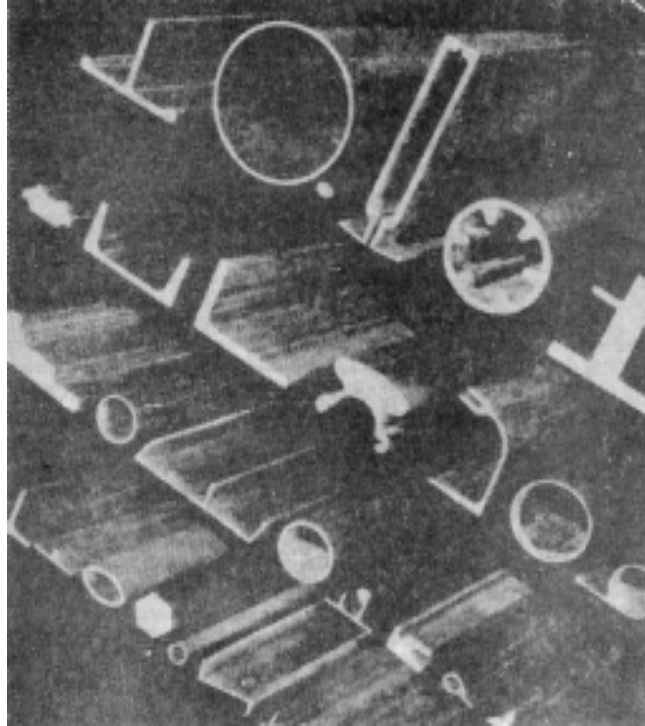
Fig.8.4. Miscellaneous Magnesium Extruded Shapes

The mechanical properties of magnesium-alloy extrusions are given in Table 8.5. Army-navy aeronautical specifications have been issued covering all the extrusion alloys used in aircraft construction. The specific characteristics of these alloys other than mechanical properties are as follows :

AN-M-24. This is a general-purpose alloy with good mechanical properties. It is susceptible to stress-corrosion cracking if severely formed or welded. This can be relieved by an annealing treatment at 400⁰F. for one hour. This alloy also has a high notch sensitivity.

AN-M-25. This alloy has the highest strength and would normally be selected for primary structural applications. In the aged and the heat-treated and aged conditions its compressive yield strength almost equals its tensile yield strength. AN-M-26.This alloy has good weldability to material of the same composition. It is moderately strong and is the cheapest of the extrusions.

AN-M-27. This alloy has the best cold-forming characteristics and elongation. It also has good corrosion resistance.

AN-T-71. This specification covers extruded tubing made from the same alloy as AN-M-24

AN-M-72. This specification covers extruded tubing made from the same alloy as AN-M-27

AN-M-73 this specification covers extruded tubing made from the same alloy as AN-M-26.

These extrusions are being used successfully for structural members, floor beams, moldings, stiffeners, seat frame work, etc. Alloys AN-M-24 and AN-M-25 are ideal for screw stock.

Forgings
Magnesium-alloy forgings are sound, pressure tight, and light in weight. They are made from extruded stock which is a fine grained, partially worked, sound material. Forgings should be specified instead of castings if shock resistance, pressure tightness, and great strength are required. The forgings alloys are all weldable.

	Specification			Tension			Compression yield (p.s.i.)	Brinell hardness (500 kg./10 mm.)	Shear (p.s.i.)	Fatigue 500×10⁶ cycles (p.s.i.)
Form	AN aero	American Magnesium	Dow Revere	U.t.s. (p.s.i.)	Yield (p.s.i.)	Elongation (%)				
Bars and rods	AN-M-24	AM-C57S	J-1	40,000	26,000	11	20,000	58	19,000	18,000
	AN-M-25	AM-C58S	O-1	43,000	28,000	9	22,000	55	20,000	19,000
	AN-M-25	AM-C58S-T5	O-1A	45,000	30,000	5	28,000	80	22,000	19,000
	AN-M-25	--	O-1HTA	48,000	33,000	4	30,000			
	AN-M-26	AM3S	M	30,000		3	14,000	42	16,000	9,000
	AN-M-27	AM-C52S	FS-1	35,000	22,000	10	17,000	49	19,000	14,000
Shapes	AN-M-24	AM-C57S	J-1	40,000	22,000	10	19,000	64		
	AN-M-25	AM-C-58S	O-1	40,000	25,000	5	22,000	67		
	AN-M-25	AM-C-58S-T5	O-1A	44,000	27,000	4	27,000	81		
	AN-M-25	--	O-1HTA	47,000	30,000	5	30,000			
	AN-M-26	AM3S	M	29,000		2	11,000	46		
	AN-M-27	AM-C52S	FS-1	34,000	20,000	10	15,000	50		
Tubing	AN-T-71	AM-C57S	J-1	36,000	16,000	7	15,000	50		
	AN-T-72	AM-C52S	FS-1	34,000	16,000	8	15,000	46		
	AN-T-73	AM3S	M	28,000		2	10,000	42		

Table 8.5, Magnesium-alloy Extrusions-Mechanical Properties

In the early days of the war 5,000,000 pounds of magnesium castings was used in one year as compared to only 10,000 pounds of forgings. At about that same time the German ME-110 fighter and the JU-88 bomber were using about 100 pounds of magnesium-alloy forgings per plane. The JU-88 engine mount an AN-M-21 magnesium-alloy forgings, 45 inches long, 14 inches wide, and with a projected area of 275 square inches.

Great progress in magnesium-forgings practice and equipment has been made in the last few years. Forgings up to 10 pounds in weight have been made for aircraft use, and a 17- pounds forgings has been made for other purposes. An 18,000- ton press standing 5 stories high and weighing over 5,000,000 pounds has been erected by the United States government in Worcester, Mass. This press is in the custody of the Wyman-Gordon Company and is available for production or research work by any company or agency with a large-forging problem.

In the design of forgings, shape corners, notches, tool marks, and rapid changes of section be avoided to minimize stressconcentrations. Generous fillets and radii of at least ___ inch should be provided. A 7 draft is required for hammer forgings but as low as 3^0 may be satisfactory for press forgings. Aluminum-forgings dies are frequently usable for magnesium if the fillets and radii are generous.

A tolerance of 0.010 inch for dimensions under 2 inches $\pm$ 0.003 inch for each additional inch can be held in width and length. For height dimensions across the parting line a tolerance of ___ inch for small forgings and $\pm$ ___ inch for large forgings is required.

$\pm$
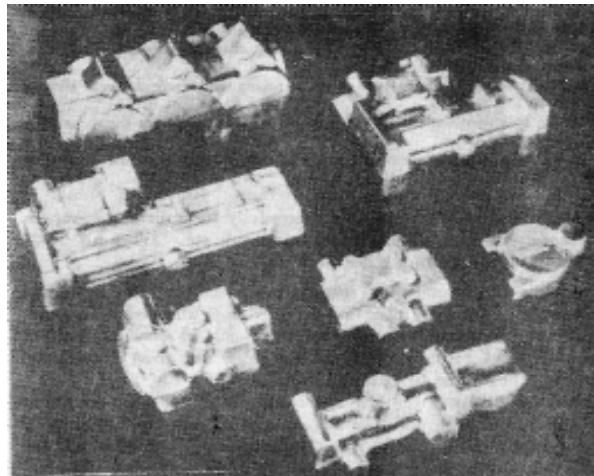
Fig.8.5. Press-forged Magnesium Hydraulic Parts

The high-strength magnesium alloys must be press forged, while the other alloys can be hammer forged. AN-M-20 and AN-M-21 alloys are hot short when subjected to the rapid blows of a forging hammer. In press forging these alloys it is sometimes necessary to apply top pressure for 1 minute to complete the metal flow. A press forge requires tremendous power as compared to a forging hammer : a 500- ton press is equivalent to a 1200- pound hammer. In many cases a forging is blocked out in the press and finish forged in the hammer. When this procedure is used it has been found desirable to finish the hammer forging when the part is at 400^0F. At the start of forging the stock is at a temperature of between $600°$ and $775°$F; depending on the alloy. The dies are heated to approximately the same temperature to prevent too rapid cooling of the forging stock.

The mechanical properties of the forging are given in Table 8.6. Other properties are as follow :

An-M-20. This alloy has good formability and weldability. It can be forced into more intricate shapes than AN-M-21.

AN-M-21. This alloy is used when maximum strength is required. It is aged after forging for 16 hours at 325^0F. to improve its strength but its elongation is reduced. To improve its creep resistance at elevated temperatures the forged material can be heat-treated for 2 hours at 700^0F., water quenched, and then aged for 16 hours at 325^0F. Crankcases have been forged of this material.

AN-M-22. This alloy has the best formability and weldability but has relatively low strength.

AN-M-23. This alloy is suitable for difficult designs as it is easier to fabricate than AN-M-20 or AN-M-21 but does not have as good corrosion resistance or strength as those alloys.
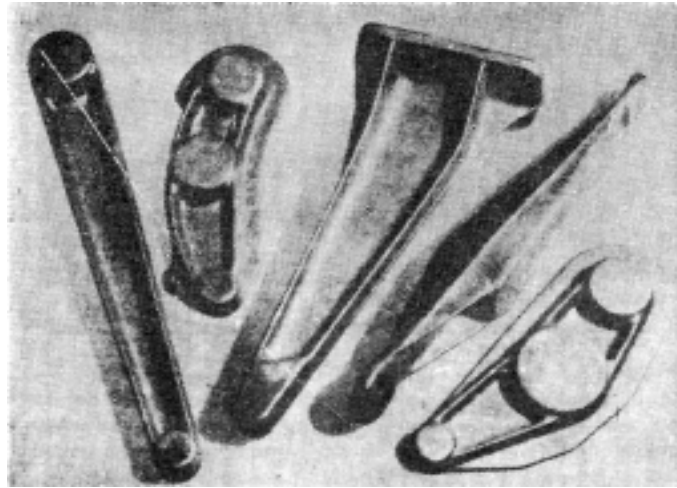
Fig.8.6. Hammer and Press-forged Magnesium Control Parts

Magnesium-alloy forgings have been used for aircraft-engine bearing caps, housings, rocker-arm supports, cargo-door and aileron hinges, hydraulic cylinders and valve bodies, levers, brackets, fittings, and crank cases.

Sheet, Plate, Strip

Three ,magnesium alloys are available in the form of sheet, plate, or strip stock. Each alloy is available in the annealed, as-rolled, or hard-rolled condition. The as-rolled condition is seldom specified. Sheet is material under 0.25 inch thick; plate is 0.25 inch or thicker; strip is material up to 8 inches in width and up to 0.125 inch thick. Strip may be coiled or as-sheared from sheet.

Sheet is available in thicknesses from 0.016 inch up. It can be obtained in lengths up to 144 inches and widths up to 48 inches. Strip is available in thicknesses from 0.016 to 0.051 inch in coils up to 125 feet long.
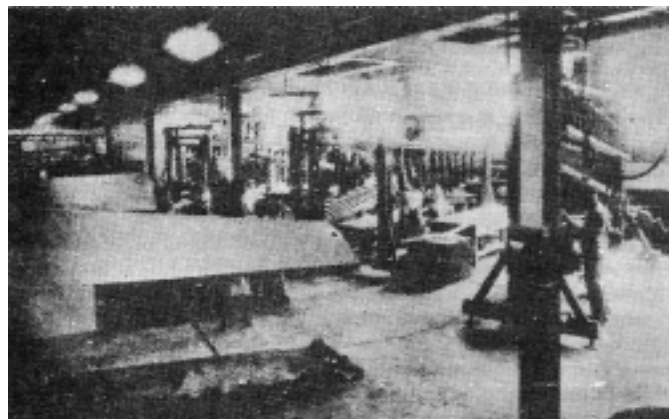
Fig.8.7. Assembly of Magnesium SNJ-2 Wings

Due to the poor cold-working properties of magnesium alloys, sheets cannot be flattened by stretcher leveling. Rupture occurs in this process before the sheets are sufficiently stretched to lie flat. Sheet stock is flattened by placing it on a flat cast-iron surface and then superimposing additional cast-iron sheets to attain 300-450 p.s.i. pressure on the magnesium-alloy sheets. This assembly is then placed in a furnace. Annealed sheets require heating to 700^0F. and cooling to 300^0F., all under pressure; hard rolled sheets require heating to 400^0F. for AN-M-30 alloy, and to 275^0F. for AN-M-28 and AN-M-29 alloys.

Magnesium alloy sheet can be drawn, spun, formed, and welded either by arc, gas, or spot. Many of these operations have to be done at elevated temperatures because of the poor cold-forming characteristics of these alloys. These operations are described in detail later in this chapter.

The mechanical properties of magnesium-alloy sheet, plate, and strip are given in table 8.7. Other properties are as follow AN-M-28 Annealed sheet has medium strength, limited formability, and excellent arc-welding characteristics. Hard rolled sheet has high strength, good hot formability, and excellent arc-welding characteristics.

Table 8.6, Magnesium-alloy Forgings- Mechanical Properties

Specification			Tension			Compression yield (p.s.i.)	Brinell hardness (500 Kg./ 10mm.)	Fatigue 500 10^6 cycles (p.s.i.)	Forging method
AN aero	American Magnesium	Dow Revere	U.t.s. (p.s.i.)	Yield (p.s.i.)	Elongation (%)				
AN-M-20	AM-C57S	J-1	38,000	22,000	6	14,000	55	16,000	Press
AN-M-21	AM-C58S	O-1	42,000	26,000	5	18,000	69	18,000	Press
AN-M-21	AM-C58S-T5	O-1A	42,000	28,000	2	20,000	72	16,000	Press
AN-M-21	–	O-1HTA	42,000	28,000	2	19,000	72	16,000	Press
AN-M-22	AM3S	M-1	30,000	18,000	3		47		Hammer or press
AN-M-23	AM65S	D-1	36,000	22,000	7			10,000	Hammer
	AM-C52S	FS-1	35,000	22,000	10				Hammer or Press

Letter A after alloy means forged and aged; letters HTA mean heat treated and aged after forgings; T5 after alloy means forged and aged.

Table 8.7, Magnesium-alloy Sheet, Plate, Strip-Mechanical Properties

Specification			Tension			Compression yield (p.s.i.)	Brinell hardness (500 Kg./ 10mm.)	Shear (p.s.i.)	Fatigue, 500×10^4 cycles (p.s.i.)
AN aero	American Magnesium	Dow Revere	U.t.s. (p.s.i.)	Yield (p.s.i.)	Elongation (%)				
AN-M-28	AN-C54S-O	JS-1a	37,000		8	16,000	58	20,000	13,000
AN-M-28	AN-C54S-H	JS-1h	42,000	30,000	3	27,000	73	21,000	14,000
AN-M-29	AN-C52S-O	FS-1a	32,000		12	16,000	56	21,000	12,000
AN-M-29	AN-C52S-H	FS-1h	39,000	29,000	4	26,000	73	23,000	14,000
AN-M-30	AN-3S-O	Ma	28,000		12	12,000	48	17,000	9,000
AN-M-30	AN-3S-H	Mh	32,000	22,000	3	20,000	56	17,000	10,000

Letter a or O after means annealed; letter h or H means hard rolled

AN-M-29. Annealed sheet has the best cold formability but limited gas and arc weldability. Hard rolled sheet has the best combination of fatigue and shear strength as well as toughness and low notch sensitivity.

AN-M-30 Annealed sheet has the best gas weldability and hot formability. It is a low-cost alloy of moderate strength. Hard rolled sheet has the best resistance to creep at elevated temperatures but is seldom used.

Magnesium-alloy sheet is used in the construction of oil and fuel tanks, ducts, fairings, wing tips, flaps, ailerons, stabilizers, rudders, experimental wings, and other structural applications.

SHOP FABRICATION PROCESSES

The fabrication of magnesium alloys into finished articles may involve any number of the standard shop processes. Magnesium alloys can be machined, sheared, blanked, punched, routed, and formed by bending, drawing, spinning, pressing, or stretching. When these processes are applied to magnesium alloys the technique required differs somewhat from that used with other materials. The application of these processes to magnesium alloys will be described in the following pages.

Machining

Machining alloys have excellent machining characteristics. A smooth finish is obtained at extremely low cost. Surface grinding is seldom necessary. Machining can usually be done at the maximum attainable speed of the machine. Light, medium, or heavy feeds can be used and the free cutting action of the material will produce well-broken chips which will not obstruct the cutting tool or machine. The power required for a given machining operation on magnesium alloys is approximately one-half that required for aluminum alloys and one-sixth that required for steel.

To take full advantage of the excellent machining qualities of magnesium, the machine equipment must permit operation at high speeds and feeds; sharp cutting tools of the correct design are necessary, and the part being machined must be rigidly supported. Due to lower cutting resistance, lower specific heat, lower modulus of elasticity, and the chemical properties of magnesium alloys, there are some essential differences in machining practice when compared with other metals. These differences may be summarized as follows :

1. Cutting edges must be kept sharp and tool faces polished to insure free cutting action and reduce the adherence of magnesium particles to the tool tip. Tools must be designed to allow for ample chip room, and tool clearances should be 10° to 15°. Large feeds are advantageous in reducing the frictional heat.
2. If the precautions of paragraph 1 are not taken the magnesium part being machined may distort, owing to excessive heat. This distortion is most likely to happen on thin sections, in which the heat will cause a large rise in temperature. Parts which tend to distort during machining can be stress-relieved by heating at 500^0F. for 2 hours. If the part is stored for 2 or 3 days prior to finish machining the same result is attained.
3. Magnesium cuts closer to size then aluminum or steel. Reamers should be specified several ten-thousandths oversize compared to those used on other metals; taps should be specified from several ten-thousandths to two thousandths over size depending on the diameter.
4. Because of its lower modulus of elasticity, magnesium will spring more easily than aluminum or steel. Consequently it must be firmly chucked but the clamping pressure must not be great enough to cause distortion. Particular attention must be paid to light parts, which can easily be distorted by chucking or by heavy cuts.
5. A cutting fluid* is used in reaming and in screw-machine work or when cutting speeds exceed 500 feet per minutes. The cutting fluid is primarily a coolant. In all other operations magnesium can be machined dry with good results.
6. In grinding, a liquid coolant* should be used or the grinding dust should be exhausted and precipitated in water.

Cutting tools designed for use with steel or brass can be used on magnesium alloys, but they must have a sharp cutting edge and good clearance. The basic principle in all cutting tools for magnesium alloys is to limit the friction to avoid the generation of heat and possible fire hazard. Carbon-steel tools can be used for reamers, drills, and taps, but high speed steel is preferred and is most generally used. High-speed steel is also used for other types of cutting tools for magnesium, but cemented carbide tools have a much longer life and should be employed wherever possible.

Turning, shaping, and planing tools should be similar to those used for brass. Coarse-tooth milling cutters should be used, because the heavier cut obtained cause less frictional heat and consequent distortion. Ordinary twist drills and spiral reamers with about 6^0 relief behind the cutting edge give satisfactory results. Threading is readily done by means of taps, dies, or lathe turning. Roll threading is not satisfactory because it involves excessive cold working of the metal. Depths of tapped holes should be 2 to 3 times the diameter of the stud. Magnesium-alloy threaded parts will not seize when mated with other common metals or even with parts made from the same composition of alloy. Band or circular saws for cutting magnesium alloys should have from 4 to 7 teeth per inch and must be very sharp. Hand hacksaw blades should have 14 teeth per inch. Single-cut files are preferable for use with magnesium alloys.

*Cutting fluids or coolants containing water should not be used without special precautions. Advice on machining practices can be obtained without charge from magnesium producers and fabricators.

Precautions must be taken to reduce the fire hazard when machining magnesium alloys. Cutting tools must be sharp, and machines and floor must be kept clean. Scrap should be kept in covered metal containers. Lubricants should be used for automatic-machine work or when fine cuts are being made at high cutting speeds, to minimize the frictional heat. There is no serious danger from fire if care is exercised by the operator.
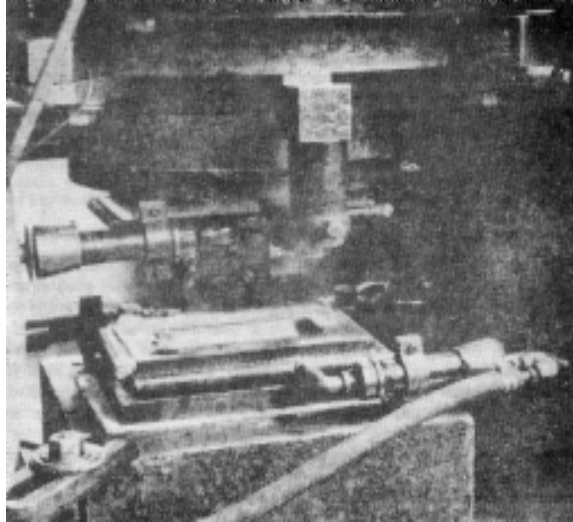
Fig.8.8. Hot Forming Magnesium Sheet-Gas Heating Dies

Shearing

In shearing magnesium sheet a rough, flaky fracture is obtained if the proper equipment is not used. The clearance between shearing blades should be on the order of 0.003 inch, and the upper shear blade should have a rake angle of around 45^0. The sheared edge may be improved by a double shearing operation known as "shaving". This consists

of removing an additional   to — inch by a second shearing. The maximum thickness recommended for cold

shearing are 0.064 for hard rolled sheet and — inch for annealed sheet. These thicknesses can be increased if shearing

is done at an elevated temperatures, but in any case sawing should be resorted to for cutting plate.

Blanking and Punching

These operations are practically the same as those used for other metals. A minimum clearance between the punch and the die is essential to obtain maximum edge smoothness. This clearance should not exceed 5% of the thickness of magnesium being worked. The punch and die are frequently made of materials of unequal hardness, so a sheared-in fit providing minimum clearance can be obtained. Magnesium alloys can be punched and blanked at room temperatures but better results are obtainable at elevated temperatures.

Routing

Routing magnesium alloys is a simple, straightforward operation. Dry routing can be done with little fire hazard if the router bit is sharp and the chips are thrown free. A low-viscosity mineral-oil coolant is frequently used as insurance against fire. Router bits of the single- or double-flute type with smooth polished flutes to provide good chip removal are used. Spiral-flute routes pull the chips from the work and have less tendency to load up.

Forming Magnesium Alloys

Magnesium-alloy sheet and extrusions, including tubing, can be processed with the same type of equipment used for other metals. One major difference is the necessity for heating the tools and the work since many of the forming operations must be done at elevated temperatures because of the close-packed hexagonal crystal structure of magnesium alloys. This crystal structure severely limits the amount of work that can be done at room temperatures without inducing a shear failure. At around 400^{0}F recrystallization occurs with a resultant decrease in capacity for plastic flow. As the temperature is further increased the ductility also increases and may reach a point as much as nine times the ductility at room temperatures.

The recommended forming or working-temperature ranges are given in Table 8.8. In addition, the minimum bend radii are given for room temperature and for the recommended working-temperature range.

It will be noted that the working-temperature range for hard rolled parts is lower than for annealed material. Hard rolled parts are stronger because of the cold working they received when rolled at the mill. If they are heated to a high temperature they will revert to the annealed condition and lose their strength. When hard rolled sheet is specified, parts must be designed to permit forming at temperature that will not anneal the material excessively.

The working of magnesium alloys at elevated temperatures involves the development of new shop techniques and methods of heating the equipment and work. There are several compensating advantages, however, in working at elevated temperatures. For one, parts can be formed in as single operation, without intermediate annealing and drawing; this saves time and the need for intermediate drawing dies. Secondly, springback is eliminated at the upper temperatures of the working range and is gratly reduced at the lower temperatures. Thirdly, by varying the temperatures of the die it is possible to correct the size of parts which might be outside permissible tolerance limits due to errors in die construction or material variations.

TABLE 8.8, MAGNESIUM ALLOY-FORMING TEMPERATURES AND BEND RADII

Alloy	Condition	Working temperature range (°F)	Bend radii for 90° bends (material) up to 0.125 in thick (t = thickness)	
			Working temperature	70°F.
AN-M-28	Annealed	550-650	2-3t	7t
AN-M-28	Hard rolld	400 max.	5-7t	14t
AN-M-29	Annealed	400-500	1-2t	5t
AN-M-29	Hard rolled	275 or 300 (less than 15 min.)	5-6t	8t
AN-M-30	Annealed	550-650	1-2t	6t
AN-M-30	Hard rolled	400 max.	6-7t	9t

When magnesium alloys must be hot formed it is desirable to preheat the sheet or extrusion to the working temperature. Gas or electric furnaces, immersion baths, or hot contact plates may be used. Preheating the work minimizes distortion due to internal stresses, keeps the dies at a uniform temperatures, and increase the production rate.

In the following pages a short description of several common methods used on forming magnesium alloys will be presented: hand forming; bending of sheet, strip, extrusions, and tubes; drawing; pressing; sizing; spinning ; roll forming and die drawing; stretch forming; drop hammering.

Hand Forming

In hand forming the material should be clamped in a soft-jawed vise or to a form block. A heat-resisting wood such as birch or a metal should be used for the form block. Metal form blocks made of magnesium alloy have the advantages of having the same thermal expansion as the work. The form block may be preheated in an oven or elecrtrically heated. The work can be heated by conduction from the hot form block, it can be preheated, or it can be heated with a torch. If it is torch heated, a contact pyrometer should be used to avoid overheating. A leather maul should be used for hammering. Hand forming should be used if the quantities are too small to justify the manufacture of dies, or if the part is very intricate.

Bending

Machine bending is frequently used for the manufacture of stringers, clips, and stiffeners made from sheet or strip. A press-type brake is used almost exclusively because of the ease with which it can be equipped with strip electric heaters on either side of the dies. Bends of the smallest possible radii are obtainable if a very slow press speed is used to finish the bend. When possible, both the dies and the work should be heated. If the dies alone are heated the work will absorb heat by contact and can be bent satisfactorily. If the work alone is heated, the bending operation must be rapid, before the dies dissipate the heat at the bend. Bends parallel to the grain direction are easier to make because of the greater elongation of magnesium alloys in the transverse direction.

Extrusion Bending

Extrution may be bent by hand, using a torch for heat and a contact pyrometer to avoid overheating. Production bending can be done with standard angle rolls, with mating dies, or on a stretch-forming machine. The work should be preheated if the working is severe, and the dies also if the operation is slow or the extruded section is large. Forming temperatures of 600°F. permit very severe working of all the extrusion alloy. Only alloy AN-M-25 is limited as to working temperalure. If it is not to be aged after forming it can be worked at 600°F., the same as the other alloys. If this material is worked between 350° and 500°F. it will be partially aged, with a resultant increase in strength and reduction in ductility. Material in the aged or heat treated and aged condition can be formed up to a temperature of 380°F, without change of properties. At this working temperature the alloy in these conditions can be bent about the same as the unaged alloy at room temperature.

Tube Bending

Standard pipe-bending machines using an internal mandrel can be used for bending magnesium-alloy tubing. Small-radius bends may require heating, as with other materials. If hot tubing is to be bent about a wood form it is advisable to metal-face the form. AN-T-71 and AN-T-72 alloys can normally be bent at room temperatures, while AN-T-72 alloys can more likely to require heating.

Shallow Drawing and Pressing

In shallow drawing the parts are more pressed than drawn, since there is very little metal flow. Wing ribs, door reinforcing panels, and fairings are typical examples of parts fabricated by this method. The Guerin patented process of using a rubber pad as the female die is most frequently used, although male and female metal dies would be justified for large quantities. In the Guerin process a rubber pad 6 to 10 inches thick is contained in a metal box and acts as the female die. A heated male die and work blank are placed on the platen of the press and the female rubber die brought in contact with them. A pressure of 1000 p.s.i. is exerted through the rubber and the blank assumes the shape of the male die. Synthetic rubbers or specially compounded natural rubbers are required for working temperatures up to 450^0F. Ordinary rubber is satisfactory for temperatures up to 350^0F. To prevent the rubber from sticking to the formed part, cornstarch or flaked mica is spread on the blank prior to pressing. Since in the Guerin process only a male die is needed it can be produced cheaply and revised when necessary without great difficulty. The male die is best made of magnesium to avoid differences in thermal expansion between the blank and the die. If aluminum is used it should be made approximately 1.002 oversize, if steel or iron approximately 1.004 oversize, to compensate for the differences in thermal expansion between these materials and the magnesium-alloy blank.

Fig.8.9. Drawn Magnesium Parts

Deep Drawing

Oil-tank ends, nose spinners, wheel dust covers, and hub caps have been deep drawn successfully. Cylindrical cups can be deep drawn to a depth 1½ times their diameter in a single draw-which is a reduction of 60% to 65%. Square junction boxes can be drawn to a depth equal to the side dimensions. Either a hydraulic or a mechanical press can be used for deep drawing. For maximum depth draws the clearance between the die and the punch should be from 0.25 to 0.35 of the stock thickness plus the stock. As explained above, dimensional allowances must be made for the differences in thermal expansion if the die material is other than magnesium alloy. The male die or punch can be magnesium alloy, aluminum alloy, cast steel, or cast iron. Dies of mild steel which has been stress relieved have been used quite generally. Heat-resisting Meehanite cast iron gives promise of working out very well as die stock. Draw rings and pressure pads are made of mild steel which is highly polished and well lubricated. The pressure pad should impart sufficient pressure to the blank to prevent wrinkling but not too much to prevent it form being drawn through the clamping surfaces. Preheating the work blanks and heating the dies to working temperature are essential to insure proper drawing temperature and a uniform product. The blank should be lubricated on both sides as well as the die surfaces to prevent scoring or galling. Colloidal graphite suspended in a volatile carrier such as alcohol or naphtha may be sprayed on both sides of the blank; other commercial products can also be used. If colloidal graphite is to be used, sheet should be ordered with an oiled finish instead of the customary chrome-pickled finish. This specification is necessary because of the

extreme difficulty of removing graphite from a chrome-pickled surface. For lubricating the dies, a mixture of 20% graphite in tallow applied by buffing with an asbestos cloth is satisfactory.

Sizing

Sizing is a cold operation employed to bring hot-drawn work closer to tolerance. When extremely accurate tolerances are required the part is normally drawn slightly oversize and then sized cold to finish dimensions. A cold-sizing die consists of a punch and a draw ring, both slightly undersize to allow for springback. The punch forces the part through the draw ring and the operation is completed.

Spinning

Spinning is used to fabricate circular articles such as propeller spinners and wheel caps. In this operation the blank is clamped against a maple or metal chuck which is shaped to the desired form. The chuck is then supported in the spinning lathe and rotated at the proper speed so that the part of the blank being worked on will move past the tool at from 1700 to 1900 feet per minute. The operator uses a wedge or a hardwood stick to force the blank against the chuck, whose shape it then assumes. Laundry soap or a mixture of 2 parts tallow and 1 part paraffin are satisfactory lubricants. Moderate spinning may be done at room temperatures. Normally, however, the blank should be heated to between 500^0 and 600^0F. by a gas torch, a properly disposed ring of gas burners, or by conduction through a heated metal chuck. The area of the original blank should be about the surface area of the finished part. The fact that the material is thinned somewhat in spinning allows sufficient additional area for trimming.
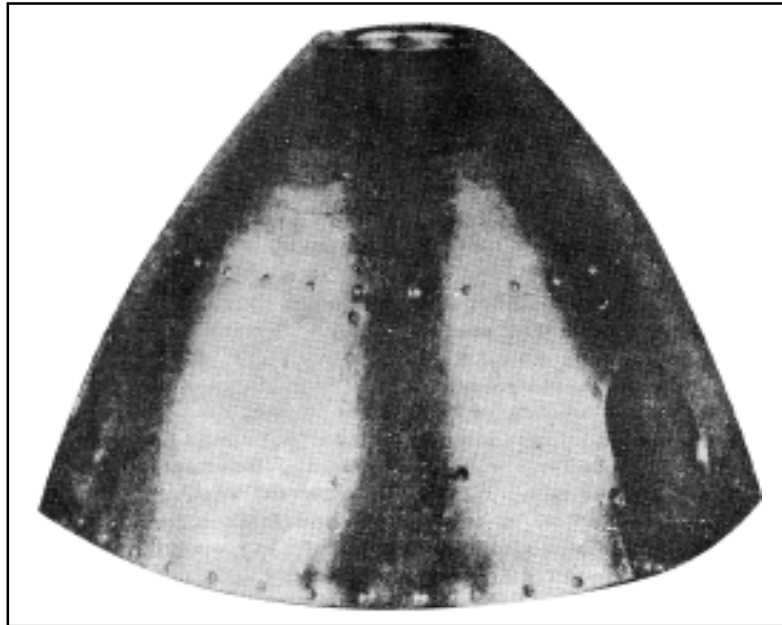
Fig.8.10 Magnesium Propeller Spinner

Roll Forming and Die Drawing

This method of fabrication is used for the production of shapes with thin walls that can not be extruded. It consists of drawing strip through a series of dies or rolls, each set of which changes the shape somewhat nearer to the finished shape desired. Heated strip, adequate bend radii, lubrication, and gradual changes in shape are all necessary for this type of fabrication.

Stretch Forming

In stretch forming, the work is held in the jaws of two machines and pressure is applied between the blank and the die Stretch forming is used primarily to obtain double curvature of a surface. It is essential that the die be heated and the blank should be preheated or heated by conduction from the die. Temperatures of from 450^0 to 550^0F. are normally used. If the magnesium-alloy sheet is held in the jaws of the stretching machine they should be lined with energy cloth rather than with serrations which would rupture the metal. Another method is to sandwich the magnesium blank between the die and a preformed mild carbon sheet which is held in the jaws of the machine. In this case the magnesium is not inserted in the jaws. Dies in this operation should be designed for some overforming to allow for springback and creepback during cooling.

Drop hammering

Drop hammering is not practical due to the difficulty in keeping the work heated long enough to complete the operation. Some drop-hammered parts have been made, but they required several reheatings of the material.

JOINING METHODS

Most of the standard methods of joining metals are adaptable for use with magnesium. Riverting, gas welding, arc welding, and spot welding are commonly used. The adaptations of these processes to magnesium alloy are described in the following pages.

Riveting

Riveting is the most commonly used method of assembling magnesium-alloy structures. Special consideration must be given to rivet selection, design of joints, driving technique, and corrosion protection of the assembly.

Magnesium-alloy rivets are not practical because they work harden too rapidly when driven cold. Aluminum-alloy rivets of 2S, 3S, A17ST, 17ST, 24ST, 53S-T61, 56SO, and 56S- ¼ H have all been used in assembling magnesium alloys. For aircraft work the use of 56S- ¼ H is recommended for all purposes except flush riveting in which case 56S-O rivets are used. A17ST rivets can be used for field repairs but requires assembly with wet zinc chromate primer and good paint protection to minimize corrosion. 56S rivets contain 5% magnesium and no copper and are less subject to galvanic corrosion than any of the other rivets listed above. 56S - ¼ H rivets can be used as received, no heat treating or quenching being required. They can be driven cold up to ⎯ inch diameter. If it is necessary to drive rivets over this diameter they should be heated to 650^0F. 56S -¼ H rivets have a minimum ultimate shear strength of 24,000 p.s.i.; A25ST rivets have a strength of 25,000 p.s.i.
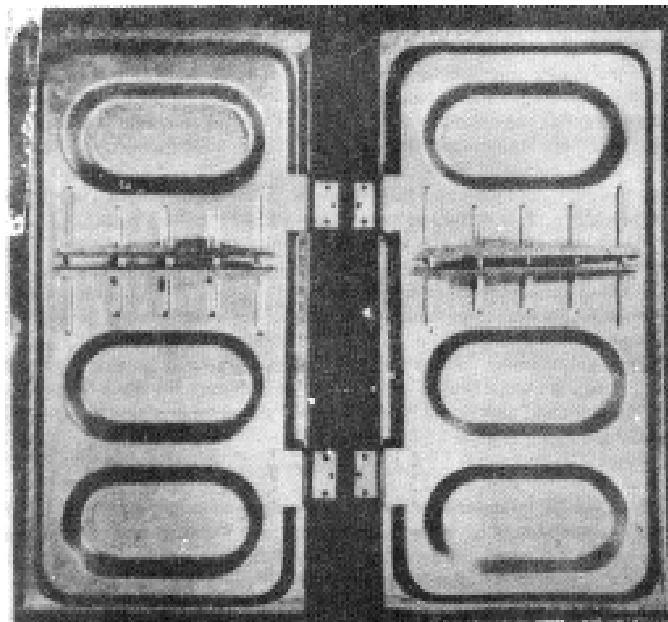
Fig.8.11. Magnesium-alloy Aircraft Doors Assembled by Riveting and Spot Welding

For well-balanced joints, rivets diameters should not exceed 3 times the thickness of the sheet, and should not be less than the thickness of the heaviest sheet being joined. For proper heading the rivets shank should protrude from 1 to 1.25 rivet diameters; this protrusion will give a flat aircraft-type bucktail with a minimum height of 0.4 rivet diameter, and a minimum diameter of 1.33 rivet diameter. An edge distance of 2½ times the rivet diameter is recommended to prevent cracking or bulging of the edge of the sheet. A rivet spacing of 4 times the rivet diameter is the minimum recommended.

Structural rivet holes should be drilled and not punched. Punching gives a hole with a flaky edge which is likely to crack under load. Non- structural sheets up to 0.040 inch thick can be punched if desired. In drilling, the use of a drill with a 10^0 helix angle will give smooth, accurate holes. When parts are clamped or assembled prior to drilling they should be disassembled after drilling and the chips removed. If this is not practical an air hose should ne used to clean the chips away.

Pneumatic hammers or squeeze riveters may be used, but excessive pressures and indentation of the magnesium should be avoided. The standard types of rivet heads may be used in assembling magnesium alloys. Up until recently it was necessary to use countersunk rivet heads with 120^0 included head angle, but now it is possible to satisfactorily dimple sheet for the standard 100^0 rivet heads. As stated above, 56- SO countersunk rivets must be used to minimize the cracking of the sheet under the riveting pressure.

Machine countersinking is limited to minimum sheet thickness for each diameter of rivet if efficient riveted joints are to be obtained. The recommended minimums are as follows :

Rivet diameter (inch)	Minimum sheet thickness for countersinking (inch)
/	0.040
/	0.051
/	0.064
/	0.081

When flush riverting is required for thinner sheets than those listed, it is necessary to pressure countersink the sheet.

In pressure countersinking magnesium-alloy sheet, it is necessary to heat the sheet in the vicinity of the dimple. This heating is best done by using dies electrically heated to between 450^0 and 550^0F. The work is heated locally by contact with the dies. By this method 15 to 30 dimples per minutes can be made in production. A 5000- pounds dimpling machine will make 3/16-inch dimples satisfactorily in 0.072- inch sheet. Prior to dimpling, holes should be punched or drilled at least 15% smaller than the rivet diameter. After dimpling, the holes should be drilled or reamed to the correct size and burred. A sharp edge should not be left on the bottom of the dimpled sheet against which rivet head is to be formed, if cracking is to be avoided. This edge should be removed and a flat provided of about 1.33 times the rivet diameter.

56S rivets do not require any particular corrosion-preventive methods when used for assembling magnesium alloys. Any other type of rivet should be set in wet zinc chromate primer. If it is necessary to use steel or brass rivets, bolts, or nuts, they should be cadmium or zinc plated and set in wet zinc chromate primer. All faying surfaces should be painted with the coats of zinc chromate primer before assembly.

Gas Welding

Magnesium alloys can be gas welded, using oxyacetylene, oxyhydrogen and methane. When using any of these gases a neutral or slightly reducing flame should be used. Oxyacetylene can only be used with difficulty on sheet thinner than 0.064 inch.

Standard welding equipment and torches are used for welding magnesium. A variety of tips from 0.035 to 0.081 inch should be available for use. An extruded filler rod of the same composition as the material being welded should be used. If two different alloys are being welded together the filler rod should match the alloy with the lower melting point. Filler rods melt between 1100^0 and 1200^0F, Filler rods are available in diameter from 1/16 to ¼ inch. A 1/16-inch rod is satisfactory for welding 0.020-inch sheet, a 3/32-inch rod for intermediate thickness, and a 1/8-inch rod for 0.128-inch material. A flux must be used to coat the rod and either side of the edges to be welded, in order to prevent oxidation of the metal. Fluxes are usually purchased in the form of powder, which must be stored in tightly closed glass bottles because of its hygroscopic nature. The flux paste for use in welding is prepared by mixing parts of powder with one part of water, by volume.

Only but joints may be made in gas welding magnesium alloys. In any other type of joint the hygroscopic, corrosion flux may be trapped in the joint with disastrous results. For the same reason, it is necessary to make welds with a single pass. This limits the material that can be welded to ¼ -inch thickness. To allow for warpage and shrinkage a 1/16-inch larger gap should be allowed between the mating edges to be welded. For thin material up to 0.040 inch thick this allowance is not essential, but the adges should be flanged up 1/16 to 1/8- inch. A gap up to 3/8- inch wide can be filled in when using thicker material. This fill is sometimes useful in making repairs. When material over 1/8-inch thick is to be welded, the top corners of the seam should be beveled before welding.

Before welding, all oils, grease, and dirt should be removed by means of gasoline or carbon-tetrachloride. Any oxide or chemical coating should be removed from the edges to be welded by using steel wool, a wire brush, or a file. Welding on a chrome-pickled surface will results in weld porosity and impair the free flow of the material.

Fig.8.12. Torch Welding a Magnesium Aircraft Oil Tank

The work should be placed in a jig to hold it in alignment while being tack welded. In tack welding the torch is held almost perpendicular to the surface. Tack welds are made from 1½ to 6 inches apart, depending on the thickness of the sheet and the nature of the part. Usually the work is then removed from the jig and finish welded. In running the seam weld, the torch should be held at 45^0 to the work. The rod should be held in the outer flame until the base metal melts and forms a puddle, and then the rod should be dipped in the puddle intermittently. At the end of the seam the torch should be lifted slowly to prevent too-rapid cooling and the formation of a crate. Leather or wooden hammers may be used for straightening buckled or warped seam welds. This hammering improves the strength of the weld. If large deformations must be straightened, the work should be reheated to 600^0 to 750^0F.

Immediately after welding the following operations should be performed :

1. Wash in hot running water, and scrub with a stiff bristle until all traces of the flux are removed and the surface is clean.
2. Chrome-pickle the work by immersing it for one minute in the following solution : 1.5 pounds of sodium dichromate, 1.5 pints of concentrated nitric acid, enough water to make 1 gallon.
3. Wash in cold running water.
4. Boil for 1 to 2 hours in the following solution : 0.5 pound of sodium dichromate, enough water to make 1 gallon.
5. Rinse in cold water, followed by a dip in boiling water.

Magnesium-alloy welds may be inspected visually, by radiography, or by the fluorescent oil penetrant method.

Only the 1.5% manganese alloy gas welds readily. This alloy is available as sand castings (AN-QQ-M-56B), sheet (AN-M-30), extrusions (AN-M-26), tubing (AN-T-73), and forgings (AN-M-22). The other two alloys which are available in sheet form, AN-M-28 and AN-M-29, are limited to free welds only without any restriction. When sheet material is welded to castings or to forgings of heavier sections, the mating edge must be tapered or beveled to the sheet thickness. The heavy part should also be preheated to 600-700^{0}F.

Arc Welding

In arc welding magnesium alloys there is no restriction on the type of joint used. An inert-gas shield is used to prevent oxidation in place of the corrosive flux that limits gas welding to butt joints. This inert-gas sheild makes multipass welds possible and removes the limitation on the thickness of material that can be welded. There is less warpage with arc welding than with gas welding because the higher heat available is more localized and fuses the joint quickly with less diffusion of heat to adjacent areas. All wrought magnesium-alloy materials have good arc weldability except AN-M-29 sheet, which is limited to unrestrained welds if cracking is to be avoided. This is the same limitation this material has

when gas welded and its strength with either type of weld is the same Arc welds in AN-M-28 and AN-M-29 material are stronger than the equivalent gas welds.

For arc welding magnesium alloys a direct-current or rectified-alternating-current machine of 100- to 200- ampere capacity is required. A machine with a stable arc equipped with a continuous amperage regulator to provide adequate current control is necessary. In arc welding magnesium, reversed polarity (electrode positive, work negative) is used. A tungsten electrode has been found to do the best job. The arc between the electrode and the work is enveloped in an inert-gas sheild which excludes oxygen from the weld area and prevents oxidation. Either helium or argon may be used, The inert gas is fed from a cup about ½ inch in inside diameter which surrounds the electrode except for ¼ to 3/8 inch at the tip. A tungsten electrode 3/32-inch in diameter is used for welding 0.030 - inch sheet; electrode diameter increases to 3/16-inch for 0.125 -inch sheet.

In arc welding, a good rigid jig must be used to hold the work in position. The complete welding operation is done in the jig, and usually tack welding is not necessary if the jig is properly constructed. A good jig will reduce warpage and hold the joints tight. No gap between joints is permissible.

Good cleaning of the joints to be welded is a must , as previously described under Gas Welding. In the welding operation the torch should be held perpendicular to the work to provide the best shielding by the inert gas. The filler rod should be fed to the arc are not dipped in the molten puddle. The filler rod should preferably be of the same composition as the material being welded. A filler rod of 1/16-inch diameter should be used for 0.030-inch sheet, increasing to 1/8-inch diameter for 0.125-inch sheet.

After welding it is essential that the assembly be stress relieved by heat treatment to release residual stresses that will otherwise cause stress corrosion cracking. These internal stresses may run as high as 15,000 p.s.i. The heat treatment must be done with the work held in a jig to prevent warpage. For annealed material the relief treatment consists of heating the work at 500^0F. for 15 minutes; for hard rolled material it must be heated for one-hour at 265^0F. for AN-M-29 sheet, and at 400^0F. for AN-M-28 or AN-M-30 sheet. After heating the work should be cooled in still air.

Since no flux is used, the welds need only be wire brushed. Inspection of the welds should be made for undercutting, cracks, porosity, craters, overlapping, or inclusions. Visual examination, radiography, or the fluorescent oil penetrant method may be used.

Spot Welding

Spot welding of magnesium alloys have been limited to low-stress applications and to parts not subject to excessive vibration. Service experience on these secondary applications has been satisfactory thus far but additional experience will be required before spot welding can be generally adopted for primary aircraft structural use. All sheet and extrusion alloys can be spot welded either to alloys of like compositions or to the other alloys. The ease with which alloys of different composition can be spot welded to each other is determined by the similarity of the alloying elements present in each. The spot welding of AN-M-28 composition material to AN-M-30 is very difficult because of the great difference in their chemical composition. Two parts of unequal thickness can be spot welded together if an electrode with a larger contact area is used against the thicker material.

Alternating-current or direct-current stored-energy spot welding machines as used for aluminum alloys are satisfactory for use with magnesium alloys. Water-cooled electrodes with 2- to 8- inch dome tips are preferable.

Areas to be welded must be free of pickle coatings or oxidized surfaces. Material to be spot welded should be purchased oiled instead of chromepickled to simplify the cleaning operation. Chemical cleaners are still in the experimental stage (immersion in a 20% chrome acid solution at 150^0F for 2 minutes appears to have promise), so wire brushing must be resorted to in order to clean the areas to be welded. Both sides of the sheet must be cleaned. A power-driven wire brush rotating at over 2500 feet per minute peripheral speed is used. The side of the sheet which the electrode will touch must then be finished with No.3 steel wool or No.160 to 240 aluminum oxide cloth. Small areas can be hand cleaned by using stainless-steel wool or aluminum oxide abrasive cloth. Stainless-steel wool is preferred for its nonmagnetic qualities.

The diameters of proper spot welds vary from 0.20 inch for 0.020-inch sheet to 0.375 inch for 0.10- inch sheet. Weld penetration should be from 30% to 80% into each of the parts being welded together. Weld penetration and diameter can be determined by cutting a cross section through the weld, smoothing the surface with emery cloth, and etching for 10 seconds with a 10% to 50% solution of acetic or tartaric acid. The weld zone will darken and becomes quite visible.

Copper pick- up in the spots from the electrodes will cause corrosion and must be avoided. The presence of copper will show up as a black discoloration after chrome pickling or etching with a 10% acetic acid solution. If copper is found, the welds should be cleaned up with steel wool or aluminum oxide cloth.

Spot welds can be made through faying surfaces freshly coated with zinc chromate primer. The primer must be well thinned so that it will squeeze out from under the spot when the pressure is applied and permit good metal-to-metal contact. Protective coatings for faying surfaces are adversely affected by the dichromate treatment finally given most magnesium-alloy assemblies. It is generally considered desirable to omit the faying-surface protection in favor of the dichromate treatment.

Inspection of the spots for cracks and porosity may be accomplished by microscopic examination or by radiography.

CORROSION RESISTANCE

Magnesium, in common with other metals, is subject to corrosion. In recent years its resistance to corrosion has been greatly improved and is now equal to or better than that of many commonly used metals. This advance in corrosion resistance is largely due to the introduction of the controlled-purity type of alloy. In these alloys impurities such a iron, nickel, and copper are limited to very small percentages. The use of chemcial treatments that provide a passive surface layer and makes good paint base is also essential for aircraft use.

Army-navy Aeronautical Specification AN-M-12 describes the following four protective treatments for use on magnesium alloys :

Type-I   Chrome-pickle treatment. Used to protect parts in shipment, storage, or during machining.

Type-II   Sealed chrome-pickle treatment. A modified chrome-pickle treatment adaptable to all magnesium alloys. It is an alternative finish to Types III and IV when a dimensional change is permissible.

Type III   Dichromate treatment. Provides maximum protection and paint adhesion and has no effect on dimensions of parts. Applicable to all alloys except the 1.5% manganese as covered by AN-M-30 for sheet material.

Type IV   Galvanic anodizing treatments. This treatment is recommended for use on the 1.5% manganese type alloy. It is also applicable to the other alloys No dimensional change.

The corrosion of magnesium alloys can be caused by any one of the following circumstances :

1.   **Environment**

     Salt atmosphere are much worse than inland exposures. In ordinary atmospheres bare magnesium alloy will for a protective coating of magnesium hydroxide, which is porous but subsequently is covered to hydrated carbonates and sulphates that are nonporous. This surface film cannot be relied on for general usage, however, and one of the protective treatments listed above plus paint protection is required to resist atmospheric corrosion.

2.   **Galvanic Corrosion**

     Metal-to-metal contact will create a galvanic cell when moisture is present. This condition is developed even when two magnesium alloys of different compositions are in contact, particularly AN-M-30 material and one of the other magnesium alloys. A protective treatment and two coats of zinc chromate primer in the faying surfaces are required for protection. When two dissimilar metals are used, this protection plus the insertion of an insulating material between the faying surfaces is desirable. Magnesium is the least noble of all the structural metals and consequently is the one to suffer when galvanic corrosion is set up. Fortunately, 56S aluminum-alloy rivets and the magnesium alloys do not react on each other. These rivets exclusively should be used in assembling magnesium alloys structures.

3.   **Surface Contamination**

     Metallic impurities in the surface resulting from wire brushing or similar operations should be removed by acid pickling or by chrome pickling. Welding flux resulting from gas welding should be removed by chrome pickling and boiling in a dichromate solution, as described under Gas Welding earlier in this chapter.

4.   **Stress Corrosion**

     This type of corrosion occurs when a part with internal residual stresses is subject to corrosion influences. It is evidenced by cracking or fracture without any prior evidence of surface corrosion. Stresses above 25% of the yield strength will cause this type of failure. Sheet material in accordance with AN-M-28 and AN-M-29 that has been arc welded is particularly subject to this type of corrosion. The relief of stresses by heat treatment is essential. This operation has been described earlier in this chapter under Arc Welding.

CHAPTER-9
HEAT TREATMENT OF STEELS

It has long been known that a great variation in the properties of steel could be obtained by heating the metal to a high temperature and quenching quickly in a liquid, such a brine, water, or oil. Unfortunately, each alloy required a different treatment, and since the actual effects were not understood, the whole science of heat treatment was a hit or miss affair. Recently a new science known as "metallography" has been developed; it deals with the internal structural of metals and the principles underlying changes in structure. By means of etching and microscopic examination the internal structure of steel in all its various states has been studied. Due to these studies and the work of numerous investigators heat treatments is today an exact science.

Heat treatment of steel is based upon the fact that the metal has a crystalline structure which assumes different forms at various temperatures. The change in structure as the temperature decreases is normally slow, and it has been found that by rapid cooling, such as dropping the hot metal in a cold liquid, the normal structure at high temperatures can be retained at atmospheric temperatures. This new structure has totally different physical properties from the normal atmospheric-temperature structure. Numerous variations are possible, depending upon the temperature from which the metal is quenched and the speed of quenching. The practical terms which describe the heat treatments normally used are: annealing, normalization, hardening, drawing. In addition to these we have special treatments called carburizing, cyaniding, and nitriding. To develop the desired properties all aircraft steels are subjected to one or more of these operations. This chapter will be devoted to the theory and practical applications of heat treating.

CRITICAL RANGE

Materials are said to be allotropic when they possess the property that permits them to exist in various forms without a change in chemical composition. Carbon, which exists as diamond, graphite, and charcoal, is a common allotropic substance. Pure iron is also allotropic, existing in three states: namely, *alpha, beta* and *gamma* iron. In this case each of these states is stable only between very definite temperature limits alpha iron up to 1400^0F., beta iron from 1400^0F. to 1652^0F., and gamma iron above the latter temperature.

When molten iron solidifies and is permitted to cool at a uniform rate, it is found that at 1652^0F. the cooling stops momentarily. At this point a change in the structure of the iron has taken place, in which gamma iron has been transformed into beta iron. This rearrangement of the structure has resulted in the evolution of heat, which accounts for the retardation of the cooling. This point is designed by the symbol Ar_3 and is called the *upper critical point*. As the cooling continues, it is found that a second retardation occurs at 1400^0F. Obviously this is caused by the transformation of beta into alpha iron with the resultant evolution of heat. This point is indicated by Ar_2, the *second critical point*.

In the heating of pure iron similar points occur in which heat is absorbed without a rise in the metal temperature. These points are designated Ac_2 and Ac_3. These heat-absorption points are some 20^0F. higher than the respective Ar_2 and Ar_3 point. The critical range is the range of temperature between the lower and upper critical points.

Carbon steels have definite critical points and a critical range. The exact temperature at which these points occur and the number of point depend upon the carbon content of the steel . Low-carbon steels have three critical points. In addition to the preceding two points described for iron, when a small amount of carbon is added to the iron another point designated as Ar_1 occurs at 1274^0F. There is, of course, a similar point on a rising heat designated Ac_1. The point Ar_1 is called the *lower critical point* or the *recalescent point because the intense evolution of heat causes the metal to glow.*

The *"r"* in the symbol *Ar* is derived from the French word *refroidissement,* which means cooling. Similarly, the "c" in the symbol Ac is the first letter of *chauffage*-heating.
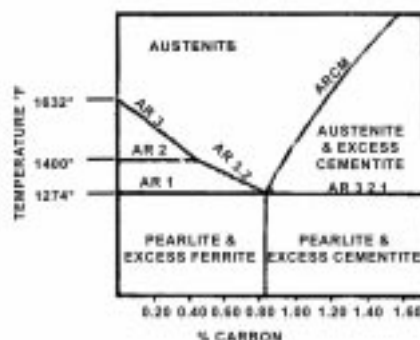
Fig.9.1. Critical Points of Steel

Referring to Figure 9.1 it can be seen that the number of critical points and the scope of the critical range depend upon the carbon content. There are three critical point up to a little over 0.4% carbon. In this region the two upper critical points merge, forming a single point, Ar_{3-2}. At 0.85% carbon all the critical points unite, and we have one point, *Ar3-2-1*. *Above* 0.85% carbon a new point designated Ar_{cm} extends above the Ar_{3-2-1} point.

Alloy steels possess similar critical points, but they occur at different temperatures for each steel. Nickel and manganese have the property of materially lowering the critical range. In fact, the 13% manganese steel has a critical range below atmospheric temperatures.

INTERNAL STRUCTURE OF STEEL

The internal structure of steel is almost wholly dependent upon the exact relationship of the iron and carbon. The carbon is in chemical combination with the iron as iron carbide (Fe_3C), called *cementite.* In steels containing 0.85% carbon, the cementite forms a perfect mixture with the pure iron (called ferrite) present. This mixture is called *pearlite* because of its resemblance in appearance to mother-of pearl. Pearlite is a mechanical mixture of six parts of ferrite to one part of cementite. Steels with less than 0.85% carbon are composed of pearlite and excess ferrite. Practically all aircraft steels are of this type. On the other hand, tool steels which contain more than 0.85% carbon are composed of pearlite and excess cementite.

In metallurgy the name *eutectic alloy* is given to that alloy of two substances which has the lowest fusing point. In every alloy there is one percentage combination of the two elements that will fuse at the lowest temperature. Variation of the percentage composition of either element, up or down, will increase the temperature of fusion. A similar condition exists in steel in the critical range, although here we are dealing with a solid solution. You will note in Figure 9.1 that the lowest temperature for the upper critical point occurs at 0.85% carbon content. This alloy has been named the *eutectoid.* Steel with less than 0.85% carbon is called *hypo-eutectoid* and with more than 0.85% *hyper-eutectoid.* Steels with excess ferrite are hypo-eutectoid, and steels with excess cementite are hyper-eutectoid.

Pearlite is normally a laminated structure consisting of alternate layers of ferrite and cementite. In some cases pearlite has a granulated appearance and is called granular pearlite. If steel is cooled very slowly through the critical range, laminated pearlite, which is the most stable form, will result. Pearlite is relatively strong, hard, and ductile. It has a tensile strength of over 100,000 p.s.i., an elongation of approximately 10%, and maximum hardening power. This latter point is extremely significant. It means that the greatest hardness from heat treatment is obtained by steel containing -.85% carbon. It is also true that starting with low-carbon steel, greater hardness is obtainable as the carbon content increases and approaches 0.85%. This point is important when selecting a steel to give great strength and hardness after heat treatment.

Ferrite is pure alpha iron in carbon steels. In alloy steels containing nickel, molybdenum, or vanadium these alloying elements are in solid solution in the ferrite. Ferrite is very ductile and has a tensile strength of about 40,000 p.s.i.. It should be noted that it imparts these properties to low-carbon steels of which it is the major constituent. Ferrite does not have any hardening properties.

Cementite is iron carbide (Fe_3C). It is very hard and brittle and produces a hardening quality on steels of which it is a part.

Austenite, the name given to steel when it is heated above the critical range, consists of a solid solution of cementite in gamma iron. It is stable only when maintained at a temperature above the critical range. It will, however, attain perfect homogeneity if sufficient time is allowed. The grain size of steel, it has been found, is smallest just above the critical range, and it is a known fact that the smallest grain size will give the strongest and best metal. For this reason, when steel is heated for subsequent hardening or working, its temperature is kept just above the upper critical point for the time necessary to insure thorough heating of the material.

THEORY OF HEAT TREATMENT

When molten steel solidifies, austenite is formed. As further cooling takes place, the critical range is reached and the austenite goes through a transition until at the lower critical limit the familiar pearlite with excess ferrite or cementite, depending upon the carbon content, is formed. The transition from austenite to pearlite through the critical range is normally a slow operation. It has been found that the transition can be arrested if this operation is speeded up by such means as dropping austenitic steel just above the critical range in cold water or oil. By this means a structure can be produced at atmospheric temperature with physical characteristics different from those which normally would be obtained with slow cooling. This operation is so severe that an extremely hard, brittle material with shrinkage strains is obtained. By reheating the metal below the critical range the normal transition in the critical range is allowed to proceed a little further and shrinkage strains are reduced, thus creating a useful condition of moderate hardness and strength.

Hardening is the name given to the first operation described in the preceding paragraph. It consists in heating steel to just above the critical range, holding the metal at that temperature until thoroughly heated (called soaking), and then rapidly cooling (or quenching) by immersing the hot steel in cold water or oil.

Drawing, or tempering as it is sometimes called, consists in reheating of the hardened steel to a temperature well below the critical range, followed by soaking and quenching.

Martensite is the main constituent of hardened steel. It is an intermediate form of cementite in alpha iron obtained when the transition from austenite to pearlite is arrested. Martensite is the hardest structure obtained in steel.

Troostite is another intermediate form, similar to martensite, which is often present in hardened steels. Troostite is also present in drawn or tempered steels whereas martensite is not.

Sorbite is the third intermediate form between austenite and pearlite. It is the main constituent of drawn steel and gives that type of steel maximum strength and ductility.

Hardened steel consists almost entirely of martensite with some troostite. When the steel is reheated, as in drawing, the martensitic structure breaks down and sorbite, with a small amount of troostite, remains. By varying the drawing temperature, different amounts of troostite and sorbite can be retained, and consequently a variation in physical properties is obtainable.

Heating through the critical range is absolutely necessary to obtain the best refinement of the grain. Fine-grain steel has the best physical properties. As steel is heated above the critical range, the grain becomes coarser,. There is a narrow limit of temperature just above the critical range within which steel must be heated if it is to retain its fine-grain structure after quenching. It should be noted that a fine-grain structure is obtained just above the critical range only on a rising heat. If liquid steel is solidified and cooled the finest grain is obtained on solidification and becomes coarser as cooling progresses.

As you will note by referring to Figure 9.1, it is absolutely necessary to know the chemical content of the steel to establish the critical range and the heat-treatment temperature. Each steel, both carbon and alloy, has its individual critical range which must be definitely known if the best results are to be obtained from heat treatment.

The effects of heating to various temperatures and cooling at different rates may be summarized as follow :

1. When a piece of steel is heated to the upper critical point, Ac_3 , it becomes as fine grained as possible no matter how coarse or distorted the grain was previously.

2. After it has been heated to Ac_3, if the steel is allowed to cool slowly, it retains the fine-grained structure and is also soft and ductile.

3. After it has been heated to Ac_3, if the steel cooled rapidly, as by quenching in cold water, it retains the fine-grained structure and is fully hardened.

4. If steel is heated above Ac_3, permitted to cool to Ac_3, and then quenched, it will be fully hardened but more coarse grained than if it had only been heated to Ac_3 originally.

5.   The higher the temperature above Ac_3 from which the steel is cooled, either slowly or rapidly, the coarser the grain. In this case slower cooling will result in coarser grain.

6. When a piece of hardened steel (which has been previously heated to Ac_3 or above, soaked, and quenched) is again heated to somewhere below Ac_1, it is softened but without change in grain size. The softening is greater as the temperature increases up to Ac_1.

Annealing

Annealing of steel is effected by heating the metal to just above Ac_3, soaking at that temperature for a definite time, and cooling very slowly in the furnace itself. This treatment corresponds to number 2 just above. The time of soaking is about one hour per inch thickness of material to make certain that all of the material is brought up to temperature. Slow cooling is usually obtained by shutting off the heat and allowing the furnace and metal to cool together down to 900^{0}F. or lower, at which time the steel may be removed from the furnace and cooled in still air. An alternate method to restrict the rate of cooling is to bury the heated steel in ashes or lime.

Annealed steel is fine grained, soft, ductile, and without internal stresses or strains. It is readily machinable and workable. In the annealed state steel has its lowest strength. For that reason it is often given a subsequent heat treatment so as to increase the strength after all machining and mechanical work are complete. The ductility of annealed steel is utilized in tube and wire drawing and in rolling sheet. After the steel has passed through the dies or rolls several times, re-annealing is necessary to relieve the stresses induced by the cold work and to prevent cracking.

There are several modifications of the full annealing treatment used when all of the effects are not essential, and speed and economy are important.

Process annealing Consists in heating below Ac_1 in the region between 1020^0 and 1200^0F. This treatment is commonly used in the sheet and wire industries to restore ductility.

Spheroidizing is a form of annealing applied particularly to high-carbon steels to improve their machinability. As indicated by the name, a globular cementite structure is obtained. In this form the cementite can be pushed aside by the cutting tool instead of offering great resistance as when present in this laminated form. The operation of spheroidizing consists in prolonged heating just slightly below the critical range, followed by slow cooling.

Shop annealing is the term used to describe the practice of heating steel with a welding torch to 900^0 to 1000^0F. and dropping it into a pail of ashes or lime to restrict the cooling rate. This treatment will relieve internal strains. It is never used in aircraft work unless it is to be followed by a regular heat treatment.

In all annealing processes, due to prolonged heating at high temperatures and slow cooling from these temperatures, the surface of metal is prone to scale. The scale on steel is iron oxide. Whenever possible, annealing should be done in closed receptacles to exclude air from the metal. The receptacle should not be opened until it has cooled almost to room temperature. In the case of high-carbon steels the prevention of scale formation is particularly important. Oxidation of the carbon at the surface will occur if not guarded against. This decarburisation is injurious to the metal and must be avoided. When steel parts have not been annealed in a receptacle, the scale must be removed by a cleaning or pickling treatment.

Normalising

Normalizing is a form of annealing which consists in heating the steel above Ac_3 and then cooling in still air. Due to the more rapid quenching obtained by air-cooling as compared to furnace-cooling, the steel is harder and stronger but less ductile than annealed material. Normalising is required whenever it is desired to obtain material of uniform physical characteristics. Forgings are generally normalised to relieve all internal stresses. Normalizsing, too, will relieve stresses. Refine the grain, and make steel more uniform just as annealing will, but, at the same time, improved physical properties are obtained. Because of the better physical properties, aircraft steels are often used in the normalised condition but seldom if ever in the annealed state. If annealed steel is used in fabrication for ease of working, it is subsequently normalized or heat treated to a higher strength.

Welded parts are frequently used in airplane construction. Welding causes strains to be set up in the adjacent material. In addition, the weld itself is a cast structure as opposed to the wrought structure of the rest of the material. These two types of structure have different grain sizes, and to relieve the internal stresses and refine the grain, all welded parts should be normalised after fabrication. Such treatment will reduce the possibility of cracks and fatigue failures in service. Normalising of welded parts is considered so important by one government department that it even requires this treatment for engine mounts. In many cases where large furnaces are not available, or the basic design of mount /will not permit normalising without too much warping, it is necessary to design an assembled mount made up of small sections. The sections can be normalised individually and bolted or riveted together.

Low-carbon steels are often normalised to improve the machining qualities and to reduce distortion in subsequent heat-treating operations. In actual practice the aircraft manufacturer buys tubing, sheet, and bar in the normalised condition, performs the necessary machining or welding operations, and then normalises or heat treats the finished article. In connection with the purchase of normalised material it is often necessary to specify the maximum tensile strength that is acceptable. This is particularly true of thin sheet which, when quenched in still air, will cool far more rapidly than heavier material. As a result, thin sheet will be composed of sorbite as well as pearlite- the usual constituent of normalised steel. The sorbite makes the steel stronger but also more brittle. Chrome-molybdenum sheet steel, as purchased in the normalised state, will often run from 110,000 to 125,000 p.s.i. ultimate tensile strength. Where severe bending is to be done, the purchase order should specify a maximum of 95,000 p.s.i. which is the accepted strength for normalized chrome-molybdenum steel.

Medium-and high-carbon steels should be normalised and then annealed before machining or fabrication. This sequence of operations is sometimes called double annealing. The resultant structure is similar to that obtained by spheroidizing, as described previously. In aircraft work the amount of machining done is usually small and the annealing is often omitted.

Some alloy steels cannot be satisfactorily hardened without first being normalised. This is especially true of alloys containing chromium. The accepted explanationof this phenomenon is the necessity for the complete solution of the chromium and iron carbides in the gamma iron. Solution is effected by normalizing prior to hardening.
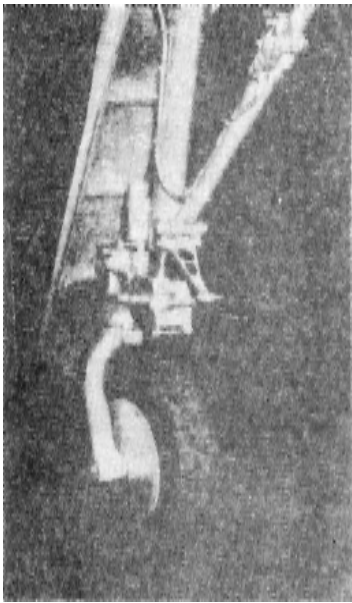
Fig 9.2.Nose-wheel Assembly; Heat-treated Chrome-molybdenum Steel
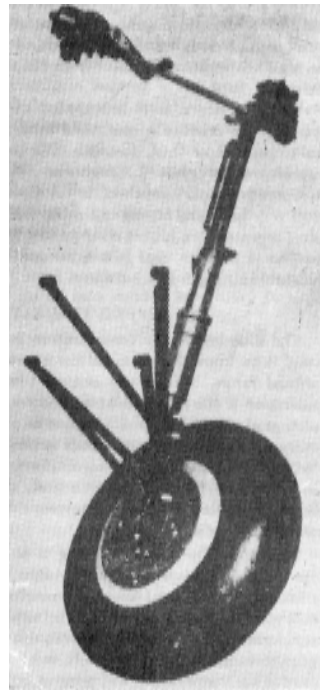
Fig.9.3.Grumman Retractable Landing Gear; Heat-treated chrome-molybdenum Tubing

Hardening.

Hardening is the first of two operations required for the development of high-strength steels by heat treatment. Hardening consists of heating above. Ac_3 soaking at that temperature until the mass is uniformly heated and then quenching in brine, water , or oil. This treatment produces a fine grain, maximum hardness and tensile strength, minimum ductility and internal strains. In this condition the material is too hard and brittle for practical use. A light blow, as from a hammer, would shatter the material.

Heating is conducted as little above Ac_3 as is practical, in order to reduce warping and the possibility of cracking when the material is quenched. On the other hand, large objects are heated to the upper limit of the hardening range in order to assure thorough heating. For the materials and sections used in aircraft work, quenching in oil is invariably the method employed. The heat absorption of oil is slower than that of water or brine, and consequently the cooling operation is more gentle. Less warping and cracking occurs and sufficient hardness is obtained.

Quench cracking is a result of nonuniform or too rapid cooling of the steel. The transition from austenite to martensite results in an increase of volume. When a piece is quenched, the external surface will cool rapidly and becomes a hard, brittle martensite shell. As the internal austenite cools and becomes martensite it increases in volume and internal stresses are set up which may crack the earlier-formed outer shell.

As explained previously under Theory of Heat Treatment, the rapid quenching from a temperature above the critical range arrests the transitions from austenite to pearlite, and results in the formation of martensite and some troostite Martensite is the hardest form of steel and is responsible for the extreme hardness and brittleness of hardened steel.

Drawing (Tempering)

Drawing (or as it is sometimes called, tempering) is the second operation required to develop high-strength, heat-treated steel. It consists of heating hardened steel to a temperature well below Ac_1, soaking at that temperature, and then quenching in oil or air. This treatment relieves the strains in hardened steel, decreases the brittleness, and restores ductility. In addition, the strength and hardness are some what reduced. The strength, hardness, and ductility obtained depend upon the temperature to which the steel was reheated. The higher the temperature, the lower the strength and hardness but the greater the ductility. By decreasing the brittleness of hardened steel, tempered steel is made tough and still retains adequate strength. Tempered steels, as used in aircraft work, have from 125,000 to 200,000 p.s.i. ultimate tensile strength.

When hardened steel is reheated as in tempering, the transition from austenite to pearlite is continued further, and the martensite is converted to troostite and then sorbite. Tempered steel is composed largely of sorbite, which gives it toughness. Hardened steel, reheated to a low temperature and quenched, is composed of troostite and sorbite, and is

still very hard and strong but more ductile than hardened steel, hardened steel reheated to a higher temperature and quenched is composed of sorbite and some pearlite, and is tougher and more ductile but still retains considerable strength and hardness.

The temperature at which tempering should be carried out, depends upon the purpose for which the article or tool is to be used, and the table below gives the temperature for high carbon steel.

When the articles have been brought to the tempering temperature, it may be quenched or allowed to be cooled naturally. The temperature for this operation is often judged by the colour of the oxide film which appears on a freshly polished surface of the article, and those colours are given in the table below :-

TEMPERATURE AND APPROXIMATE COLOUR GUIDE

The colour and corresponding temperature are given in the table below :-

COLOUR OF STEEL	APPR. TEMP. DEG. C	APPLICATION
Dazzling white	1400 - 1500	
Brilliant white	1300 - 1400	
White	1200 - 1300	High speed tungsten steel
Pale yellow	1100 - 1200	
Yellow	1000 - 1100	Austenite Nickel -Chrome stainless steel.
Orange	900 - 1000	High Chromium stainless steel
Light Cherry red	800 - 900	Low carbon and nickel chrome steel.
Cherry red	700 - 80	High carbon steel
Dull red	600 - 700	
firs Visible red	500 - 600	
Oxide Colours		
Blue	300	Tempering range tools, such as springs, axes,
Purple	295	screw drivers, chisels hacksaw blades etc.
Purple Brown	285	
Brown	270	
Golden yellow	250	
Straw	240	
Pale Straw	200	

"ONE HEAT" METHOD OF HARDENING AND TEMPERING

This method is used for tools which require a hard point or cutting edge with the remainder left tough to withstand shock, e.g. cold chisels, lathe tools etc.

The complete procedure for making, hardening and tempering a chisel is as follows :-

a)   First get the appropriate metal of approximate shape and size. Then heat it to bright red, and forge to shape as required.

(b)   Normalise, when cold grind roughly to shape

(c)   Heat the cutting end half of the tool to cherry red, plunge vertically into water to about a quarter of the length and keep it moving a little up and down to prevent a sharp line between the quenched and unquenched parts, which would cause "Water line" cracks.

(d)   When the point is black withdraw from the water polish the point with emery or sand stone and observe the tempering colours formed as the heat flows down from the unquenched parts.

(e)   When the desired colour appears, instantly quench the tip, wait if necessary, till all visible red heat dies away before dipping the remainder to cool it.

(f)   Grind the cutting edge, taking care not to over heat the tool.

PRACTICAL HEAT TREATMENT

The first important consideration in the heat treatment of a piece of steel is to know its chemical composition which, in turn, determines its critical range. When the critical temperature is known the next consideration is the rate of heating and cooling to be employed to insure completion of transition or retardation of transition as the case may be. The carrying out of these operations is beset with practical problems. These involve the use of furnaces for uniform heating,

pyrometers for controlling temperatures, handling of hot metal, and quenching in suitable mediums. Some notes on the more vital considerations in heating, soaking, and quenching are given below.

Heating

The aim in heating is to transform pearlite to austenite as the critical range is passed through. This transition takes time; so a relatively slow rate of heating is employed. It is customary to insert the cold steel in the furnace when it is from 300^0 to 500^0F. below the hardening temperature. In this way too rapid heating of the cold steel through the critical range is prevented. It is cheaper to keep a furnace up to the hardening temperature and remove heated steel and insert new cold steel periodically without permitting the temperature to drop several hundred degree before inserting the new cold work. This is sometimes done where the work is not extremely important, but it does the possibility of cracking, depending on the shape of the material, due to rapid heating and expansion.

In reheating for tempering, the furnace should not be above 800^0 to 1000^0F. when the work is inserted and ,in any case, not above the tempering temperature of the steel which is being treated. If the tempering temperature is too high, the transition from martensite to sorbite will be accelerated beyond control of the heat treater.

Several types of furnace are employed in heating. The common type is a "dry heat" furnace and is fired by oil, gas, or electricity. A uniform temperature must be maintained throughout the furnace, and the work must be properly placed to insure uniform heating. The work must not be placed too close to the wall of the furnace; otherwise radiated heat from the wall will heat one face of the work beyond the rest, with resultant uneven heating. In a dry furnace it is desirable to maintain a neutral atmosphere, so that the heated steel will neither oxidise nor decarburise. Practically, however, this condition is difficult to realise, and considerable scaling of the work results. In this respect the electric furnace is the most satisfactory because only a slight amount of scaling takes place. An atmosphere free of oxygen is maintained in one type of electric furnace. There is practically no scaling of the work in this type of furnace. Special paint coatings, such as "Galvo Anti-scale," are sometimes used to minimize scaling during the heating operation when atmospheric control is not available.

A "liquid heat" furnace is frequently used for parts which have been finished-machined before heat treatment. In this type of furnace, parts are heated in a molten salt bath. Here there are several advantages, the most important being the complete elimination of scaling. In addition, better temperature regulation and more uniform heating are attainable. For production work where speed is essential, faster heating is possible with the liquid bath than with dry heat. Numerous other advantages are claimed for the liquid bath, but those just given are the most important.

Soaking

During the soaking period the temperature of the furnace must be held constant. It is in this period the rearrangement of the internal structure is completed. The time of soaking depends upon the nature of the steel and the size of the part. Heavier parts require longer soaking to insure equal heating throughout. In specifying hardening temperatures, it is customary to give a range of from 50^0 to 75^0 F. within which the material must be soaked. Light parts are soaked in the lower part of this range and heavy parts in the upper part of the range. For the steels and sizes normally used in aircraft construction a soaking period of from 30 to 45 minutes is sufficient. During the tempering operation the steel is soaked from 30 minutes to one hours, depending on the thickness of the material.

Quenching

The rate of cooling through the critical range determines the form that the steel will retain. In annealing, the heated steel must be furnace cooled to 900^0F., which is below the critical range, provides sufficient time for complete transition from austenite to pearlite, which is the normal, stable condition of steel at atmospheric temperatures. In normalising, the heated steel is removed from the furnace and allowed to cool in still air. The cooling is more rapid than in annealing, and complete transition to pearlite is not attained. Some sorbite remains in normalisedsteel, which accounts for the improvement in physical properties over annealed material. Air cooling is a very mild form of quench.

In order to harden steels, it is necessary to use a more rapid quenching medium. There are three mediums commonly used-brine, water, and oil. Brine is the most severe quenching medium, water is next, and oil the least severe. In other words, oil does not cool the heated steel through the critical range as rapidly as water or brine. However, oil does cool rapidly enough to develop sufficient hardness for all practical purposes. In aircraft work high-carbon and alloy steels are oil quenched. Medium-carbon steel is water quenched and mild-carbon steel (S.A.E. 1025) is quenched in either brine or water. A severe quench is required for steels with relatively low carbon contents in order to develop the required hardness. This observation agrees with the comments previously made in the paragraph under Internal Structure of Steel relative to the importance of the carbon content on the hardening properties of steel.

Oil quenching is preferred to water or brine when sufficient hardness is obtainable because of the reduced strain, warpage, and cracking of the steel when cooled more slowly. When the structure changes from austenite to martensite, the volume is increased; and if the change is too sudden, cracking will occur. Cracking occurs particularly in the lower

temperature ranges when the steel is no longer plastic enough to readjust itself to expansion and contraction. The shape of a part is extremely important if excessive warping and cracks are to be avoided. Thin flanges on heavy sections are especially bad. When tubular parts are quenched, they should be immersed with the long axis vertical to reduce warpage.

Small parts when quenched cool more rapidly than large parts, and harden more uniformly throughout. In large parts the inside core is usually softer and weaker than the rest of the material. This fact must be given consideration in design in calculating the cross-sectional strength. Values obtained from heat-treated parts of small sectional cannot be applied directly to larger sections. Strength values normally quoted are based on heat-treated sections 1 to 1½ inches in diameter. As explained in the chapter on Steel and Its Alloys, many possess the property known as penetration hardness. These alloys harden quite uniformly throughout when heat treated and quenched, and no allowance need be made for a soft core unless the section is excessively large. Such sections are seldom used in aircraft work.

The quenching oil is normally maintained between 80^0 and 150^0F., but if water is used as the quenching medium it is held at a temperature below 65^0F. This control involves a large reservoir of liquid and some method of providing circulation and cooling. The rate of cooling through the critical range is governed by the temperature maintained in the quenching medium. In as much as variations in this temperature have an appreciable effect on the rate of cooling, it is obvious that the quenching-medium temperature must be held within limits if consistent results are to be obtained.

After steel is reheated and soaked for tempering, it is quenched in either air or oil. Chrome-nickel steels, however, must be quenched in oil-not air-after tempering in order to avoid "temper brittleness" to which this particular group of steels is subject if air quenched.

HEAT TREATMENTS FOR AIRCRAFT STEELS

As previously explained, each type of steel has different hardening qualities which are governed by its composition. For this reason the practical heat treatments of various steels differ somewhat as to heating temperatures, soaking periods, and quenching methods. In the following pages an effort has been made to describe the heat-treatment operations commonly used on aircraft steels. Since these data are presented purely for the general information of the reader, and not as a reference for the practical heat treatment, there has been no hesitancy to discuss an interesting point right in the body of the description. For more specific information on the steels listed, or on others not listed, the steel manufacturer should be consulted and he will gladly furnish the required data.

The heat treatments listed in the following pages do not conform wholly to the Army or Navy specifications or S.A.E. recommendations but are an average of the three. Due to slight variations-in the chemical composition of steel made by different manufacturers, in heat-treating equipment, in the size of average parts, and in the technique of heat -treater- a definite, narrow range for hardening and tempering temperatures cannot be laid down. The figures given will satisfy average conditions, but the individual heat treater may have to vary them a little to obtain satisfactory results.

The range of hardness numbers for a given tensile strength is also an average figure. Each factory should establish its own correlation between tensile strength and hardness numbers by heat-treating tensile test specimens, recording their hardness, and then testing to determine their ultimate tensile strength. For important work tensile specimens should be heat treated along with the work and tested. Absolute faith should not be placed in hardness readings alone.

It will be noted under Item 4 of S.A.E. 2330 steel that there is a discussion of the relationship between the tempering temperature to be used and the actual hardness of the steel after the hardness operation. Use of the suggested proportion on material above or below average may save time and labor, particularly where too soft tempered material would otherwise be obtained, thus requiring both re-hardening and re-tempering.

The lower part of the heating ranges should be used for material less than ¼ inch thick. A majority of airplane parts fall in this category. Prolonged heating of this material should also be avoided to prevent grain growth.

S.A.E. 1025-MILD CARBON STEEL

Normalizing:
1. The temperature of the furnace should not exceed 1100^0F when the work is inserted.
2. The temperature should be increased to $1625-1675^0$F gradually and held at that temperature for 30 to 45 minutes depending on the thickness of the part.
3. The parts should be removed from the furnace and allowed to cool in still air.

Final hardness should be as follows : Rockwell B-62 to B-74, Brinell 105 to 130.

Ultimate tensile strength : 55,000 to 67,000 p.s.i.

Heat Treatment
1.   The temperature of the furnace should bot exceed 1650^{0}F when the work is inserted.
2.   The temperature should be held from 1575 to 1650^{0}F for 15 minutes or longer, if required, to insure uniform heating.
3.   The parts should be removed from the furnace and quenched in water at 65^{0}F.
4.   The hardened parts should then be inserted in a furnace whose temperature is not over 1150^{0}F.
5.   The furnace temperature should then be increased to 1150-1200^{0}F. (the temperature will have dropped when the parts were inserted) and held for 30 minutes to one hours, depending on the thickness of the material.
6.   The parts should then be removed from the furnace and allowed to cool in still air.

Final hardness should be as follows : Rockwell B-77 to B-85, Brinell 140 to 165

Ultimate tensile strength : 70,000 to 82,000 p.s.i.

This heat treatment is used for S.A.E.1025 steel when used in the manufacture of nuts. AN Standard steel nuts, which are used exclusively in aircraft construction, fall in this category.

S.A.E. 1035-MEDIUM-CARBON STEEL
Heat Treatment
1.   The treatment of the steel and furnaces should be increased gradually aver a period of one hour until a temperature of 1525-1575^{0}F. is attained. This temperature should be held for ten minutes or more.

2.   The parts should be removed from the furnace and quenched in water if over — inch in diameter or in oil if

smaller than − inch. Quenching small parts in water will cause fractures.

3.   The hardened parts should be reheated slowly for a period of 45 minutes or more, until a temperature of 950-975^{0}F. is reached. This temperature should be held for at least 45 minutes.
4.   The parts should then be removed from the furnaces and allowed to cool in still air.

Final hardness should be as follows : Rockwell B-85 to B-100, Brinell 160 to 250.

Ultimate tensile strength : 80,000 to 118,000 p.s.i.

S.A.E. 1045 -MEDIUM-CARBON STEEL
Heat Treatment (Technique similar to that described for S.A.E. 1035. Temperatures differ.)
1.   Hardening temperature 1500-1550^{0}F.
2.   Quench in oil.
3.   Tempering temperature 1000^{0}F.
4.   Cooled in still air.

Final hardness should be as follows : Rockwell B-92 to B-102 Brinell 193 to 259.

Ultimate tensile strength : 95,000 to 124,000 p.s.i.

S.A.E. 1095-HIGH-CARBON STEEL
Heat Treatment (Technique similar to that described for Mild-carbon Steel).
1.   Hardening temperatures 1450-1500^{0}F.
2.   Quench in oil. (High-carbon steels are sometimes quenched in water until they have cooled to the temperature of boiling water when they are transferred to oil 750F. This method results in rapid cooling through the critical range and slower cooling at low temperatures where cracking occurs.)
3.   Tempering temperature 800-850^{0}F.
4.   Cooled in still air.

Final hardness should be as follows : Rockwell C-42 to C-45, Brinell 400 to 430.

Ultimate tensile strength : 195,000 to 213,000 p.s.i.

This heat treatment is applied to S.A.E 1095 steel when it is to be used for structural parts or springs. Leaf springs made from this material are commonly used in aircraft construction.

S.A.E. 2330--- NICKEL STEEL
Heat Treatment
1. The temperature of the furnace should not exceed 1100^0F. when the work is inserted.
2. The temperature should be increased gradually to 1450-1500^0F. and held for 20 minutes.
3. The parts should be removed from the furnace and quenched in oil or water.
4. At this stage the Brinell hardness should be checked to ascertain that it is approximately 500. If it is over 500 the tempering temperature given below should be reduced somewhat. The tempering temperatures should be increased or decreased about in the same proportion that the actual Brinell number bears to 500.
5. As previously explained in the paragraphs under Tempering, the final ultimate strength and hardness of a piece depends on the temperature to which hardened steel is reheated and drawn. Thus different tempering temperatures must be used if different strength values are to be obtained for the same type of steel. S.A.E. 2330 steel is commonly used in two different strengths; the tempering temperatures to obtain these conditions are

Ultimate tensile strength	Tempering temperature
125,000 p.s.i.	950^0F
150,000 p.s.i.	800^0F.

Parts should be held at the tempering temperature for a minimum of 30 minutes.
6. Parts should then be removed from the furnace and allowed to cool in still air.

Final hardness should be as follows :

Ultimate tensile strength (p.s.i.)	125,000	150,000
Rockwell hardness, C scale	25 to 32	33 to 37
Brinell hardness	250 to 300	310 to 360

S.A.E. 2330 steel heat treated to 125,000 p.s.i. is used for a great many AN Standard parts, particularly aircraft bolts.

S.A.E. 3140-CHROME-NICKEL STEEL
Heat Treatment
1. The temperature of the furnace should not exceed 1100^0F. when the work is inserted.
2. The temperature should be increased gradually to 1475-1525^0F. and held for 15 minutes or longer, if necessary, to insure uniform heating.
3. The parts should be removed from the furnace and quenched in oil.
4. The furnace temperature should not exceed 800^0F. when parts are inserted for tempering.
5. The tempering temperature should be raised to the required value for the strength desired and held for 30 minutes to one hours, depending on the thickness of the material.

Ultimate tensile strength	Tempering temperature
125,000 p.s.i.	1050^0F.
150,000 p.s.i.	950^0F.
180,000 p.s.i.	800^0F.

6. Parts should be removed from the furnace and cooled by quenching in oil. An oil quench is mandatory for chrome-nickel steels to avoid temper brittleness.

Final hardness should be as follows :

U.t.s. (p.s.i.)	Rockwell	Brinell
125,000	C-25 to C-32	250 to 300
150,000	C-33 to C-37	310 to 360
180,000	C-38 to C-42	360 to 400

S.A.E. 4037-MOLYBDENUM STEEL
Heat Treatment
1. Hardening temperature 1525-1575^0F.
2. Quench in oil or water.
3. Tempering temperature 1100^0F. for 125,000 p.s.i. ultimate tensile strength.
4. Cool in still air.

S.A.E. 4037 with this heat treatment has been used as a substitute for S.A.E. 2330 in the manufacture of aircraft bolts.

S.A.E 4130--- CHROME-MOLYBDENUM STEEL
Annealing
1. The temperature of the furnace should not exceed 1100^0F. when the work is inserted.
2. The temperature should be increased gradually to 1525-1575^0F. and held at that temperature for 15 minutes or longer to insure uniform heating throughout.
3. The furnace should then be shut down and the work and the furnace allowed to cool slowly to at least 900^0F. at which point the work may be removed and allowed to cool in still air.

Ultimate tensile strength : approximately 78,000 p.s.i.

Normalizing
1.   and
2.   Identical with annealing process except that temperature range of 1,600-1,700^{0}F. is used.
3.   The work should be removed from the furnace and allowed to cool slowly in still air.
Final hardness should be as follows : Rockwell B-89 to B-99, Brinell 180 to 240.

Ultimate tensile strength : 90,000 to 110,000 p.s.i.

Heat Treatment
1.   The temperature of the furnace should not exceed 1100^{0}F. when the work is inserted.
2.   The temperature should be gradually increased to 1550-1650^{0}F. and held for 15 minutes or longer, if necessary, for thorough heating. For sections under ¼ inch thickness the lower part of the temperature range should be used.
3.   The parts should be removed from the furnace and quenched in oil.
         Bars or forgings can be quenched in water.
4.   The hardened parts should be inserted in a furnace whose temperature is not above the desired tempering temperature and in no case above 800^{0}F.
5.   The temperature of the furnace should then be raised to the tempering temperature required to obtain the desired physical condition. These temperatures for the tensile strength used in aircraft construction are as follows.

Ultimate tensile strength	Tempering temperature
125,000 p.s.i.	1,075^{0}F.
150,000 p.s.i.	900^{0}F.
180,000 p.s.i.	700^{0}F.
200,000 p.s.i.	575^{0}F.

Parts should be held at the tempering temperature for 30 minutes to one hour, depending on the thickness.
6.   Parts should be removed from the furnace and allowed to cool in still air.
         Final hardness should be as follows :

U.t.s. (p.s.i.)	Rockwell	Brinell
125,000	C-25 to C-32	250 to 300
150,000	C-33 to C-37	310 to 360
180,000	C-38 to C-42	360 to 400
200,000	C-42 to C-46	400 to 440

S.A.E. 4140---CHROME-MOLYBDENUM STEEL (HIGH CARBON)
Due to its higher carbon content this steel responds to heat treatment better than 4130 steel. For heavy parts machined from bar or forging stock it has replaced 4130 steel entirely. The heat-treatment process is practically identical with that given for 4130 steel, excepting that the hardening range is 25^{0}F. lower, making it 1525-1625^{0}F. This change is due, of course, to the higher carbon content. Tempering temperatures are approximately 100^{0}F. higher than those for 4130.

S.A.E. 4340---CHROME-NICKEL-MOLYBDENUM STEEL
Heat Treatment
1.   The temperature of the furnace should not exceed 1100^{0}F. when the parts are inserted.
2.   The temperature should be increased gradually to 1475-1525^{0}F. and held for 15 minutes or longer if necessary, to insure thorough heating.
3.   The parts should be removed from the furnace and quenched in oil.
4.   The hardened parts should be inserted in a furnace whose temperature is not above the desired tempering temperature and in no case above 1,000^{0}F.
5.   The temperature of the furnace should then be raised to the tempering temperature required to develop the desired physical properties.

Ultimate tensile strength	Tempering temperature
125,000 p.s.i.	1,200^{0}F.
150,000 p.s.i.	1,050^{0}F.
180,000 p.s.i.	950^{0}F.
200,000 p.s.i.	850^{0}F.

Parts should be held at the tempering temperature for 30 minutes to one hour, depending on the thickness.
6.   Parts should be removed from the furnace and quenched in oil.

Final hardness should be the same as recorded for 4130--chrome molybdenum steel-- for equivalent tensile strengths.It should ne noted that this steel is one of the chrome-nickel series and must be quenched in oil after tempering to avoid temper brittleness.

S.A.E. 6135---CHROME-VANADIUM STEEL (MEDIUM CARBON)

Heat Treatment

1.   The temperature of the furnace should not exceed 1100^0F. when the work is inserted.
2.   The temperature should be increased gradually to 1575-1625^0F. and held for 15 minutes or longer, if necessary, to insure thorough heating.
3.   The parts should be removed from the furnace and quenched in oil.
4.   The hardened parts should be inserted in a furnace whose temperature is not above 800^0F.
5.   The temperature of the furnace should then be raised to the required tempering temperature, which depends on the tensile strength desired in the finished part.

Ultimate tensile strength	Tempering temperature
125,000 p.s.i.	$1,050^0$F.
150,000 p.s.i.	925^0F.

Parts should be held at the tempering temperature for 30 minutes to one hour, depending on the thickness.

6.   Parts should be cooled in still air.
        Final hardness should be as follows :

U.t.s. (p.s.i.)	Rockwell	Brinell
125,000	C-25 to C-32	250 to 300
150,000	C-33 to C-37	310 to 360

S.A.E. 6150---CHROME-VANADIUM STEEL (SPRINGS)

Heat Treatment

1.   The temperature of the furnace should not exceed 1100^0F. when the parts are inserted.
2.   The temperature should be increased gradually to 1550-1625^0F. and held for 15 minutes or longer, if necessary, to insure thorough heating.
3.   The parts should be removed from the furnace and quenched in oil.
4.   The hardend parts should be inserted in a furnace whose temperature is not above 700^0F,
5.   The temperature of the furnace should then be raised to 700-850^0F. and held for 30 minutes to one hours, depending on the diameter of the spring material.
6.   Parts should be allowed to cool in still air.

Final hardness should be as follows : Rockwell C-42 to C-47, Brinell 400 to 444.

Ultimate tensile strength : approximately 200,000

S.A.E. 8630, 8735, 8740 these NE steels which are now established as standard steels are heat treated the same as S.A.E. 4130 or S.A.E. 4140 steels.

INTERRUPTED QUENCHING

In the last five years commercial application of so-called interrupted-quenching procedures has been made to attain special characteristics or economies in the heat treating of steel. These procedures are known as cycle annealing, austempering, and martempering. Cycle annealing gives better control of the final annealed structure and can be accomplished in a fraction of the time required for full annealing and spheroidizing operations. Austempering is limited to small sizes and deep-hardening steels but greatly increases the toughness and ductility of steels heat treated to high hardness. Martempering is applicable only to relatively small sizes of deep-hardening steels but minimizes distortion and cracking due to quenching, reduces internal stresses, and gives good physical properties.
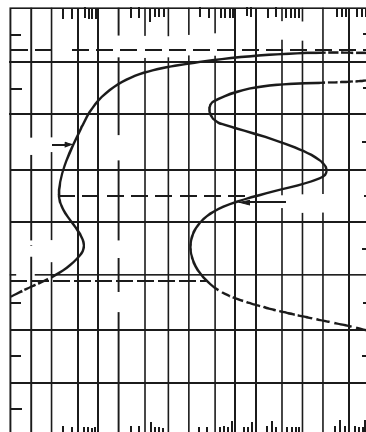
Fig.9.4. Typical Isothermal Transformation Diagram

The development of these processes is directly related to the TTT (time-temperature-transformation) or S curves, similar to that for S.A.E. 4104 steel, is shown in Figure 9.4. The first of the diagrams of this type was published in 1930 but they are now available for a wide variety of steels. Each composition of steel has its own diagram, which may be obtained from the steel companies.

An S curve or isothermal transformation curve for a given steel is established as follows : Above the critical range austenite is the stable structure of steel; below the critical range austenite is unstable and will transform to another type of structure if held at a constant temperature for a period of time. The length of time before the transformation of the unstable austenite begins varies at different temperatures and is plotted as the left hand curve in Figure 9.4 ; the time required to complete the transformation also varies with the temperature and is plotted as the right-hand curve in Figure 9.4. The type of structure obtained by transformation depends on the temperature at which the isothermal transformation takes place. At the higher temperatures pearlite is formed (As found in annealed steel), while at lower temperatures a structure named bainite is formed. Bainite is equivalent to a tempered martensite and is a feathery, acicular constituent that makes a hard but ductile and tough material.

The *Ms* line at the bottom of the diagram represents the temperature below which transformation to martensite takes place. Ms is the abbreviation of "martensite start". The Ms temperature varies from 260^0F. to 640^0F for different steels. For carbon tool steel it is 380^0F for S.A.E. 4140 it is 590^0F; and for S.A.E. 4340 it is 530^0F.

It will ne noted in Figure 9.4 that time is plotted on a logarithmic scale in order to include the very short as well as the extremely long time intervals covered by this type of diagram. The time required for transforation to begin may vary from a fraction of a second to 30 minutes or more, while the time to complete transformation may vary from less than 5 seconds to several days.

An examination of Figure 9.4 will show that the S curve has a so-called "nose" or "knee" at a temperature around 9000F The location of this "knee" along the time scale is of primary importance in determining the hardenability of a steel. The reason is that the steel being hardened must be cooled to a point below the "knee" within the time interval shown in the diagram or the martensite structure desired will be diluted with other types of structure (referred to as "nose products" or "knee products" which are softer than martensite. The "knee" is moved to the right (thus increasing the time interval in which quenching can be completed to insure the formation of pure martensite) by the addition or increase of alloy content. Manganese, chromium, nickel, and molybdenum are very effective in accomplishing this movement of the "knee" to the right. These steels have good hardenability.

It should be understood that the entire mass, including the center of the part, must be below the "knee" temperature within the time interval shown on the S curve for any particular steel. The austempering and martempering processes are limited by this requirement to deep-hardening steels of relatively small cross-sections.

Isothermal quenching must be done at temperatures above which brine, water, or oil are practical. A molten salt bath composed of half sodium nitrate and half potassium nitrate is frequently used for quenching. This salt bath can be operated from 350^0 to 1100^0F. A molten salt bath around 400^0F has greater cooling power than ordinary quenching oil at room temperature-a characteristics advantageous in quenching steel adequately to below the "knee" temperature in the permissible time interval.

Cycle Annealing
This is a process in which austenite is transformed isothermally to pearlite at high temperatures, and this latter structure is retained when the work is cooled to room temperature. In actual practice the steel is austenitised (heated to a temperature above the critical temperature and soaked until a stable austenitic structure is formed through out the part) at a temperature above but within 100^0F. of the critical temperature. It is then quenched in a molten salt bath maintained at a temperature below the critical temperature but above the "knee" temperature unless the shape of the S curve is such that too long a period of time would be required to complete the transformation, in which case a somewhat lower temperature is used. After complete transformation is effected the work is cooled to room temperature by air or water without further changing the microstructure.

Sometimes the transformation is allowed to proceed only a certain amount before the work is removed from the quenching bath and allowed to air cool. By this means a variation in properties is obtainable. Cycle annealing permits better structure in a fraction of the time required for the full annealing and spheroidizing operation. Cycle annealing requires from 4 to 7 hours as compared with 18 to 30 hours for standard annealing.

Austempering
This is a process in which austenite is transformed isothermally to bainite at moderate temperatures The material is austenitised and then quenched in a molten salt bath maintained at a temperature above the *Ms* but below the "knee" temperature. The work is held in the bath until the transformation to bainite is complete and then it is removed and cooled

to room temperature by air or water. In some cases, to insure adequate cooling to below the "knee" , it is necessary to quench in a bath maintained at a lower temperature than that required for the final hardness desired. In this case the bainite product is transferred for tempering to a second bath maintained at a higher temperatures. This procedure permits the austempering of slightly larger sizes of material than would be possible by using only the second bath for quenching. The double operation is sometimes referred to as isothermal quenching.

Austempering is most useful when the steel is to be used in the hardness range of Rockwell C-48 to C-58. As compared to standard quench and temper steels of the same hardness, austempered steel has about 30% additional elongation, 100% greater reduction of areas and impact strength, but slightly less yield strength. Spring products and other items requiring increased elasticity as well as hardness are obtainable by austempering. Then finish of the part after austempering is the same as the initial material before heat treatment. The relative gentleness of the quench results in minimum distortion and cracking of the work.

As explained previously, a rapid-quenching or deep-hardening steel is required to get by the "knee" of the S curve. This requirement limits the austempering process to carbon steels above 0.55% carbon and to alloy steels . The maximum cross-sectional area of S.A.E. 1095 steel that can be austempered is the equivalent of a rod 0.148 inch in diameter; S.A.E. 4140 is limited to a 0.50- inch diameter; and a material like SAE 4365 is limited to a 1.0- inch diameter.

Martempering

This is a process in which austenite is uniformly transformed to martensite at low temperatures by continuous cooling. In this process the work is austenitised and then quenched in a molten salt bath maintained at a temperature just above the Ms temperature of the steel being treated. The work is held at this temperature only a short period of time-long enough to permit all of the material to reach the same temperature, but not long enough for the transformation to bainite to begin. The work is then removed from the bath and allowed to air cool. The transformation from austenite to martensite occurs during this air cooling, at which time the difference in temperature between the outer skin and the centre of the work is negligible. When room temperature is reached and the transformation to martensite is complete the work is subjected to a normal tempering operation to obtain the desired physical properties.

It should be noted by quenching a part in the salt bath at a temperature above Ms, temperature uniformity throughout the part is obtained before any transformation or change in microstructure takes place. When the part is slowly cooled in air from this temperature the transformation occurs uniformly throughout. By this means nonuniform volume changes are reduced, high internal stresses are avoided, and warpage, cracking, and distortion are minimized. These are the particular advantages of martempering. Martempering is limited largely to high-alloy steels and small cross-sectional areas for the same reason that applies to austempering, namely, the necessity for getting by the "knee" of the S curve in quenching if the full advantage of the process is to be realised. S.A.E. 8630 steel can be martempered up to a cross-sectional area equivalent to a round of 1- inch diameter; S.A.E. 8740 can be processed up to 1½-inch diameter.

HARDENABILITY

In recent years hardenability has come to the forefront as the primary basis for the selection of a particular type of steel. This criterion is logical since the physical properties normally required for a given application are directly related to the hardness of the material. Steels with equivalent hardening characteristics can be used interchangeably irrespective of their chemical compositions. In the future it is anticipated that most steel will be purchased under "H" steel specifications, which prescribe hardenability limits as well as over- all chemical compositions. When steel is purchased under this type of specification the aircraft manufacturer's heat-treating problems will be simplified, as all material will come up to the required hardness when properly heat treated. In the past, when material was purchased solely by chemical composition, there were many occasions when a sour lot of material would not respond to heat treatment for some unexplainable reason.

"H" steel specifications have been prepared for most of the commonly used steels. Steel in accordance with this type of specification is designated by adding an H to its numerical designation. Thus we have 4130 H, 8740H, etc., to identify steels manufactured to hardenability-band limits. Tables and charts have been prepared for each type of steel to define its hardenability limits.

A jominy or end-quenched hardenability test has been adopted as the standard method for determining hardenability limits in order to permit comparisons between different steels. This test is based on the concept that the hardening of steel by quenching is a function of heat extraction--rapid extraction resulting in high hardness and slow extraction resulting in low hardness.

The standard Jominy specimen is a round 1 inch in diameter by 4 inches long which has been machined after normalising to remove all scale or decarburized surfaces. To insure uniformity the specimen is normalised at the temperature listed below for one hour, machined to finished dimensions, and the is held for 30 minutes at the austenitising temperature

listed below. The furnace should be at the austenitising temperature when the specimen is inserted. A protective atmosphere furnace or other means is essential to protect the bottom end of the specimen from scale or decarburization.

Quenching of the specimen must start within 5 seconds after its removal from the furnace. The specimen is quenched by suspending it vertically with its bottom end ½ inch above a water orifice with a ½-inch opening which discharges water at a rate of approximately 1 gallon per minute. The water must be at a temperature between 40^0 and 85^0F and must impinge against only the bottom or quenched end of the specimen. Quenching in this manner is continued for 10 minutes.

A cooling rate of 600°F per second is attained at the quenched end. The rate of cooling is slower as the distance from the quenched end increases and is only 4 ° per second at the opposite end. Since the cooling rate varies along the entire length some point will duplicate every quenching condition met with in practice from water to air quenching, and from the surface to the centre of various sizes of material .for instance, the cooling of the specimen at 3/8, 3/4, 1 1/16. and 1½ inches from the quenched end will result in hardness equivalent to that obtained at the centre of 1-, 2-, 3-, and 4-inch rounds respectively when quenched in still oil. This type of results can be consistently correlated and therefore can be used to predict the attainable hardness for any shape from data supplied by the end-quenched specimen.

Steel series	Maximum carbon content (%) temperature (^{0}F).	Normalising temperature (^{0}F.)	Austenitising
1000			
3100			
4000	Up to 0.25 incl	1700	1700
4100	0.26 to 0.36 incl	1650	1600
4600	0.37 and over	1600	1550
8600			
8700			
	Up to 0.25 incl	1750	1750
6100	0./26 to 0.36 incl	1700	1650
	0.37 and over	1650	1600
2300			
2500	Up to 0.25 incl	1700	1550
3300	0.26 to 0.36 incl	1650	1500
4800	0.37 and over	1600	1475
9200			
9200	0.50 and over	1650	1600

To obtain the hardness readings of the end-quench specimen, two flats 180^0 apart are carefully ground along the entire length of the specimen. Wet grinding is preferable, to avoid changing the quenched condition, and the flats should be at least 0.015 inch deep. Rockwell C hardness readings are then taken every 1/16-inch from the quenched end for 1 inch and at greater intervals for the remainder of the length. The Rockwell readings are then plotted on a standard chart in which the ordinates represent hardness and the abscissas represent distance from the quenched end. The chart applying to each steel is necessarily a band bounded by a maximum and a minimum curve. This spread is due to the variations permitted in the chemical compositions of a given steel.

In ordering "H" steel it is customary to specify two specific points of the desired hardenability band. In the preferred method , the distance from the quenched end where a specified Rockwell C hardness is desired is called for. Usually a minimum and maximum distance is given within which the desired hardness number must fall. In the alternate method, a minimum hardness number (or a range of hardness numbers which will be acceptable) at a specified distance from the quenched end is called for. In addition, in either of these methods, the minimum and maximum hardness 1/16-inch from the quenched end may be specified. The steel producer will list on the shipping papers the heat hardenability at the specified points or at 1/16, 1/8, 1/4,1/2 inches, etc., from the quenched end.

CHAPTER-10
SURFACE (CASE) HARDENING OF STEELS

For some design purposes it is necessary to have a hard, wear-resisting surface and a strong , tough core. This condition can be obtained in steel by a number of methods. Heat treating alone, as discussed in the previously chapter, will give a uniform condition, either extremely hard and strong, or moderately hard and tough, throughout the entire cross section of the metal. By the methods of surface hardening described in this chapter, it is possible to obtain a surface harder than the highest obtainable by heat treatment, combined with a tough core. Since any depth from a mere skin to over 1/8-inch can be produced, the case thickness can be varied to suit the design requirements. The hard case resists wear and abrasion, and the soft, tough core resists shock stresses. This combination of properties is essential in the design of gears, pinions, wrist pins, trunnions, and other parts subject to abrasion and shock loads.

The methods commonly used for surface hardening are known as carburising, cyaniding, and nitriding. The combination of carburising and the subsequent heat treatment which always follows this operation is called casehardening. Casehardening is used more often than the other methods in aircraft work.

CASEHARDENING

As commonly practiced, casehardening consists of carburising a piece of steel, quenching either mildly or rapidly, reheating to refine the core, quenching rapidly, reheating again to refine and harden the case, quenching rapidly, tempering at a low temperatures, and cooling slowly. For un-important parts and with some steels one or more of these operations can be eliminated. A detailed discussion of the theory and practical application of each of these operations follows.

Carburizing

Carburising steels may be either carbon or alloy steels but must be within the low-carbon range. The carburising process consists in heating these steels in contact with a carbonaceous material. This material may be either solid, liquid, or gaseous. Above the critical range the iron carbide in steel passes into solution in the gamma iron, as explained under Heat-Treatment. Low-carbon steels are weak solutions and will absorb free carbon. The carbon-rich carbonaceous materials when heated give off a gas containing carbon which diffuses into the steel surface. The depth of penetration depends upon the carbonaceous material, the temperature, and the time allowed.

The absorption of carbon at the surface will greatly increase the carbon content in this region. This carbon content will range from 0.80 to 1.25% at the surface and will taper off toward the centre with the core remaining at the original content. Subsequent heat treatment will harden the case and toughen the core. This behaviour is to be expected   from the explanation made under Heat Treatment, where it was shown greater hardness could be obtained from high-carbon steels.

Solid Carburising

The oldest and most commonly used method of carburising is with a solid carbonaceous material. This material is usually bone, charred leather, wood charcoal, or coke. These materials are used singly or mixed together and usually contain an energiser to increase the formation of carburising gases when treated.

The parts to be carburised are packed in a metal box (usually nichrome) with at least 2-inch legs, so that the furnace gases may circulate freely around the entire box. All surfaces of the parts must be covered with at least ½ inch of the carburising material. The box must have a lid which can be sealed tight. A common seal is most fire clay to which a little salt has been added to prevent cracking. When the box is properly packed and sealed it is ready for insertion in the furnace.

The furnace should be brought up to 1600-1700⁰F. as quickly as possible. The range of some carburising steels is 1600-1650⁰F., other 1625-1675⁰F., and still others 1650-1700⁰F. All fall under 1700⁰F. More rapid penetration can be obtained at higher temperatures, but grain growth will increase rapidly and affect the quality of the steel. The temperature should be kept as close to the critical range as possible to avoid grain growth. It should be borne in mind, however, that due to the size of the box and the packing, the enclosed parts will lag about 100⁰F. behind the furnace when being heated. The furnace must be kept at the carburizing temperature some what longer to allow for this lag.

The carburising temperature is held until the desired depth of case is obtained. The time required varies for the different carburising steels. For S.A.E. 1020 carbon steels, which is often used for case-hardened parts, the variation of depth

of case with time at temperature is as follows :

Depth of case	Time at 1,650⁰F.
/ inch	one hour
/ inch	Two hour
/ inch	Four hours
/ inch	Six hours
/ inch	Sixteen hours

In aircraft work a case depth of 1/64 or 1/32-inch is commonly used, since the abrasion is seldom great and shock resistance is important. Thick cases are liable to crack under shock loads.

After carburising the box is removed from the furnace and allowed to cool in air, or the parts removed and quenched in oil from the carburising temperature. The slower method of cooling is employed when warpage must be avoided. This cooling completes the carburising process, and the parts are then ready for grain refinement, hardening, and tempering.

Liquid Carburising

Carburising in a liquid salt bath has recently been successfully developed. This method is applicable to small parts where a depth of case not greater than 0.040 inch is satisfactory. Liquid carburising has the advantage of forming a case uniform in depth and carbon content. In the use of solid carburising it is often impossible to obtain uniform results on small parts packed in a box since temperatures near the sides differ from those in the centre. Furthermore, liquid carburizing is faster than solid carburising because laborious packing is eliminated.

A salt that melts several hundred degrees below the carburising temperature is used as the liquid heat. An amorphous carbon is added to the bath to furnish the required carbon. Periodically, additional carbon is added to keep the bath saturated. A layer of carbon covers the top of the bath to reduce volatilisation loss.

As with the solid material the depth of case obtained is dependent on the time and temperature. The following are typical figures for S.A.E. 1020 steel :

Depth of case, inches		Time, hours
1,600⁰F	*1,675⁰F*	
0.006	0.006	1/3
0.010	0.012	2/3
0.016	0.018	1
0.020	0.024	2
0.026	0.030	3
0.035	0.040	4

After carburizing, the parts may be quenched in water or oil. They are then ready for refinement hardening, and tempering.

Gas Carburising

Gas carburising is becoming more generally used. One process consists in exposing small parts in a rotating retort to gas as a carburizing medium. Solid carburiser is sometimes added in the retort to enrich the carburizing atmosphere. Parts in the rotating retort are tumbled about, with resultant damage to corners and edges.

The latest improved process is done in the electric furnace with a carbon atmosphere as mentioned in the chapter on Heat Treatment. When carburising, about twice as much carbon vapor is admitted to the furnace as when heat treating. In this process the parts remain stationary.

Refining the Core

Due to the fact that the carburising temperature is well above the critical range and is held for a long period of time, an excessive grain growth takes place in the steel. In order to obtain a fine ductile grain in the core, it is necessary to reheat the steel to just above the upper critical point, soak until the metal is uniformly heated, and then quench in oil.

In actual practice the following typical procedure is used for S.A.E. 1020 steel : The furnace is preheated to 1200⁰F,. and after the parts are inserted, it is brought up to 1600⁰F. in 45 to 60 minutes. A longer time is taken for complex parts. The parts are soaked for 10 minutes or longer, if necessary, and then quenched in oil.

Hardening the Case

Since the case of a carburised steel part has a high carbon content, the temperature required above to refine the low-carbon core is considerably above the critical range of the case. This high temperature results in grain growth and embrittlement of the case. It is, therefore, necessary to reheat the steel to just above the critical range of the high-carbon case and then quench in oil. This treatment refines the grain and hardens the case. The hardening temperature for the high-carbon case is well below the upper critical point for the low-carbon core. The only effect this reheating has on the core is a tempering action.

For S.A.E. 1020 steel the hardening procedure is as follows : The furnace is preheated to 1000^0F., and after the parts are inserted, it is brought up to 1400-1430^0F. fairly rapidly. The parts are soaked for ten minutes and then quenched immediately in oil.

Tempering

In order to relieve hardening strains, carburised steel parts are tempered by heating in the region of 300-400^0F. This tempering should be done immediately after the hardening quench. The furnace or oil bath should be at the tempering temperature when the parts are inserted. The low part of the tempering range should be used if extreme hardness is desired since hardness decreases as the tempering temperature increases. The parts should be soaked until uniformly heated and then removed and cooled slowly in still air.

SELECTIVE CASE HARDENING

In many designs it is desired to harden only that portion of the part subject to severe wear. Methods have been evolved to protect the other portions of the part from carburizing. The best method is to copper plate the sections to be left soft. A few thousandths of an inch of good dense copper plate will resist the penetration of carbon, provided too much energiser is not present in the carbonaceous material. Before copper plating, the sections to be hardened are japanned to protect them from being plated. The japan is removed after plating but before carburising.

It is customary to finish hardened carburised parts by grinding. In some cases, where soft sections are desired, sufficient material is left on in the original machining to allow for grinding. By this method the case is completely removed by grinding where a soft section is desired. This method is slow and expensive.

Sometimes a portion of a carburised part is threaded. It is essential that the threads be true and soft while the remainder of the part must be hard to resist wear. If the threads are cut and then carburized and hardened, the threads will be warped and thrown out of centre with the hardened ground surface. To avoid this condition the following procedure is recommended :
1.   Machine for carburising, leaving ¼ - inch of stock on the section to be threaded.
2.   Carburised for the desired depth of case.
3.   Turn off all but 1/64-inch of excess stock on the section to be threaded. All the high-carbon case will thus be removed from the threaded portion.
4.   Heat treat to refine the core and harden the case, and temper to remove strains.
5.   Finish-grind the hardened surface, turn the threaded section to size true to the ground surface, and then thread. Machining operations are possible on the threaded section even after the hardening treatment because its low carbon content will not permit appreciable hardening.

Warpage and Cracking

Warpage of carburised parts is very common and is caused by improper packing or severe quenching. It is customary to finish-grind casehardened parts to reduce the distortion.

Cracking of parts occurs in the hardening quench. It is absolutely necessary to avoid all sharp corners, notches, or sudden changes of section in parts to be hardened. In some cases it is preferable to design a part in two or more pieces to avoid hardening cracks.

Some carburising steels require a less severe quench than others and are not as subject to warping and cracking. Where absolute accuracy is necessary the proper steel should be selected with minimum distortion properties. S.A.E. 4615 is generally recommended.

Carburising Steels.

Carburising steels are either plain carbon or alloy steels but are invariably in the low-carbon range. A low carbon content is necessary to retain a tough core after the heat treatment. In special cases steel with a carbon content as high as 0.55% has been successfully carburised. Normally, however, the carbon content is restricted to a maximum of 0.25%. For light parts requiring extremely tough cores, 0.18% carbon is the maximum that should be permitted. For heavy parts strong cores, the carbon content of the steel should be 0.15 to 0.25%.

Since the carbon content is limited in these steels, an increase in strength cannot be obtained by merely using a higher carbon steel. In order to obtain greater strength without a decrease in toughness after heat treatment, it is necessary to use an alloy steel. The alloy steels commonly used are nickel, nickel-chromium, and molybdenum steels. The greatest core strength is obtained by using a nickel steel, S.A.E.2515.

A good case is also extremely important. The plain carbon steel S.A.E. 1020 gives a file-hard case that is slightly better than that obtained with the alloy steels. Alloys decrease the hardness of the case somewhat. An increase in the nickel content decrease the case hardness. S.A.E. 2515 steel has the softest case of the carburising steels.

The following listed steels are used most frequently for carburising parts.

Their core strengths are also given :

S.A.E. number	Core strength (p.s.i.)
1020	60,000
2320	80,000
2515	120,000-160,000
3115	85,000
3312	100,000
4615	80,000-100,000
6115	90,000

CYANIDING

Cyaniding is a surface hardening of steel obtained by heating it in contact with a cyanide salt, followed by quenching. Only a superficial case-hardening is obtained by this method, and consequently it is seldom used in aircraft work. It has the advantage of speed and cheapness, however, and may be used to advantage on relatively unimportant parts.

The cyanide bath, which is usually sodium or potassium cyanide, is maintained at 1550-1600^{0}F. The work to be hardened is preheated to 750^{0}F. and then immersed in the bath for from 10 to 20 minutes. It is then withdrawn and quenched in water until cold. A superficial case of 1/64 -inch maximum depth is obtained. The case is hard but not homogeneous. Great care must be taken to remove all scale before cyaniding and to insure uniform cooling, or soft spots will be present in the case. Immersing the work for 20 minutes does not increase the case materially but results in high-carbon spots and brittleness.

In cyaniding it is also important to use a closed pot since the fumes are extremely poisonous.

The hard case obtained from cyaniding is not due wholly to a high carbon content; as a matter of fact, the carbon content is relatively low. Chemical analysis shows the presence of nitrogen in the form of iron nitride in the case. It is this constituent which imparts the hardness as well a brittleness to the case. It should be noted that the core is also hard and brittle after cyaniding, which is, of course, undesirable.

NITRIDING

Nitriding is the surface hardening of special alloy steels by heating the metal in contact with ammonia gas or other nitrogenous material. The process of nitriding has great possibilities, however, and should eventually supersede casehardening by carburizing on all important work. A harder case is obtainable by nitriding than by carburizing. In addition, there is no distortion or cracking associated with nitriding and the case obtained appears to be corrosion resistant in most mediums, including salt water.

Nitriding is applicable only to special steels, the most common of which are called nitralloys. A process has recently been developed for nitriding stainless steels to obtain an ultrahard corrosion-resistant material. In aircraft work, steel in accordance with Army-Navy Aeronautical specification AN-S-19 is normally used. This specification describes two types of nitralloy-composition A, which is a high-core strength steel, and composition B, which is a free-machining steel. The chemical and physical properties of these steels are as follows :

CHEMICAL COMPOSITION		
	A(%)	B(%)
Carbon	0.38-0.45	0.30-0.40
Manganese	0.40-0.70	0.50-1.10
Phosphorus	0.040 max.	0.040 max.
Sulphur	0.050 max.	0.060 max.
Silicon	0.20-0.40	0.20-0.40
Chromium	1.40-1.80	1.00-1.50
Aluminum	0.85-1.20	0.85-1.20
Molybdenum	0.30-0.45	0.15-0.25
Selenium	------	0.15-0.35

PHYSICAL PROPERTIES

Composition	Thickness, inches	Tensile strength (p.s.i.)	Yield strength (p.s.i.)	Elongation (%)
	1½ and less	135,000	100,000	16
A	Over 1½ to 3	125,000	90,000	15
	Over 3 to 5	110,000	85,000	15
	1½ and less	106,000	76,000	26
B	Over 1½ to 3	102,000	74,000	28
	Over 3 to 5	95,000	70,000	30

The physical properties listed above are the minimum acceptable when subjected to the following heat treatments:

Composition A.
Heat at 1725^0 to 1750^0F., quench in oil (or water if diameter exceeds 2 inches), and draw at a temperature of 1100^0F or higher for 5 hours.

Composition B
Heat at 1700^0F., quench in oil, and draw at a temperature of 1050^0F. or higher.

Before being given the nitriding operation the steel should be hardened and tempered to obtain a sorbitic structure. If annealed material is nitrided the nitrogen will penetrate the boundaries of the relatively large grains and cause a brittle, nonuniform casehardening. When no distortion is permissible in the nitrided parts, it is necessary to normalise the steel prior to nitriding to remove all strains resulting from the forging, quenching, or machining.

The nitriding operation consists of heating the steel to 950^0F. in the presence of ammonia gas for from 20 to 100 hours. The container in which the work and ammonia gas are brought in contact must be airtight and equipped with a fan to maintain good circulation and an even temperature throughout. The depth of the case obtained by nitriding is about 0.015 inch if heated for 50 hours, and the case has a Vickers Brinell hardness number over 950. The nitriding process does not affect the physical state of the core if the preceding tempering temperature (as is usual) was 950^0F or over.

The molybdenum present in nitriding steels imparts ductility to both case and core. In spite of this fact, however, the case is still very brittle . It is possible to improve its ductility by increasing the nitriding temperature to 1150^0F for a period of two hours at the end of the regular treatment. The increased ductility is grained at the expense of 100 points in hardness.

It should be noted that there is no quenching associated with the process of nitriding. As a result there is no distortion or cracking of the work, particularly of properly normalized material without internal strains, as explained above. Due to the brittleness of the case, care must be taken in the design to avoid sharp corners. The reason is that nitrides are formed on both sides as well as the edge, which makes a brittle corner or edge that is easily chipped.

No scaling of the work occurs during the nitriding operation. The slight oxide film formed is easily removed by buffing or by using emery paper.

Tinning of any surface will prevent it from being nitrided. This fact is utilized when a piece of work is to be partially treated only.

Nitrided surfaces can be reheated to 950^0F. without losing any of their hardness. If heated above that temperature, they lose their hardness rapidly and cannot be retreated to regain the lost hardness.

Gas welding of nitriding steels is not practical since a large part of the aluminum is burnt away and the remaining metal will not nitride properly. Spot welding after nitriding has been successful.

Care must be taken to remove all the decarburized metal caused by preliminary heat treatment prior to nitriding. If the decarburized metal is not removed, the nitride case will flake. Nitriding steels decarburize more than other steels during heat treatment. They also are increased in size slightly by the nitriding process. This increase is of the order of 0.002 inch for a piece 12 inches in diameter.

As previously stated, nitrided steels are reputed to be corrosion resistant in fresh or salt water as well as under ordinary atmospheric conditions. The steel, however, has not been in use long enough to make a definite statement on its corrosion resistance.

INDUCTIONHARDENING

Induction hardening is one application of induction heating which is finding numerous applications in aircraft and automotive work. Induction heating is the process of heating metallic substances by means of a powerful, rapidly alternating electromagnetic field. The current that produces this field is usually carried in a copper coil that encircles that work to be heated. Induction heating is a differential heating, that is, the surface of the work heat up first very rapidly and then the core of the material. When steel is used and the work is quenched immediately after the surface is heated to a high temperature, a casehardened surface is obtained without having effected the properties of the core material. The depth of the case and or heat penetration varies with the frequency and intensity of the electromagnetic field and the length of time the current is on. Induction heating is used for surface hardening, and thorough-heating for heat treating, annealing, normalizing, brazing, soldering, forging, forming, or melting of metals. The required frequency, power, and heating time must be determined for each application.

Dielectric heating is similar to induction heating but is applicable only to nonconducting materials (dielectric materials) such as might be used for electric insulation. Plastics and compressed wood are typical applications. Dielectric heating is done by means of an electrodynamic field, the work being placed between two or more plates. Dielectric heating uniformly heats the material from the surface to the center as opposed to the differential heating of the induction-heating process.

There are four types of induction-heating equipment in common use. They are different in principal and in the current frequencies they can provide. The four types are as follows :
1   The first type uses the power-line frequency of 60 cycles per second and voltages up to 880. Transformers are used if required to attain the desired voltage. Current requirements range up to 1,500 amperes. This type of equipment is used for the preheatment of joints to be welded, the stress-relieving of welds, and the heating of ingots for rolling or forging.
2.   The motor-generator type of equipment converts 60- cycles power to frequencies from 1,000 to 12,000 cycles at capacities up to 1,000 kilowatts rated power. This type of induction-heating equipment is the most widely used. It is used for surface hardening of crankshafts, gears, and similar parts, for brazing tool tips, for melting metals in large quantities, and for heating forging stock. This method of heating forging stock has the advantage of eliminating scale, uniformly heating the stock to the working temperature, and saving considerable time and space normally required by furnace heating.
3.   Spark-gap generator equipment produces a rapid reversal of the electromagnetic field at frequencies up to 4000,000 cycles and 25 kilowatt output. It is used for the heat treatment of gears and precision gages and for the annealing of continuous strip for stamping and forging.
4.   Vacuum-tube oscillator equipment producing frequencies from 1000,000 to 10,00,000 cycles at capacities up to 400 kilowatts. The electronic induction-heating equipment consists of a transformer which raises the line voltage to that required for the oscillator-tube operation, a set of rectifier tubes which converts the alternating-current line power into direct current to supply the oscillator circuit, oscillator tubes of the high-frequency type, capacitors, and inductance coils which produce the high-frequency current to be delivered to the heater coil.

The heater coil is a separate unit which is designed to suit the size, shape, and material of the work to be heated. It may be a long cylinder of many turns or just a few turns, a flat pancake of only 1 or 2 turns, or a special shape to adapt it to the contour of the work. Copper tubing equipped with provisions for running cooling water through the inside is frequently used in the construction of heater coils. With this type of coil, high frequencies and current densities can be used to raise the surface temperature of a steel piece above its critical temperature in a fraction of a second.

The surface hardening of steel parts, usually referred to as induction hardening, is the primary application of induction heating in aircraft and automotive work. In this process the heat is applied so rapidly that the high temperatures are confined to the surface layers with the inner core remaining relatively cool and unaffected. When the current is shut off the rapid conduction of the surface heat to the cooler interior results in self-quenching of the hardened surface. For full hardness, however, a water quench is usually necessary.

When the current is applied the surface heat is transmitted by conduction almost instantaneously to the inner core of the material. To permit dissipation of this heat without raising the core temperature to a point where its structure is affected it is necessary to have adequate core material. A piece of tubing, for instance, must have a wall thickness at least twice the depth of the surface hardening. In induction hardening there is no sharp line of demarcation between the hard surface case and the inner core. There is a gradual transition from a hard case to the original properties of the core.

A normalised structure is desirable to obtain the best results from induction hardening. The short time during which the surface of the work is above its critical temperature requires a very rapid solution of the carbides as required to attain a hardened surface. This solution is assisted by starting with a sorbite or fine pearlite structure.

To permit uniform heating of the surface it is desirable that its cross section be symmetrical. Variations in cross-sectional areas along the length of the work are all right. Symmetrical coils may be used for heating unsymmetrical objects, since the natural tendency of high-frequency currents is to follow the contour.

There is no distortion of the work due to induction hardening.

The selection of induction-heating equipment should be predicated on the thickness of the work to be heated or hardened. Frequencies above 100,000 cycles are required for 1/8-inch or thinner material; 9600 cycles or higher are required for ¼ - inch material; and 1920 to 9600 for ½ - inch material. The thinner the material, the higher the frequency required.

Induction-heating equipment is frequently used for soldering and brazing. In this operation the brazing material or solder is set in place at the joint and the work placed in or near a heating oil. A closely controlled heat is developed at the joint in both the brazing material or soldering material and the adjacent portion of the work. Both the leading and trailing edge of hollow steel propeller blades are inside brazed. Beads of brazing material are laid along the inside edge and the propeller is moved edgewise through the coil. The brazing material melts and fuses with the steel to form an even, firm joint. The numerous wires leading into an electrical connector can be soldered simultaneously with a simple setup.

In dielectric heating, an alternating electric field of between 1,000,000 and 200,000,000 cycles per second is set up by means of a high-frequency vacuum-tube oscillator. This high frequency results in a uniform heating of the entire cross section of the work. It is particularly adaptable for heating thick sections of nonconducting material which otherwise would take several hours of surface heating because of limited thermal conductivity. Material is heated between two or more plates from which the electrostatic current emanated. This type of heating is employed in curing impregnated materials, gluing, bonding, and preheating plastics prior to molding. A typical application is in the manufacture of compressed and impregnated wood-propellers which consist of wooden sheets, plastic impregnated, which are bonded together under high heat and pressure. Dielectric heating cures the assembly uniformly in a fraction of the time required by any other method.

SHOT PEENING

Shot peening is sometimes referred to as shot blasting. It should not, however, be confused with sand blasting or other surface-cleaning processes. Shot peening is a recent development that improves the fatigue and abrasion resistance of metal parts. It is applicable to ferrous and nonferrous parts, but it is mostly used on steel surfaces. This process has been reported to increase the life of parts subject to repeated stresses (such as springs) from 3 to 13 times. The fatigue loads of shot-peened parts can be increased if an increase in the life of the part is not a consideration.

The shot-peening process consists of throwing hardened steel balls at the surface of the work to be peened. The steel balls, or shot, are thrown against the surface either by compressed air or by centrifugal force as the shot is fired from a rotating wheel. The intensity of the process can be varied by regulating the size of the shot, the hardness of the shot, the speed at which it is fired, and the length of time the work is exposed to the shot. If the shot peening is too intense the work may be fractured internally, thereby undoing all the good expected from the peening. Saturation of the surface with the little indentations made by the shot is a quick visual method of inspecting the intensity of the shot-peening operation. It is desirable to run a sample piece to set up the conditions to be used in the production process.

Shot peening prestresses the surface of the work and adds to the fatigue and abrasion resistance. It leaves the surface with a countless number of shallow indentations where the hardened shot has struck. The surface of each of these indentations has been cold-worked by being stretched in every direction, and becomes harder, stronger, and less ductile than before. The net results is an increase in compressive stress in the skin, and an increase in tensile stress just below the surface. The compressive stress in the skin will counteract any tensile stress that normally might start a crack or fracture.

Fractures usually start at a point of localized stress concentration. Sharp shoulders, tool marks, scratches, and notches should be avoided for this reason. The indentations made by the hardened steel balls are well rounded, and they are so numerous they dissipate any stress concentration over a wide area. Care must be taken to chamfer all sharp external corners before shot peening, however, or they will be worked out into sharp, fin-like extensions which will induce early failures. Shot peening of relatively rough surfaces can be done considerably cheaper than polishing, and the fatigue of the peened surface equals or exceeds that of the polished surface.

Shot peening can be applied to irregular or complicated surfaces such as gear teeth, helical springs, universal joints, axles, rocker arms, bearings, propeller shanks and hubs. It has been applied to fillets and grooves to offset stress concentrations. When applied to gear teeth it produces a surface with increased resistance to wear and to pitting corrosion. Shot peening appears destined for more and more applications.

INTENTIONALLY BLANK

CHAPTER-11
HEAT TREATMENT OF NON-FERROUS METALS AND ALLOYS

HEAT TREATMENT OF NON-FERROUS METALS

The major requirements of heat treatments in non-ferrous metals and alloys is of strengthening them. Single-phase metals can be strengthened by *solid solution hardening* technique while ductile metals can be *strain hardened.* Similarly, *dispersion hardening* can be employed for eutectic forming alloys. However, the most widely used and effective method for non-ferrous metals and alloys is *precipitation hardening* or *age hardening*.

Precipitation hardening or Age hardening

Most of the *non-ferrous* alloys can be heated into a *single phase solid solution.* On account of their decreasing solid solubility with lowering of temperature their structure is transformed into two distinct phases at low temperatures. When they are cooled down at a faster rate from the hot single phase state the resulting structure is a *supersaturated solid solution* i.e., *one of the materials,* which was supposed to form the second phase of the structure, called *solute*, gets trapped in the lattice of the other material called *solvent,*. When this alloy is further subjected to *ageing, i.e.,* heating back to a predetermined temperature, the solute atoms *precipitate* out of the super-satured solid solution and this phenomenon is responsible for hardening of the alloy. Hence, the name *precipitation hardening.*

θ
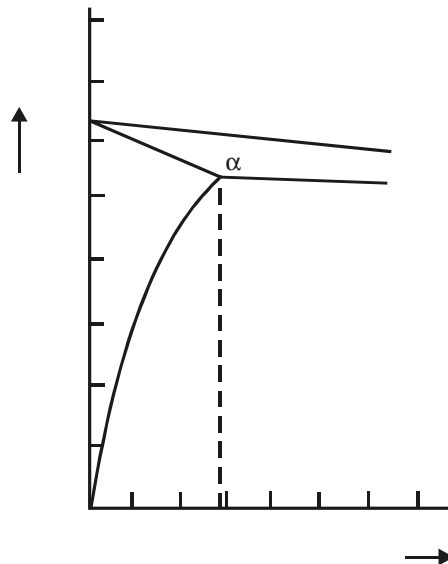
Fig. 11.1, Phase diagram of an aluminium-copper alloy.

The process will be more clear by considering a concrete example. Let us consider an *aluminum-copper alloy* consisting of 96% aluminum and 4% copper and study its phase diagram shown in Fig. 11.1. It shows that a solid solution of aluminum with copper is formed in which the maximum solubility of copper at the eutectic temperature of 548°C is 5.7%.Now, if the alloy is cooled slowly from this stage the second phase (*θ*)precipitates out of the *α* solid solution because the solubility of copper in aluminum reduces from 5.7% to about 0.2% at room tmperature, as indicated by the solubility curve. If, however, this alloy was cooled from the liquid state at a faster rate there will not be enough time for the transformation to usual two phase structure and the resulting structure will be a single phase in a supersaturated form, which is not a normal condition. Consequently, the excess copper will tend to precipitate out of this form and mixup with the phase. It is an unsatble condition needing diffusion. To achieve that, it is reheated to between 150°C to 200°C and held there to allow precipitation of copper, resulting in a single phase structure consisting of *α* -solid solution and the precipitate. This is known as *ageing* and if this is carried out under carefully controlled conditions the resulting structurre (hence, the material) will be extremly hard and strong.

Fig. 11.2, Graph of hardness values of two Jominy test bars in Jominy hardenability tests conducted on test bars made of carbon steel and alloy steel.

The phase diagram shown in Fig 11.1 is almost identical for all the non-ferrous aloys which can be hardened. The entire *precipitation hardening* process consists of the following three controlled stages :

Stage I
This stage consists of heating the metal to a temperature where it forms a single phase solid solution, soaking it there to allow formation of a uniform structure, followed by rapid cooling by quenching in water to disallow diffusion and enable formation of a supersaturated solid solution. The heating temperature should, however, not exceed the eutectic temperature otherwise melting may occur.

Stage II
This stage comprises *age hardening*. Some metals and alloys get age hardened at room temperature itself. For them no reheating is required because diffusion occurs at this very temperature and the supersaturated solution transforms into a stable two-phase structure. Against this, some metals and alloys respond differently and need reheating and artificial ageing, as described earlier in this article.

Stage III
This stage consists of methods to controls the properties. For this the natural ageing type materials are subjected to refrigeration while in case of artificial ageing type materials this control is exercised by properly adjusting the temperature and time of high temperature ageing.

ALUMINUMALLOYS
There are two types of heat treatments applicable to aluminum alloys. One is called solution heat treatment, and the other is known as precipitation heat treatments. Some alloys, such as 2017 and 2024, develop their full properties as a result of solution heat treatment followed by about 4 days of aging at room temperature. Other alloys, such as 2014 and 7075, require both heat treatments.

The alloys those require precipitation heat treatment (artificial aging) to develop their full strength also age to a limited extent at room temperature; the rate and amount of strengthening depends upon the alloys. Some reach their maximum natural or room-temperature aging strength in a few days, and are designated as - T4 or -T3 temper. Others continue to age appreciably over a long period of time. Because of this natural aging, the -W designation is specified only when the period of aging is indicated, for example, 7075-W (½ hours). Thus, there is considerable difference in the mechanical and physical properties of freshly quenched (-W) material and material that is in the -T3 or -T4 temper.

The hardening of an aluminum alloy by heat treatment consists of four distinct steps :
1. Heating to a predetermined temperature.
2. Soaking at temperature for a specified length of time.
3. Rapidly quenching to a relatively low temperature.
4. Aging or precipitation hardening either spontaneously at room temperature, or as a result of a low-temperature thermal treatment.

The first three steps above are known as solution heat treatment, although it has become common practice to use the shorter term, "heat treatment" . Room-temperature hardening is known as natural ageing, while hardening done at moderate temperatures is called artificial aging, or precipitation heat treatment.

SOLUTION HEAT TREATMENT
Temperature
The temperatures used for solution heat treatment vary with different alloys and range from 825^0F. to 980^0F. As a rule, they must be controlled within a very narrow range (plus or minus 10^0) to obtain specified properties.

If the temperature is too low, maximum strength will not be obtained. When excessive temperatures are used, there is danger of melting the low-melting constituents of some alloys with consequent lowering of the physical properties of the alloy. Even if melting does not occur, the use of higher -than- recommended temperatures promotes discoloration and increases quenching strains.

Time at Temperature
The time at temperature, referred to as soaking time, is measured from the time the coldest metal reaches the minimum limit of the desired temperature range. The soaking time varies, depending upon the alloy and thickness, from 10 minutes for thin sheets to approximately 12 hours for heavy forgings. For the heavy sections, the nominal soaking time is approximately 1 hours for each inch of cross-sectional thickness (See Table 11.1).

The soaking time is chosen so that it will be the minimum necessity to develop the required physical properties. The effect of an abbreviated soaking time is obvious. An excessive soaking period aggravates high-temperature oxidation. With clad material, prolonged heating results in excessive diffusion of copper and other soluable constituents into the protective cladding and may defeat the purpose of cladding.

Quenching
After the soluable constituents are in solid solution, the materials quenched to prevent or retard immediate re-precipitation. Three distinct quenching methods are employed .The one to be used in any particular instance depends upon the part, the alloy, and the properties desired.

Table 11.1 Typical Soaking Time for Heat Treatment

Thickness, in.	Time Minutes
Up to .032	30
.032 to 1/8	30
1/8 to 1/4	40
Over 1/4	60

Cold Water Quenching
Parts produced from sheet, extrusions, tubing, small forgings, and similar type material are generally quenched in a cold water bath. The temperature of the water before quenching should not exceed 85^0F. A sufficient quantity of water should be used to keep the temperature rise under 20°F. such a drastic quench ensures maximum resistance to corrosion. This is particularly important when working with such alloys as 2017, 2024, and 7075. This is the reason a drastic quench is preferred, even though a slower quench may produce the required mechanical properties.

Hot Water Quenching
Large forgings and heavy sections can be quenched in hot or boiling water. This type of quench minimises distortion and alleviates cracking which may be produced by the unequal temperatures obtained during the quench. The use of a hot water quench is permitted with these parts because the temperature of the quench water does not critically affect the resistance to corrosion of the forging alloys. In addition, the resistance to corrosion of heavy sections is not as critical a factor as for thin sections.

Spray Quenching
High-velocity water sprays are useful for parts formed from clad sheet and for large sections of almost all alloys. This type of quench also minimises distortion and alleviates quench cracking. However, many specifications forbid the use of spray quenching for bare 2017 and 2024 sheet materials because of the effect on their resistance to corrosion.

Lag Between Soaking and Quenching
The time interval between the removal of the material from the furnace and quenching is critical for some alloys and should be held to a minimum. When solution heat treating 2017 or 2024 sheet material, the elapsed time must not exceed 10 seconds. The allowable time for heavy sections may be slightly greater.

Allowing the metal to cool slightly before quenching promotes re-precipitation from the solid solution. The precipitation occurs along grain boundaries and in certain slip planes causing poorer formability. In the case of 2017, 2024, and 7075 alloys, their resistance to intergranular corrosion is adversely affected.

Re-heat Treatment
The treatment of material which has been previously heat treated is considered a re- heat treatment. The unclad heat-treatable alloys can be solution heat treated repeatedly without harmful effects.

The number of solution heat treatment allowed for clad sheet is limited due to increased diffusion of core and cladding with each re- heating. Existing specifications allow one to three re- heat treatments of clad sheet depending upon cladding thickness.

Straightening After Solution Heat Treatment
Some warping occurs during solution heat treatment, producing kinks, buckles, waves, and twists. These imperfections are generally removed by straightening and flattening operations.

Where the straightening operations produce an appreciable increase in the tensile and yield strengths and a slight decrease in the percent of elongation, the material is designated -T3 temper. When the above values are not materially affected, the material is designated-T4 temper.

PRECIPITATION HEAT TREATMENT
As previously stated, the aluminum alloys are in a comparatively soft state immediately after quenching from a solution heat-treating temperature. To obtain their maximum strengths, they must be either naturally aged or precipitation hardened.

During this hardening and strengthening operation, precipitation of the soluble constituents from the supersaturated solid solution takes place. As precipitation progresses, the strength of the material increases, often by a series of peaks, until a maximum is reached. Further aging (overaging) causes the strength to steadily decline untill a some what stable condition is obtained. The submicroscopic particles that are precipitated provide the keys or locks within the grain structure and between the grains to resist internal slippage and distortion when a load of any type is applied. In this manner, the strength and hardness of the alloy are increased.

Precipitation hardening produces a great increase in the strength and hardness of the material with corresponding decreases in the ductile properties. The process used to obtain the desired increase in strength is therefore known as aging., or precipitation hardening.

The strengthening of the heat-treatable alloys by aging is not due merely to the presence of a precipitate. The strength is due to both the uniform distribution of a finely dispersed submicro-scopic precipitate and its effects upon the crystal structure of the alloy.

The aging practices used depend upon many properties other than strength. As a rule, the artificially aged alloys are slightly overaged to increase their resistance to corrosion. This is especially true with the artificially aged high copper-content alloys that are susceptible to intergranular corrosion when inadequately aged.

The heat-treatable aluminum alloys are sub- divided into two classes, those that obtain their full strength at room temperature and those that require artificial aging.

The alloys that obtain their full strength after 4 or 5 days at room temperature are known as natural aging alloys. Precipitation from the supersaturated solid solution starts soon after quenching, with 90 percent of the maximum strength generally being obtained in 24 hours. Alloys 2017 and 2024 are natural aging alloys.

The alloys that require precipitation thermal treatment to develop their full strength are artificially aged alloys. However, these alloys also age a limited amount at room temperature, the rate and extent of the strengthening depending upon the alloys.

	Solution heat-treatment			Precipitation heat-treatment		
Alloy	**Temp.,⁰F**	**Quench**	**Temper desig**	**Temp ⁰F.,**	**Time of aging**	**Temper design.**
2017	930-950	Cold water	T4			T
2117	930-950	Cold water	T4			T
2024	910-930	Cold water	T4			T
6053	960-980	Water	T4	445-445 or	1-2 hr	T5
				345-355	8 hr	T6
6061	960-980	Water	T4	315-325 or	18 hr	T6
				345-355	8 hr	T6
7075	870	Water		250	24 hr	T6

Fig. 11.3, Condition for heat treatment of aluminum alloys.

Many of the artificially aged alloys reach their maximum natural or room temperature aging strengths after a few days. These can be stocked for fabrication in the -T4 or -T3 temper. High-zinc-content alloys such as 7075 continue to age appreciably over a long period of time, their mechanical property changes being sufficient to reduce their formability.

The advantage of -W temper formability can be utilised, however, in the same manner as with natural aging alloys; that is, by fabricating shortly after solution heat treatment, or retaining formability by the use of refrigeration.

Refrigeration retards the rate of natural aging. At 32⁰F., the beginning of the aging process is delayed for several hours, while dry ice(-50⁰F. to - 100⁰F.) retards aging for an extended period of time.

Precipitation Practices.
The temperature used for precipitation hardening depend upon the alloy and the properties desired, ranging from 250⁰F. to 375⁰F. They should be controlled within a very narrow range (plus or minus 5⁰) to obtain best results. (See figure 11.3.).

The time at temperature is dependent upon the temperature used, the properties desired, and the alloy. It ranges from 8 to 96 hours. Increasing the aging temperature decreases the soaking period necessary for proper aging. However, a closer control of both time and temperature is necessary when using the higher temperatures.

After receiving the thermal precipitation treatment, the material should be air cooled to room temperature. Water quenching, while not necessary, produces no ill effects. Furnace cooling has a tendency to produce overaging.

ANNEALING OF ALUMINUM ALLOYS
The annealing procedure for aluminum alloys consists of heating to an elevated temperature, holding or soaking them at this temperature for a length of time depending upon the mass of the metal , and then cooling in still air. Annealing leaves the metal in the best condition for cold-working. However, when prolonged forming operations are involved, the metal will take on a condition known as "mechanical hardness" and will resist further working. It may be necessary to anneal a part several times during the forming process to avoid cracking. Aluminum alloys should not be used in the annealed state for parts or fittings.

Clad parts should be heated as quickly and carefully as possible, since long exposure to heat tends to cause some of the constituents of the core to diffuse into the cladding. This reduces the corrosion resistance of the cladding.

Heat Treatment Of Aluminum Alloy Rivets
Aluminum alloys rivets are furnished in the following compositions : alloys 1100, 5056, 2117, 2017, and 2024.

Alloy 1100 rivets are used in the "as fabricated" condition for riveting aluminum alloys sheets where a low-strength rivet is suitable. Alloy 5056 rivets are used in the "as fabricated " condition for riveting magnesium alloys steels.

Alloy 2117 rivets have moderately high strength and are suitable for riveting aluminum alloy sheets. These rivets receive only one heat treatment, which is performed by the manufacturer, and are anodized after being heat treated. They require

no further heat treatment before they are used .Alloy 2117 rivets retain their characteristics indefinitely after heat treatment and can be driven anytime. Rivets made of this alloy are the most widely used in aircraft construction.

Alloy 2017 and 2024 rivets are high-strength rivets suitable for use with aluminum alloy structures. They are purchased from the manufacturer in the heat-treated condition. Since the aging characteristics of these alloys at room temperatures are such that the rivets are unfit for driving, they must be reheat treated just before they are to be used.   Alloy 2017 rivets become too hard for driving in approximately 1 hours after quenching. Alloy2024 rivets become hardened in 10 minutes after quenching. Both of these alloys may be re-heat treated as often as required; however, they must be anodized before the first re-heat treatment to prevent intergranular oxidation of the material. If these rivets are stored in a refrigerator at a temperature lower than 32^0F. immediately after quenching, they will remain soft enough to be usable for several days.

Rivets requiring heat treatment are heated either in tubular containers in a salt bath, or in small screen-wire baskets in an air furnace. The heat treatment of alloy 2017 rivets consists of subjecting the rivets to a temperature between 930^0F. to 950^0F for approximately 30 minutes, and immediately quenching in cold water. These rivets reach maximum strength in about 9 days after being driven. Alloy 2024 rivets should be heated to a temperature of 910^0F to 930^0F and immediately quenched in cold water. These rivets develop a greater shear strength than 2017 rivets and are used in locations where extra strength is required. Alloy 2024 rivets develop their maximum shear strength in 1 days after being driven.

The 2017 rivet should be driven within approximately 1 hour and the 2024 rivet within 10 to 20 minutes after heat treating or removal from refrigeration. If not used within these times, the rivets should be re-heat treated before being refrigerated.

HEAT TREATMENT OF MAGNESIUM ALLOYS

Magnesium alloy castings respond readily to heat treatment, and about 95 percent of the magnesium used in aircraft construction is in the cast form.

The heat treatment of magnesium alloy castings is similar to the heat treatment of aluminum alloys in that there are two types of heat treatment :(1) Solution heat treatment and (2) precipitation (aging) heat treatment. Magnesium, however, develops a negligible change in its properties when allowed to age naturally at room temperatures.

Solution Heat Treatment

Magnesium alloy castings are solution heat treated to improve tensile strength, ductility, and shock, resistance. This heat-treatment condition is indicated by using the symbol-T4 following the alloy designation. Solution heat treatment plus artificial aging is designated -T6. Artificial aging is necessary to develop the full properties of the metal.

Solution heat-treatment temperatures for magnesium alloy castings range from 730^0F to 780^0F, the exact range depending upon the type of alloy. The temperature range for each type of alloy is listed in Specification MIL-H-6857. The upper limit of each range listed in the specification is the maximum temperature to which the alloy may be heated without danger of melting the metal.

The soaking time ranges from 10 to 18 hours, the exact time depending upon the type of alloy as well as the thickness of the part. Soaking periods longer than 18 hours may be necessary for castings over 2 inches in thickness. Magnesium alloys must *never* be heated in a salt bath as this may result in an explosion.

A serious potential fire hazard exists in the heat treatment of magnesium alloys. If through over-sight or malfunctioning of equipment, the maximum temperatures are exceeded, the casting may ignite and burn freely. For this reason, the furnace used should be equipped with a safety cutoff that will turn off the power to the heating elements and blowers if the regular control equipment malfunctions or fails.

Some magnesium alloys require a protective atmosphere of sulphur dioxide gas during solution heat treatment. This aids in preventing the start of a fire even if the temperature limits are slightly exceeded.

Air-quenching is used after solution heat treatment of magnesium alloys since there appears to be no advantage in liquid cooling.

Precipitation Heat Treatment

After solution treatment, magnesium alloys may be given an aging treatment to increase hardness and yield strength. Generally, the aging treatments are used merely to relieve stress and stabilize the alloys in order to prevent dimensional changes later, especially during or after machining. Both yield strength and hardness are improved some what by this treatment at the expense of a slight amount of ductility. The corrosion resistance is also improved, making it closer to the "as cast" alloy.

Precipitation heat-treatment temperatures are considerably lower than solution heat-treatment temperature and range from 325^0F. to 500^0F. Soaking time ranges from 4 to 18 hours.

HEAT TREATMENT OF TITANIUM

Titanium is heat treated for the following purposes :
1.   Relief of stresses set up during cold forming or machining.
2.   Annealing after hot working or cold working, or to provide maximum ductility for subsequent cold working
3.   Thermal hardening to improve strength.

Stress Relieving

Stress relieving is generally used to remove stress concentrations resulting from forming of titanium sheet. It is performed at temperatures ranging from 650^0F. to $1,000^0$F. The time at temperature varies from a few minutes for a very thin sheet to an hour or more for heavier sections. A typical stress-relieving treatment is 900^0F. for 30 minutes, followed by an air cool.

The discoloration or scale which forms on the surface of the metal during stress relieving is easily removed by pickling in acid solutions. The recommended solution contains 10 to 20 percent nitric acid and 1 to 3 percent hydrofluoric acid. The solution should be at room temperature or slightly above.

Full Annealing

The annealing of titanium alloys provides toughness, ductility at room temperature, dimensional and structural stability at elevated temperatures, and improved machinability.

The full anneal is usually called for as preparation for further working. It is performed at $1,200^0$F. to $1,650^0$F. the time at temperature varies from 16 minutes to several hours, depending on the thickness of the material and the amount of cold work to be performed. The usual treatment for the commonly used alloys is $1,300^0$F. for 1 hours, followed by an air cool. A full anneal generally results in sufficient scale formation to require the use of caustic descaling, such as sodium hydride salt bath.

Thermal Hardening

Unalloyed titanium cannot be heat treated, but the alloys commonly used in aircraft construction can be strengthened by thermal treatment, usually at some sacrifice in ductility. For best results, a water quench from $1,450^0$F. followed by re-heating to 900^0F. for 8 hours is recommended.

CHAPTER-12
IDENTIFICATION OF METALS

GENERAL

1. Owing to various grades of material in the same metallic group, metals are not designated by name, but are marked to indicate clearly the specification with which they comply. Identification markings are usually made with metal dies, but where such at procedure may harm the material, stenciling or painting with paint, enamel or ink is employed. As such before metal is accepted into store, it should be marked to indicate the specification to which it confirm.

STANDARD COLOUR SCHEME

2. The markings described above may not be easily observed, so an additional method, known as standard colour scheme has been devised as the best practical means of attaining effectual identification. The colour scheme, as a means of ready identification, is additional to the identification requirements stipulated in the respective specifications. The use of two are more methods of identification is obviously inadmissible; Consequently, all the metals concerned should bear the standard colour markings, whether or not they have previously borne some other mark of identification. The appropriate identification colours for each specification are given by manufacturer.

3. Difficulty in identification may be caused by colour markings becoming indistinct or oblituated by the effect of handling or weather conditions; confusion may also be caused if the colours fade. To ensure that colour markings may be as permanent as possible, especially where material is stocked in the open the use of paint is recommended. The most distinct colours are as follows :-

    Blue, Brown Green, Orange, Red, Yellow and Violet. Should it be necessary to cut off material from a marked sheet, tube, or rod, the cutting should be done in such a manner that the identification colours remain on the material.

METHODS OF APPLICATION

4. **Bars and Tubes**

    The stipulated colour or colours should be painted in the following manner at each end of every metal bar and tube :--

For one colour	...	1 band 12 in. wide
For two colours	...	2 bands each 6 in wide.
For three colours	...	3 bands each 4 in wide.

5. **Sheets and strips**

    Three methods of marking sheet and strip metals are used as follows :-

    (a) A band or bands of the required colour is painted diagonally across the corner bearing the identification stamp marks. The width of the band or bands is as indicat for bars and tubes, and the painting should commence six inches from the corner, measured at right angles to the length of the band. Sheets and strips less than one foot wide are painted at one end in similar manner to bars and tubes.

    (b) A disc of colour is painted on each sheet or strip. For a single colour the disc is three inches in diameter, and additional colour when required are applied in concentric rings 1½ inches wide.

    (c) This method is suitable when a large number of metal sheets or strips require to be marked. The sheets are stacked and then slide end wise, so that 1½" of the end of each sheet is exposed in addition to the whole surface of the top sheet. Bands of paint of the widths, as indicated for bars and tubes, are then painted in one operation on the sheets, resulting in an identification mark 1½ inches by 12 inches in size on each sheet. The paint is applied to the face of the sheet which bears the identification stamp markings, and preferably adjacent to them.

6. **Wire and Rods**

    In identification colours are painted in bends on the outside of each bundle of rods and on the outer turns or each wire coil. The band or bands are at right angles to the wires or rods and are not less than 3`` wide, e.g. one band 3 inches wide, or three bands 1 inch wide. The paint marks extend at least half-way around the bundle or coil.

7. The colour markings on metals intended for use in aircraft construction are normally applied by the manufacturers. Such materials are sometimes protected from corrosion by the application of lanoline resin protective. This protective is red in colour and to avoid mistakes in identification, a ½ in wide band of black paint is interposed

between the identification colour markings and the red lanoline resin coating. The lanoline resin can be removed, if necessary, by washing the metal surface with unleaded gasoline.

8. **Practical Tests**

The approximate identification of some of the more commonly known metals may be established by making the following tests, but such tests, are unreliable and must not be employed when material to specification is required for use.

FERROUS METALS-PRACTICAL TESTS

Metal	Note when dropped on anvail	Behaviour when chipped.	Cooled in air from red heat	Quenched in water from red heat	Appearance of fracture.	Types of spark thrown when held against grinding wheel
Grey cast iron	No. ring.	Chips break off from base metal before bending.	Files easily, free carbon makes dirty depost.	No apparent change	Dark grey crystals of uniform size	Dull red, non-bursting
Wrought iron	Low pitch ring	Very easily chipped. Chippings bend without breaking.	Soft, files Easily.	No apparent change	Very coarse and fibrous	Bright yellow, non-bursting
Low carbon steel (mild steel)	Medium pitch ring.	Easily chipped. Chippings bend without breaking.	Soft, files easily.	No apparent change.	Bright silvery, rather large crystals.	Bright yellow, few carbon bursts.
High carbon steel	High pitch ring	Usually harder to chip than mild steel. Chippings bend without breaking.	Can be filed but tougher than mild steel	Hard and cannot be filed	Pale grey Very fine crystals	Bright yellow, all bursting
Tungsten steel	Very high pitch ring	Cannot be chipped	Hard and cannot be filed	Hard and cannot be filed	Silky-blue-grey Very fine.	Red. Non-bursting (follow the wheel)

NON-FERROUS METALS-PRACTICAL TESTS

Metal	Identification tests
Aluminum	Tin white in colour, light in weight, non-magnetic, soft, and bends easily. Application of caustic soda turns metal white.
Alclad	Differs from sheet aluminum by being springy and more resistant to bending; application of caustic soda turns the surface of the sheet white and the edge black.
Duralumin	Same properties as alclad except that the application of caustic soda turns surface black.
Magnesium	Tin white in colour, very light, non-magnetic, easy to file and filings ignite in a flame; application of copper sulphate causes effervescence and the affected parts turn black.
Solder	Tin white in colour, very heavy and soft, non-magnetic, low melting point (ascertained by use of hot soldering iron) : will mark white paper due to lead content and a cracking sound (is known as cry of tin) when bent indicates high tin content.

Note :   Alloy steel vary much in composition, but the following hints will be of use concerning their identification. Austenitie steels are non-magnetic. Copper is not deposited on stainless steel when copper sulphate solution is applied.

CHAPTER-13
MECHANICAL TESTING OF METALS

INTRODUCTION

A wide range of materials find use in engineering applications. This includes both, metals as well as non-metals. However, in manufacturing practice metals and their alloys still have a wider application, although it is not at all possible to altogether ignore the non-metallic group of materials. With the development of newer non-metallic materials, which have overcome their inherent drawbacks to a considerable extent, there is a tough competition many a times between these two groups while selecting the material for a component. If both are found to be equal in performanece requirements it is the cost factor that decides as to which of the two should be selected.

The basic concern of an engineer while selecting the material for a particular component is to match the service requirements of the component with the proporties of the material under consideration. As such, in order that an engineer is capable of selecting a proper material for a specific application he should be fully conversant with the different properties found in different materials, methods of determining these properties, procedures for testing them, their limitations, etc. Also, it is well known that a larger part of manufacturing and fabrication activities involve the use of soild materials, especially metals and their alloys. Our discussions in this chapter will, therefore, be in the context of metals and metal alloys.

Further , as stated above, different materials possess different properties in varying degrees and, therefore, behave in different ways under given conditions. These properties include *mechanical properties,electrical properties, thermal properties, chemical properties, magnetic properties* and *physical properties.*A design or manufacturing engineer is basically intrested in knowing as to how a particular material will behave under applied loads, i.e., in knowing the *mechanical properties* of the material under consideration. Our discussions in this chapter will, therefore, mainly confine to the review of main mechanical properties of metals and their alloys, although a brief review of main mechanical properties of metals and their alloys, although a brief review of other properties will also follow at the end of this chapter.

STRESS AND STRAIN

When a load is applied to a structure or a component its material may either deform or break. The ultimate result will depend upon the amount of load applied, cross sectional area of the section under and the nature of the material. Natural tendency of the material is to resist deformation. This resistance against the action of the applied load is offered by the internal forces, called *stresses,*which are developed in the material when the external load is applied. Mathematically, the *stress* is expressed as the force or load per unit area of cross-section of the component, i.e.,

$$S = \overline{}$$

where,   S = stress, P = Load applied, and A = Area of cross section.

Strain represents the deformation caused per unit length of a body, i.e., the change in length per unit length of the body.From this it follows that it is a ratio of change in length of a body to its original length. Since it is a ratio it has no unit. however, it can by expressed in millimeter per metre or as a percentage. Mathematically, it is expressed thus:

$$e = \frac{\Delta}{} = \text{longitudinal strain (or unit strain)}$$

where,   e = Strain

Δ L = Change in length

and,   L = Original length of the body.

The strain caused in a body can be *lateral strain* or *shear strain* according to the manner in which the load is applied on to the body.

The stresses caused in a body and the corresponding strains developed are also named according to the nature of loading a body. For example, if a body is subjected to pulls from either end it is under tension, i.e., the tendency of the applied load is to elongate the body. The resulting stress in the body is, therefore, known as *tensile stress* and the corresponding strain as tensile strain. Similarly, when a body is so loaded that the tendency of the load is to squeeze it, i.e., to shorten it, the stress caused is termed as compressive stress and the coresponding strain as compresive strain. In the same way, if a body is acted upon by two equal and opposite loads, acting upon its opposite surfaces, the tendency

of the load will be to make a portion of the body slide over the other, i.e.. to shear the body along a common plane. Such a loading will cause a shear stress and the corresponding strain will be known as shear strain.

Let it also be clear that the deformation in the material due to applied load is not necessarily along the length alone. It can be in length, volume or both, which ultimately leads to a change in shape of the body. In order to generalise the above definition of strain we can better say that engineering strain is the deformation per unit dimension. If this deformation is along the length then it is called longitudinal strain, if in the volume then volumetric strain and when in transverse direction the shear strain or transverse strain.

Hooke's Law

Named after its developer Robert Hooke, this law states that within the elastic limit, the stress is direcly propertional to the strain, i.e., the ratio of stress to strain is a constant. This constant is known as Young's modulus of Elasticity or Coefficient of Elasticity and is represented by the letter 'E'. Mathematically expressing :

$$E = \quad = \text{constant}$$

this constant of proportionality is different for different materials and also different types of stresses. In case of tensile and compressive stresses it is known as Young's modulus of elasticity (E), in case of shear stresses and strains it is known as Modulus of rigidity (G) and when volumetric stresses and strains are in play this consatnt is known as the Bulk modulus (K). In general, this constant is known as the Modulus of material.

Poisson's ratio

If a force is applied on a uniform body, say a bar or a test specimen, along its axis, the body is strained both in the direction of application of force as well as in a direction normal to it.The strain in the direction of application of force is called longitudinal strain and that in the direction normal to it the lateral strain. The ratio between the lateral strain and longitudinal strain is called Poisson's ratio.Its value is constant for a particular material but varies for different materials. For each material it is an important elastic constant. For most of the materials commonly used in engineering practice its value ranges between 0.3 to 0.6. Mathematically expressing :

$$\text{Poisson's ratio} = \frac{\rule{3cm}{0pt}}{\rule{3cm}{0pt}} = \text{constant.}$$

STRESS-STRAIN RELATIONSHIP

The relationship between stress and strain can be best under stood with the help of a *stress-strain curve. This* curve can be easily drawn by plotting a graph between the different values of stresses and corresponding strains, obtained during the tensile test of a material specimen, stress values being taken along the ordinate and the corresponding strain values along the abscissa.
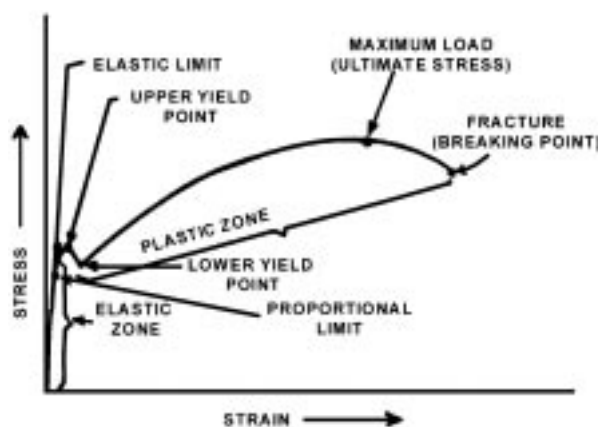
Fig. 13.1, An engineering stress-strain curve for a ductile material.

In order to make it quite clear let us take the example of tensile test performed on a specimen made from a ductile material, say low carbon steel (mild steel). Fig.13.1. represents the curve plotted from the data obtained during such a test. When engineering stresses of different magnitudes are applied to the test specimen they cause corresponding changes in the length of the specimen. Both these readings, i.e., the magnitudes of the applied stresses and the corresponding changes in length, recorded on strain measuring devices, are noted down. By dividing the latter data by the original length of the specimen different values of *engineering strains,* corresponding to different values of applied *engineering stresses,* are calculated and recorded. A graph is then plotted between the different values of applied loads (stresses)

and the corresponding values of resulting strains. By joining these points a curve of the type shown in Fig.13.1 is obtained

A close study of the curve reveals that the material elongates elastically in the beginning of the test, i.e., the strain increases in direct proportion to the applied stress. Obviously, if the load is removed during this range the specimen will automatically return to its original length, i.e., the material will perfectly obey the Hooke's law. This state will continue till the stress-strain values reach a specific common point called the *Limit of proportionality* or simply *proportional limit*. If the material is loaded beyond this stage it will not obey the Hooke's law perfectly.

Beyond this point you will notice another point on the curve, called the elastic limit. This point corresponds to the maximum stress value upto falling between the 'zero' stress value and the elastic limit is known as *elastic region*. In some materials the proportional limit and elastic limit are almost identical, but in most of the materials the elastic limit is slightly higher than the proportional limit.

If the material is loaded beyond the elastic limit the applied stresses cause plastic deformation, i.e. the material fails to return to its original shape and size or we can say that it retains its elongation permanently even after the loads are removed. Also, beyond the elastic limit the increase in strain does not bear the same direct proportionally with the corresponding stress. In fact, beyond the elastic limit, the strain is found to increase more rapidly than the corresponding stress. This process continues till a point is reached where it is noticed that the strain increases even without any further increase in the stress. At this point the material is found to stretch suddenly. This point is known as *yield point.* In case of the material under consideration there are two distinct yield point, called the *upperyield point* and the *lower yield point*. The *upper yield point* corresponds to the maximum stress preceding the extensive strain, the *lower yield point* following this strain.

With further straining of material into the plastic range its *load-bearing ability* increases. In other words its *nominal stress,* which is the ratio of applied load to original cross- sectional area of the specimen, increases. The reason for this increase is **work hardening.** The load bearing ability of the material is said to be equal to the product of its strength and cross-sectional area. Because the cross-sectional area of the specimen decreases during its tensile stretching its strength increases, and so its load-bearing ability. During tensile testing a stage is arrived where the decrease in cross sectional area with increased strain acquires a predominant position compared to the corresponding increase in strength. At this stage the load bearing capacity of the material is at its peak and so is the value of the *tensile stress.* This represents the value of the stress at maximum load. It can be found out by dividing the load at that point by the original cross-sectional area of the specimen and is known as *ultimate tensile stress* or simply *ultimate stress,* which corresponds to the *ultimate tensile strength* of the material.

At this point a typical phenomenon works in that the strain continues to increase slowly without any increase in the load, i.e., stress. This phenomenon of slow increase in strain with time without any further increase in stress is called *creep.* The cross sectional area of the specimen is the weaker point of the test bar at this stage, which continues to become weaker and weaker as the slow extension continues, and further deformation becomes localized around this weakest point and a *neck* is formed there. The entire further deformation takes place within the neck. Further straining of the material is surprisingly accompanied by a reduction in applied stress and that is why the stress-strain curve falls beyond the point of ultimate stress. If straining is continued further the test specimen finally fractures (breaks) at a point where its cross sectional area is minimum. The strength at this point is known as the *fracture strength* or *breaking strength.* In ductile materials the fracture strength is less than the ultimate tensile strength and final fracture is always preceded by necking. In brittle materials, however, the stress-strain curve is terminated before necking can start and, therefore, fracture takes place without necking.

ENGINEERING AND TRUE STRESS AND STRAIN

We have seen in the previous article that when a tensile test specimen loaded it elongates and its cross-sectional area reduces. This reduction, however, is not uniform through the length of the specimen but is confined to a relatively smaller portion somewhere near the middle of the length. It is also seen that the change in cross-sectional area is negligible within the elastic zone, but appreciable beyond the elastic limit. Another notable feature of the test is that one portion of the specimen starts deformation more rapidly than the rest as the test progresses.

The obvious question, therefore, is as to which area should be considered for computing the stress for a known load, i.e., weather it should be the original area of the specimen to the actual area at the instant when the stress is being calculated. Both these options are used. When the original area is considered for this purpose the stress obtained is known as *engineering stress* or *nominal stress* and when the actual area is considered the computed stress is called the *true stress*. Mathematically expressing :

$$\text{Engineering stress} = \frac{\qquad}{\qquad} = \frac{}{}$$

$$\text{True stress} \quad = \frac{\qquad\qquad\qquad}{\qquad} = \overline{\quad}$$

$$\text{Similarly, Engineering strain} = \frac{\qquad\qquad}{\qquad} = \frac{\varDelta}{\quad}$$

But, as stated above, after the start of necking one portion of the specimen deforms more rapidly than the rest, i.e., the elongation in this portion will be more than the rest of the specimen. It, therefore, follows that the strain will not be homogeneous and, as such, it is not logical to consider the entire length of the specimen for findings out the *true strain*. The strain can be calculated from the following relationship :

$$\text{True stain} = \int \frac{\varDelta}{\quad}$$

Or, in terms of area,

$$\text{True strain} = \frac{\qquad\qquad\qquad}{\qquad}$$

PRINCIPAL MECHANICAL PROPERTIES

Those characteristics of the materials which describe their behaviour under external loads are known as *mechanical properties* of materials. Since all the engineering components, articles, tools and machinery, structures, etc., manufactured and fabricated through various processes are likely to be subjected to external loading in some way or the other at some stage, specially during use, it is essential that the design and manufacturing engineers possess a sound knowledge of the mechanical properties of materials in order to design and manufacture sound articles, components and structures to avoid failures during use. It is only with the sound knowledge of these properties that the selection of a proper material for a particular part will be possible.

These properties largely depend upon the structure of the material and the various factors contributing to this structure, such as grain size, type of bonding, presence and nature of imperfections , grain boundaries, etc,. as explained in the last chapter. A brief review of these properties will follow in this chapter.

STRENGTH

It can be described as the measure of ability of a material to withstand external forces. In other words, we can say that it is resistance offered by a material when subjected to external loading. Higher the strength the higher is the resistance offered by the material to deformation and, therefore, higher is the amount of the external load it can withstand without failure.

Depending upon the type of load applied the strength can be *tensile, compressive, shear or torsional.* The various strengths shown by a material during a tensile test are shown on the curve in Fig.13.1 and describe earlier. The stress in the material at the elastic limit is known *yield strength* and the maximum stress before the fracture is called *ultimate strength.* When in tension, the ultimate strength of the material represents it *tenacity.* Analogues strengths for a material in compression, shear and torsion can also be determined through respective tests.

ELASTICITY

It is a type of tensile property of a material due to which it resists permanent deformation under applied loads, i.e., the property which enables the material to spring back to its original size and shape as soon as the external loads are removed. It has already been discussed in sufficient detail under stress and strain. Also, several related terms like yield point, proportional limit, elastic zone, etc. have been fully explained.

STIFFNESS

It is also known as *rigidity*. It is that property of a material due to which it is capable of resisting *deflection* or *elastic deformation* under applied loads. This is very important for those parts or components which are required to remain perfectly aligned under externally applied loads. The degree of stiffness of a material is indicated by the *young's modulus* if it obeys the Hooke's law, by *Modulus of elasticity, in case of tensile and compressive stresses, modulus of rigidity in case of shear stresses and Bulk modulus* in case of volumetric deformation.

PLASTICITY

It is the property of a material due to which it can undergo permanent deformation without failure or rupture. This property is widely used in several mechanical processes like forming, shaping, extruding, rolling, etc. Due to this property various metals can be transformed into different products of required shapes and sizes. This conversion into desired shapes and sizes is effected either by the application of pressure, heat or both. In general, it is found that plasticity increases with increase in temperature.

MALLEABILITY AND DUCTILITY

Both *malleability* and *ductility* in a material are due to plasticity. It should be clearly understood that while plasticity is the controlling property *malleability* and *ductility* indicate the ability of the material to undergo specific mechanical working processes without rupture. Some other terms used in the same sense, i.e., to indicate the response of the material to specific mechanical processes are *formability and workability*.

Coming specifically to the above two main terms, *malleability* can be defined as the ability of a material for being flattened into sheets without cracking through cold or hot working. *Ductility* of a material relates to its ability to be drawn into wires without rupture and without losing much strength. Some common ductile metals are lead, tin, silver, aluminum, copper, iron, steel, etc.

All the metals are not necessary both ductile and malleable . For example, lead can be easily shaped into sheets by rolling or hammering but cannot be drawn into wires, i.e., while it is *malleable* it is not *ductile*. It is generally reckoned that while ductility is a tensile characteristics malleability is a compressive characteristics. *Ductility* of a material is usually indicated by *the percentage elongation prior to necking or the percentage reduction in area in the necked region* during the tensile test of the material.

BRITTLENESS

A material is said to be brittle if it fails with little or no ductility. Thus, it can be considered as the opposite of ductility. But, a brittle material should not be considered as lacking in strength. It only shows the lack of plasticity. To elaborate it further let us consider the example of cast iron, which is a brittle but sufficiently strong material. It is found to break suddenly as soon as its stress strain curve begins deviating from a straight line.

TOUGHNESS

It is the property on account of which a material is able to withstand bending or torsion without fracture and is equal to the work per unit volume needed to fracture the material. In other words we can say that it indicates the amount of energy adsorbed by the material before its actual failure or fracture occurs. One method of determining toughness of a material is to conduct tensile test on its specimen and construct a stress-strain diagram from the data obtained through the test. The total area under the stress-strain curve will represent the energy (work) required per unit volume to fracture the material. However, in order to get correct values the variation in temperature and rate of application of load during testing should be taken into account because they can appreciably change the nature of the stress-strain curve and, therefore, the toughness value of the material. The work or energy absorbed by the material is usually expressed as *modulud of toughness*.

To understand it more clearly let us compare two different materials, one brittle (say glass) and the other tough (say wrought iron). If sudden load is applied to two pieces, one each of the above materials, the glass piece breaks suddenly while the wrought iron piece will absorb a substantial amount of energy before failing. Accordingly, therefore, wrought iron is supposed to be much tougher than glass. Since this property enables a metal to withstand both elastic and plastic deformations it is of very great significance for design and manufacturing engineers who have to design and manufacture a large number of parts and structures which are supposed to bear shock loads and vibrations during use. It's, therefore, amply clear that it is commonly associated with shock or impact loading and, hence, to *impact strength*.

RESILIENCE

It is the measure of the capacity of a material to absorb energy within the elastic limit. When a material is externally loaded within elastic limit it absorbs *strain energy*. It is a potential energy and it is released when the applied load is removed. The amount of energy that a unit volume of material can absorb within the elastic range (Fig.13.1.) is known as *resilience*. The maximum amount of energy that can be stored in a material (body) upto the elastic limit is called *proof resilience*. The amount of proof resilience per unit volume of the material is known as *modulus of resilience*. This property indicates the capacity of a material to withstand shock loads and vibrations.

HARDNESS

This property is quite closely related to the strength of a material. Although it is a basic and very important property of materials no precise definition of this property has yet been established. However, a common way to defining this property is in terms of the capacity or ability of a material to resist permanent indentation, such on scratching, wear, penetration, abrasion, cutting, etc. Several types of tests are used to determine the hardness of materials. Of these, the

most commonly used tests are *brinell, rockwell* and *Vickers* hardness tests. These tests will be described in detail later on in this chapter.. These tests give numbers which are indicative of the relative hardnesses of the material under test.

A particular term which often used in the description of this property, specially in the context of steel, is *hardenability*. It is indicative of the degree of hardness that the metal can acquire through the hardening process, i.e., heating and quenching. Not only the degree but even distribution of the induced hardness in the metal is determined. The more uniformly the induced hardness is distributed throughout the structure of the metal the higher will be the hardenability of the metal concerned.

IMPACT STRENGTH

This property encompasses both toughness and strength of a material. In short, it can be defined as the resistance of the material to fracture under *impact loading, i.e.*, under quickly applied dynamic loads. Two standard tests are normally used to determine this property (1) The *Izod* impact test and (2) The *Chirpy* test. Details of these tests will be described later in this chapter.

FATIGUE

This property of a material decides its behaviour under a particular type of loading, in which a much smaller load than the one required for material failure in a single application is repeatedly applied innumerous times. Thus, the material is subjected to repetitive cycles, in very large number, of fluctuating stress. Under such conditions the material fails at a much lower stress than the one required for its failure fracture under a single application of steady loads. This phenomena of material failure, under the conditions described above, is known as *fatigue*. The stress at which the material fails due to fatigue is known as *fatigue strength*. The fatigue always shows a brittle fracture with no appreciable deformation of the material at the fracture. It is also reckoned that in almost all metals there is a well defined value of stress below which the material will not fail due to fatigue even if there is a repeated application of load in the above manner. This value of stress , which is much below the normal yield stress, is known as the *fatigue limit* or *endurance limit* of the material.

The phenomenon of fatigue failure is very important from the point of view of design and manufacture of various components which are supposed to be subjected to repeated or cycle loading continuously. Some examples of such components are rotating machine parts, motor shafts, gears, components of high speed turbines and aero engines, aircraft wings, etc. The factors which generally govern the fatigue strength of a material are its chemical compositions, extent of cold working and grain size.

CREEP

The property of material due to which it is progressively deformed at a slow rate with time at a constant stress is called *creep*. A large number of components in different engineering applications such as pressure vessels in high temperature chemical processes, aircraft, steam and gas turbines, power plants, furnaces, etc. , are subjected to constant stresses for long periods. Under such conditions the material undergoes slow deformation over a long period of time, rendering it unserviciable. If this deformation is allowed to continue even after that it may result in total failure of the structure. It is due to *creep*.

Most metals show creep at elevated temperatures. Creep in materials occurs in three stages, known as *primary, secondary and tertiary*. *Creep strength* is the term used to denote the stress for a definite rate of strain at a constant temperature.

MACHINABILITY, FORMABILITY AND WELDABILITY

These three terms, instead of being truely the properties of materials, are actually indicative of the response of materials to specific methods of metal processing. For example, the ease with which a material can be cut to provide it the desired shape and size indicates its degree of machinability, which is expressed as a percentage. This percentage, called *machinability index* is determined by comparing the metal under consideration with *free cutting steel* of which the machinability rating is assumed to be 100 percent. However, this is not the only aspect that effects the suitability of a material. Several other properties of the material are to be considered to decide upon its suitability because the type of machining operation, required degree of surface finish, desired tool life, etc., call for specific properties in the material to be machined.

Similarly, *formability* indicates the response and suitability of the material for plastic deformation processes. Materials, however, behave indifferent manner at different temperature and also respond differently to different deforming processes. Some materials may exhibit very good formability at high temperaturte but show a very poor response if deformed at room temperature. Some materials may readily flow when deformed at slow speed but they will break, as if they are brittle materials, if higher deformation speeds are employed. So, while deciding the overall *formability* of a material all these aspects should be taken into consideration.

The term *weldability* of a material indicates its ability to respond to the welding process under given fabrication conditions in order to enable successful fabrication of a well designed structure which, in turn, should successfully render the intended service when put to use.

TESTING OF METALS

Many types of mechanical tests are conducted on metal specimens in order to ascertain their different mechanical properties and, thus, their suitabilities for specific uses. The data obtained from theses tests is of direct use for the design engineers in order to decide as to whether a particular material conforms to the required specifications or not. This helps in the selection of a suitable material for a specific use and also its soundness. All the test procedures have been standardised. The prominent Indian institutions involved in standardising the test procedures, developing standard specifications for materials and standard definitions of the related terms are the *Bureau of Indian Standards (*formerly *I.S.I.), National Physical Laboratory (NPL)* and the *National Test House (NTH)*. All the mechanical tests can be grouped into two main categories :

1. **Destructive tests.**

    Which include tensile test, compression test, hardness tests, impact test, fatigue test, creep test, etc.

2. **Non-destructive tests.**

    Which include visual examination, radiographic test, ultrasonic test, penetrating-liquid test, magnetic particle or magnetic dust test, etc.

These test procedures will now be described in detail in the following articles.

THE TENSILE TEST

It is a very commonly used test, performed to determine different tensile properties, viz., ultimate tensile strength, yield strength., elastic limit, proportional limit, breaking strength, % elongation, % reduction in area, modulus of elasticity, etc. This test can be performed either on an exclusive *tensile testing machine* or on a *Universal testing machine.* The latter type of machine is more commonly preferred because, bending test, etc., can also be performed on this machine whereas the former type is a single purpose machine. These days *Electronic Universal Testing Machines* with *microprocessors* are also available in the country. These machines carry high loading efficiency of the order of $\pm$ 1% and incorporate digital readouts, effective safety devices, simple controls, a plotter or printer to draw the graph as the test proceeds, load stabilizers, etc., together with the usual features of the conventional type machines. All these and attachments to enable counductance of different tests on the same
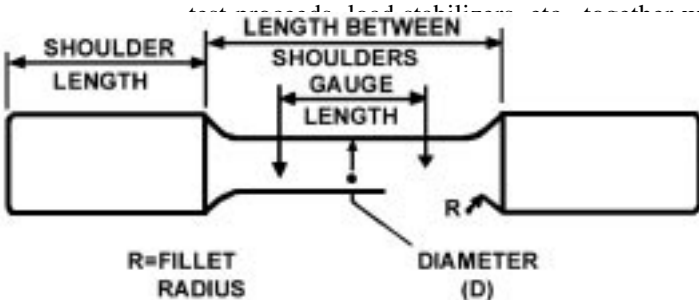
Fig.13.2 Main parameters of tensile test specimen with plain ends

Described below is the procedure for performing *tensile test* on mild steel test specimen. The test specimen is made into the shape of a stepped circular bar by machining, or else it may be flat. When circular, it may carry either plain ends (shoulders) or threaded ends. A test specimen with plain ends is shown in Fig.13.2 with all the essential feature indicated on it.
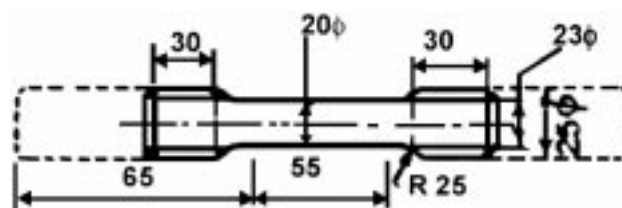
Machining tolerance in dia = $\pm$ 0.5
All dimensions are in mm

Fig.13.3. Dimensions of test bars (machined) for tensile tests

An important point to be borne in mind here is that the shape and size of the test specimen do influence the values of the mechanical properties determined through the test. It is, therefore, necessary to use a standard specimen instead of using an arbitrarily shaped and dimensioned test piece. For this purpose many standards are in use, viz., ASTM in U.S.A., BS: 18 : 1962 in U.K., and so on . Bureau of Indian Standards (I.S.I), New Delhi, has also standardised (IS : 210 - 1978) the essential dimensions of tensile test pieces, as shown in Fig.13.3. and such test pieces are highly recommended for use in our country.

Fig.13.4. Schematic setup of a U.T.M., showing the test specimen gripped between the two cross heads.

For performing the test one end of the specimen is gripped in the *upper cross-head* of the machine, which is a fixed head. The other end of the specimen is gripped in the *adjustable (moveable) cross-head.*This set-up is schematically shown in Fig.13.4. Tensile load is gradually applied to the specimen by means of the loading unit of the machine. In all modern machines a *hydraulic drive* is used to move the adjustable crosshead downwards to apply the desired tensile load on the test piece. A separate load measuring unit incorporated in the machine shows the magnitude of the applied load. A *strain gauge* or an *extensiometer* is attached to the test piece to show the elongation. With increase in load there is a corresponding increase in the length between the two extremities of the gauge length, i.e., there is elongation in the length of test piece. It is, therefore, clear that elongation is obtained as a function of load.

Fig 13.5. Broken pieces of specimen joined together for final measurements.

As the load is increased further, a point is arrived after which the stress-strain proportionality is lost but elastic elongation continues upto another point (elastic limit). Further loading of the test piece leads the material to another specific point (*yield point)* from where plastic deformation starts. With further addition of load the point of maximum stress (*ultimate stress)* is reached. Here from the test piece starts developing the *neck*. Further deformation of the metal is concentrated on this neck and its area goes on reducing till such time when the specimen breaks. The stress at this piece is the *breaking stress*.

The two broken portions of the test piece are then joined together as shown in fig.13.5. and the distance between guage marks and the smallest diameter in the neck found out. The different tensile
properties are then calculated from the following relations :

Elastic limit = $\overline{}$

Yield strength = $\overline{}$

Ultimate tensile strength = ———————————

Young's modulus of elasticity (*E)* = ———————————

Percentage elongation = ——————————— $\times 100$

Percentage reduction in area = $\times 100$

Breaking strength =

COMPRESSION TEST

This test is not very commonly needed for testing metals, of course except some brittle metals like cast iron which can not be subjected of tensile test for testing their strength. The common materials tested in compression include ceramics, mortar, bricks, concrete, etc.

In respect of the direction of application of the axial load it is just reverse of the tensile test. In tensile test the applied loads tend to pull the specimen apart while in compression test the applied loads tend to squeeze the test piece between them. The test specimens are normally made as right circular cylinders or prisms with their end faces flat and parallel to each other.
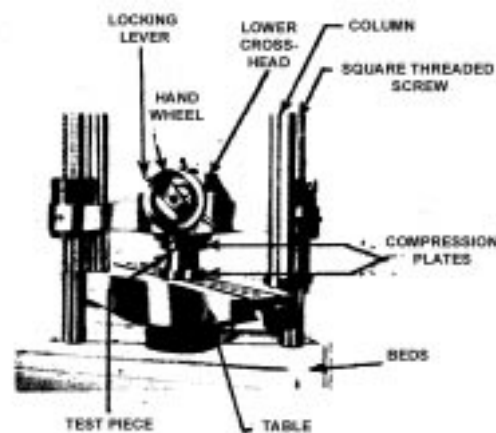
Fig.13.6. Setup for a compression test on a universal testing machine.

While the tensile test piece is held between the two crossheads on a *universal testing machine* the specimen for compression test is held between the lower crosshead and the *table* provided on the machine, as shown in Fig.13.6. Two *grip plates or compression plates* are provided with the machine for this purpose. One of these is attached to the bottom of the lower crosshead and the other to the top surface of the table. After the specimen is correctly placed and firmly gripped the *strainometer or compressometer,* a strain guage specially designed to measure compressive strain, is attached to it. Thereafter , the procedure for conducting the *compression test* is similar to that for conducting the tensile test. Loads are applied at regular intervals and the strain produced is measured. With recorded data a *stress-strain curve* is drawn and various strength values calculated.

HARDNESS TESTING

As explained earlier the hardness of a metal surface is the direct outcome of the interatomic forces working on the metal surface. This is not a basic property of a material but a relative one. However, the most significant aspect of this property is that it appears to have a more or less constant relationship with the tensile strength of the material. Other favourable features with this property are that its testing is simple, quick and of non-destructive nature.

A large number of tests for evaluating hardness of materials have been developed on the basis of material resistance to permanent indentation under static or dynamic loading, resistance to cutting, etc. However the most common hardness tests are :

1.   Brinell hardness test
2.   Rockwell hardness test.
3.   Vickers hardness test.

These three tests, together with a couple of others in briefs, will now be described in the following articles.

BRINELL HARDNESS TEST

Several different designs of Brinell hardness testing machines have been developed, ranging from conventional to those having *electronic digital readouts.* The simplest designs have a manual loading and unloading system while the advanced designs carry a hydraulic power pack and control circuit for loading and unloading. Some carry only a dial guage in front to read the ball penetration while the more sophisticated designs carry an *electronic digital readout* on which not only the relevant test that are displayed but also the *Brinell Hardness Number*. All these machines carry a number of accessories with them to facilitate easy and proper testing.

Well, whatever be the design, loading system, reading system and other features of the machine being used the basic principal of this test is common to all. It involves making a prism type test block of the metal being tested, placing the test sample on the table and raising the table to such a position that the top surface of the specimen will just touch the ball. The ball under reference is a hardened *steel ball* (usually of 10 mm $\pm$ 0.01 mm diameter). Once that position is reached the ball is pressed into the surface of the specimen by gradually applying the load either mechanically or hydraulically, depending upon the type of machine being used. The load is maintained there for about 10 to 15 seconds and then withdrawn. In the meanwhile the spherical ball has made an impression or indentation on the test piece. The diameter of the impression made is measured and the *Brinell Hardness Number (BHN),* which is indicative of the relative hardness of the material being tested, calculated from the following relation (refer to Fig 13.7.) :

Fig 13.7. Important parameters of a Brinell hardness test.

$$BHN = \overline{\qquad\qquad\qquad\qquad\qquad}$$

where, P = Applied load in kg.
         D = Diameter of the spherical ball in mm
         d = Diameter of the impression in mm.

The load applied varies from 500kg to 3000 kg according to the material being tested. The lower values of the load are used in the testing of softer metals and alloys like brass while higher values are used for testing of harder materials like steel, steel alloys and cast iron. The magnitude of the BHN is indicative of the relative hardness of the material. The higher this number the harder the material.

ROCKWELL HARDNESS TEST

It is a very widely used test because of its speed and also because it is free from personal errors. The *rockwell hardness* is determined through an indentation made under a static load and in this since it is similar to *Brinell hardness test. But*, it differs from the latter in that it employs the use of much smaller *indenters (penetraters)* and application of much smaller loads than those used in Brinell hardness test. The *penetrater* can be in the shape of a small ball or a *diamond cone,* known as *brale.*

The test is carried out in two stages. First the indenter is set firmly against the specimen with the application of a small enough (10 kg) load. This load is called *minor load.* This results in a very small penetration into the surface. A dial indicator is provided on the front of the machine to show the applied load. After the initial small penetration the indicator

on the dial is brought to 'zero' reading and a heavier load is applied to the indenter in order to produce a deeper indentation. This load is called *major load* .After the indetation is made the major load is removed. The dial then reads 'zero', implying that the minor load is still in application. The hardness test guage then indicates the *rockwell hardness number,* which corresponds to the depth of *permanent penetration made* by the indenter due to the major load. Fig.13.8. illustrates the principle of *Rockwell testing.* The two positions of the indenter shown in dotted represent the positions attained by the indenter after the applications of minor load and major load. The increment in the depth of indentation (*t)* is a linear measurement and is used as the basis of determining *Rockwell hardness number (R). Mathematically* : $R = 100 - 500\,t$
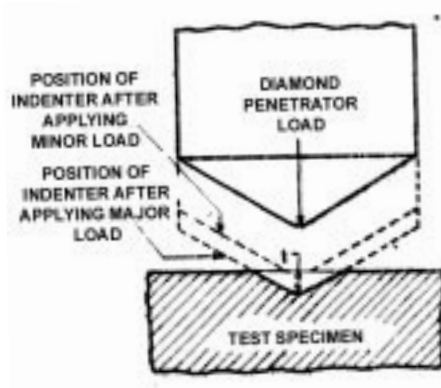
Fig.13.8. Principle of Rockwell testing   Fig 13.9. Details of square pyramid and indentation produced during Vickers hardness test.
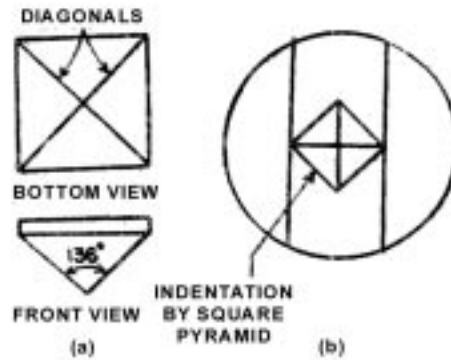
However, no such calculations are required to be made. The guage fitted on the machine is calibrated to give different values of 'R' corresponding to different values of 't', from where the hardness values can be directly read. Several scales A,B,C,D etc. are provided and each of these scales suits a particular class of material. A chart is usually provided with the machine with the help of which a suitable combination of major load and type of indenter can be selected to suit a material carrying a particular degree of hardness. Out of the many scales available scales B and C are most commonly used since they cover most of the commonly used metals as shown in the table 13.1 below :

TABLE 13.10, USE OF ROCKWELL SCALES

Scale	Majorload	Indenter	Suited for Rockwell testing of :
A	60	Brale	Hard surfaces like those of case hardened steel,cemented carbides, etc.
B	100	Ball	Aluminum, copper, brass, malleable cast iron and grey cast iron
C	150	Brale	Hardened steel, white cast iron, etc.

Other scales from *D* onwards are meant for relatively softer and annealed material. Also, with the help of conversion tables it is possible to convert Rockwell hardness number into Brinell hardness number.

VICKERS HARDNESS TEST

This test is similar to Brinell hardness test in the sense that here also an indentation is made in the surface of the test specimen by pressing an indenter point at static load into it. The method of determining the hardness number also is same i.e., through the relationship between the load applied and the surface area of the penetration made. But, there is a marked difference between the indenters used and the smaller loads applied. In case of *Vickers hardness test a square-based diamond pyramid,* containing 136° angle between opposite faces [see Fig 13.9.(a)], indenter is used instead of the ball type or core type indenter used in Brinell hardness test. The loads employed vary from 5 kg to 120 kg.

The procedure adopted for conducting the test is similar to that used for Brinell hardness test. The impression made by the indenter on the surface of the specimen is as shown in Fig 13.9. (b). The magnitude of the load to be applied depends upon the thickness and hardness of the material. The main advantage of this method over Brinell method lies in the shape of the indenter used which assures a higher accuracy. It is because the diagonals of a square can be

measured more accurately than the diameter of a circle. Therefore, the results obtained are more accurate. Another advantages of this method is that plastic deformation is caused even by lighter loads. After indenting, the measurements can be taken and the *Vickers hardness number (VHN) or Diamond pyramid hardness number (DPN)* can be calculated from the following relationship :

$$VHN = DPN \quad = \quad \frac{\rule{3cm}{0.4pt}}{}$$

$$= \quad \frac{\rule{2cm}{0.4pt}}{\theta} = \frac{\theta}{\rule{2cm}{0.4pt}}$$

or $\qquad\qquad = \quad \boxed{1.8544 \; \overline{}}$

where,	P	$=$	Applied load in kg
	d	$=$	Average diagonal length in mm
	θ	$=$	Contained angle between opposite faces $= 136^0$

In practice, however, the *VHN* can be directly obtained from a standard table against the measured value of the length of diagonal (d). The unit of both VHN and BHN is same, i.e., kg/mm^2, and the two hardness numbers are also practically the same upto 400. At hardnesses above this the VHN is greater than BHN. This method is widely favoured for determining the hardnesses of very thin and hard metals and alloys.

MICROHARDNESS TESTING

Microhardness tests are conducted when the requirement is to determine hardness over a very small area of the material. The testing machine most commonly used in this process is known as *Tukon tester.* The spot where the test is to be conducted is carefully selected under high magnification. A special type of indenter, called the *Knoop indenter* (Fig 13.10) is used in the test. It is a diamond indenter ground to pyramid shape such that the two diagonals of its cross-section are unequal, as shown in the Fig.13.10. The ratio of their lengths is approximately 1 : 7.
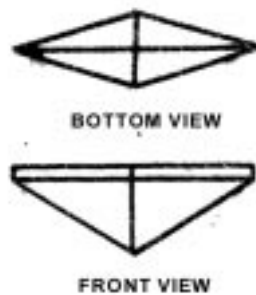
Fig.13.10.Diamond Knoop indenter used in Knoop hardness test

The load applied in the test are of very small magnitudes ranging from 25 gram to 3600 grams. To obtain correct results it is necessary that the test specimen should possess a perfectly polished surface. For testing the hardness the indenter is pressed into the surface of the specimen by applying a predetermined load. The hardness number, called the *Knoop hardness number,* is then calculated by dividing the load by the projected area of the indentation. This test is also known as *Knoop hardness test* after the name of the indenter used.

OTHER HARDNESS TESTS
Scratch test
It is a test which determines the ability of a material to resist scratching by other materials having different hardness levels. The test involves filing of the material by different files possessing different known hardnesses and observe which file is able to scratch it and which file fails to do so. This indicates the relative hardness level of the material. Although crude, it is quite a useful method for common shop floor purpose.

A more accurate and quantitative method is to measure the hardness on *Mohs scale*. This scale, devised by a German Scientist Friedrich Mohs, carries 10 members (1 to 10) each corresponding to the ability of a particular material for being scratched. Diamond, the hardest material is given No. 10 and Talc No.1, which happens to be the softest material on the scale. This, however, is not popularly used in engineering practice because of its failure to precisely quantify the hardness of each material.

Rebound test

It is also known as *sclereoscope test. The* testing equipment used in this test is known as *shore-sclereoscopy*. In this test a small diamond tipped hammer, normally weigning 1/120 oz, is dropped on to the surface of the material from a height of 250mm. The hammer is enclosed in a glass tube which carries graduations. When the hammer falls on the surface of the material from a height it rebounds and the height of this rebound is noted with the help of the graduations on the glass tube. The relative hardness of the material is measured in terms of the height of the rebound.

IMPACT TESTS

The *impact tests* are performed to determine the resistance to fracture of a material under *impact loading, i.e.,* under suddenly applied dynamic loads. An *impact test measures the fracture energy, i.e.,* the energy required to fracture a standard notched specimen by an impact load. It is measured in kg-m on a scale provided on the machine. The measured energy is indicative of the relative *toughness* of the material. The two most commonly performed impact tests are *Izod* and *Charpy*.

For both these tests a standard *pendulum type* impact testing machine is used. This machine, along with all its parts and control is shown in Fig 13.11. Before conducting the tests, standard test specimens are prepared. The test specimen is held in the *specimen support,* provided on the column, and struck by a load, attached to the *pendulum brake,* suddenly by releasing the pendulum from its stationary position. The striking load provides a heavy impact on the specimen and breaks it in a single blow. The pendulum, after breaking the specimen, continue to swing in the same direction and the ultimate height attained by it at the end of the swing is measured. With the help of this data the energy consumed in breaking the specimen can be calculated. This can also be directly read on the scale provided on the machine. The pointer on the machine scale, which also moves as the pendulum swings, at the end of the swing not only indicates the energy consumed during the test but also shows the energy remaining unspent.
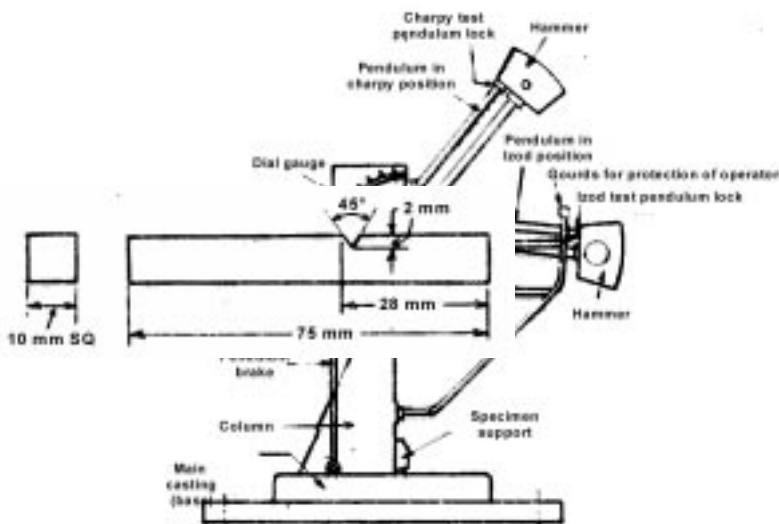
Fig 13.11.A pendulum type Impact testing machine.   *Fig.13.12. Standard dimensions of an Izod impact*

The test specimen used for **Izod impact test** is held in the support in a cantilever position, as shown in Fig .13.13. dimensions of the specimen are shown in Fig.13.12. For breaking the specimen during the test the swinging load strikes it near its upper end as shown in the diagram

The **Charpy impact** test is another very commonly used test. Its test specimen is similar to the one used in Izod test but is shorter in length and the position of 'V' notch is in centre. A charpy test specimen with its principal dimensions is shown in Fig 13.14 for conducted the test the specimen is held in the supports as a *simply supported beam.* The position of the V-notch is kept in such a way that the pensdulum hammer will strike the specimen on the face opposite to the one which carries the notch (see Fig 13.15). The test is performed in the same way as Izod impact test, i.e., the pendulum is locked at a proper height in starting position, the specimen is placed in supports in proper position and pendulum is unlocked to swing and strike the specimen at its centre to break the specimen at its centre to break the specimen. As usual, the pendulum swings to the other side after breaking the specimen and its final height at the end of the swing is noted.

The principle of both the tests is shown mathematically in Fig 13.16 and the method of calculation of the energy consumed in the fracture of the test specimen in either test is as follows :
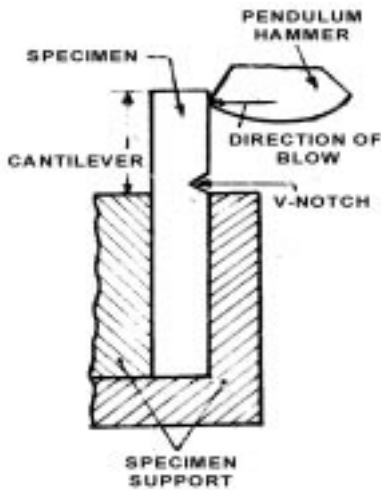
Fig 13.13 The test specimen held in contilever position for Izod impact test.
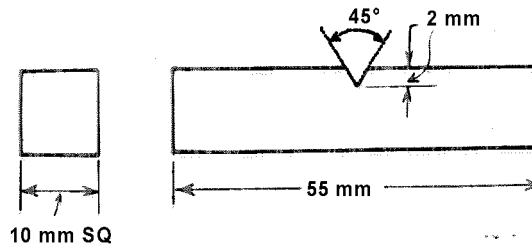
Fig 13.14. Principal dimensions of a charpy Impact test specimen
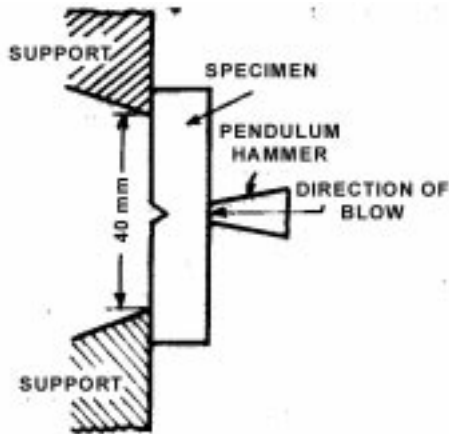
Fig.13.15.Charpy test specimen held in supports in proper position for test.
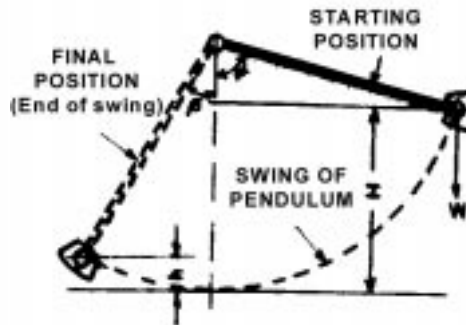
Fig.13.16. Schematic diagram showing the principle of Izod and charpy impact tests.

Initial energy of pendulum = Potential energy at height *H*
Weight = *WH*
= Kinetic energy for striking the specimen
Remaining energy after = Kinetic energy spent in carrying the fracture pendulum weight to a
fracture. vertical height '*h*' after
= *Wh*
∴ Energy consumed = Initial energy - remaining energy after in fracture of specimen fracture
= *WH - Wh*
= W (H-h).

FATIGUE TESTING

Components which have to withstand static loads can be easily designed on the basis of the yield strengths of the materials of which these component are to be made. But there are situations in which a component has to withstand cyclic loading, i.e., its fatigue properties including the *fatigue strength* or *endurance limit*, which are used in the design of such components.

Several different designs of fatigue testing machines are available. The criteria used for classifying these machines are the type and method of application of load. Laboratory tests are usually carried out on a constant load machine. The test specimen used looks like the one used in tensile testing. It is loaded in the machine with its both ends being supported. It is loaded at two points just like a simple beam subjected to pure bending. When it is rotated each point on its circumference will alternate between maximum tension and maximum compression in each rotation, *i.e.*, in each

rotation of the specimen the given point on its surface will once undergo the *maximum tensile stress* and then *maximum compression stress*. This will continue to be repeated so long as the specimen will rotate.

Fig 13.17. Fatigue (S-N) curve for mild steel   *Fig.13.18. S-N curve for Aluminium*

The number of cycles to be used, *i.e.* the number of rotations required to be made by the specimen, until fatigue failure occurs, will depend upon the magnitude of the applied stress. Greater the magnitude of the applied stress smaller will be the number of cycles required and vice versa. Depending upon the amount of stress several thousand cycles per minutes may be required. A number of failure tests are conducted in a row using different loads and a *stress (s) Vs* log of *no. of cycles (N)* curve, called *SN curve,* is drawn with stress values taken along the ordinate and logarithms of *N* (No. of cycles used until failure) taken along the abscissa. The value of stress below which failure of material will not occurs is known as *endurance limit.*

Figs. 13.17 and 13.18 above shows the fatigue curves drawn for two different metals- mild steel and aluminum. It will be observed that the S-N curve for mild steel shows a distinct *fatigue limit* or *endurance limit* while that for a aluminum does not. This characteristics is found common with most metals in two distinct categories *i.e.,* the S-N curves for most *ferrous metals* will show *distinct endurance limit* while those for non-ferrous will not.

CREEP TEST

As already explained materials (specially metals) under specific service conditions are subjected to steady loads under varying conditions of temperature and pressure for a very long period of time. In such situations, the material continues to deform slowly until it loses its usefulness. With time, this deformation may grow to such alarming dimensions that it may lead to fracture of the component without any increase in load. This phenomenon is called *creep.*

Although elongation in metals does take place at low temperature it is more pronounced at high temperatures and occurs more rapidly and, therefore, acquires a high significance in that range. A *creep cruve* is obtained by drawing a plot between percent elongation (or percent strain) and time at constant temperature and constant *true stress.* For this, a constant load is applied to a tensile test specimen, maintaining a constant temperature, and the elongation in this specimen determined as a function of time. A plot is then made from the data obtained and the curve drawn. A typical *creep curve* drawn from the data obtained from a *creep test* is shown in Fig. 13.19, which clearly indicates the different stages of creep.
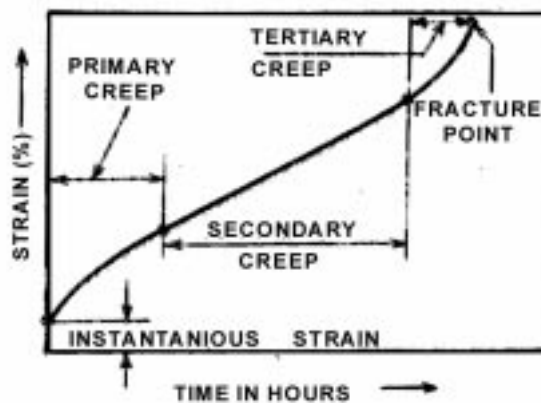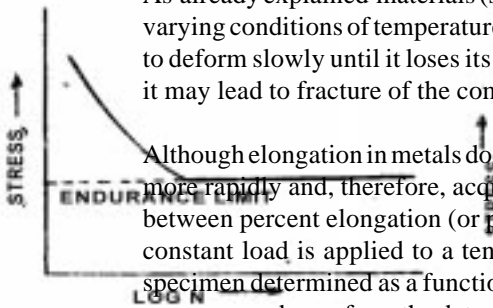
Fig.13.19. A typical creep curve showing different stages of creep

As soon as the load is applied there is an *instantaneous strain* created in the metal. During *primary creep* stage work hardening takes place due to deformation and the creep rate is found to be decreasing. During *secondary creep* stage the creep rate is steady and deformation takes place at almost constant rate.

The last stage or *tertiary creep* stage is attained if the applied stress and temperature both are substantially high. This results in an accelerated rate of creep and finally the metal fails.

In brief, it is commonly noticed that steels with coarse grains are more creep resistant than those with fine grains at elevated temperatures. It is also reckoned that addition of alloying elements like nickel, manganese, tungsten, vanadium, chromium, molybdenum, etc. help in reducing the creep rate in steels.

Stress-rupture curves
These curves are of great significance for design engineers while designing components for high temperature applications. These curves, called *stress-rupture curves,* are drawn with the help of the data obtained from *stress-rupture tests.* These tests are simply extensions of the creep tests, wherein a test specimen is subjected to a definite applied load at a constant temperature until its failure. A number of such tests under different applied loads and different temperatures are conducted and the rupture-time data collected is plotted to draw a number of *curves* on a single diagram.

CHAPTER: 14
MATERIAL'S CORROSION-ITS NATURE AND CONTROL

INTRODUCTION

This chapter gives general guidance on the causes, appearance and prevention of corrosion which, if not detected in its early stages, can have disastrous consequences . Information on corrosion theory is included where it has bearing on the practical aspect of the inspection and maintenance of aircraft and the practical aspect of the inspection and maintenance of aircraft and aircraft parts.

All metals are subject to chemical and electro-chemical attack which converts them into metallic compounds such as oxides, hydroxides, carbonates, sulphates or other slats. Some metals resist attack better than others but the resistance of most metals may vary with such factors as physical environment, applied or internal stress, heat treatment state or working temperature. Although many of the metals used in aircraft construction have reasonable resistance to corrosion, it is essential that all possible action is taken to prevent its occurrence and to detect and remedy any corrosive attack, even if it appears to be insignificant.

As corrosion may arise from many different causes and can affect all kind of metallic structures and components, it is beyond the scope of this chapter to enumerate all the defects that may result from it. It is also impracticable to enumerate every remedy as the treatment of each affected part must be determined by its nature and its function in the particular aircraft. Guidance on the repair and re-protection of corroded parts should be obtained from the appropriate Manufacturer's Publications, but whenever doubt exists the Manufacturer should be consulted.

TYPE OF CORROSION

Corrosion is largely an electro-chemical phenomenons and is liable to occur whenever a difference in potential exists between two metals or a metal and substance in its vicinity in the presence of an electrolyte. It can also occur when a difference in potential exists between separate regions of a single piece of metal or between the different constituents of an alloy. The degree of which will be negligible; serious attack usually takes place only if moisture is present to act as an electrolyte between the poles created by any differences in potential. Two changes converted into a metallic compound, whilst the cathodic pole of the circuit may be reduced.

Direct Chemical Attack

When metals combine with atmospheric oxygen or are attacked by acids, the anodic and cathodic changes occur at the same point. Impurities in the atmosphere can be responsible for this type of corrosion. Thus, aircraft operating near the sea are affected by airborne salt particles, whilst the high sulphur content of industrial atmospheres has a markedly deleterious effect on some exposed metallic surfaces. There is also the possibility of accidental contact with harmful substances. Where this form of attack occurs, the attacked metal is converted into a chemical compound by the corrosive agent, e.g. aluminium may be converted to a aluminium sulphate by battery acids.

NOTE

On aircraft used for crop spraying, special care must be given to the inspection of the structure owing to the corrosive nature of some of the chemicals used.

Electro-chemical Attack

The close proximity of dissimilar metals in aircraft, aided by the presence of conductive media such as water, encourages the establishment of circuits and results in the metal which is anodic to the other being attacked. In some cases, such as when aluminium alloy and magnesium alloy are in contact, both metals may be corroded. Electro-chemical attack will be encouraged by the existence of stray currents from electrical apparatus or electrostatically-charged bodies.

Evidence of Attack

Both types of corrosive attack start on the surface of the metal but can work their way into the core if undetected. Evidence of corrosion will be indicated in the following manner.

(a)   **Aluminium Alloy**

Corrosion of the aluminium surface is usually indicated by whitish powdery deposits with dulling of the surface on unpainted parts. The white powdery deposit also forms at discontinuities in protective coating and may spread beneath paint causing blistering or flaking. As the corrosion attack advances, the surface will appear

mottled or etched with pitting. Swelling or bulging of skins, pulled or popped rivets are often visual indications of corrosion.

(b)   Alloy and Carbon Steels
Corrosion is indicated by red rust deposits and pitting of the affected surfaces.

(c)   Corrosion Resistant Steels
Corrosion is indicated by black pits or a uniform reddish-brown surface.
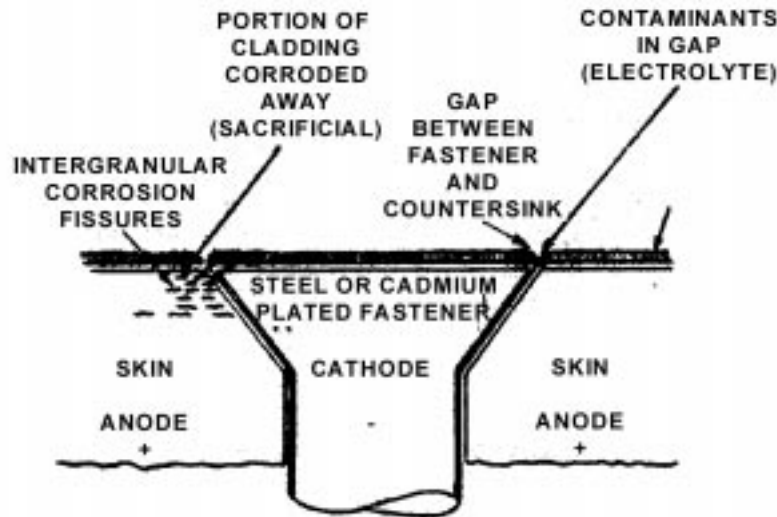
Fig. 14.1, Electrical Asepct of Corrosion

Terminology
The terminology used in describing corrosion is based on either the appearance of the corrosive attack or the mechanism associated with its formation. Frequently, several types of corrosion will occur simultaneously and it becomes difficult to determine the specific cause. The following types of corrosion are those most commonly experienced.

Surface Corrosion
This may take the form of a uniform etching of the surface, pitting or exfoliation of the surface grain boundaries. Light alloys are usually blotched by white or grey powdery deposits, whilst ferrous materials other than stainless steels become covered with reddish-brown rust, and a greenish powder forms on copper. Surface corrosion reduces the amount of sound material remaining and so weakens the structure but, since there is usually an indication of its existence, it is possible for it to be remedied by careful and systematic maintenance.

Note
In many instances the reduction in strength of a structure due to corrosion attack is out of all proportion to the reduction in thickness of the metal.

Intergranular Corrosion
The detection of this type of corrosion is difficult as the surface evidence may only be visible through a magnifying glass. Indications of the presence of corrosion can be obtained by anodising the part and examining for discoloration (black spots). Considerable experience is required for correct recognition, and often a metallurgical microsection examination will be necessary. The attack penetrates into the core of the material along the boundaries of the metal grains. As the material at the boundaries is usually anodic to the grain centres, the corrosion products often become concentrated at the boundaries, although sometimes the attack is transgranular and it is the material adjacent to the boundary which is attacked. The rate of attack is not limited by the lack of oxygen but is accelerated if applied or residual stress is present. Repeated tensile or fluctuating stresses encourage separation of the boundaries, so accelerating the spread of intergranular corrosion and giving rise to corrosion fatigue. As a result higher stress concentrations occur in the remaining sound material, cracks spread and complete failure follows. As there is no effective method of limiting or determining the loss of strength that occurs through this form of corrosion, material or parts showing any signs of it must be rejected immediately.

Pitting
Detected as a series of pits on the metal surface, usually in small, well defined local areas.

Filiform and Exfoliation (or Laminar) Corrosion
Filiform corrosion usually occurs under thin oil, grease or varnish films and is likely to be found on metal surfaces which have a protective film of any sort if there is evidence of a lack of adhesion of the protective film, and appears like 'worm-casts' on aluminium and magnesium alloys. Exfoliation appears as eruptions or flakiness on extruded alloys and can be a serious problem, although it is a relatively less harmful form of intergranular attack.

Note
Intergranular corrosion may occur without stress in the presence of acid chloride solutions or urine, etc., and the latter is often the cause of intergranular cracks which lead to component failure.

Galvanic
Galvanic corrosion is usually visible as pitting and is often referred to as dissimilar metal corrosion. However, it is not limited to just dissimilar metal couples. Various types of concentration cells, where electron flow occurs between areas or points of different electrical potential, are also examples of galvanic corrosion. Pitting results when in the presence of a conducting solution, electron flow occurs between different metals or between different points or areas on a metal surface exhibiting different electrical potential.

Microbial
Microbial (microbiological) corrosion occurs in integral fuel tanks and is caused by the presence of bacteria and fungus in aviation kerosene. The fungus grows at the fuel \ water interface, and the metabolic products formed corrode the metallic structure.

Stress Corrosion
This type of corrosion usually manifests itself as fine cracks. It occurs in alloys that are susceptible to cracking when exposed to a corrosive environment while under a tensile stress.

CONDITIONS CAUSING CORROSION
Because of the stringent weight limitations of aircraft, structural parts and components cannot be designed so that they are heavier than is dictated by the requirements of mechanical strength. Thus, any loss of strength through corrosion damage is more critical than in other forms of transport. Aircraft parts should therefore be manufactured, protected and assembled so that corrosion is unlikely to occur and, after entering service, every precaution should be taken to preserve the original finish. Cleaning and inspection, and when necessary re-protection, are essential at frequent intervals throughout the working lives of all components and parts.

Basic Factors of Material and Assembly
The following factors are important as a guide to the prevention of corrosion.

Selection of Materials
As material specification used in initial construction or for subsequent repair are chosen by the Manufacturer, who should make resistance to corrosion a factor in selecting the appropriate specification, maintenance responsibility is normally limited to ensuring that all instructions for handling, storage, heat treatment, assembly and protection are correctly carried out and that a close watch is maintained for sign of incipient corrosion.

Dissimilar Metals
The contact of dissimilar metals, which occurs in many parts of aircraft structures and in most accessories and components, is always likely to cause electro-chemical reaction, but in many instances such reaction can be prevented by maintaining protective or insulating layers between the metal surfaces. It should be remembered that parts to the same materials specification may have a relative difference in potential if their heat treatment states are compound, etc., as though they were dissimilar metals . Some examples of dissimilar metal contacts are quoted:
(a)   Steel bolts through aluminium alloy spares and structural members.
(b)   Steel brake components secured to magnesium alloy wheels.
(c)   Parts made of brass, steel, tungsten, etc., such as clips or brackets, attached to aluminium alloy structural members.
(d)   Aluminium alloy skin panels riveted to extruded stringers.
(e)   Steel levers, shafts and gears housed in castings of light alloy.

HEAT TREATMENT
Incorrect heat treatment may lower the corrosion resistance of the material treated, thus it is essential that all heat treatment should be applied strictly in accordance with approved specifications. The corrosion resistance of high-

strength aluminium alloys is affected by their cooling rate; if this is rapid their susceptibility to intergranular corrosion is reduced, provided that locked-up quenching stresses are afterwards relieved.

NOTE

Heat is sometimes applied to structural parts for purposes other than the development of particular mechanical properties of the metal, e.g. when metal to metal joints are bonded by thermo-setting synthetic resins under the influence of heat and pressure. Since 'heat treatment' of this kind is not always covered by official specification, close adherence to the aircraft Manufacturer's instructions is essential to ensure that the corrosion resistance and other properties of the metal are not impaired.

Welding

Welded joints are sometimes subject to corrosion because the heated strip has been rendered anodic to the surrounding metal but the danger can be greatly reduced by the exercise of skill and care. It should be remembered that the fluxes used in welding are often corrosive and hence all residues from fluxes should be thoroughly cleaned off immediately after welding. Some stainless steels are particularly susceptible to intergranular attack in the welded region (weld decay), although the likelihood of this can be reduced if the part is annealed after welding or if the steel contains stabilizing elements such as titanium or niobium . Inert gas welding processes which do not require flux are sometimes used when the removal of flux would be difficult.

Fretting

This is a type of corrosion which can have serious consequences, as it reduces the fatigue strength of the structure; it occurs when parts are bolted tightly together and yet slip slightly on one another during flexing or other movements of aircraft parts. the heating caused by friction promotes oxidisation of steel parts and the oxide is then rubbed off to form dust frequently described as "cocoa". Fretting of aluminium alloys produces a black oxide. Structural assembly bolts should be inspected to ensure that the protective treatment plating is intact and should be assembled within the stipulated torque loading limits and in accordance with the Manufacturer's instructions.

Stress

Metals under stress generally corrode more rapidly than unstressed metals. The influence of stress on the development of intergranular corrosion is mentioned. Corrosion that is continuing on parts under repeated stress is very much mor eharmful than corrosion for the same length of time without stress, and can lead to rapid failure of the part from fatigue. In many cases, stress corrosion cracks have resulted from initial pits in the surface.

High Temperatures

Parts which become heated in service, such as brake drums, combustion chambers and exhaust pipes, tend to oxidise more rapidly than unheated parts. This tendency is reduced if the parts are made from alloys containing nickel or chromium, although the corrosive effects of the sulphur present in exhaust gases may still do harm to heated engine parts.

Electrical Equipment

Faults in the insulation of electrical equipment which lead to current leakage can cause the equipment itself to corrode or can encourage electro-chemical attack in the surrounding structure. Insulation should therefore be carefully tested as outlined. Sparking in confined spaces will produce nitric acid in the presence of moisture and this acid will then attack the surrounding material.. Nitric acid attack can be prevented by ensuring that the vents of such equipment as magnetos are kept clean so as to permit the escape of the oxides of nitrogen evolved. Certain insulating materials give off vapours which are corrosive, e.g. phenolic resin-bonded insulating materials give off vapours which corrode cadmium plate.

Factors Due to Environment and Operation

Corrosion can arise from many circumstances, some of which are unavoidable but many of which can be anticipated and controlled. When conditions that create corrosion are an inevitable accompaniment of storage or operation, the only safeguard is adequate maintenance.

Damage to Protective Coatings

Metallic surfaces protected by chemical films, metal plating or organic coatings, may suffer severe attack if the protective coat is physically damaged. Some protective coatings are susceptible to attack from certain types of lubricants, de-icing fluids or hydraulic fluids, but this danger can be reduced by selecting protectives that are specially resistant for the items that are likely to be in contact with these fluids. Scratches caused by careless handling and abrasion from grit or water striking the aircraft at high speed can provide starting points for corrosion, but the seriousness of such defects depends on the materials affected. Thus aluminium alloy sheet clad with pure aluminium is not much harmed by minor scratches since the aluminium cladding provides 'sacrificial protection'. On the other hand, chromium plated steel will rust readily if the chromium is damaged.

Surface Defects

Corrosion may arise from particles of foreign matter, such as rolling-mill scale or emery particles, which are embedded in the surface. Particular care is necessary after such operation as filing, grinding or abrasive grit blasting to ensure that all particles are completely removed. A high polish is given to some components to enable them to resist attack, and this resistance will be lowered if polished surfaces are roughened or scores.

Crevice Corrosion

Intense corrosion is often found where non-conducting materials, such as plastics, glass-wool or upholstery, are in contact with metal. A similar effect may occur in inaccessible corners formed in metal parts. In such places, oxygen is replenished less quickly than elsewhere with the result that the crevice is rendered anodic to the surface outside and is therefore subject to electro-chemical attack. It follows that the contact of metals and non-conductors should be treated like the contact of dissimilar metals, and that all enclosed regions in aircraft structures should be vented and drained as adequately as possible. Ventilation also helps to prevent the accumulation of condensed moisture and discourages the growth of moulds and bacteria which can also promote corrosion.

Marine Corrosion

The salt present in sea water will attack many metals directly. Landplanes may be affected by airborne particles or spray droplets, whilst amphibians require constant attention to keep them free from the salt deposited by evaporated spray. If trapped in the aircraft structure, sea water will provide a particularly active electrolyte for electro-chemical action. Hulls are sometimes damaged because of the voluminous character of the corrosion products precipitated in crevices; as the material accumulates, plates may be bulged and rivets fractured. The inside of the chine members where the side sheeting joins the planing bottom is particularly vulnerable to corrosion because of its moisture trapping shape.

Fuels, Oils and other Liquids

Although petroleum products contain sulphur compounds and organic acids, they do not usually corrode fuel tanks, pipe-lines, etc., because of the resistant nature of the materials from which these items are made. The danger of corrosion chiefly arises from the water content of oils and fuels; the water acts as an electrolyte to promote combination with oxygen dissolved in the oil or fuel. This effect is most pronounced with leaded patrol, and light alloy tanks containing such fuels should be protected with inhibitor cartridges. Careful inspection of the external surfaces as well as the internal structure of the keel areas, particularly of pressurised aircraft, is necessary due to condensation and spillage from toilet and galley installations. Battery acids, de-icing fluids, disinfectants, water methanol spillage and urine can also cause extensive attack on structural parts and care should always be taken to wash off any of these fluids which may be spilt. Integral fuel tanks should be designed to give good water collection and drainage. Water in aviation kerosene may cause serious corrosion within the fuel system. It may be saline or brackish, which with other contaminants such as iron oxide, micro-biological organisms, etc., may have very serious effects.

NOTE

All aviation fuels absorb moisture from the air and the amount of dissolved water contained varies with the temperature of the fuel. When the temperature of the fuel decreases, some of the dissolved water comes out of solution and falls to the bottom of the tank. When the temperature of the fuel increases, water is drawn from the atmosphere to maintain a saturation solution. Changes in temperature, therefore, result in a continuous accumulation of water.

THE CONTROL OF CORROSION

Details of corrosion control during design and production are outside the scope of this chapter: the following paragraphs relate to care and maintenance under operating conditions.

Cleaning

It cannot be too strongly emphasized that frequent cleaning is essential for the prevention of corrosion. During take-off and landing, aircraft are splashed with mud and water; during flight, engine oil and exhaust products are deposited on parts of the structure, and at all times contamination by atmospheric dirt is likely to occur.

Metal-skinned structures should be washed down thoroughly using solutions, materials and equipment which are recommended by the aircraft Manufacturer. Non-flammable de greasing cleaners for aluminium alloys are available in powder or ; they should be applied with a bristle brush, care being taken to remove all dirt from odd corners, panel edges, screw and rivet heads, etc. If deterioration of protective treatments or signs of corrosion are revealed by cleaning, the affected parts should be treated. Cleaning preparations should be washed off with cold water after they have loosened the dirt, and the parts should be dried thoroughly before restoring any protective treatments.

NOTE

There are certain proprietary cleaners which , although harmless to metals, are inclined to rot fabric and other textile

materials. It follows that care should be taken to prevent them from wetting fabric or upholstery. Transparent plastics can also be damaged by cleaning chemicals and should therefore be suitably protected.

At the intervals specified in the Approved Maintenance Schedule, marine aircraft should be beached and hosed down with fresh water. The bilges should be drained and flushed through with fresh water at the same time. Care should be taken that all deposits of salt and marine growths are removed from both the inside and outside of the aircraft and that all damage to protective coatings is made good. All submerged parts of the hull and floats should then be sprayed with liquid lanolin, pigmented lanolin or seaplane varnish, the spraying being continued to approximately 0.6 m (2ft) above the water line.

Where battery or other acids have been spilled, the surrounding area should be rinsed with generous quantities of clean water to dilute and remove the acid. The affected part should then be brushed with a dilute solution of sodium bicarbonate for lead acid batteries, and diluted acetic acid for nickel cadmium batteries, to neutralize any remaining electrolyte. After this has remained on the surface for a few minutes, the area should again be washed with water, finally wiped dry, and the protective treatments restored.

NOTE

In cases where spillage of acid or heavy concentrations of battery fumes (e.g. due to a runaway battery) have occurred which are not contained within a known area, it may be necessary to dismantle parts of all the surrounding structure to ensure the effective removal of all traces of electrolyte.

High octane fuels, which are doped with tetra-ethyl-lead and ethylene dibromide, produce lead bromide when burnt. This is ejected in the exhaust gases and can do considerable harm if deposited on aluminium alloys. Such deposits should be removed by using detergents or emulsifiable cleaners which will not soften the underlying paint coat. Where possible all apertures at wing root joints, etc., should be sealed to exclude exhaust gases from the inside of the structure, but if the gases do penetrate, internal cleaning will also be necessary. If the deposits are so hardened that they will not yield to normal cleaning, a paint stripper should be applied . Using a high pressure jet of water or rubbing with a damp rag, the stripper and paint can then be removed together. Afterwards the cleaned area must be re-protected

NOTE

Paint strippers containing methylene dichloride or ethylene dichloride can seriously reduce the strength of resin-bonded joints, and hence aircraft on which processes such as "Redux " bonding have been used should only be cleaned with strippers which are recommended for the purpose by the aircraft Manufacturer. Information on acceptable materials, if not in the appropriate Manual, is normally available in Service Bulletins published by the Manufacturer's Service Department.

Although accumulation of oil and grease may not in themselves be corrosive, they tend to retain dirt and metal particles, to damage surface finishes and prevent inspection for cracks, etc. They should be removed from such parts as the landing gear and engine nacelles by means of solvents or emulsifiable cleaners. The cleaning agents recommended by the aircraft Manufacturer should always be used.

NOTE

It is important that the cleaning fluids specified by the manufacturers are used in the strength recommended and in applications where their use has been specified. Cases have arisen where cleaning fluids in combination with kerosene have had a deleterious effect on aircraft structures, the penetrating qualities of kerosene promoting seepage into skin joints. Such cases are particularly troublesome and it becomes difficult to diagnose the cause of corrosion. Also, unspecified cleaning fluids might contaminate or destroy jointing compounding, bonding adhesives or sealing mediums.

Wrong methods of cleaning can do more harm than good. The following points should be noted:
a.   Steel wool should not be used on aluminum alloy or magnesium alloy surfaces as particles may be lodged in crevices or embedded on organic coating and so provide starting points for electro-chemical attack.
b.   Aluminium-clad light alloy sheet should not normally be polished with mechanical buffing wheels, except under a carefully controlled technique, as this will remove the coating of pure aluminium and the unprotected alloy core will be subjected to corrosion.
c.   Dirt and swarf should not be washed or brushed inside the structure where particles may be trapped behind stringers, frames, etc. (Trapped water can do more damage than the dirt.) Interior cleaning should be done with an efficient vacuum cleaner.
d.   Pressure cleaning should be used with caution, particularly where bearings are in use. Steam cleaning should only be used when specified, for it can penetrate joints and leave water residues.

INSPECTION

Every precaution must be taken to ensure that all corrosion is detected in its early stages. Corrosion cannot always be found by visual examination alone, and one of the methods of non-destructive examination such as radiological examination may be of assistance. However, corrosion tends to blister paint and its presence can be suspected if the paint flakes off when pressed.

NOTE

Because of the rapid improvements that have been made in radiological techniques, the latest information on this subject should be sought from the aircraft Manufacturer.

At the time specified in the Approved Maintenance Schedule and whenever the aircraft has been subjected to especially corrosive conditions, the inside and outside of the structure should be thoroughly examined . The upholstery and floor coverings should be removed and all access panels should be opened to facilitate inspection. With a strong light, a detailed examination should be made of the spars, ribs, frames, bulkheads, stringers, etc.. Particular attention should be given to poorly vented regions and to places where dampness and condensation are apparent or suspected. Strontium chromate inhibitor pellets are sometimes used in areas where water accumulates and the condition of such inhibitors should be assessed. The satisfactory adhesion of sealant fillets and paint work should also be verified.

(a)   Special attention should be given to parts of the fuselage where condensation may tend to collect. Considerable condensation will occur on the inner surfaces of pressure cabin structures. Water will run down the cabin wall structure and this will tend to start corrosion in the lower parts of the structure.

(b)   Inspecter should give special attention to such areas and particularly to the faying surface between stringers and skin, where moisture may remain trapped and promote corrosion. In some cases it may be necessary to dismantle parts of the structure to ensure adequate inspection.

NOTE

On some types of aircraft operating under widely different conditions, recent investigations have revealed the presence of serious corrosion which had remained undetected in parts of the structure. In some instances it has been shown that normal methods of inspection and radiological examination were inadequate, and dismantling, particularly of pressurised skin structures, was therefore necessary.

Where evidence of surface corrosion exists, the extent of pitting or exfoliation should be tested by probing with a fine needle. Whenever possible, the strength of all suspect rivets should be tested by applying a moderate shear load to the rivet head. The remedial action to be taken will depend on the depth and extent of the attack and the thickness and function of the affected parts, but any areas where rivets fail must obviously be repaired in accordance with the appropriate Repair Manual. Elsewhere , if the attack is not serious , the corrosion can be cleaned off and the part re-protected, but any intergranular or widespread surface corrosion will also necessitate repair by renewal of the damaged areas.

Assessment of the condition of parts subjected to high temperatures is not easy but, as a general rule, discoloration and light scaling are normally acceptable (light scale sometimes protects the metal from further attack) whlist heavy scale is an indication that the strength of the metal has been reduced. However the majority of exhaust systems fitted to aero engines are manufactured form stainless steel or inconel and visual examination of these components is often misleading. This is because those parts of the system which are subjected to the highest temperatures will, after extensive periods in service, suffer form intergranular corrosion. If undetected this is obviously dangerous and may constitute a fire hazard, but detection is possible by measurement of magnetic permeability . A rough check for this condition can be made with a small horse- shoe magnet, the component under examination being rejected if the magnet shows any tendency to adhere to it, but sensitive instruments which measure the relative magnetic permeability should be used whenever possible. The guidance of the Manufacturer should be followed when assessing the condition of particular exhaust systems.

It is a wise precaution to remove a sample number to key assembly bolts during major inspections, care being taken to ensure that different bolts are removed at each inspection. Bolts securing engine mounting, wing and empennage attachment bolts, and undercarriage assembly bolts should be examined for signs of fretting corrosion. The bolt holes and surrounding material should be inspected for intergranular penetration and fatigue cracks.

NOTE

This should only be done by skilled personnel with the appropriate jigs and assembly equipment.

It should be remembered that metal tubes may corrode internally as well as externally. Sealed tubes, which have been protected internally before assembly should not cause concern, but open-ended tubed can accumulate moisture.

Visual examination for corrosion is one of the most essential aspects of inspection and is necessary on all components, pipelines, control cables, electrical equipment, instruments, etc. For further information on the inspection of particular systems and components, reference should be made to the appropriate Manual .

Storage
Aircraft, engines and components will deteriorate rapidly when stored unless adequate precautions are taken to protect them from climatic conditions, damp, condensation and accumulations of dust. It should be remembered that conditions suitable for some materials may not suit others. The following information stresses some important factors of good storage.

The most suitable environment for storing complete aircraft is a cool, dry hangar with a relative humidity of less than 60 % where the structure is protected from strong sunlight, rapid changes of temperature, atmospheric impurities of marine or industrial origin, and the corrosive effect of blown dust. Before prolonged storage is contemplated it is advisable, where possible, to remove all sound insulating and textile materials of a hygroscopic nature. After storage, special attention should be given to parts of the structure which have remained in contact with material of a hygroscopic nature. It should also be noted that damp wood will evolve acids that can be harmful to adjacent metal even though the wood may not be in direct contact with it.

Aircraft should be stored in a dry, clean condition, all drains and vents should be clear and unobstructed, and blanks should be fitted to intakes and apertures in which condensation might occur. Colour indicator type of silica gel may be used in enclosed spaces to absorb atmospheric moistures.

Temporary protectives such as rust inhibitors and lanolin should be applied to the exposed metal surfaces which are likely to corrode. Guidance on the protection of particular aircraft should be obtained from the Manufacturer concerned.

If aircraft have to be stored for long periods in the open or under detrimental climatic conditions, they should be adequately covered and protected by a special process. Packaging by the spray application of a plastics film is a satisfactory method ,provided every precaution is taken to control the humidity of air inside the protective covering and an externally visible moisture absorption indicator is used.

There are numerous precautions, with variations in materials, equipment and methods of application, which are specific for various engine types and installations; these must be applied strictly in accordance with the appropriate Manual and related technical documents.

Metals held in stores should not only be stored under controlled conditions but should be protected by a method suitable to the specification and shape of the material. Thus a coating of lanolin is usually applied to light alloy castings, whilst sheet and strip light alloys are most effectively safeguarded by spraying them with an approved plastics film on to a pre-oiled surface. Plastic films, which can be peeled off before fabrication, have the added advantage of protecting them against mechanical damage.

Components such as instruments, hydraulic valves and electrical equipment are usually packaged by their Manufacturers and given a guaranteed shelf life. However, it should be remembered that the shelf life is only valid if the storage conditions are suitable; in humid conditions corrosion may occur even if the packaging appears to be undamaged. The only remedy is periodic inspections, cleaning and re-protection throughout the shelf life of the component.

Aircraft, engines and components which have been stored for any considerable period should be carefully examined and tested before being put into service. Temporary methods of protection should be removed, and all permanent protection should be inspected and rectified as necessary.

CHAPTER: 15
CORROSION-REMOVAL AND RECTIFICATION

INTRODUCTION

This chapter gives general guidance on the removal of corrosion products and on the cleaning and pre-treatment of the metal parts of aircraft.

Many of the processes recommended in this chapter are covered by specifications issued by the Ministry of Defence or the British Standards institution. Since these specifications are frequently re-issued, the alphabetical suffix of each DTD Specification has been omitted, but the application of any particular process should always conform to the latest issue of the relevant specification. All processes should be approved by the aircraft manufacturer.

TREATMENT OF STRUCTURAL PARTS

Wherever corrosion is found in aircraft it is essential that the corrosion products should be completely removed. This is necessary for two reasons, firstly to permit the extent of the damage to be assessed and secondly because the presence of corrosion products assists in the continuation of the attack. The full value of protective treatments will only be achieved if the surfaces are thoroughly cleaned and the treatments are applied immediately after cleaning.

Preliminary Cleaning of Corroded Areas

Parts which cannot be removed for cleaning should have all oil, grease, moisture and surface dirt cleaned off before the application of corrosion-removing chemicals. Oil and grease should be wiped off with rags soaked in organic solvents such as trichloroethylene fluid (BS 580) (Type 2 or other suitable grade), or a mixture of equal volumes of white spirit (BS245) and either (a) solvent naptha (BS 479) or (b) 3 $^\circ$ xylene (BS 458), used at room temperature as recommended in DEF STAN 03-2. (De greasing procedures are detailed in specification DEF 1234.) Surface dirt should be removed with detergent solutions, using hand brushes with non-metallic bristles such as nylon.

Removal of Old Protective Coatings

To facilitate the inspection and re protection of corroded surfaces, the protective coatings in the vicinity of the damage should be removed. Whenever possible this should be done chemically, as mechanical methods such as wire brushing, grinding or rubbing with emery, may overheat the surface or remove an undesirable amount of material. There is also the danger that abrasive methods may drag surface metal over the corroded area or cause particles to become embedded which will cause further corrosion later.

Air-blast abrasive equipment has been proved satisfactory, particularly for relatively large areas of surface corrosion removal. The abrasive must in all cases be aluminium oxide or glass beads. Never silicon carbide; for coarse and rapid removal the particle size should not exceed 180 mesh (0.08 mm) and for fine control the size should be 400-600 mesh (0.038-0.0225 mm). Due to the possibility of cladding removal from aluminium skins and cadmium plating form steel fasteners, etc., abrasive should only be considered if a completed organic finish is to be applied.

Removing Organic Coatings

Non-flammable paint strippers should be used to remove paint, varnishes, synthetic enamels, cellulose, etc., A number of proprietary solutions are available which are satisfactory for the majority of organic coatings; they are neutral and will not attack the underlying metal provided they are rinsed off after the paint has been removed. The strippers should be brushed over the paint, left on the surface for a few minutes and loosened paint then wiped off with a cloth, aluminium wool or non metallic material, e.g. wood, Tuflon or suitable plastics materials. Steel wool should not be used.

Where a paint coating is required or renewed in localised areas only, surrounding areas should be masked by means of suitable tapes, and these should be removed at suitable stages during the painting process to prevent subsequent contamination of later stages, and as soon as practicable after completion of the painting operation.

Where damage or removal of pressure cabin sealants or other sealing or stopping material has occurred, these should be renewed either before or at some convenient point during repainting operations. Where stopping materials have been used originally, these may be replaced with an approved air drying scheme compatible with original.

NOTE

The effects of certain strippers on adhesive-bonded joints, plastic parts and windows should be borne in mind, and care should be taken to avoid caustic strippers on aluminum, alloys. Rubber gloves and goggles should be worn to prevent any contact between the stripper and the skin.

When the paint has been removed, all traces of the stripper and residue should be removed by one of the following methods.

(a)   **Water-miscible paint remover:**
            Washing with clean water and drying, followed by solvent cleaning.

(b)   **Solvent-miscible paint remover:**
            Washing with the appropriate solvent only.

Removing Chemical Coatings

It is not always essential to remove chemical coatings such as anodic film, from aluminium alloys or phosphate coats from steels. As it is generally impossible to restore chemical coatings without removing the part and immersing it in a suitable bath, it is sometimes advisable to retain as much as possible of the original coating and, after local cleaning of the corroded areas, to apply one of the brush-on processes, followed by organic coatings for subsequent protection. If the affected parts can be removed it is preferable to clean them completely and then re-protect by the original methods.

a)   **Anodic Film**: Anodic films may be removed from aluminum alloys by the application of a solution of 10% sulphuric acid by volume in water plus 4% by weight of potassium fluoride .

b)   **Chromate Films**: Magnesium alloy parts which can be immersed should be cleaned as recommended . Local cleaning where immersion is not justified can be effected by swabbing with a solution of 100 g of chromic anhydride in 1 litre of water, with 14 drops of concentrated sulphuric acid added (2 oz of chromic anhydride in 1 pint of water, with 8 drops of concentrated sulphuric acid added). Where parts are not machined to fine tolerances, abrasion with fine 'wet' glass paper is permissible. The glass paper should be well wetted before use and care should be taken to prevent abrasive particles from remaining embedded in the surface. After rubbing down, the chromic-sulphuric acid solution should be applied and let on the surface for 2 or 3 minutes. The surface should finally be washed off with generous quantities of water and thoroughly dried.

c)   **Phosphate Films**: Phosphate films on steel are generally tenacious and are not easy to remove without immersion in acid solutions. To clean a small area of a part in situ, mechanical cleaning is usually most satisfactory, but when complete stripping is required a dip in dilute hydrochloric acid is recommended.

Removing Metallic Coatings

Coatings of cadmium, zinc, nickel, copper, and tin are frequently used to protect steel aircraft parts, light alloys are usually by other methods. Immersion in an acid solution is usually the most effective method of removing a metallic coating, but it should be remembered that the removal of original deposits before replateing is necessary only if the thickness of the deposit is critical. Mechanical cleaning is also used on occasions, particularly if the old deposit is flaking or peeling, but whichever method is used care should always be taken to avoid removing too much material, especially on parts to close dimensional tolerances.

Removal of Corrosion Products

Although the cleaning methods outlined in paragraph above will remove superficial corrosion, surfaces which have been seriously attacked may still retain powdered oxides, salt crystals, etc., in pits and surface cavities. Chemicals suitable for cleaning each of the principal materials used in aircraft construction are available, but in some cases the chemicals will themselves cause corrosion if they penetrate faying surfaces. There is also evidence that some pickling and electro-chemical polishing techniques have an adverse effect on fatigue life and this aspect should receive serious consideration when selecting cleaning processes for parts which are subjected to fluctuating stresses in service. When doubt exists regarding the corrosive nature of certain chemicals, they should be tested as recommended in the following paragraph.

Test for Cleaning Chemicals

a.   Prepare two panels of approximately 900 cm^2 (1 ft^2) area from material of the same specification as that to be treated.

b.   Apply the chemical to be tested to one face of each test pieces and clamp the treated faces together.

c.   Expose the sandwiched test panels to alternate humid and dry atmospheric conditions in temperature conditions of 38°C (100° F). About 16 hours a day in humid conditions and 8 hours a day in dry conditions is recommended.

d.   After approximately 10 days the panels should be separated, rinsed and scrubbed , and examined for corrosions.

e.   The chemical will be acceptable if the metal is only lightly etched, but should not be used on the aircraft if it has caused deep pitting or intergranular corrosion of the test panels.

Chemical Cleaning of Steel

The removal of rust from steel by pickling in acid is often recommended, but it is not a practical method for in situ parts or welded steel tubular structures. A variety of proprietary rust removing solutions is available; most of them are solutions containing phosphoric acid, which, in addition to dissolving oxide film, partly inhibit the steel surface from further rusting. These solutions should always be applied as directed by their Manufacturers.

NOTE
Where parts are removable, the use of alkaline de-rusting solutions (with cleaning agents) is recommended.

Chemical Cleaning of Aluminium Alloys

Cleaning methods will vary according to the extent and location of the corrosion and the specification of the alloy concerned. General guidance on some recommended methods of cleaning are given below:

a. Light corrosion deposits on aluminium alloys can often be wiped off with solvents or detergents which will leave a clean surface ready for pre-treatment and re-protection. The use of nonflammable preparations which are free of caustic substances is recommended. Swabbing with trichloroethylene is not advised because concentration of the fumes can be harmful and, in any case, the function of this chemical is to remove grease and not corrosion products. When solid particles are held in suspension with surface grease, they will be removed if the parts can be immersed in boiling trichloroethylene laquor but this is seldom a practical method of cleaning aircraft structural parts during maintenance. The use of an inhibited phosphate chemical brightener is also recommended.

b. Heavy deposits on clad aluminium alloys should be removed chemically because mechanical cleaning will take off the protective cladding and expose a greater area of the core to subsequent corrosion. Preparations of thickened phosphoric acid are recommended for this purpose. All other material, including non-clad aluminium alloys, should be masked to prevent them being attacked by the acid. The corroded surface should then be brushed with the acid and, after an interval of not more than 3 minutes, scrubbed with a stiff nonmetallic brush until all corrosion products are removed from pits, rivet heads, etc. The surface should then be rinsed off with generous quantities of water to remove all traces of remaining acid, and should then be thoroughly dried.

c. Heavy deposits on non-clad aluminium alloys can be removed mechanically, i.e. by scraping, wet sanding with fine sandpaper or by light abrasion with aluminium wool (steel wool should not be used), provided dimensional tolerances are not exceeded. A general purpose surface wash which will also form a base for painting can be made up as follows:

Butyl alcohol	40%	
Isopropyl alcohol	30%	By volume
Phosphoric acid (85% solution)	10%	
Water	20%	

The alcoholic-phosphate wash should not be used on high strength wrought aluminium alloy such as DTD 5024,5044,5114 and 5124. On other alloys it should not be allowed to remain on the surface for longer than 15 minutes; in fact shorter times are desirable, particularly if the temperature is high. It should be applied with a soft cloth or bristle brush, washed off with water and the surface dried. As an alternative proprietary 'brush on' solutions mentioned in paragraph below may be used.

d. The use of phosphoric acid corrosion removers is usually followed by the application of a chromate bearing conversion coating treatment such as the Alocrom series. These remove the final traces of corrosion and provide an improved surface conditions for painting. The application of a 10% chromic anhydride solution for a few minutes is also efficacious, particularly on polished skins.

Chemical Cleaning of Magnesium Alloys

A solution of 10% by weight of chromic acid in distilled water with 0.1 % sulphuric acid added is a satisfactory chemical for removing corrosion products from magnesium alloys. The solution should be brushed over the corroded area, working it well into pits and crevices, and should be left for about 5 minutes. It should then be rinsed off with clean water. Reference should be made to the requirements of specification DTD 911.

Note on Mechanical Cleaning

Although mechanical cleaning is often necessary when preparing fabricated parts for anti-corrosive treatments, its use should be restricted during maintenance work on complete aircraft.

a. Steel and non-clad aluminium parts should be rubbed down with fine 'wet' glass paper in preference to emery papers. Wet sanding methods are more efficient, as water acts as a lubricant and permits a finer grain to be used; the rubbing should be in the direction of the working stress.

b. Castings, forgings and extruded members can be hand scraped to blend out corrosion pits. Steel carbide tipped scrapers are recommended and should be used so that pits are transformed into saucer-shaped depressions which relieve stress concentration. Afterwards the depth and area of the depressions, and the total number per unit area of surface, should be assessed to ensure that the material has not been unduly weakened.

c.   Light abrasion is sometimes helpful in removing heavy deposits from skin panels. Pumice powder applied with a solvent-moistened cloth is generally satisfactory. If clad aluminium alloy sheet is cleaned by this methods, a simple test with caustic soda should be made afterwards to determine whether sufficient aluminum remains to protect the alloy core. If the surface layer of pure aluminium has been rubbed off, a spot of dilute caustic soda solution will turn the surface black. After making the test the caustic soda should be thoroughly washed off.

TREATMENT OF COMPONENTS
The information in this paragraph relates to component parts which can be removed for immersion treatments.

Degreasing
The trichloroethylene vapour method is satisfactory for most aircraft materials, but in cases of heavy contamination the following alternative may be used:

Aluminium Alloys
Mild alkaline baths effectively remove grease from aluminium but the baths should be inhibited to limit attack on the metal. A satisfactory bath can be prepared from a 4-5 % w\v (36 to 48 g\ litre (6 to 8 oz\ gal)) of a mixture of crystalline trisodium phosphate and sodium metasilicate in proportion between 2:1 and 1:2 w\w (if anhydrous trisodium phosphate is used , the proportion will be between 1:1 and 1:4) with or without a suitable wetting agent.

Steels
The immersion pickling processes will remove residual grease as well as rust, scale and other surface dirt. However, cleaning with trichloroethylene or other solvents is necessary prior to pickling.

Magnesium Alloys
Sometimes pickling in a 5 to 10 % solution of concentrated nitric acid in water is recommended for castings and parts which are not machined to close tolerances. The electrolytic-fluoride process will also remove corrosion products and has the further advantage that the fluoride film created on the surface is, to a certain degree, corrosion-resistant.

Pickling Processes
The following immersion processes are of value in preparing metal parts for subsequent protection treatment. Their action is generally twofold: they remove corrosion products and the residue of original treatments, and to some degree they etch the treated surfaces to provide a better key for organic protective.

Aluminium Alloys
Treatments should be selected to suit the nature of the parts and to prepare them for the finish specified in the drawings or repair scheme. Some suitable processes for the preparation of clad sheet for painting are described in DEF STAN 03-2; they are for use as an alternative to etch primers. When proprietary processes are used the Manufacturer's instructions should be carefully followed to ensure that the fatigue resistance of the metal will not be lowered.

a.   **Chromic-sulphuric Acid Process**
      After degreasing and rinsing the parts, they should be immersed for approximately 20 minutes in one of the alternative solutions given below. The temperature of the solutions should be maintained between 43 to 65 $^\circ$ C (110 to 150 $^\circ$F). This process should not be used for spot welded or riveted assemblies but is satisfactory for castings, forgings, extrusions, etc., provided they are thoroughly rinsed and dried afterwards.

Solution 1	Sulphuric acid (Sp.Gr. 1.84)	15 % by volume
	Chromic acid (CrO_3)	5 % by weight
	Water	Remaider
Solution 2	Sulphuric acid (Sp.Gr. 1.84)	15 % by volume
	Sodium bichromate	7 1\2 % by weight
	Water	Remainder

b.   **Phosphoric Acid Processes**
      The constituents of an alcoholic-phosphate wash are given in paragraph before; this solution can be used in a mild steel tank to pickle aluminium alloy components. A variety of proprietary solutions containing phosphoric acid are also available; some of these build up a thin phosphate film which provides a good base for painting. However, a distinction should be made between phosphoric acid processes which create phosphate films and those which only clean and etch. The proprietary cleaning processes listed in DTD 900 include Titanine metal degreasing paste, Jenolite AKSI etching compound and the ICI Deoxidine process 202. These are materials which can be brushed over aluminum assemblies surfaces thoroughly after treatment, drying carefully after washing. Deoxidine 170 is a hot dip process which is suitable for both steel and aluminium alloy ; another

treatment not covered by the specification is Deoxide 125 which can be applied to both these metals by fold dipping or by brushing. If any of these treatments are applied by brush, all crevices and seams should be blown out with compressed air before proceeding to paint the treated area. Painting should follow promptly since none of these treatments builds a resistant film.

c.   Chromic-phosphoric Acid Process

After degreasing and rinsing the parts, if specified in the Maintenance Manual or other appropriate instructions, they should be immersed in a near-boiling aqueous solution as follows, for 20 minutes, if of sheet material, or up to 1 hour if cast.

Chromic acid (CrO_3)	0.75-1.0 % w/v
	[7.4 - 9.9 g/litre (1.2-1.6oz/gal)]
Phosphoric acid (Sp.Gr. 1.75)	0.5 - 0.75 % v/v
	[5 - 7.4 cm^3/litre [0.8-1.2 fl.oz/gal)]

NOTE

The use of Deoxidine 624 followed by Alocrom 1200 is recommended. Alocrom 1200 or other similar conversion coating treatment should be used after pickling processes (particularly phosphoric acid) prior to painting, except when etch or wash primers are to be used.

Steels

The chemical treatments for steel can be divided into two main groups. Pickling is a process in which acids are used to remove rust and scale so that a chemically clean surface is produced which requires immediate protection to safeguard from further corrosion. In contrast, phosphoric acid processes, in addition to de-rusting, coat steel surfaces with insoluble phosphate films which confer a measure of protection and form a good base for paint.

NOTE

Phosphating processes should only be used on aircraft parts if cadmium plating is impracticable.

a.   Pickling Solutions

Information on the pickling of steels is given in DEF STAN 03-2 , which specifies solutions of 10% hydrochloric acid in water or 10 % sulphuric acid in water. Since immersion in these solutions causes hydrogen absorption, heat-treated steels of more than 1004 MN/m^2 (65 tonf/in^2) ultimate tensile stress (UTS) should only be pickled by the electrolytic method given in paragraph (b) below. The danger of blistering and embrittlement of other steels due to hydrogen entering the metal can be reduced by adding inhibitors (such as quinoline ethiodide) to the acid, but if inhibitors or wetting agents are used the parts should have a final dip for not more than 2 minutes in an acid solution free of such substances. After immersing parts in dilute acid solutions they should be rinsed in clean water and dried. Limited brittleness can be reduced by heat treating the steel at 150 to 200 $^\circ$ C.

b.   Electrolytic Pickling

The advantages of this method are twofold. Chemical cleaning is assisted by the evolution of oxygen of the surface of the metal and, as hydrogen is only produced on the cathode, no embrittlement occurs. An electrical bath is required containing a solution of 30 % by volume of concentrated sulphuric acid in water, to each litre of which can be added 18 g of potassium dichromate (3 oz\gal). With the part as the anode, a current density of 1000 amps/ m^2 (100 amps/ft^2) should be applied for approximately 5 minutes, after which the part should be rinsed in clean water and thoroughly dried.

c.   Phosphating Processes

Certain commercial phosphoric acid treatments, such as Waterisation, Jenolising and Bonderising, are approved for aircraft use by the provisions of DTD 900. These processes should be considered as foundation treatments for painting and not as reliable anti-corrosive measures in themselves. To obtain satisfactory phosphate films they should be applied in accordance with the instructions issued by their Manufacturers.

NOTE

Some laboratories state that electrolytic pickling of steels does produce embrittlement in high tensile steels, and that heat treatment is necessary afterwards for steels above 1004 MN/m^2 (65 ton/in^2) UTS. If plating is to be carried out, the heat treatment should follow that process as soon as possible and, in any event , within 2 hours.

ASSESSMENT OF CORROSION DAMAGE

After removing paint, greases and corrosions products, the affected parts should be examined to determine whether their strength has been lessened beyond permissible limits. Pitting may cause local stress concentrations which may seriously impair both the static and the dynamic strength of thin sections whilst surface corrosion, without causing pitting, can lower the fatigue strength of load-bearing members. Cleaning operations often cause an appreciable reduction in cross-sectional area which must also be considered when evaluating the decrease of strength.

NOTE

A corrosive attack on a structural member will cause a reduction in strength out of all proportion to the reduction in thickness of the member; this should be borne in mind at all times when assessing corrosion damage and particularly when light gauge construction is involved such as a pressurised skin structure.

Skin Panels

Corrosion damage to aircraft skins should be classified as negligible according to the extent, depth, loading and location of the damage. It is not possible to give a general rule for classification based on the percentage reduction of skin gauge or the number of pits per unit area, as the load distribution through the affected panels must be considered. It is therefore essential to consult the approved repair scheme for the aircraft concerned. Some general guidance on the assessment and rectification of damage is given in the following paragraphs. It must be appreciated, however, that all pervious corrosion rectification must be taken into consideration.

If no pronounced pitting or roughening of the skin is evident after the removal of corrosion products, it is usually satisfactory to re-protect the part by applying the appropriate finishing scheme .

Skin panels which have a rough and pitted surface after the corrosion products have been removed should be smoothed down with fine grade wetted sandpaper. The minimum reduction of cross-sectional area consistent with the blending out of jagged pits should be the aim. After smoothed down with fine grade wetted sandpaper. After smoothing the minimum skin thickness in the affected region should be computed by measuring the depths of the deepest depressions.

NOTE

Where access is difficult, radiological and \or ultrasonic examination techniques are often prescribed to determine the presence or extent of a corrosive attack. In some instances, however, such as at faying surfaces of stringers to skin panels, dismantling of specified parts of the structure has been found necessary as the only means of ensuring adequate inspection.

If the damage exceeds the general limits specified by the Manufacture as negligible but is not thought to be of such a severs nature as to warrant renewal of the whole panel affected, the Manufacturer may, in some instances, issue a repair scheme whereby the original strength of the panel can be restored by the addition of local reinforcements.

If the smoothing down of corrosion damage would reduce the thickness of skin panels or similar components beyond permissible limits, they should be renewed. During removal the condition of rivets and faying surfaces should be examined. If these show signs of corrosion, repairs will be necessary over a wider area than that indicated by the extent of the surface damage.
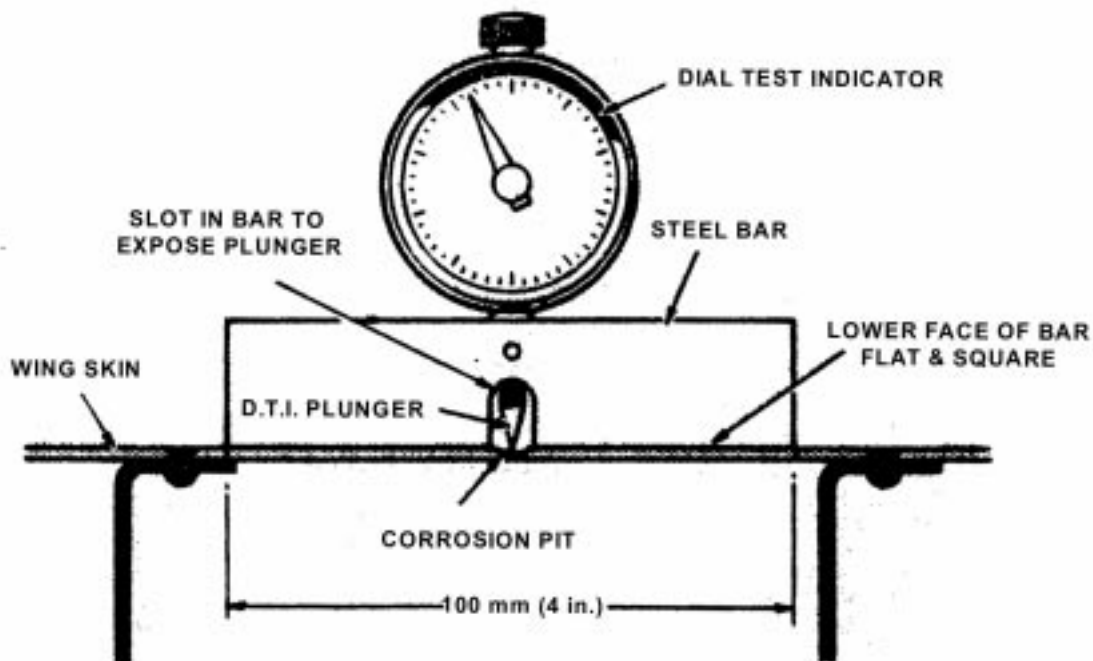
Fig. 15.1, Assessment of Skin Panel Corrosion

Load-bearing Members

The effects of corrosion on the strength of main load bearing members can be serious. It has been clearly established that the fatigue life of wing spars can be drastically shortened by corrosive attack and these member should therefore receive the most careful attention during periodic inspections.

The inspection of spars is often rendered difficult because of limited access to the interior of the wing structure and because portions of the spar are obscured by electrical cable installations, fuel pipes, control mechanisms, etc. Special optical aids to facilitate inspection should be used to detect corrosion and, after its removal, to assess the damage it has caused. Areas affected by pitting should be checked for cracks by the penetrant dye method

Serious cases of spar corrosion should be reported to the Manufacturer of the aircraft. If minor corrosion is discovered, rectifications should be possible in accordance with the approved repair manual for the aircraft.

When specified in the appropriate publication or at other times at the discretion of the inspector, a selection of the main assembly bolts should be removed and examined for sign of corrosion. The aircraft structure must be adequately supported to prevent strain and distortion before the bolts are removed Before replacing assembly bolts they should be magna-flux tested and the bolt holes should be carefully inspected for evidence of attack on the surrounding material. If cadmium has been removed from the bolts, they should be replated before replacement and at all times jointing compound should be applied immediately before insertion, in accordance with the appropriate instructions.

NOTE

The inspection of bolt holes is a matter of great importance but often of usual difficulty. Pits and cracks tend to be concealed by corrosion products, which are forced into them as the bolt is extracted. If the hole is reamed before inspection, the reaming action tends to close the edges of cracks; the hole should therefore be inspected both before and after reaming. In some cases satisfactory results may be obtained by cleaning the hole with a round bristle brush using the mixture of white spirit and naphtha . After cleaning it may be possible to adapt the penetrant dye or fluorescent method of detection to the particular job, using an endoscope or a light probe in the bore of the hole. The eddy current method of examining bolt holes is effective and is often used where inspection by optical means is impracticable.

Tubular Members

Welded steel or aluminium alloy tubes used in aircraft construction are usually thin-walled and can therefore be seriously weakened by corrosion . Although external corrosion can be seen during inspection, internal corrosion may remain undetected until the tube is so weakened that failure occurs. For this reason it is essential that tubes are protected internally during assembly and sealed to prevent accumulation of moisture. Open-ended tubes should be protected internally and externally by the same method.

There is no completely reliable method of determining whether a sealed tube is corroded internally, short of cutting it open, but ultrasonic and radiological methods of examination will give an indication of reduction of thickness.

During assembly or after repair the interior of sealed tubes should be flushed with a protective material and reference should be made to the Manufacturer for the appropriate one to be used. Some such corrosion inhibitors are hot linseed oil, lanolin or zinc chromate pigmented lanolin to specification DTD 279 being particularly suitable. The flushing liquid is normally introduced through small holes, for which the appropriate design approval should first be obtained, drilled in the tubing. Surplus liquid should be drained off through suitable drain holes. It may be possible as an alternative, to remove an existing bolt or rivet ensuring that the hole is not enlarged. When sufficient liquid has been introduced to give a good coating, the holes should be plugged to exclude air or moisture.

NOTE

(1)   If, for any reason, the above procedure cannot be carried out, the danger of corrosion will be greatly reduced if the enclosed air is dry and the tube is effectively sealed against the ingress of moisture. The interiors of steel tubes can be further safeguarded by the introduction of a Vapour Phase Inhibitor . Marketed in powder form, vapour inhibitors consists of stable organic nitric compounds which release corrosion-inhibiting vapour at a slow rate. The vapour will prevent corrosion even when oxygen and moisture are both present.

(2)   During maintenance and overhaul, radiological methods of examination are sometimes used for the detection of damage in tubes of relatively thin cross section. This method will show changes in sectional thickness when corrosion is present and, with the correct technique, some idea of the depth of the corrosive attack can be obtained. Similarly, in some instances where tubular members are made of heavy gauge, ultrasonic methods of examination will give an indication of local reductions in thickness.

General

Components which are not part of the structure can usually be removed for anti-corrosive treatment. If items such as pumps, valves and electrical equipment are found to be corroded, rectification appropriate to the particular material and its duty should be made. Reference to the relevant Manufacturer's publications for the aircraft concerned should be made at all times. Some points of special interest are listed below.

Doped fabrics in contact with painted metal surfaces sometimes cause the paint to deteriorate with the result that the metal is attacked. The metal should be protected by the application of a dope-resisting paint on top of the normal finish.

A method of protecting seaplane floats is to tie bags of potassium or sodium dichromate to the keelson so that the dicromate permeates the bilge water.

Light alloy tanks containing leaded fuels should normally be protected by corrosion inhibitor cartridges. Typically, these cartridges consist of strontium chromate or calcium chromate tablets contained in a linen bag. It is a requirement with such cartridges that the linen bag should be thoroughly wetted with water before installation, and after tank repair operations.

When locking wire is used, it should be of a material which will not cause electro-chemical reaction with the part locked.

Control cables should be protected after installation, and at intervals, by applications of rust-preventing compounds. Lanolin-resin compounds or preparations containing zinc chromates are sometimes recommended; theses should be diluted and applied so as to ensure penetration of the compound between the strands of the cable whilst avoiding an excess accumulation which would cause stickiness of controls in fairleads and pulleys.

NOTE
British Standards W9 and W11 call for a lubricant to be applied during the spinning of cables. It is therefore important, when cleaning these cables, not to wash out the lubricant by saturating the cables with a grease solvent.

During assembly and repair, dissimilar metals should be insulated form each other unless there are overriding structural and functional considerations. Corrosion-inhibiting sealing compounds should be applied wet between all faying surfaces immediately prior to assembly : solutions containing zinc or barium chromate are generally used. Most of the proprietary materials and processes are to be found in specification DTD 900. The compound should be applied in sufficient quantities to cover all contacting faces and to cause a small quantity to be squeezed out at the boundaries to form sealing fillets. Where special compounds are used for particular purposes. e.g. to seal pressure cabins or integral fuel tanks, they should be used to insulate dissimilar metals in addition to forming a seal.

NOTE
Unsatisfactory results will be obtained if inhibiting jointing compounds are kept in open containers which allow the compound to become semi-dry before application. This trouble can be avoided if the compound is supplied in squeeze-tubes, from which it can be directly applied to the joint.

Metal parts in contact with wood should be treated with the prescribed compound before assembly, in order to prevent corrosion due to moisture in the wood.

Protective Treatments
Metal surfaces (on other than stainless steels and un-alloyed titanium) should never be left unprotected after cleaning or repair. Where practicable the original protective treatment should be restored. In other cases alternative treatments suitable for application during maintenance work may be authorised.

CHAPTER:16
CORROSION-METHODS OF PROTECTION

INTRODUCTION

This chapter gives guidance on the selection and application of protective treatments to safeguard aircraft from corrosion. When re-protecting aircraft, reference must be made to the appropriate Manufacturer 's publications for guidance on the anti-corrosive treatments specified for the aircraft concerned. Reference should also be made to the latest issues of the relevant British Standards and Ministry of Defence DTD Specifications when these are quoted.

PREVENTION OF CORROSION

Protection against corrosion can be provided in a number of ways. Some of the principles involved are briefly summarised in the following paragraphs.

Choice of Metal

Certain metals and alloys have a high natural resistance to corrosion. This applies to the noble metals because they have a low affinity for oxygen and other nonmetallic elements, but the resistant materials which are used in aircraft construction, e.g. stainless steel and aluminium , owe their properties to thin films of oxides which protect the metal from further attack. However , because of strength or weight considerations, many aircraft parts cannot be made of 'self-protecting' material and hence require anti-corrosive treatment.

Passivity

In certain conditions metals and alloys commence to corrode and the initial products of corrosion form protective films which limit further attack. Natural passivity is sufficient protection for pure aluminium and the stainless steels, but passivity has to be produced under controlled conditions to be of value for aluminium alloys. The anodic treatment is a form of artificial passivation.

Surface Finish

The oxide films on non-stainless steels do not become passive but corrosion-resistance can often be greatly increased by careful attention to mechanical finish. Thus some internal engine parts are highly polished but otherwise are only protected by a coat of clear varnish.

Chemical Inhibition

One of the most widely used methods of protection is to treat the metal with chemicals which inhibit or stifle corrosion and so artificially induce a form of passivity. The phosphate process for steel and the chromate and fluoride treatment for magnesium alloys are inhibiting treatments. Paints and primers usually contain inhibiting substances to increase the effectiveness of the protection they offer. It should be appreciated, however, that the inhibiting treatments are temporary and that the full treatment will include oil or paint films .

Sacrificial Protection

When two metals of different electric potential are in close contact, the elements of a voltaic cell are established and the metal which is anodic to the other may be preferentially attacked. This principle is often deliberately applied to protect constructional materials . For example, cadmium and aluminium coatings protect steel because these metals are anodic to steel ; at the same time the protection they render is long-lasting because they corrode at a much slower rate than steel. Similar protection is extended to aluminium-alloy sheet when it is clad by surface coats of pure aluminium; this protection is effective even at the sheared edges and where holes are drilled.

Mechanical Protection

Corrosion can be prevented by excluding water, oxygen and corrosive chemicals from the surface of the metal. This form of protection is the basis of most organic coatings, such as varnishes, paints and enamels, which are applied on top of inhibitive priming coats. To be effective the coats should be as watertight as possible, but, since even the best paint coats only delay rather than prevent the ingress of water, periodic re-protection is essential. Metallic coatings applied by spraying, dipping or electro-deposition may also give satisfactory mechanical protection.

TREATMENT OF AIRCRAFT PARTS

It is the responsibility of Approved Design Organisations to specify the forms of protection to be used during the manufacture of each particular type of aircraft. During the operational life of the aircraft the original treatment should be renewed when necessary, but where this is impracticable a suitable alternative method should be specified.

Chemical and Electro-chemical Treatments

Treatments in this category are those which strengthen the natural oxide film of the base material or which convert the metal surface chemically to a protective coating of phosphate, chromate, etc. The most satisfactory results are usually obtained by immersion treatments but where these are impracticable brush-on applications can often be used. In the following paragraphs the standard immersion treatments for the principal aircraft constructional materials are given, together with brush-on substitutes which can be used for repair or in emergencies.

Steel

The majority of chemical treatments for steel involve the formation of phosphate films. Proprietary immersion and brush-on applications, if approved under the provision of the latest issue of DTD 900, can be used to inhibit corrosion and to form a base for painting steel parts which cannot be protected by metallic coatings. Certain process can be followed by immersion in mineral oil to render them suitable for moving parts; the phosphate coating absorbs the oil and provides a wear-resisting surface. Chemical treatments do not provide adequate protection for steel if used alone; further corrosion-proofing, e.g. painting, is usually specified.

Aluminium and Aluminium Alloys

The most satisfactory chemical treatment for these materials is anodic oxidation. Unless clad with pure aluminium, the majority of aluminium alloy parts are anodised. Anodised structural components usually receive further protection from priming and paint coats.

a.   There are a number of proprietary processes which increases corrosion resistance and improve the adhesion of paint to aluminium and aluminium alloys. They are mostly simple chemical processes in which the parts are immersed in hot solutions of salts for periods of up to 10 minutes. It is not essential to apply paint immediately after the application of such processes as Alocrom or Walterisation L, as these render the surface passive ; on the other hand it is undesirable to leave the treated surfaces so long that they become dirty before being painted.

   ### NOTE
   Processes which merely pickle the surface of aluminium-alloys , such as the Chromic-Sulphuric acid treatment of Speechification DEF 130 and the Deoxidine treatments, do not protect against corrosion and should be followed immediately by priming and painting.

b.   Films can be produced by the application of pastes to parts in situ, e.g. Alocrom 1200; they are not as satisfactory as films produced by immersion treatments but are useful for items not exposed to weathering or abrasion.

Magnesium Alloys

The immersion processes are all chromating processes but local repairs to protective films can be effected by the Alocrom 1200 chromate conversion by swab method. Another method of protecting these alloys is by the electrolytic fluoride method known as "Fluoridising ". This involves anodising the components in a solution of ammonium fluoride. It is a particularly effective method for the removal of moulding contaminants and for restoring corrosion resistance which may have been reduced by processes such as shot or grit blasting. The process consists of applying a.c. current when the items are immersed in the solution, the voltage being gradually increased to a value of 100 volts. The current falls proportionately as impurities are removed from the surface of the magnesium alloy and a thin coating of magnesium fluoride is formed. This coating has a protective value about equal to that of a chromate film and forms a good paint base. To obtain satisfactory results, full details of the process should be obtained from the Manufacturer.

Zinc Coated Components

Metallic coatings of zinc are sometimes used to protect steel parts, but zinc coatings tend to corrode rapidly unless rendered passive. After plating with zinc, the chromate passivation process described in DTD 923 should be employed.

Metallic Coatings

The protection of one metal by the application of a surface coating of another of greater corrosion resistance is common practice. Thus, aluminium-alloy sheet used in aircraft construction is usually clad on both faces with thin layers of pure aluminium rolled on during manufacture. Steel is protected by a greater variety of methods, the more important of which are summarised below.

Cadmium Plating

The electro-deposition of cadmium provides the most satisfactory form of protection for AGS and other parts of non-stainless steel. It is the standard anti-corrosive treatment for streamline wires, tie-rods and similar parts which are not usually painted. Where steel bolts and other parts are in close contact with light alloys, cadmium plating greatly reduces the danger of corrosion resulting from the proximity of dissimilar metals; it has been found that this is so even when the cadmium coat is scored or partially rubbed off. Cadmium plating can be applied to close dimensional limits and is suitable for the protection of closely fitting attachment bolts. The relevant British Standards for cadmium plated bolts with close tolerance shanks are A59 and A111, and for shear bolts A60 and A112.

NOTES

1.   It should not be assumed that stainless steels in contact with aluminium alloys are unlikely to promote inter-granular corrosion or corrosion fatigue. For this reason it is advisable that they too should be cadmium plated, but a special technique is essential to ensure good adhesion of the cadmium. A plating technique is essential to ensure good adhesion of the cadmium. A plating technique that is suitable for some specifications of stainless steel involves degreasing, anodic pickling in dilute sulphuric acid , the deposition of a preliminary coating of nickel and, finally cadmium plating by the usual method.

2.   Further protection by painting is not usually necessary on interior cadmium plated parts but, if it is specified, the cadmium coating should first be passivated by the process given in Specification DEF 130 or an etch primer should be used.

Nickel and Chromium Plating

These two metals are electrically deposited in a similar manner to cadmium; nickel-plating is cathodic to steel but will give good corrosion resistance if the coating is uniform and free from discontinuities. It is used for some turbine parts which are subjected to fairly high temperatures, and for the protection of many springs. Chromium is sometimes applied directly to the steel parts of aircraft as an anti-corrosive treatment and sometimes is deposited on top of nickel plating to improve appearance. Chromium plating is also used to resist wear in some engine cylinders, landing-gear shock-struts, jack rods, etc.

Metallising

Aluminium, zinc, cadmium and certain other metals can be sprayed directly on to steel from special pistols. The metal is fed into the pistol as a wire or a powder and is melted by an oxyacetylene flame. Compressed air then blows it in the form of tiny molten globules on to the surface to be coated, where it solidifies. Spray coats of aluminium are applied to engine bearers, steel tube assemblies, combustion chambers, etc.   Some of these items are afterwards painted but this is not always necessary.

Flame Plating

This process, similar to some metallising, is carried out on many aircraft part which are subject to wear by fretting, particularly engine components such as compressor and impeller blades, combustion chamber parts and seals. It is sometimes applied to hydraulic pumps and motors. Briefly, the process consists of a charge of powdered tungsten carbide, chromium carbide or similar hard material, suspended in an oxygen\acetylene mixture in the breech of a special gun. The mixture is detonated and the particles become plastic; they are then blasted on to the areas being coated. This is repeated until the entire surface is coated to the required depth. Stripping of worn coatings can be carried out and new coatings applied, and thus the life of expensive components is considerably extended.

Powder Processes

Metal coatings of zinc and aluminium can be produced by packing steel parts, after sand blasting, in suitable mixtures containing the appropriate metal and heating them in sealed containers to specified temperatures. The application of aluminium by this method is known as Calorising. Sheradising, covered by BS 4921, creates a coat of zinc-iron alloy on steel parts.

Replating Local Areas

Local repairs to damaged metallic plating, and the deposition of metals in places where accessibility is limited. Can be accomplished by certain plating processes without immersion in a plating bath. The part to be plated should be made cathode by connecting it to a d.c. power unit. The electrolyte is brushed over the metal surface by an absorbent pad attached to the end of a graphite anode ; the anode, which is called a "tampon " , is air or water-cooled according to size. Plating solutions and current densities should be selected according to the Manufacturer 's recommendations. Cadmium, copper, zinc, tin, etc., can be deposited very rapidly by this method.

Organic Coatings

Paints, varnishes and enamels protect metals by inhibition, by mechanical exclusion of corrosion influence, or by a combination of both these methods. Before application, the metal surfaces should be cleaned and pre-treated to provide a good key for the paint; Mechanical roughening, chemical etching, chemical film formation or preliminary deposition of metal coating should be in accordance with approved practice for the materials concerned. Reference should always be made to the relevant aircraft Manufacturer for details of the organic coating scheme to be applied to a particular aircraft.

Priming Coats

Most aircraft painting schemes commence with the application of a primer containing an inhibiting chemical such as zinc chromate. The majority of primers are air drying, but when a stove enamel finish is specified the priming coat is also stoved (BS X 31). Primers can be directly applied by brush or spray to aircraft parts in situ, but dipping is sometimes preferred for detachable items. Primers to suit the wide range of finishing schemes covered by the Ministry of Defence

Process Specification selected is appropriate to the particular job. When painting certain aluminium alloy structures it is sometimes advantageous to use etching primers which obviate the need for preliminary etching by Deoxidine and similar chemicals.

Cellulose Finishes

Cellulose finishes are specified for many individual components of civil aircraft as well as for the exterior finishing of metal-skinned aircraft, as they give finishes which have good adhesion and resistance to weathering. Although the best results are obtained by spraying on top of a suitable primer, one-coat applications direct to pre-treated aluminium or aluminium-clad alloys have sometimes been used.

Synthetic Finishes

A number of external finishing schemes for the metal surfaces of aircraft are based on the use of pigmented oil varnishes or pigmented synthetic resin finishes. The relevant British Standard is BS X 28 and the Ministry of Defence Specification is DEF 1044. The majority of finishing schemes are tow-coat treatments; the pre-treated metal surface is given a brush or spray coat of the primer application to the scheme and , after the primer has dried, spray coat of the primer applicable to the scheme and, after the primer has dried, the finishing coat is applied by spray. Synthetic finishes should only be thinned with approved thinner (DTD 96); thinner for cellulose paints and dopes are generally unsuitable. As a general rule priming coats require a longer drying period for synthetic finishes than for cellulose finishes.

Lanolin-resin Finishes

Lanolin-resin preparations to Specifications DTD 279 and 633 are brush, spray or dip treatments which remain soft for considerable periods and are only occasionally applied to parts of aircraft in service. They have a limited application for the protection of marine aircraft. DTD 420 covers a range of matt pigmented lanolin-resin finishes suitable for use on metal surfaces exposed to sea water. Generally, two-coat finishes applied by brush or spray are recommended.

Stoving Finishes

Stoving enamels generally have a much higher degree of resistance to abrasion than air-drying finishes and are therefore used for some power-plant components and certain airframe parts which are not adversely affected by stoving temperatures. For maximum durability, two-coat schemes are recommended. High temperature stoving finishes, such as those covered by DTD 56, generally consist of two coats of enamel, each of which is baked separately; low temperature finishes, whether proprietary or to BS X 31, usually consist of a preliminary priming coat which is baked first, followed by application of the enamel and further stoving.

NOTE

There are some kinds of enamel, e.g. the synthetic glossy black enamel specified in DEF 1044, which can be either air dried o r stoved. The principal advantage of stoving is that it shortens the drying time.

Epoxide Finishes

Interior and exterior protective finishing schemes of the cold curing epoxide type are now frequently used. There are three schemes: Scheme 1 consists of etch primer, filler and finish or epoxy primer, filler and finish ; Schemes 3 consists of etch primer, epoxy primer and finish. Details of the schemes are covered in Specification DTD 5555 whilst the requirements for the materials are detailed in Specification DTD 5567.

Special Fuel Tank Treatments

Special sealing and anti-corrosion treatments are often given to fuel tank structures. In certain instances where there are undrainable areas, these are filled with a light 'void' filler, to prevent the formation of stagnant water pockets in which microbiological growths can form. Basic structural components are chemically treated, e.g. Alocrom 1200, etc., and in assembly all joints are inter-layed with a sealant such as Thiokol PR 1422. After assembly, all joints are brush-treated with rubber sealant compound such as Buna-N (EC 776) and PR 1005 L, and some tanks are then given a final 'slushing ' treatment with Buna-N in the tank, to impart a uniform protective final 'slushing' treatment with Buna-N in the tank, to impart a uniform protective film on all inner surfaces. The tank (or structural assembly) is slowly rotated in a special rig, and this ensures that the protective film is free from pinholes. Reference should always be made to the relevant aircraft Manufacturer for the appropriate treatment for any particular aircraft.

TESTING PROTECTIVE TREATMENTS

The efficacy of a protective treatment depends on its nature, its adhesion to the surface of the base metal, its thickness, its uniformity and its chemical stability. In many cases the only guarantee of satisfactory protection lies in close control of pre-treatment, but sometimes it is necessary to test the treated part, or an equivalent test piece, to ensue that the specified properties have been obtained. It is, advisable to consult the relevant aircraft Manufacturer for the preferred methods.

Chemical Treatments

There is no simple and reliable test for chemically produced films, since they are usually too thin to permit measurement of the thickness of deposits by checking the gauge. Parts on which phosphate films have been produced should be inspected for colour; a finely crystalline grey surface is required, as coarse or sparkling films indicate inadequate cleaning or wrong bath composition. Chromate films on magnesium alloys are judged by their colour .

Anodic Treatment for Aluminium Alloys

Two practical methods of testing anodic films, are the methyl violet test for sealing and the electrical potential test. The average thickness of anodic films can be checked by the method given in B S 1615, in which a test piece with a surface area of not less than 32 cm^2 (5 in^2) is anodised and then stripped in a boiling solution of phosphoric acid and chromic acid in distilled water. The test piece should be immersed until constant weight is obtained, the loss of weight being taken as the weight of the anodic film.

NOTE

Eddy current instruments are available and can be utilised to gauge anodic films.

Coating Thickness Measurement

The thickness of conducting or non-conducting coating on ferrous or nonferrous bases can be measured using basic eddy current methods, although measurement becomes difficult where the conductivity of the coating and base metal are similar. When measuring thin coatings it is recommended that equipment designed specially for coating thickness measurement should be used.

Electro-Plated Coatings

The British Non-Ferrous Metal Research Association has devised a standard test for the inspection of elector-deposited metallic coatings; the BNF Jet Test is for local thickness measurements and has the advantage over other chemical methods in that it gives the thickness at any desired point . An adhesion test for the detection of local non-adherence of metallic coatings is given in BS 1224, Appendix C.

The BNF Jet Test

The apparatus for conducting this test is illustrated in Figure 16.1 The separating funnel should be filled with a reagent solution appropriate to the nature of the metal; suitable solutions for testing cadmium and zinc coatings are given below. The test should be made as follows:

a.   The article to be tested should   be clamped   so that the surface under test is at an angle of about 45 ° to the horizontal and about 6 mm (1\4 in) below the tip of the jet.

b.   Jet Test solutions for cadmium and zinc coatings are :

	Cadmium	**Zinc**
Ammonium nitrate	17.5 g	70 g
N\1 Hydrochloric acid	17.5 ml	70 ml
Distilled water to produce	1 litre	1 litre

c.   The tap should be opened and, simultaneously, a stop-clock should be started. At the end of 5 to 10 seconds, the tap should be closed and the clock stopped simultaneously and, without moving the specimen, the test piece should be examined for penetration.

d.   The process in (c) should be repeated until the first sign of penetration is seen below the jet. The total time of impingement is taken as a guide for a further test in which the reagent is allowed to run continuously until the end-point is nearly reached.

e.   The temperature of the solution and the total time for penetration are the data from which the thickness is calculated. The time required for a particular penetration at the temperature of the test should be obtained from curves supplied by the Manufacturer of the test apparatus and the total time of penetration should be divided by this time.
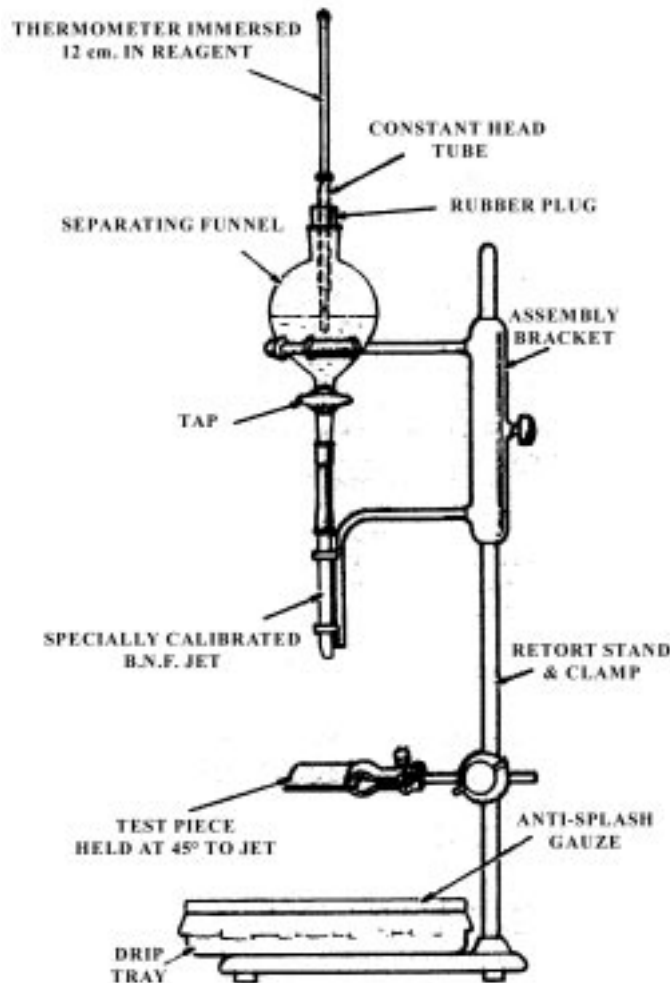
Fig. 16.1, Apparatus for BNF Jet Test

Test for Determination of Adhesion

An area of $6\,cm^2$ ($1\,in^2$) of the plated surface should be rapidly and firmly rubbed for 15 seconds with the smooth edge of a metal implement such as a copper coin, the pressure being sufficient to burnish the film at every stroke without cutting into it. If inspection then shows no detachment of the deposit, the adhesion is satisfactory. A blister which grows with the rubbing indicates poor adhesion; splitting and peeling of the deposit shows it to be of inferior quality.

Organic Finishes

The standard method of testing the corrosion-resistant properties of paint, varnish, lacquer and related products is by means of the salt spray test specified in Method No. 24 of Ministry of Defence Specification DEF 1053. The apparatus for making this test is shown in Figure 16.2 . It consists of a glass tank with a close fitting lid in which a salt mist is produced by spraying the test solution through an atomiser. Test panels, the preparation of which is given in detail in Method No. 2 of the specification, are painted with the finish under test and are then supported on nonmetallic supports with their test faces upwards. They should be at approximately 15^0 to the vertical in the tank so that they will be evenly coated with droplets of solution. But the spray must be prevented by a baffle from impinging directly on to the test faces. The salt solution drained from the panels should not be re-circulated. The composition of the solution should be as follows:

Calcium sulphate (CaSO 4)	1.3 g
Magnesium chloride (MgCl 2)	2.6g
Magnesium sulphate (M gSo 4)	1.7 g
Sodium chloride (NaCI)	21.4 g
Water (distilled)	1000 ml

Test panels are normally exposed for periods of 10 days, at the end of which period they should be removed, washed in running water and dried with absorbent paper. Any deterioration in the paint film should then be noted, after which a strip 150 mm x 50 mm (6 in by 2 in) should be cleaned off with a suitable paint remover to permit inspection of the underlying metal for corrosion.

NOTE: When required, the thickness of paint coats can be gauged by using the electrodes of a capacitance-type proximity meter. This method is applicable whether the base is ferrous or nonferrous. Eddy current (for nonferrous bases) and magnetic (for ferrous bases) thickness meters are now in use. They are not greatly affected by permeability or curvature of the base material and may be used on organic or metallic coatings.

EXTERNAL FINISHING OF AIRCRAFT
Finishing schemes for metal-skinned aircraft are selected to provide the maximum of corrosion protection with the minimum weight of paint. Adherence of finish, effect on aircraft performance and appearance are also important; therefore, verification of the scheme used should be obtained from the relevant aircraft Manufacturers.

Surface Finishes
Cellulose or synthetic finishes give satisfactory protection if applied on top of suitable primers. After pre-treatment the metal surface should be finished in accordance with a recognised scheme; for the best results it is advisable to use compatible primers, undercoats and finishing coats from the same Manufacturer. Polyurethane and acrylic finishes are now widely used in some modern aircraft, whilst others utilise epoxy paint and epoxide primers.

Retouching Local Areas
It is not always necessary to clean down to the bare metal before touching up a damaged finish but this is advisable if there is any evidence of flaking or blistering. The area should be flattened down with 'wet' sandpaper or with pumice powder applied with a damp cloth. The edges of the area should be feather-edged. If stopping is required, the stoppers should be applied with a knife. The priming coat should then be sprayed on using a round instead of a fan spray and spraying from the feather-edge inwards. The same technique should be used for the finishing coat, for which it is advisable to adjust the spray gun to give a finer spray than usual.
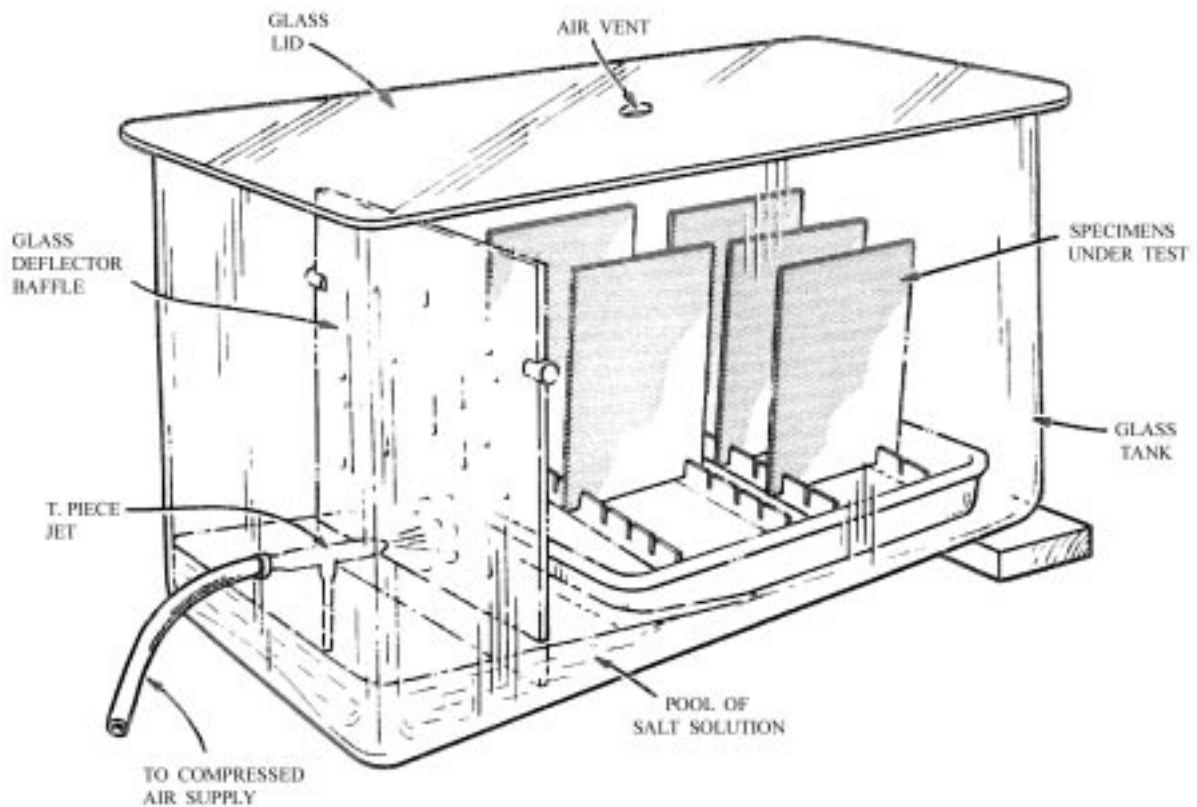
Fig.16.2, Apparatus for Salt Spray Test

Experience has shown that external paint schemes reduce maintenance labour and enhance the appearance of an aircraft. Stoving is carried out where practicable, but the paint materials used, including the latest epoxy\polyamide, will be suited to air-drying touch-up operations which might be necessary form time to time. Most paint materials are described in Ministry of Defence Specification DTD 827, 5555, 5567, 5580 and 5599.

INTERNAL FINISHING OF AIRCRAFT

The interior of wings, fuselage, etc., are usually protected by at least one coat of zinc- chromate or general purpose primer. This should be applied by spray, care being taken to ensure that all corners and enclosed spaces are adequately covered. Where greater resistance to abrasion is required, a cellulose or synthetic finish is applied on top of the primer. Special additional treatments are given to areas subject to excessive contamination.

Some aircraft Manufacturers ensure that every component receives a full protective treatment, including painting, at the detail stage. Paint is applied to clean pre-treated metal surfaces and stoved to ensure the best adhesion and durability. This finish has good resistance to knocks and abrasives, and the parts are thus protected from damage during assembly, paint and interfaying compound is present in all joints, giving enhanced protection from corrosions and fretting.

Aluminium-alloy parts are often protected by the Alocrom 1200 process which has no deleterious effect on the fatigue properties of the metal, and gives a good bond for paint adhesion. Steel components are cadmium plated and then given chromate passivation, which improves the paint adhesion and provides increased corrosion resistance. The paint treatment is often an epoxy/polyamide system using a chromate pigmented primer and a gloss finish which is suited to air-drying touch up operation. Areas subject to slight contamination may receive chemical cleaning, chemical protection and primer painting only, whilst areas contaminated by water, oil, etc,., may receive an additional process of hard gloss finishing paint. Those areas subject to attack from acid or corrosive fluids are given a further treatment of epoxy nylon lacquer.

Some Manufacturers apply a water displacing corrosion inhibitors to supplement the finishing scheme, and similar material may also be used, where permitted, incases where interior paint work has been damaged. These inhibitors are volatile liquids which are sprayed or brushed on the surfaces to be treated; the liquid carrier then evaporates leaving a waxy film on the surface. The inhibitor penetrates small cavities and between faying surfaces and thus prevents the ingress of moisture.

These inhibitors are usually slightly toxic and the appropriate precautions should be observed during their application. In addition, corrosion inhibitors may contain flammable components and may present a fire hazard when mixed with oxygen or subjected to high temperatures. All safety precautions recommended by the Manufacturer should therefore be observed.

CHAPTER: 17
MERCURY CONTAMINATION OF AIRCRAFT STRUCTURES

INTRODUCTION

This chapter describes the possible effects of the spillage of metallic or mercury salts and solutions on aircraft structures, and the methods by which these substances may be removed. Contact between mercury and aircraft structures is, fortunately, infrequent, but on those occasions when it does occur, immediate action is necessary to prevent serious loss of strength in the contaminated components, since the effects of spilt mercury are potentially more dangerous than those of spilt battery acid. The aircraft must not be moved, and no action must be taken which might disturbed the mercury and increase the area of contamination. The area must be isolated, and decontamination must be carried out as quickly as possible. Metallic structural members, exposed wires, electrical cables, terminal blocks, and other metallic parts susceptible to mercury attack, must be carefully examined, and replaced or repaired if evidence of corrosion is found.

GENERAL

If mercury is spilled (by breakage of a container, mercury vapour lamp, thermometer or similar instrument) the mercury will spilt into small globules, which will quickly disperse over a wide area, and attack many of the metals with which they come into contact. If the spillage occurs in the passenger or freight compartments of an aircraft, some of these globules are likely to find their way through joints in the floor panels and insulation blankets, and come to rest on the aircraft skin and structure, where corrosion and embrittlement of the aluminium may start. A film of oxide, paint, grease or oil, will delay the onset of mercury attack, but where the mercury attack, but where the mercury is in contact with bare metal, and moisture is present, the attack will progress rapidly and cannot be arrested by any normal cleaning process.

Amalgamation

If metallic mercury, or mercury salts or solutions come into contact with any of a number of materials, they combine with the basic material, and form an amalgam which has no appreciable structural strength. This process is very rapid, particularly in moist conditions, and the affected component may be completely destroyed.

Embrittlement

Intergranular penetration by the mercury results in embrittlement, which will initiate cracks, and accelerate crack propagation. Degradation of the structural strength of the material may be complete, and will be accelerated if the material is under stress.

Recognition of Mercury Attack

Evidence that corrosion and embrittlement have commenced, may be recognised visually as follow:-

i.   On aluminium or aluminium alloys; a greyish powder, fuzzy deposit, or whiskery growth.
ii.   On copper, brass or gold; a silvery stain or coating.
iii.   On silver, cadmium or zinc; the surface of the affected area will appear slightly brighter than that of the surrounding metal. This may be very difficult to see.

In all cases where visual signs of mercury attack are found or suspected, the affected part must be replaced, or repaired by the insertion of new material.

HEALTH HAZARDS

Both mercury and its vapour are toxic, and at normal room temperatures a toxic concentration will be present in the air above spilled mercury. Care must be taken to prevent mercury and its vapour from being inhaled or swallowed, or from coming into contact with the skin or eyes. If a person finds that his hands have come into contact with mercury, he should not eat, smoke or blow his nose without first washing carefully with soap and hot water. Protective clothing and rubber gloves must be worn by personnel engaged in decontamination, and adequate ventilation must be provided in the working area. After decontamination has been carried out, the protective clothing should be discarded, and the hands, and any tools used, thoroughly washed with soap and hot water.

DETECTION

Large globules or pools of mercury are normally easily visible, but small particles may be difficult to locate. Fortunately, even minute particles of mercury show up well on an X-ray radiograph, appearing as white dots, while corrosion and embrittlement appear as treelike forms in the aluminium structure.

CLEANING METHODS

There is no satisfactory method of removing mercury corrosion, but a number of methods have been developed for picking-up spilled mercury, and these may be broadly classified as mechanical or chemical. On no account should normal methods of cleaning such as washing, wiping with a cloth, or using an air- jet, be employed, as these will merely increase the area of contamination. When collecting loose mercury, care must be taken not to scratch the metal surface, as this could result in mercury attack on a previously unaffected area.

NOTE

Jars containing mercury or other corrosive fluids should always be contained within an unbreakable case, so that accidental damage to, or spillage from, the jar will not introduce additional problems.

MECHANICAL METHODS

Suction

A powerful vacuum-cleaner, or vacuum pump, may be used to pick up pools or large globules of mercury. However, since mercury or mercury vapour may have an adverse effect upon their mechanisms, a glass trap should be used to collect the spilled mercury, and should be located near to the free end of the suction pipe. By using suction, rubber pipes of small bore may be adapted to remove mercury from otherwise inaccessible corners. A medicine dropper, or a rubber battery- water syringe, may, be used for picking up large globules if no mechanical suction device is available.

Brush

A tool developed specifically for picking up spilled mercury, consists of a brush with nickel-plated carbon fibre bristles. When the brush is drawn lightly over the contaminated surface, mercury is picked up by capillary action. The brush should be carefully shaken into a suitable container after each stroke.

Foam Pad

A commercially made plastic foam collector may be used on flat surface to pick up small globules of mercury. The pad should be pressed onto the mercury, and, when pressure is released the globules will be drawn into the pad. Mercury may then be expelled into a suitable container by squeezing the pad in a special holder.

Adhesive Tape

Small globules of mercury may be picked up by pressing adhesive tape or medical plaster onto them, but care is necessary to prevent spreading the contamination during removal of the tape.

Chemical Methods

If calcium polysulphide is brought into contact with mercury, an inert solid (mercuric sulphide) is formed, and this can be easily removed. The normal method of application is to make a thin slurry of calcium polysulphide in water, and to brush this onto the contaminated area. When the mixture is thoroughly dry (after approximately two hours), it may be removed by brushing and vacuum cleaning. An alternative, but less effective method, is outlined in paragraph .

Chemical Recovery

In this method a length of flexible electrical cable, comprising fine strands of bare copper wire, is used, together with glass jars or test tubes containing separately, dilute nitric acid (5 % by volume in water), distilled water, methylated spirits, and a small quantity of mercury. The recovery process is as follows :-

i.   Bare the cable for 2.5 cm (1 inch) approximately, untwist the wire to form a brush, and immerse the bared wires in the nitric acid for a few seconds to remove any staining.

ii.   Wash the brush quickly in the distilled water to remove the acid, and then in the methylated spirit.

iii.   After shaking off excess liquid, dip the brush in the jar of mercury. An amalgam should form on the bared wires.

iv.   Insert the brush into the spilled mercury to pick up a small quantity, then shake off this mercury into the mercury jar. Repeat this step until all spilled mercury is recovered

NOTES

1.   Over exposure to air between steps (iii) and (iv) may result in oxidation of the copper wire and failure to form an amalgam.

2.   The active life of the brush after step (iii) may be a few minutes only, and the process will have to be repeated as necessary.

3.   The brush must be discarded if the copper strands show signs of breaking away as a result of amalgamation with the mercury.

DECONTAMINATION PROCEDURE

Whenever spillage of mercury has been reported or discovered, the area should immediately be isolated to prevent the spread of contamination through transfer by footwear and clothing. If radiographic facilities are available, the following actions should be taken :-

i.   Locate and remove the source of contamination, taking care to prevent further spillage.

ii.   Carry out a radiographic examination at floor level.

iii.   Remove all mercury from the floor panels, paying particular attention to the joints, and using an appropriate cleaning method .

iv.   Remove the floor panels, and carry out a further radiographic examination of the underfloor skin and structure, including electrical cables and terminals, and any components of a material which is likely to be affected by mercury attack.

v.   Remove any mercury indicated on the radiographs.

NOTE

If mercury has penetrated between riveted or bolted joints, it will be necessary either to separate the joints, or to completely remove the panels or structure concerned, in order to clean the contaminated surfaces. Drill bits used on contaminated structure should be discarded.

vi.   Carry out a careful visual examination of the area, using a lens of 10 x magnification, and renew or repair any components which show signs of mercury attack.

vii.   Carry out a final radiographic inspection to ensure that all traces of mercury have been removed, and reassemble the skin and structure, using approved repair schemes where necessary.

viii.   Apply a film of oil to the area as to prevent any minute particles of mercury, which may have been overlooked, from causing future corrosion.

If contamination is discovered at an airfield without radiographic facilities, the source should be carefully removed and the affected area progressively stripped to the metallic structure. A thorough examination for mercury should be carried out before removing any item, and any mercury found should be removed by a suitable method before proceeding with the stripping. Material exhibiting signs of mercury attack must be renewed or repaired, and the suspect area should be marked with chalk or grease crayon. The aircraft must be routed to a base with radiographic facilities, for complete decontamination and inspection as outlined in above paragraph .

Details of the occurrence, including the exact area affected and the action taken, should be entered in the appropriate records.

After the aircraft has been in service for a short time, a further inspection of the previously contaminated area should be carried out, to ensure that no further corrosion or embrittlement cracking has occurred.

CHAPTER: 18
NON-DESTRUCTIVE EXAMINATION
OIL AND CHALK PROCESSES

INTRODUCTION

This chapter gives guidance on the surface defects, such as cracks and porosity, by processes involving the use of oil and chalk. The principle upon which the process is based is the absorption by chalk of fluids. A penetrant oil is applied to the surface of the parts to be checked and, after removing the surplus oil, a layer of chalk is applied. Oil entrapped in defects is absorbed by the chalk, the resulting stains indicating their position.

There are two basic methods of applying the process, i.e. the "Hot fluid Process" & the "Cold Fluid Process". Of these, the process employing hot oil is the more efficient and should be used wherever possible, but methods suffer serious limitations. However, some proprietary processes, e.g. the "Bristol Modified Method of Oil and Chalk Test", which is an adaptation of the hot fluid process, are not subject to such deficiencies.

LIMITATIONS OF PROCESSES

The oil and chalk processes were devised for the detection of surface defects in nonferrous and some nonmetallic materials, but the deficiencies described in the following paragraphs should be considered before deciding upon the suitability of either of the processes for the work in hand. The processes are nor considered suitable for the detection of minute flaws or tightly shut cracks.

The processes are quite effective for such applications as the detection of large cracks in rough castings, but in general, the degree of contrast obtained by oil exudation is very poor and, unless the pre-cleaning and final drying processes are efficiently done, spurious indications of defects may be given.

Defect indications, at best, will appear only as dark grey stains on a light grey background, and are not sufficiently defined to make the detection of small cracks practicable, particularly when examining parts having dark surfaces, e.g. chromated magnesium alloy parts.

When the hot oil process is used for parts which are dimensionally large or are of intricate shape, it is often not possible to remove the surplus oil quickly enough to be able to apply the chalk before the parts become cool, thus the object of heating is defeated. On the other hand, if the drying is not done efficiently, masking of defects may occur due to the spontaneous staining of the chalk in damp areas.

HOT FLUID PROCESS

To obtain satisfactory results it is essential that the parts should be thoroughly cleaned before immersion. If the parts have previously been immersed in an acid pickle bath, paint stripper, or some other strong solutions, all traces of such solutions must be removed by adequate washing to avoid contamination of the test oil.

The parts to be examined should be immersed or (if a specified area only is to be examined) partly immersed, in a solution consisting of approximately 28 per cent (by volume) of lard oil in paraffin . The solution should be maintained at a temperature of approximately 80 o C., and the period of immersion must be sufficient to allow the parts to attain this temperature. If preferred, solutions consisting of three parts paraffin and one part lubricating oil, or 50 per cent paraffin and 50 per cent spindle oil, may be used.

After immersion the parts should be dried quickly and thoroughly with a non fluffy rag ; excellent final cleaning can be achieved by the use of un glazed tissue paper.

The parts should then be placed in the chalk cabinet and a fine layer of dry powdered French chalk should be applied, preferably by a method that will distribute the chalk in a gentle cloud. A paint spray gun with a conical funnel fitted in front of the jet, operated at a pressure of about 10 lb. sq. in. , will be found suitable for this purpose. The gun should be provided with an efficient water trap. Surplus chalk should be removed by lightly tapping the parts on a block of wood.

NOTE

The chalk cabinet should form an enclosed area in which the parts to be examined can be placed. It should have a transparent front and should be fitted with an exhaust fan to remove surplus chalk. The parts can be coated more rapidly if a turntable is used.

The parts should be inspected for defects when quite cool and it will be found that if any cracks are present, the fluid will have been forced from them as the metal contracted on cooling, causing the chalk to become stained. A gentle air stream from a source pressurized at not more than 10 lb. sq. in., if directed on to the surfaces of the parts , may assist in the revelation of defects by removing the adjacent un stained chalk. It is essential that the examination should be made with the aid of a strong light.

COLD FLUID PROCESS

The efficiency of this process is not equal to that of the hot fluid process, and it should be used only where the application of the latter process would not be practicable, e.g. when examining parts of assembled structures or parts too large for immersion.

The parts should be thoroughly cleaned and then coated with a solution of lard oil and paraffin, or lubricating oil and paraffin, in the proportions recommended in. After the surfaces to be examined have been thoroughly coated, all traces of the solution should be removed with a non-fluffy rag, followed by final wiping with un glazed tissue paper. The surface should then be coated with French chalk .

Any oil entrapped in defects will be drawn out by the absorbent chalk, the resulting stains indicating the position of the defects. It is essential that the examination should be made with the aid of a strong light.

THE BRISTOL MODIFIED METHOD

In this process, finished parts or rough castings are immersed in hot oil, are removed and have the surfaces degreased, and are then sprayed or dusted with dry French chalk.

The parts to be examined should be immersed or (if a specified area only is to be examined) partly immersed, in a solution consisting of 50 per cent paraffin and 50 per cent spindle oil. The solution must be maintained at a temperature of 70ºC., and the period of immersion should be sufficient to allow the parts to attain this temperature, one hour usually being sufficient.

After immersion, the parts should be allowed to stand until all surplus oil has drained off, after which they should be transferred to a degreasing tank containing a solution consisting of the following :

$$\left.\begin{array}{c} \\ \\ \\ \\ \end{array}\right\} \quad \leftarrow$$
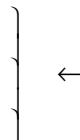
The solution should be maintained at a temperature of between 70º C. to 80⁰ C. When the cleansing action deteriorates, additions of Teepol and cresylic acid should be made to restore the above proportions.

NOTE

The cresylic acid should comply with the requirements of British standard 524, Grades A or B.

The parts should be immersed in the degreasing solution for 3 to 5 minutes and should be agitated throughout this period.

After degreasing, the parts should be transferred to a tank containing clean hot water, and should be thoroughly swilled for a period of from 3 to 5 minutes, after which they should be allowed to drain.

When dry, the parts should be coated with a layer of dry French Chalk, the equipment described under Hot Fluid Process being suitable for this purpose, except that an air pressure of 60 to 80 lb. sq. in. is recommended, after which surplus chalk should be removed by the application of a jet of air at about 25 to 30 lb. sq. in. pressure.

The parts should now be examined for defects, and cracks will be indicated by a thin white line of chalk.

CHAPTER: 19
NON-DESTRUCTIVE EXAMINATION
PENETRANT DYE PROCESSES

INTRODUCTION

This chapter gives guidance on the penetrant dye processes used for the detection of defects which break the surface of the part, such as cracks, cold shuts, folds, laps and porosity.

Penetrant dye processes are used mainly for the detection of flaws in non-ferrous and non-magnetic ferrous alloys but may also be used for ferrous parts where magnetic flaw detection techniques are not specified or are not possible. However, in some instances both penetrant dye and magnetic flaw detection techniques may be specified for a particular part. Penetrant dyes may also be used on some non-metallic materials but their use with perspex-type materials is not recommended, since crazing may result.

Although the processes are usually marketed under brand names, those used on aircraft parts for which a penetrant process of flaw detection is a mandatory requirement must comply with the requirements of Process Specification DTD 929. It must be ensured that any storage limiting period prescribed by the manufacturer of the process is not exceeded.

The processes available can be divided into two main groups. One group involves the use of penetrants containing an emulsifying agent (termed water-emulsifiable or water-washable processes) whilst in the other group a dye solvent has to be applied separately after the penetration time has elapsed if the surplus dye is to be removed by a water-wash operation. The processes may be further sub-divided in so much that with some processes the use of a dry developer is recommended whilst with others a wet developer is used. The manufacturer 's recommendations and instructions for each individual process must be followed carefully to ensure satisfactory results.

NOTE

An emulsifier is a blending of wetting agents and detergents which enables excess dye to be removed with water and, in the case of wide flaws, assists in preventing the dye seeping out too quickly.

Basically all the processes consist of applying a red penetrant dye to the surface of the part to be tested, removing after a predetermined time the dye which remains on the surface and then applying a developer, the purpose of which is to draw to the surface any dye that has entered into defects, the resultant stains indicating the positions of the defects.

The selection of the most suitable type of penetrant process (e.g. penetrant dye or fluorescent penetrant; with or without post-emulsification for any given application must largely be governed by experience, sine when used correctly a high degree of efficiency can be obtained with any of the processes. Guidance on some of the factors which should be given consideration is provided in the following paragraphs.

Within a given type of process, the post-emulsification method is generally considered to be the most sensitive and is usually selected for finished machined parts and for the detection of " tight " defects. However, its use on rougher surfaces (e.g. castings) may be less effective than would be the use of a penetrant containing an emulsifier, since it may pick up the surface texture of the material, thus rendering the detection of actual defects more difficult.

Where large heavy parts are concerned, and particularly where mechanical handling is involved, the use of penetrant dyes may be more practical than that of fluorescent penetrants, since the necessity of darkening a relatively large area before the examination can be made does not arise.
When making " in situ" checks on aircraft, the use of penetrant dyes may be more suitable where their is sufficient light but in darker areas a fluorescent process may provide better definition of defects.

NOTE

Battery-operated ultra-violet light sources are now available.

With steel castings, for example, porosity may be detected more easily by a penetrant process than by a magnetic flaw detection technique and for this reason the application of both processes is sometimes specified. If the magnetic flaw detection test precedes the penetrant test, great care will be necessary with the intervening degreasing process to ensure that all traces of the magnetic testing medium are removed, otherwise the subsequent penetrant test may be unsuccessful.

Some of the materials associated with penetrant testing have low flash point and the appropriate fire precautions should be taken.

SURFACE PREPARATION

The major reason for the failure of penetrant processes to provide indications of defects is incorrect or inadequate surface cleaning . For example, embedded extraneous matter can seal off cracks, etc., whilst contaminants remaining on the surface can trap the dye and give rise to false indications or, more detrimentally, obscure genuine defects. Thus the surface to be tested must be free from oil, grease, paint, rust, scale, welding flux, carbon deposits, etc., and the method of cleaning should be selected with the intention of removing extraneous matter from within the defects as well as from the surface to permit maximum dye penetration.

On un machined steel stamping and forging it may be necessary to remove rust or scale by sandblasting and to prepare aluminium alloy forging by light sandblasting. However, the use of such processes must be given careful consideration, since they may result in the filling or " Peening-over " of defects. Generally, unless specified otherwise, aluminium alloy forging should be prepared by a suitable pickling process (e.g. by one of the methods prescribed in Process Specification DTD 901).

Magnesium alloy castings should be tested after chromating in order to reduce the risk of corrosion, but the requirements of Process Specification DTD 911, with regard to surface protection, must be taken into account and a suitable sequence devised.

Where contamination is mainly of an organic nature, degreasing by the trichloroethylene process (unless their are instructions to the contrary) is usually suitable. However, not all types of trichloroethylene are suitable for use with titanium alloys. The cleaning of titanium alloys by methanol should be avoided.

Where parts have to be tested " in situ " , the use of volatile solvents (e.g. carbon tetrachloride) as cleaning agents should be given consideration. Where paint is present, this should be removed from the surface to be tested prior to cleaning. Subsequent to the test, the surface should be re protected in the prescribed manner.

NOTE

Suitable fire precautions must be taken when flammable materials are used.

Sufficient time should be allowed after cleaning for drying out, otherwise the efficiency of the penetrant dye may be determined by the prevailing conditions of temperature and humidity and the type of solvent used.

APPLICATION OF THE DYE

The penetrant dye can be applied to the surface by dipping, spraying or brushing, the method used depending largely on the size, shape and quantity of the parts to be examined. The surface must be dry before the dye is applied. Even the condensation which forms on a cold surface in humid conditions may interfere with dye penetration ; in such conditions the part should be warmed to a temperature of about 90° F. to 100° F. but temperatures in excess of 140^{0}F. must be avoided, since these may result in the volatilization of some of the lighter constituents of the dye.

Dipping Method

Dipping should generally be used where large numbers of small parts are to be examined. The parts must be completely dried before immersion, since apart from affecting penetration, water or solvents will contaminate the dye.

During dipping care must be taken to ensure that the parts are so racked that air pockets are avoided and all surfaces to be examined are completely wetted by the dye.

It is not necessary for the parts to remain submerged in the tank during the penetration time but only for a period sufficient to permit thorough wetting. " Drag-out " losses can be reduced if the dye is allowed to drain back into the tank during the penetration time.

Flooding Method

The flooding method should generally be used where large areas are to be examined . The dye should be applied with low-pressure spray equipment which will not permit atomization of the fluid, any surplus dye being allowed to drain back into the tank.

Aerosol can Method

Penetrant contained in Aerosol type cans is often used for " in situ " inspections. The best results are obtained when the can is held about twelve inches from the surface under test.

Brushing Method
The brushing method is generally used for individual items and items of complicated shape. A clean soft bristle brush should be used and retained only for this purpose.

PENETRATION TIME

The penetration time is the time which has to be allowed for the dye to penetrate effectively into the defects. It is dependent upon a number of factors, such as the characteristics.. of the process being used, the material from which the part is made, the size and nature of the defects being sought, the processes to which the part has been subjected and the temperatures of the atmosphere, the part and the dye. Clearly the time can be decided only by experience of the particular local conditions but is usually in the range of 5 minutes to 1 hour, the smaller the defect the longer the time necessary.

Temperatures below 60° F. will retard the penetrant action of the dye, thus the penetration time should be extended proportionately. Testing in temperatures at or near freezing point should, if possible, be avoided, since in such conditions the performance of the penetrant is considerably reduced. Where the effectiveness of the pre-cleaning process cannot be guaranteed or where parts have been sandblasted, the penetration time should be extended but it should be borne in mind that this is no guarantee that defects will, in fact, be revealed in such conditions.

REMOVAL OF EXCESS DYE

Any dye remaining on the surfaces of the parts after expiry of the penetration time should be removed as thoroughly as possible but without disturbing the dye which would have found its way into any defects present. Excessive cleaning, however, may result in the dilution of the dye or its complete removal from defects. The method of removal depends on whether a water-washable or post-emulsifiable dye was used and the situation and condition of the surface under test.

WATER-WASHABLE DYE

Water-washable dye should be removed as indicated in the following paragraphs.

The dye should be removed from " in situ " parts with clean rags saturated in water, followed by wiping with clean rags until the surfaces are both dry and free from dye.

The dye should be removed from small parts with clean rags saturated in water, followed by drying as recommended

The dye should be removed from large areas or irregularly shaped parts by flushing with an aerated spray of water, followed by drying .

Post-emulsifiable Dye

Post-emulsifiable dye should be removed from small areas and " in situ " parts first by wiping with a clean rag damped with dye solvent, followed by wiping or blotting with a clean dry rag. The bulk of the dye may be removed from large areas, irregularly-shaped parts and rough-textured surfaces by a quick water wash (allowing this to drain) followed by the application of the dye solvent and a final water wash. The dye solvent should be applied by spraying, swabbing dipping or brushing, except that brushing should not be used where relatively large defects are suspected. Washing should be followed by thorough drying.

Surface Drying

Prior to applying the developer it should be ensured that the surfaces of the part under test are completely dry. The following methods of surface drying are recommended which, although slower than the use of, for example, compressed air, air less likely to disturb entrapped dye.

Small areas may be wiped dry but since this may disturb the dye in the wider defects, the use of warm air is preferred.

Hot-air ovens and similar equipment may be used for drying , a temperature of about 130 ° F. being suitable ; temperatures in excess of 175° F. must be avoided. The use of lamps for drying is not recommended unless uniform heat application can be guaranteed.

APPLICATION OF THE DEVELOPER

The developer usually consists of a very fine absorbent white powder which may be applied in
 (a)   the form of a spray, the powder being suspended in a volatile carrier liquid which rapidly evaporates, leaving a white coating on the surface.
 (b)   as a dip with the powder suspended in water or
 (c)   as a dry dipped. The action of the absorbent powder is to draw out the dye from the surface defects, thus indicating their position by the resulting stain.

Where it is suspected that microscopic defects may be present, great care is necessary to ensure that the developer is applied evenly and very thinly, since a thick layer might conceal completely a defect holding only a minute quantity of dye.

Where a wet developer is concerned, the best results are obtained when the developer is applied by means of a paint-type spray gun operating at an air pressure not in excess of 15 lb. sq. in. The pressure pot of the spray gun should be equipped with a stirrer to keep the developer agitated and the absorbent particles in suspension. Before pouring the developer into the spray gun it should be well shaken to ensure a thorough distribution of the absorbent particles.

When requirements are not too exacting, small parts can be dipped into a bath of developer but the action must be performed rapidly to minimize the possibility of the dye being washed out of shallow defects. The bath should be agitated from time to time to ensure that the absorbent particles are kept in uniform suspension. The formation of pools of developer on the parts during draining must be avoided, otherwise the resultant thick coatings may mask defects.

Due to the usually uneven results obtained, the use of a brush for applying the developer is not recommended.

If the developer dries with a slightly pinkish hue, this is probably due to faulty cleaning or " carried over " penetrant in the penetrant remover but provided sufficient contrast remains to enable minute defects to be detected, the condition is acceptable.

Water must not be permitted to enter the developer containers, since its presence will retard considerably the drying rate of the developer.

INTERPRETATION OF DEFECTS

If defects are present and all stages of the process have been applied correctly, the position of the defects will be indicated by red marks appearing on the whitened surface. The majority of defects are revealed almost immediately the developer dries by additional time (approximately equal to the penetration time) should be allowed for "tight" flaw indications to appear and for flaw patterns to reach their final shape the size. Figure 19.1

By noting and comparing the indications that appear during the first 30 seconds of development with those which exist after about 10 minutes, a more accurate assessment of the characteristics of the defects is possible. For example, the dye exuding from a shallow crack is little more after 10 minutes than after 30 seconds but in the case of a deep narrow crack, considerably more dye is present, causing a much wider indication to develop over a similar period of time. Thus the rate of staining is an indication of the width and depth of the defect, whilst the extent of staining is an indication of its volume.

Scattered dots of dye indicate fine porosity or pitting Figure 19.1 (d) whilst gross porosity may result in an entire area becoming stained. Where doubt exists as to whether the overall pinkish effect is due to inadequate washing, the process should be repeated, more care being taken particularly during the stage of cleaning off the excess dye.

(a)

(b)

(c)

(d)

Fig. 19.1, Indications Given by Defects

Closely spaced dots in a line or curved pattern Figure 19.1 (c) usually indicate tight cracks or laps but such patterns are also characteristic of very wide defects from out of which most of the dye has been washed. Wide cracks, lack of fusion in welded parts and other similar defects are indicated by continuous lines as shown in Figures 19.1(a)and 1 (b).

Examination by means of a powerful magnifying glass is often useful when minute defects are being sought.

All defects should be suitably marked prior to removing the developer, but crayons should not be used on highly-stressed components subject to heat treatment, since this is known to induce fractures.

REMOVAL OF DEVELOPER
Developer can be removed by brushing or by air or water under pressure, but since the surface is then in a condition susceptible to corrosion (where this is applicable) the prescribed protective treatment should be applied with the minimum of delay. It should be noted that the adhesion of paints and resins may be seriously impaired by certain oil-base dyes if thorough cleaning is not ensured.

LEAK TESTING WITH PENETRANT DYES
On components or assemblies where the main purpose of the test is to locate defects which would result in a fluid leakage (e.g. cracks in pressure vessels) the methods of testing described in the previous paragraphs may not be conclusive. In such cases the inner and outer surfaces should be thoroughly cleaned and degreased, the dye being applied to one surface (usually the inside of pressure vessels) and the developer to the other. After the penetration time has elapsed, the surface should be inspected for evidence of staining.

Where no definite penetration time has been determined then, with a wall thickness of from 1/16 in. to 1\8 in., the penetration time should be at least three times that which would   be allowed for a standard " one-side-only " test.

More than one application of the dye is often required and as a general rule an additional applications for each 1/16 in. to 1/6 in. wall thickness is recommended.

CHAPTER:20
NON-DESTRUCTIVE EXAMINATIONS
MAGNETIC FLAW DETECTION

INTRODUCTION

This chapter gives guidance on the detection of surface and subsurface defects in ferro-magnetic materials by magnetic processes. The procedures recommended in this chapter are complementary to British standard (BS) M35, and should not be taken as overriding the techniques of examination prescribed by the manufacturer of a particular component, either in drawings or in approved manuals.

Magnetic flaw detection tests are applied to many steel parts at the manufacturing, fabrication and final inspection stages. The process is normally applied to all Class 1 aircraft parts manufactured from ferro-magnetic materials, and to any other parts where the designer or inspection authority considers it to be necessary.

NOTE

A Class 1 part is defined as a part, the failure of which, in flight or ground manoeuvres, would be likely to cause catastrophic structural collapse, loss of control, power unit failure, injury to occupants, unintentional operation of , or inability to operate, essential services or equipment.

The methods of magnetising in general use are the magnetic flow and the current flow processes, which are described in paragraph below. By choosing the most suitable process, or combination of processes, for a particular component, both surface and subcutaneous defects may be revealed.

Great care must be taken when establishing a technique of examination suitable for a particular component, in order to ensure that consistent results are obtained. Operators of magnetic flaw detection equipment should be thoroughly trained in its use, and experienced in interpreting technique requirements and the indications obtained from a test.

THE PRINCIPLE OF MAGNETIC FLAW DETECTION

If a component is subjected to a magnetic flux, any discontinuity in the material will distort the magnetic field and cause local leakage fields at the surface. Particles of magnetic material applied to the surface of the magnetised component will be attracted to the flux leakage areas and reveal the presence of the discontinuity.

The sensitivity of magnetic flaw detection depends largely on the orientation of the defect in relation to the magnetic flux, and is highest when the defect is at 90° to the flux path. Sensitivity is considerably reduced when the angle between the defect and the flux path is less than 45°, so that two tests are normally required with each component, the flux path in the first test being at 90° to the flux path in the second test. Components of complex shape may require tests in several different directions.

A component may be magnetized either by passing a current through it, or by placing it in the magnetic circuit of a permanent magnet or electromagnet. The required strength of the applied magnetic field varies considerably, and depends largely on the size and shape of the component and on the magnetic characteristics of the material from which it is made.

The magnetic particles used to reveal defects are either in the form of a dry powder, or suspended in a suitable liquid. They may be applied by spray, pouring, or immersion, depending on the type of component. Magnetic flaw detection 'inks' complying with BS 4069 are used in aircraft work, and consist of finely divided black or red magnetic oxides of low corrosivity (i.e. they will not retain the magnetism induced during testing), suspended in a liquid (normally kerosene). Pigments may be added to provide a contrast with the surface of the specimen. Black inks are suitable for use on bright, machined components, but red inks may be more suitable for unmachined parts or, alternatively, a thin coat of white paint or strippable lacquer may be added to the component before carrying out the test.

If magnetic inks are left standing for long periods the solid particles settle at the bottom of the container and form a sediment which may be difficult to redisperse. If the machine does not have pump agitation, frequent manual agitation must be provided during tests to ensure satisfactory inking of the specimens. The solids concentration in inks manufactured to B S 4069 should be 0.8 to 3.2 % by volume, but with fluorescent inks the solids content is approximately one tenth of these values. Methods of determining the solids content of magnetic inks are detailed in BS 4069. Magnetic ink should be discarded if it becomes diluted by solvents or contaminated with oil or any foreign substance likely to reduce its effectiveness as a detecting medium.

Fluorescent inks are also widely used and are often specified where high sensitivity is required. Inspection of a component to which fluorescent ink has been applied, should be carried out under black light.

METHODS OF MAGNETIZATION
Current Flow Method

If an electric current is passed through a conductor, a magnetic flux is induced, both within the conductor and in the surrounding atmosphere, in a series of concentric circles at 90° to the direction of current flow. With steady current the strength of the internal magnetic flux is greatest at the surface of the conductor and decreases uniformly to zero at the centre, but with alternating current both the current and magnetic flux are confined to a thin layer at the surface, because of the effects of induction. Magnetization at the surface can be greater with alternating current than with direct current, but direct current has the advantage of greater depth of penetration. In practice, machines are often designed so that alternating or rectified current can be applied to a specimen, to make use of the advantages of each method.

Current flow machines normally provide a sustained current through the specimen, ink being applied while current flows. The specimen is usually clamped between contact pads on a static machine, but portable units are available in which the contacts take the form of hand-held prods, and these are often used for checking components which are difficult to mount in a static machine. Good electrical contact is essential, and the contacts are usually provided with copper gauze pads, sufficient pressure being used to prevent arcing between the pads and specimens. Because of the danger of burning and possible subsequent fatigue cracking, the use of prods is often prohibited on finished parts, especially those of high tensile steel.

A variation of current flow magnetisation is the " impulse " methods, which employs either direct or alternating current in the form of a short impulse (generally less than one second). Difficulty may be experienced in satisfactorily inking the specimen while current is flowing, and the specimens may be immersed in a bath of magnetic ink. Alternatively, with some materials, remaining magnetism may be sufficiently strong to provide defect indications when ink is applied after current has ceased to flow. The alternating current impulse method is not often used, due to the difficulty of interrupting the current at a point in the hysteresis loop which will leave the specimen adequately magnetised.

For testing purposes it is usual to apply a sufficiently heavy current to give a satisfactory magnetic flux in the specimen, and to use a low voltage to safeguard the operator.   As a rough guide to the basic current setting to use, most steels can be satisfactorily tested using an alternating current of 500 A rms per inch diameter or, for specimens of irregular shape, 150 A rms per inch of periphery. Some steels, e.g. nickel-chrome steels, may require a higher magnetising force due to their low permeability. Current values for irregular shaped components should be decided by fixing an artificial defect to the area required, applying ink, and varying current value until a satisfactory indication is obtained.

NOTE

The effective current value with regard to magnetisation is the peak value. Ammeters do not usually record the peak value however, and testing techniques must state whether the current values specified are rms (root mean square) or peak. It is normally assumed that an ammeter reading rms is fitted to an a.c. machine, and an ammeter reading mean current is fitted to a rectified a.c. or constant potential d.c. machine. Current values producing a magnetic flux equivalent to that produced by 500 A rms, a.c., with these types of ammeter fitted , are:-

d.c.	710 A
half-wave rectified a.c.	225 A
full-wave rectified a.c.	450 A

If a peak-reading ammeter is fitted to an a.c. machine, the current value should be the same as for d.c. (i.e. 710 A). In cases where the wave form is unknown, the relationship between peak and average values must be determined empirically, and the current adjusted accordingly.

The passage of a heavy current will have a heating effect on the specimen, particularly when direct current is used. This could cause burning in specimens such as thin tubes, and possibly have an adverse effect on any heat treatment previously applied. The duration of each test should, therefore, be limited to as short a time as possible, consistent with satisfactory inking of the specimen.

Induction Methods

In all induction methods , the magnetic field external to the current-carrying element is used to induce a magnetic flux in the specimen.
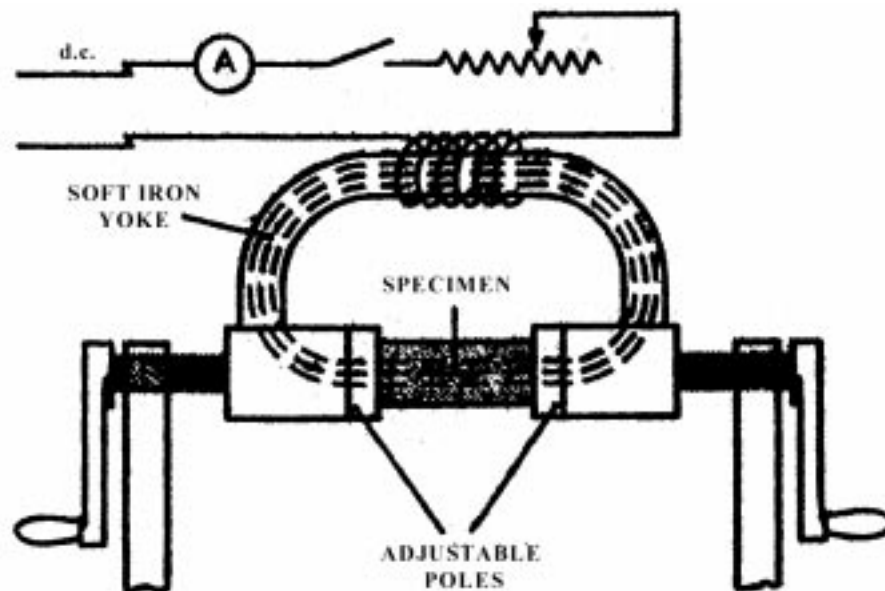
Fig. 20.1, Magnetic Flow Machine

Magnetic Flow Method

Figure 20.1 shows the arrangement of a typical magnetic flow machine, the specimen being clamped between adjustable poles in the magnetic circuit of a powerful electromagnet,   Good contact between the poles and specimen is essential, otherwise a marked lowering of the field strength will result. Laminated pole pieces are often used to ensure that good contact is maintained with specimens of curved or irregular shape, and in some portable equipment which employ a permanent magnet, contact is obtained through a number of spring-loaded pins.
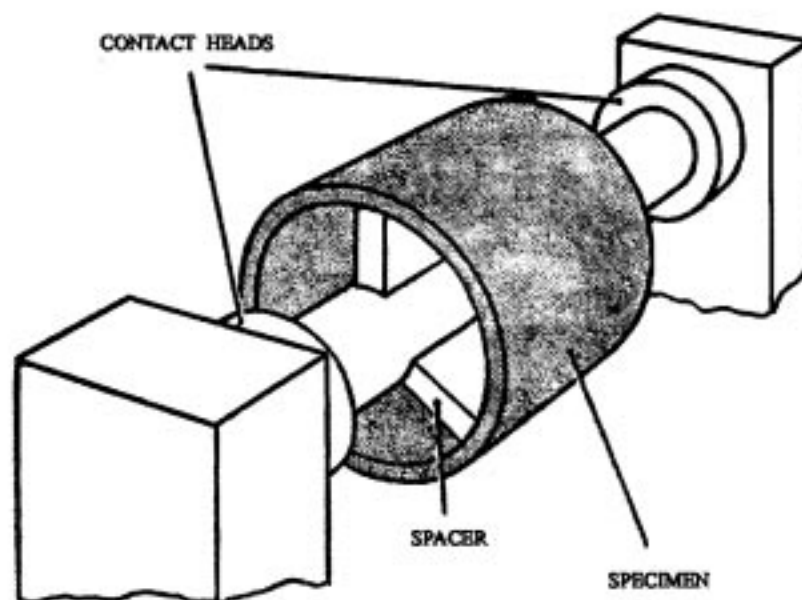
Fig. 20.2, Threading Bar Method

(i)   The magnetising force required to carry out a test using a magnetic flux machine, will depend on the length, cross-section and permeability of the yoke, the number of turns of the winding, and the magnetic characteristics of the test piece. No set current value would be suitable with all machines, and tests should be conducted to ascertain the current value which will ensure magnetisation just below the saturation level. Saturation is

indicated by a heavy build-up of magnetic ink at the ends of the specimen, or an overall coating on its surface . In all tests the cross-sectional area of the pole pieces should be   greater than that of the specimen, but the maximum cross-sectional area which can be tested will normally be stated in the operating instructions for a particular machine.

(ii)   To ensure that the strength of the magnetic flux in a specimen is sufficient to reveal defects during a test, it is common practice to employ portable flux indicators. These may take the form of thin steel discs containing natural cracks, which, when attached to the surface of a specimen during a test, will give an indication of flux strength and also , with some indicators, the flux direction.

(iii)   With many machines it is easy to over-magnetise, particularly when carrying out tests on small specimens. It the machine does not have controls for adjusting the energising current, a reduction in magnetic flux can be achieved by inserting non-magnetic material between the pole pieces and the specimen.

(iv)   Magnetic flow machines are generally designed to operate with direct current, the magnetising coil containing a large number of turns of wire and carrying a current of a few amps only. This type of coil would be unsuitable for use with alternating current, since the coil would have too much inductance. If it is required to use alternating current for magnetic flow tests, the coil must be replaced by one having a few turns and carrying a heavy current.

Threading Bar Method

This method is used for testing rings and tubes, and is illustrated in Figure 20.2. A current flow machine is used, and a conductor connected between the contact heads of the machine. Current flowing through the conductor induces a magnetic flux in the specimen at 90^0 to the direction of current flow; this flux may be used to reveal defects in line with the axis on the specimen. Best results are obtained when the air gap is smallest, i.e. the conductor is only slightly smaller than the internal diameter of the specimen, but a larger air gap is often necessary in order to permit examination of the interior surface.

(i)   A symmetrical flux may be obtained in the specimen by inserting non-conducting spacers between the conductor and the specimen, but this is not essential except to prevent burning should the conductor overheat. If the shape of the item under going test precludes the use of a straight conductor, a heavy flexible cable may be used.

(ii)   The basic current setting should be determined from the length of the flux path, i.e. the outside periphery of the specimen,. 100 to 200 amps per inch being a satisfactory basic setting for most steel specimens. The current required   is unaffected by the length of the specimen, except that if the specimen is very long the resistance of the conductor may limit the available current.
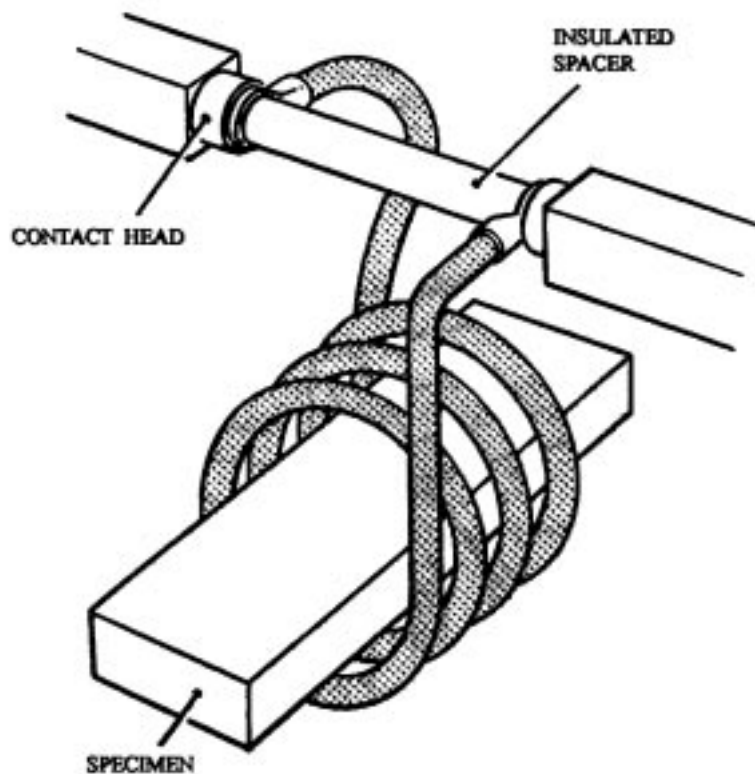
Fig. 20.3, Magnetising Coil Method

Magnetising Coil Method

A current flow machine is also used for the magnetising coil method. An insulated heavy gauge copper wire or strip is connected between the contact heads of the machine as shown in Figure 20.3, and formed into a coil ; a.c. coils have 2 1\2 to turns and d.c. coils 6 to 10 turns, the space between turns being less than the cross-sectional diameter of the wire in order to minimize flux leakage. The magnetic lines of force resulting from passing current through the coil, will induce a magnetic flux in the specimen, in the direction of the coil axis.

(i)   Components of simple shape may be placed within the coil during a test, but satisfactory magnetisation will only be obtained within the length of the coil. Difficulty may be experienced with short components, due to the demagnetising effect resulting from the close proximity of the free poles (i.e. the ends of the specimen), and it is often advisable to complete the magnetic circuit using a yoke manufactured from mild steel, or extend the effective length of the component with end blocks.

(ii)   When components of complicated shape are being tested, it is difficult to estimate the strength and direction of the magnetic flux in all parts of the specimen during a single test. It is often preferable to make several tests with the coil located at several positions within or around the specimen, inspecting only those parts adjacent to the coil at each position.

(iii)   As with the magnetic flow method, the current required depends on a number of factors, including the relative diameters of the specimen and coil, and the length\diameter ratio of the specimen. BS M35 gives a formula for calculating the current required under specified conditions, but the most suitable values are generally obtained by experiment, and by selecting a current which gives a field strength just less than that required to saturate the material.
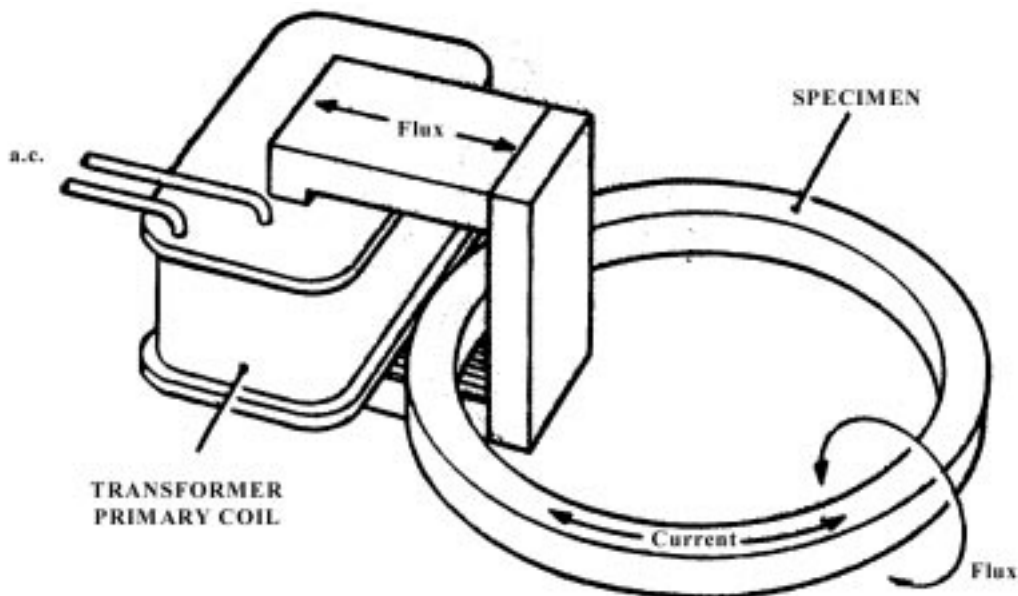
Fig. 20.4, Induced Current Flow Method

INDUCED CURRENT FLOW METHOD

Figure 20.4 shows the coil arrangements for this method, in which current is induced to flow through the specimen by the action of the primary coil of a transformer. The induced current itself provides a magnetic field within the specimen, which may be used for detecting defects lying mainly in a longitudinal direction. This method is often used on ring specimens of large diameter.

TESTING PROCEDURES

Techniques of testing by magnetic methods are established after preliminary tests have shown that defects can be consistently revealed in similar parts to those under test. When carrying out routine tests in accordance with a specified technique, each instruction must be carefully followed in order to obtain satisfactory results. The full test procedure consists of degreasing, magnetising, application of magnetic ink or powder and interpretation of indications, this process being repeated for each test specified on the technique sheet and concluding with final demagnetising and cleaning. The use of a hand lens of low magnification is normally specified for the examination of defects.

GENERAL CONSIDERATIONS

Before carrying out a test the equipment should be checked to ensure that it is functioning properly. The technique sheet will usually specify the capacity of the machine required for a test, and stipulate the type of magnetic ink or powder to use. An initial test, using a specimen containing known defects, may be carried out to verify that these defects can be revealed. Alternatively, in the absence of a cracked specimen a test may be carried out using a " portable crack "

taped to the surface of the specimen. This often consists of a thin strip of material in which a crack has been artificially induced, and may be used as a guide for acceptance or rejection of the specimen under test. Equipment is usually checked with standard test pieces.

Good lighting is essential for examining the specimen. Good daylight provides the best illumination for normal inks, but fluorescent lighting, free from highlights and of correct intensity, is a suitable substitute. When using fluorescent inks, black light is essential and daylight should, as far as possible, be excluded from the viewing area ; efficiency of the black light source should be checked periodically (BS 4489).

Adequate bench space should be provided adjacent to the testing machine and, where the nature of the work permits, should be away from noisy or otherwise distracting locations.

When specimens are tested in batches and set aside in a magnetised condition for subsequent examination, they should not be permitted to come into contact with one another, or with any other magnetic material, such as steel-topped benches or steel brackets, until the examination has been completed. If specimens do come into contact with other magnetised objects a local disarrangement of the magnetic field many occur, giving an effect similar to that obtained with a real defect.

Selection of Method
In cases where a technique of examination has not been specified, tests must be made to ensure that defects in the specimen can be satisfactorily revealed.

Factors to be considered are the size and shape of the specimen, and the capacity of the machines available. Changes of cross-section in a component will result in variations in the intensity of magnetisation through the component, requiring several tests using different current settings at each change of cross-section. The shape of a component may also modify the distribution of magnetic flux and result in misleading indications in the ink pattern. Examples of difficult specimens are toothed gears, turbine blades with fir tree roots and threaded components, where over-magnetisation may result in buildup of iron oxide at the extremities, and cause defects to be hidden. This type of component may often be examined using a remanining magnetism technique, a d. c. supply being used with fluorescent ink ; the part should be gently swilled in paraffin after application of the ink to clear the background, but retain any defect indications.

Since the majority of specimens must be tested for longitudinal and transverse defects, both current flow and magnetic flow tests are normally required ; both tests may be carried out on a single universal machine.

Table below gives guidance on the most suitable methods of testing materials of various simple shapes; components of complicated shape may require special techniques. Test using flux detectors and portable cracks will permit a satisfactory technique to be established, however, and great difficulty is not often experienced

TABLE 20.1

Specimen	Suitable Test Method
Bar	Current flow for longitudinal defects.
	Magnetic flow for transverse defects.
	Magnetising coil for transverse defects.
Tube	Threading bar for longitudinal defects.
	Magnetic flow for transverse defects.
	Current flow for longitudinal defects.
	Magnetising coil for transverse defects.
Ring	Threading bar for defects in line with ring axis, and radial defects.
	Current flow or induced current flow for circumferential defects.
Plate	Current flow or induced current flow using prods for both longitudinal and transverse defects.
Disc	
	Current flow or current flow using prods, with the disc rotated 90^0 between successive tests.
Sphere	Current flow or current flow using prods, sphere being rotated to reveal any defects.
	Magnetic flow or magnetising coil may also be used if flux path is extended using steel extension pieces.

Preparation

Specimens should be free from dirt, grease or scale, since these may hide defects and contaminate the magnetic ink. Scale may usually be removed by abrasive blasting or approved chemical methods, and trichloroethylene or other suitable solvents are normally used for degreasing when the parts are being tested away from their assembled positions. Trichloroethylene should not be used for cleaning parts in situ, due to the health hazard. It is not usually necessary to remove paint or plating except to provide good electrical contact for the current flow process.

NOTE

The fluorescent properties of certain magnetic inks may be diminished by chemical reaction with acids. When acid pickling is used as a cleaning process, care is necessary to ensure that all traces of acid are washed off.

Preparation of the specimen should also include demagnetisation. Magnetisation may have been induced by working, by machining in a magnetic chuck, or by lying adjacent to magnetised components or material. In the case of raw material, magnetisation may be removed by heating to a temperature above the Curie point for the material, but generally, for finished parts , it must be removed as detailed in paragraph.

Apertures such as oilways and deep tapered holes, which do not form part of the area to be examined, should be plugged to prevent the intrusion of ink, which may be difficult to remove.

Magnetisation

Components of simple shape will normally require magnetising in two directions, by a selection of the methods described in paragraph , so that defects of any orientation will be revealed . Components of complicated shape may require further magnetisation in selected areas to ensure completed coverage. A component should normally be demagnetized between each test, to remove the effects of residual magnetism, which could cause spurious indications.

Inking

Except where remanent magnetism is used to reveal defects , magnetic ink should be applied gently, immediately before and during the period of magnetisation. With a.c. machines the magnetic flux should be applied for at least three seconds to allow time for the ink to build up defects, but d.c. machines are often fitted with a time switch which limits the application of flux to between 1\2 and 1 second. When the immersion method is used, extreme care is necessary during removal of the specimen form the bath, in order to avoid disturbing the magnetic ink and any indications of defects which it may show.

Interpretation of Indications

Particles of magnetic ink are attracted to flux leakage fields, and these may occur at defects, brazed joints, the heat affect zone in welds, or sudden changes of section. The presence of a sudden buildup ink on a specimen is not, therefore, necessarily an indication of a crack, inclusion or similar discontinuity, and experience is essential in interpreting the indications produced by a test.

Cracks are revealed as sharply defined lines on the surface of the specimen, the magnetic particles often building up into a ridge which stands proud of the surface.

Subcutaneous defects such as may occur during manufacture of the material, will be more blurred than surface cracks. Nonmetallic inclusions are often revealed by a diffuse clustering of magnetic particles, but may sometimes give an indication which is as sharply defined as a crack.

Grinding cracks are usually readily identified, and consist of a pattern of irregular lines over the affected area, or, on small radius bends or teeth, they may appear as short parallel lines.

Tool marks may give an indication similar to cracks, but the bottom of a tool mark can usually be seen with the aid of a hand lens with approximately 5x magnification, whereas cracks are usually deep and narrow.

Localised magnetic flux resulting from ineffective demagnetisation, or careless handling after a specimen has been magnetised, may give indications known as magnetic writing. Careful demagnetising and retesting will show whether the magnetic writing is spurious, or an indication of a real defect.

Excessive magnetisation causes furring, and magnetic particles tend to follow the grain flow, giving the appearance of clusters of inclusions. The remedy is to reduce magnetization when testing areas of reduced cross-section.

Changes in permeability within a specimen, such as may occur at welds, may give misleading indications. Magnetic detection methods may not be suitable in these instances, and radiography may have to be used.

Recording of Defects

Defects are normally marked with grease pencil or paint for future reference, but it may be necessary, for record purposes, to preserve the indications obtained in a test, either on the specimen or as a separate permanent record.

If the magnetic ink has an oil based carrier, the specimen should be drained and dried or, alternatively, another test may be carried out using an ink containing a volatile carrier fluid. If dry powder is used no preparation is necessary.

In cases where the specimen is to be retained, it should be gently sprayed with quick -drying lacquer or covered with a transparent adhesive film, care being taken not to disturb the surface indications.

If a separate permanent record is to be retained the specimen may be photo-graphed, or one of the following actions taken :-

(i)   The indications may be covered with a transparent adhesive tape, which may then be peeled off and applied to a paper or card of suitably contrasting color, to show the defects.

(ii)   A stripe able adhesive coating may be gently sprayed on to the surface of the specimen. When carefully removed, this coating will retain the indications of defects, and these may be viewed on the surface which was in contact with the specimen.

(iii)   The specimen may be heated and dipped in a thermosetting plastic powder material. When cured and stripped off, this material may be viewed as in (ii) above.

Demagnetisation

There are a number of reasons why specimens should be demagnetised before, during or after magnetic particle testing. These include the effects of magnetic writing , the difficulty which would be experienced in any subsequent machining operation due to the adherence of swarf, bearing wear due to the adherence of fine metallic particles, and interference with the aircraft magnetic compasses. A specimen should, therefore, be demagnetised before starting tests, between tests which involve a change in flux direction, and after tests have been completed.

The most commonly used demagnetiser is an aperture type of coil carrying an alternating current. The specimen should be placed inside the energised coil and withdrawn a distance of at least 1 1\2 meters (5 feet) along the coil's axis with the current switched on, or may be placed inside the coil and the current gradually reduced to zero. Ideally, the coil should be just large enough to accept the specimen.

If a demagnetising coil is not available the crack detecting machine may be used. Alternating current from the machine may be passed through two or three turns of heavy cable, which may be used in the same way as a demagnetising coil;. Alternatively, a suitably equipped direct current electromagnet machine may be used, the specimen being placed between the poles and the current being gradually reversed and reduced simultaneously to zero.

For demagnetising parts in situ an alternating current yoke is normally used. This consists of a coil wound on a laminated yoke, which is used in a stroking action on the specimen. The strokes should always be in the same direction along the specimen and the yoke should be moved away in a circle on the return stroke.

After demagnetising, the specimen should be removed from the vicinity of the demagnetising coil, the testing machine, or any other magnetised material.

Tests for Demagnetization of Parts

Any components which are manufactured from steel and liable to affect the aircraft compass, should be demagnetised and a test for remanent magnetism carried out before assembly in the aircraft. The standard test for remanent magnetism in aircraft parts is the deflection of a magnetic compass needle under controlled conditions, but an alternative method, such as the use of a flux meter, may be permitted, and suitable limits prescribed.

The test consists of placing a suitable magnetic compass in a position away from all stray magnetic influences, and slowly rotating the component at a position along the east\west axis of the compass. The distance of the component from the compass should be specified for the test, and should be the same as the distance from the aircraft compass to the installed component. Deflection of the compass needle by more than 1^0 will require the component to be demagnetised again and the test to be repeated.

Final Cleaning

When a component has been accepted following a magnetic detection test, all traces of detecting ink, contrast paint or temporary marking should be removed. Wiping or washing in solvent, or immersion in an approved degreasing agent are the methods normally used. During cleaning, any plugs or blanks fitted during the preparation for the test, should be removed. A temporary rust protective should be applied after cleaning, and the part should be identified in accordance with the appropriate drawing, to indicate that magnetic flaw detection has satisfactorily carried out.

TECHNIQUE SHEETS

A technique sheet is a document detailing all the magnetising operations to the performed when inspecting a particular component by the magnetic particle method. It may be accompanied by an illustration of the component and by instructions applicable to all magnetic particle tests, such as the methods of cleaning and demagnetising to be used.

A technique sheet should show all the relevant details for each magnetising operation, including type of equipment, strength and form of current, acceptance standard, contact areas, positions of flux detectors, type of coil, size of threading bar, and test pattern, as appropriate to the particular test. It is recommended that the symbols used in BS M 35 should be used on all technique sheets and, where appropriate, on related drawings or sketches.

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CHAPTER: 21
NON-DESTRUCTIVE EXAMINATION
FLUORESCENT PENETRANT PROCESSES

INTRODUCTION

This chapter gives guidance on the fluorescent penetrant processes used for the detection of defects in a component, such as cracks, cold shuts, folds, laps and porosity when these break the surface of the component.

Fluorescent penetrant processes are used mainly for the detection of flaws in non-ferrous and non-magnetic ferrous alloys but may also be used for ferrous parts where magnetic flaw detection techniques are not specified or are not possible. In some instances both fluorescent penetrant and magnetic flaw detection techniques may be specified for a particular part. Fluorescent penetrants may also be used on some non-metallic materials, such as plastics and ceramics, but in each case a suitable process for the particular material must be selected. The processes are not suitable for use on absorbent materials.

Although the processes are usually marketed under brand names, those used on aircraft parts for which a penetrant process of flaw detection is a mandatory requirement must comply with the requirements of Process Specification DTD 929. It must be ensured that any storage limiting period prescribed by the manufacturer of the process is not exceeded.

There are two types of fluorescent penetrants, a minor water-based group and a major oil-based group ; the manufacturers of the processes usually specify the materials for which each process is suitable. There are variations in the processes which must be taken into account. For example, some types of penetrants contain an emulsifier, whilst in other processes the penetrant and the emulsifier are applied as separate stages. Again in some processes the use of a dry developer is recommended whilst in others a wet developer is used. The manufacturer 's recommendations and instructions for each individual process must be followed carefully to ensue satisfactory results.

NOTE

An emulsifier is a blending of wetting agents and detergents which enables excess penetrant to be removed with water.

Fluorescent penetrant testing is based on the principle that when ultra-violet radiation falls on certain chemical compounds (in this case the penetrant) it is absorbed and its energy is re-emitted as visible light (i.e. the wavelength of the light is changed). Thus , if a suitable chemical is allowed to penetrate into surface cavities, the places where it is trapped and has been drawn to the surface by the developer will be revealed by brilliant greenish-yellow lines or patches (according to the nature of the defect) under the rays of an ultra-violet lamp.

The selection of the most suitable type of penetrant process e.g. penetrant dye or fluorescent penetrant ; with or without post-emulsification for any given application must largely be governed by experience, since when correctly used a high degree of efficiency can be obtained with any of the processes. Guidance on some of the factors which should be given consideration is provided in the following paragraphs.

Within a given type of process, the post-emulsification method is generally considered to be the most sensitive and is usually selected for finished machined parts and for the detection of " tight" defects. However , its use on rougher surfaces (e.g. castings) may be less effective than would be the use of a penetrant containing an emulsifier, since it may pick up the surface texture of the material, thus rendering the detection of actual defects more difficult.

Where large, heavy parts are concerned, and particularly where mechanical handling is involved, the use of penetrant dyes may be more practicable than that of fluorescent penetrants, since the necessity of darkening a relatively large area before the examination can be made does not arise.

When making " in situ " checks on aircraft, the use of penetrant dyes may be more suitable where there is sufficient light but in the darker areas a fluorescent process may provide better definition of defects.

With steel castings, for example, porosity may be detected more readily be a penetrant process than by the magnetic flaw detection techniques and for this reason the use of both processes is sometimes specified. If the magnetic flaw detection test precedes the penetrant test, great care will be necessary with the intervening degreasing process to ensure that all traces of the magnetic testing medium are removed, otherwise the subsequent penetrant test may be unsuccessful.

Some of the materials associated with penetrant testing have low flash points and the appropriate fire precautions should be taken.

SURFACE PREPARATION

The major reason for the failure of penetrant processes to provide indications of defects is incorrect or inadequate surface cleaning. For example, the surface can trap the penetrant and give rise to false indications or, more detrimentally, obscure genuine defects. Thus the surface to be tested must be free from oil, grease, paint, rust, scale, welding flux, carbon deposits, etc., and the method of cleaning selected must be capable of removing extraneous matter from within the defects as well as from the surface to permit the maximum penetration.

With un machined steel stamping and forging it may be necessary to remove rust or scale by sandblasting. Aluminium alloy forging may also need light sandblasting.   However, the use of such processes must be given careful consideration, since they may result in the filling or " Peening-over " of defects. Generally , unless specified otherwise, aluminium alloy forging should be prepared by a suitable pickling process (e.g. by one of the methods prescribed in Process Specification DTD 901).

Magnesium alloy castings should be tested after chromating in order to reduce the risk of corrosion, but the requirements of Process Specification DTD 911, with regard to surface protection, must be taken into account and a suitable sequence devised.

Where contamination is mainly of an organic nature, degreasing by the trichloroethylene process (unless there are instructions to the contrary) is usually suitable. However, not all types of trichloroethylene are suitable for use with titanium alloys. The cleaning of titanium alloys by methanol should be avoided.

Where parts have to be tested " in situ ", the use of volatile solvents (e.g. carbon tetrachloride) as cleaning agents should be given consideration . Where paint is present this should be removed from the surface to be tested prior to be tested prior to cleaning. Subsequent to the test, the surface should be re protected in the prescribed manner.

NOTE

Suitable fire precautions must be taken where flammable materials are used.

Sufficient time should be allowed after cleaning for drying-out, otherwise the efficiency of the penetrant may be affected. The time interval allowed for the evaporation of solvents can only be determined by the prevailing conditions of temperature and humidity and the type of solvents used.

APPLICATION OF THE PENETRANT PROCESS (WITHOUT POST EMULSIFICATION)

Application of Penetrant The penetrant can be applied to the surface by dipping, spraying or brushing, the method used depending largely on the size, shape, and quantity of the parts to be examined. The surface must be dry before the penetrant is applied. Even the condensation which forms on a cold surface in humid conditions may interfere with penetration ; in such conditions the part should be warmed, preferably within the temperature range of 70° F. to 90° F.

Dipping Method

Dipping should generally be used where large numbers of small parts are to be examined. The parts must be completely dried before immersion, since apart from affecting penetration, water or solvents will contaminate the penetrant.

i)   During dipping care must be taken to ensure that the parts are so racked that air pockets are avoided and all surfaces to be examined are completely wetted by the penetrant.

ii)   The parts should be dipped for a few seconds and allowed to drain, care being taken to ensure that the solution is able to drain away from any pockets or cavities in the parts. If there is a tendency for the penetrant to dry on the surfaces the parts should be redipped.

Flooding Method

The flooding method should generally be used where large areas are to be examined. The penetrant should be applied with low-pressure spray equipment which will not permit atomisation of the fluid, care being taken to ensure that the penetrant completely covers the surface and remains wet. On no account should the penetrant be allowed to dry during the penetration period.

Aerosol Method

Penetrant contained in aerosol-type cans is often used for "in situ" inspections. The best results are obtained when the can is held about 12 in. from the surface under test.

Brushing Method

The brushing method is generally used for individual items and items of complicated shape. A soft clean bristle brush should be used and retained only for this purpose. On no account should the penetrant be allowed to dry during the penetration period.

Penetration Time

The penetration time is the time which has to be allowed for the penetrant to enter effectively into defects and usually a period of up to ten minutes is sufficient for the larger type defects, but longer times may be necessary where minute defects are being sought. (see Table 21.1)

Typical penetration times are given in Table 21.1 but these may vary according to the temperature and process used. The manufacturer's recommendations must always be followed where these differ from the figures given.

Where the effectiveness of the pre-cleaning process cannot be guaranteed or where parts have been sandblasted, the penetration time should be extended but it should be borne in mind that this is no guarantee that defects will, in fact, be revealed in such conditions.

TABLE 21.1

Material	Nature of Defect	Penetration Time. (Minutes)
Sheets and Extrusions	Heat treatment cracks, grinding cracks and fatigue cracks.	15
Forgings	Laps, cracks.	30
Castings	(i) Shrinkage, cracks and porosity. (ii) Cold Shuts.	3-10 20
Welds	(i) Cracks, porosity. (ii) Included flux.	20 1
Plastics	Cracks, crazing.	1-5

Removal of Excess Penetrant

Excess penetrant should be removed by spraying with running water at a mains pressure of about 30 lb. sq. in. or by the use of an air \ water gun. In the case of self-emulsifying penetrants, it may be necessary with some surfaces to use a detergent solution, supplied by the manufacturer, prior to spraying the developer. It is most important to ensure that the rinsing operation is completely effective, otherwise traces of the residual penetrant may remain on the surface and interfere with the subsequent diagnosis of defects.

After rinsing, the surfaces of the component should be quickly inspected by means of ultra-violet light to ascertain the efficiency of the rinse. If any general fluorescence it still evident the rinsing operation should be repeated.

If a wet developer is to be used, the surfaces need not be dried but drying is essential if a dry developer is to be used. On large parts the excess water can be blown off with clean, dry, oil-free air but when parts are of convenient size, drying in a recirculating hot-air drier is recommended. Excessive time in the drier should be avoided, as the penetrant will slowly evaporate.

Application of the Developer

The developer usually consists of a very fine white powder which may be applied in (a) the form of a spray, the powder being suspended in a volatile carrier, (b) as a dip with the powder suspended in water or (c) as a dry powder which may be blown on to the component or into which the component may be dipped. The action of the absorbent powder is to draw out the dye from the surface defects, thus indicating their position by the resultant yellowish-green stain when viewed under ultraviolet light.

Where it is suspected that microscopic defects may be present, great care is necessary to ensure that the developer is applied evenly and very thinly, since a thick layer might completely conceal a defect holding only a minute quantity of dye.

Where a wet developer is concerned, the best results are obtained when the developer is applied by means of a paint-type spray gun operating at an air pressure not in excess of 15 lb. sq. in. The pressure pot of the gun should be equipped

with a stirrer to keep the developer agitated and the absorbent particles in suspension. Before pouring the developer into spray-gun it should be well shaken to ensure thorough distribution of the absorbent particles.

When requirements are not too exacting, small parts can be dipped into a bath of developer but the action must be performed rapidly to minimise the possibility of the penetrant being washed out of shallow defects. The bath should be agitated from time to time to ensure that the absorbent particles are kept in uniform suspension in the solvent. The formation of pools of developer on the parts during draining must be avoided, otherwise the resultant thick coatings may mask defects..

Due to the unusually uneven results obtained, the use of a brush for applying the developer is not recommended after the developer has been applied, the parts should be allowed to stand for at least 15 minutes and should then be examined in a darkened room, using ultra -violet light. Where doubt exists as to the validity of an indication, the part should be left for at least two hours and then re-examined. It viewing periods are to exceed 30 minutes, the use of special viewing goggles is recommended to reduce the risk of eyestrain and headaches.

NOTE
Portable lamps specially manufactured for fluorescent viewing are available.

APPLICATION OF THE PENETRANT PROCESS (WITH POST EMULSIFICATION)
In principle the process is similar to that described in the previous paragraph, except for the addition of the emulsification step. However, the separate application of penetrant and emulsifier does introduce additional factors which must be taken into account and these are described below.

After the parts have been dipped in the penetrant, the drain-off period should not be less than 15 minutes and not more than 2 hours. If the period is less than 15 minutes, dilution of the emulsifier by the penetrant may occur and penetration of contaminated defects may not be complete. If the period exceeds 2 hours, partial drying of the penetrant may occur, resulting in exceptionally long emulsification times. Once an optimum draining period has been determined for a particular part, it should be adhered to within ± 20 per cent, since this period directly influences the process and effects of emulsification.

The parts should be dipped into the emulsifier (the length of time the emulsifier is allowed on the parts being somewhat critical), and should be held to the minimum time necessary to give a good water wash, since this will result in the highest sensitivity. It should be determined by experience for each type of part and finish and then strictly adhered to.

An average emulsification time is about 2 minutes, but may vary between 30 seconds to 5 minutes, according to the surface condition of the part.

After removal of the emulsifier, the part should be dried, treated in the dry developer and then inspected for defects.

INTERPRETATION OF INDICATIONS
If defects are present and all stages of the process have been applied correctly, they will be indicated by brilliant greenish-yellow marks on the surface of the part ; some may appear immediately as the developer dries but others may take longer to develop. The characteristics of the markings, such as the rapidity with which they develop and their final shape and size, provide an indication as to the nature of the defect revealed see Figure 21.1.

The rate of staining is an indication of the width and depth of the defect, whilst the extent of staining is an indication of its volume. A wide shallow defect is revealed almost instantly but narrow deep defects may take some time to display the final pattern.

Scattered dots indicate fine porosity or pitting Fig. 21.1 (d), whilst gross porosity may result in an entire area becoming stained.

Closely spaced dots, in a line or curved pattern Fig. 21.1 (c) , usually indicate tight cracks or laps but such patterns are also characteristic of very wide defects from out of which most of the penetrant has been washed. Wide cracks, lack of fusion in welded parts and other similar defects are indicated by continuous lines as shown in Fig 21.1 (a) and 21.1 (b). All defects should be suitably marked prior to removal of the developer, but crayons should not be used on highly-stressed components subject to heat treatment, since this is known to induce fractures.

Fig. 21.1, Indications given by Defects.

REMOVAL OF DEVELOPER

Developer should be removed by washing with water spray or by dipping the component in an aqueous solution of 2 per cent chromic acid. Since the surface is then in a condition susceptible to corrosion (where this is applicable) the prescribed protective treatment should be applied without delay.

CHAPTER: 22
NON-DESTRUCTIVE EXAMINATIONS
ENDOSCOPE INSPECTIONS

INTRODUCTION

This chapter gives guidance on the use of endoscope inspection equipment (also known as baroscope, introscope or fibrescope equipment, depending on the type and the manufacturer) for the assessment of engine serviceability, both on a routine basis and for the investigation of developed defects. Although endoscope inspections are utilised in other areas, the information in this chapter is intended primarily for the inspection of gas turbine engines ; it is not related to any particular engine and should , therefore, be read in conjunction with the relevant Maintenance Manuals and approved Maintenance Schedules, which should also be consulted for specific damage and time limits.

Endoscope equipment permits the inspection of gas turbine engine parts which would otherwise be inaccessible with the engine installed and in service. Early gas turbine engines had poor provision of ports for this type of inspection, apart from the igniter plug and burner holes, but engine manufacturers now tend to provide improved facilities for endoscope inspection of the rotating and combustion sections of the engine. Other large engine components may also have limited facilities, as do some airframe air-conditioning turbine units, etc.

Engineers should be conversant with the techniques of endoscope inspection to enable them to use the equipment as an effective inspection and diagnostic tool and as part of normal inspection procedures. This form of use will result in a more effective assessment being made of damage caused by an in-service incident such as a bird strike or foreign object ingestion.

ENDOSCOPE EQUIPMENT

Manufacturers of endosopes tend to market the complete range of units required and it is, therefore, usual to be able to interchange parts of one system with those of another. The following general description of the equipment is not related to any particular manufacturer and should be read in conjunction with the appropriate manufacturer 's technical instructions or service manual.

The Probe

The probe is an optical instrument which performs two functions; (a) it relays and directs a beam of light for illumination, and (b) it displays a focused and undistorted image at the eyepiece. Probes differ in that some have an integral light source, while others rely on a remote 'light box' ; another version has a small bulb at the tip of the probe to provide the illumination. In addition, facilities for adjusting the focus and magnification may be incorporated.

The probe shaft usually consists of concentric tubes, the inner one of which is the view tube, while the outer one provides a separate light path for the illumination beam. This beam is carried through an annular 'fibre optic bundle ' to the tip where the necessary change in direction is made through prisms. The image is modified throughout its travel through the view tube by a series of lenses and may also be changed in direction by the same method.

At the tip, the prisms are protected by windows which prevent dust, grit or direct contact harming the optical clarity of the image. If the probe is of the nonadjustable type, the angle of view at the tip will be marked and there are the following four variations:
a)   Straight view, where the centre of the field of view is parallel to the probe shaft.
b)   Lateral view, where the centre of the field of view is at right-angles to the probe shaft.
c)   Oblique view, where the centre of the field of view is at an oblique angle to the probe shaft.
d)   Retro view, where the centre of the field of view is at an acute angle to the probe shaft, resulting in an amount of doubled-back view.

The field of view is designed to give a fairly useful amount of visible area and magnification at the kind of distances required in the internal inspection of a gas turbine engine. The eye-piece makes the final adjustment to the image before visual perception, and provision is usually made here to indicate the relative direction of view with respect to the engineer. An array of inscribed lines, called a graticule, is sometimes provided to indicate, under specific conditions of use, a measurement of distance useful for damage assessment. Accessories can enable a still camera to be used to provided a permanent record of defects, etc., and television and video equipment can be used for applications where direct access to the probe would be uncomfortable or unsafe.

Flexible endoscopes Figure 22.1 rely on fibre optic bundles to transmit an image in the same way as the illumination beam is transmitted along the rigid probes. However, for the transmission of an image, the relationship of each fibre to all of its neighbours must be the same at the eye-piece as at the probe tip. The image bundle and the illumination bundle forming the central core. The flexible probe tips are usually changeable and are of less elaborate construction, allowing the tip to be shorter, thus not having a cumbersome non-flexible end to restrict use in a confined space.

Migration of fluids by capillary action along the bundles between the individual fibres is prevented by the application of a transparent resin to the bundle ends. Compression, twisting and kinking of the fibre optic bundle is prevented by fitting the bundles in a flexible conduit, normally of spiral or 'armadillo' construction, which will restrict the manipulation of the probe to within the capabilities of the bundles.

The Light Source

Most endoscope equipment now in use utilises a separate and remote light source to illuminate the view area. This normally takes the form of a self-contained 'light box' containing the lamps, transformers, switch gear and cooling fans to provide a high-intensity beam. This beam is focused upon an adaptor in the box to which the fibre optic light bundle from the probe is connected. Ouartz\halogen or quartz\iodine lamps provide the source of light, which may be varied in intensity to suit both the application and personal preference. Mains power supplies are normally used although some equipment can be arranged to allow typical aircraft voltage and frequencies to provide the system with power.
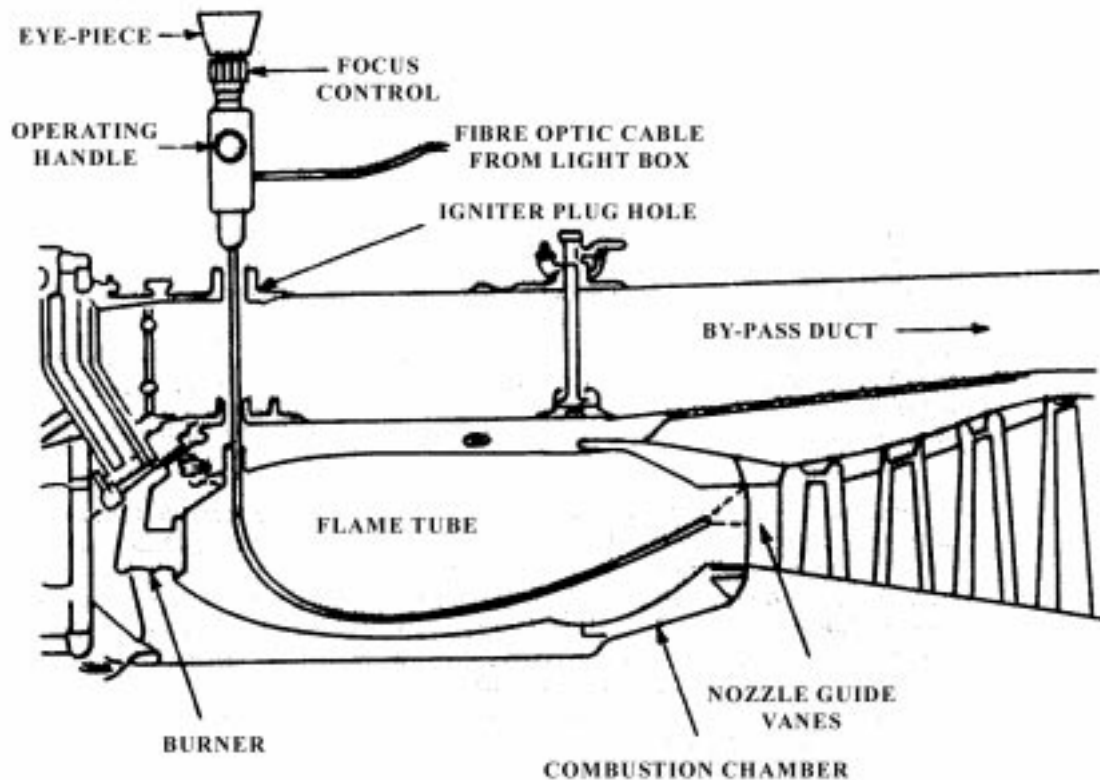
Fig. 22.1, Flexible Endoscope Inspection Equipment

PREPARATIONS

Precautions

Consideration must be given to the potential hazards involved in the inspection of gas turbine engines while under ramp or first-line maintenance conditions, and special precautions should be taken because of the engineer's preoccupation at the engine. A dangerous situation could occur in the event of the inadvertent operation of a starting system, ignition system, thrust reverser system or any mechanical or electrical controls; these systems should therefore be inhibited.

Other factors to be considered when inspecting engines under these conditions include:
a)   Dissipation of residual heat.
b)   Effect of windmilling.

c)   Endoscope equipment contamination.
d)   Electrical potential difference between the probe\light source and the aircraft structure.
e)   Fuel and oil leakage.

Access

Engines designed for endoscope inspections have access ports fitted with blanking plugs at various points in the casings, and the areas visible through these parts are detailed in the relevant Maintenance Manual. However, if specific access is not provided, a general knowledge of the layout of the engine together with access provided by the removal of igniter plugs, temperature probes, pressure sensing lines, compressor bleed valves and other air off-takes enables useful condition assessments to be made. Forward view endoscopes can also be used to view through the air intake of an axial flow compressor or, to a more limited degree, through the turbine, the latter being restricted because of the greater curvature of nozzle guide vanes

Access-port blanking plugs are subject to high temperatures and high rates of temperature change. This has the effect over a period of time of ' pinching' the blanking plugs to a higher torque than was applied at assembly. During removal, therefore, care must be taken to select a spanner which is a good fit on the plug and will provide adequate leverage. Plugs which are fitted into blind holes in engine casings invariably have thread inserts and these, under high torque removal stresses, can become extracted with the plug and will require replacement.

The 'pinching' effect can be overcome to a certain extent by applying an anti-seize compound when fitting the blanking plugs. Manufacturers usually recommend the application of a graphite-based release agent which forms a dry film on the threads. Alternatively, a paste with metal or metal oxide content is applied. Neither paste nor dry film should be applied unless it can be established which of the compounds had been used previously, as any mixing will result in the formation of a hard-setting compound.

NOTE
In consideration of this 'pinching' effect, the initial torque settings for the blanking plugs must be those recommended in the relevant Maintenance Manual..

Orientation

Familiarity with the layout of an engine and experience in the use of endoscope equipment enables an engineer to recognise the area being viewed and the extent of inspection possible through a given access port.

NOTE
Parts frequently appear larger when viewed through an endoscope and damage can seem more extensive than it really is. Familiarisation with the size (height and width) of the item being viewed is therefore essential and ideally a spare part should be available to be held in the hand and viewed with and without an endoscope probe to ensure the item is correctly assessed.

Non-rotating assemblies cause few problems because major components such as burners and stators provide points of reference. Damage reporting on non-rotating components requires that burners, flame tubes, etc., be numbered to a standard form and that areas and components are named. An inspection report can then identify areas of damage by stating :-
(a)   Access port used.
(b)   Direction of view.
(c)   Area or component inspected (by name and \or number).
(d)   Dimensions of and type of damage.

Components of rotating assemblies need to be identified for the same reasons. At overhaul, marks may be applied to the convex surface of turbine blades, together with the balance details normally applied, to number the blades consecutively around the disc. This procedure will enable positions to be fixed for the parts of the whole spool connected to that turbine. For instance, if HP turbine blades are numbered, HP compressor blades can be identified by stating:
(a)   Compressor access port used.
(b)   Direction of view.
(c)   Details of damage.
(d)   Turbine access port used.
(e)   The turbine blade number visible at the centre of the field of view.

The number of blades in a particular compressor or turbine stage should be known and the blades counted while viewing to ensure that all blades in the stage are checked. When viewing large blades, such as early compressor stages, it will

be necessary to make two or three passes to cover the complete blade length, i.e. view the outer third of the aerofoil, mid span section and inner third adjacent to the inner platform.

If damage is found on a rotating assembly which has no consecutive numbering of blades, point reference must be established by using an externally or internally recognisable point on the rotating assembly. Again, access ports must be stated and consecutive blades must be counted to locate the point of damage.

For ease of inspection, the HP shaft can be rotated (at a suitable speed to permit a satisfactory inspection) by an air-driven motor through the high-speed gearbox on engines with a drive facility; otherwise, hand-turning may be accomplished by using either a redundant component drive coupling or a standard socket fitting in the gearbox. Air-driven motor systems in general use have hand or foot controls to vary direction and speed; this is an advantage over using the hand-turning method which requires one person to turn the shaft while another performs the inspection.

LP shafts must be turned by hand, and to rotate an Intermediate Pressure shaft in a three-spool engine, without a gearbox, a locally - made tool may be required to turn the shaft through the IP intake..

INSPECTIONS
One of the reasons for the increased use of endosopes is the high cost involved in engine changes, either due to suspected internal damage or because of a Maintenance Schedule based on a " Hard Time Life " philosophy. It is, therefore, an advantage to allow the engines to remain in service until defects are revealed via performance analysis, oil analysis, endoscope inspection, or by repetitive monitoring of allowable damage.

Scheduled Inspections
Scheduled inspections are the regular ones which are carried out as part of an approved Maintenance Schedule. The frequency of such inspections is dependent upon either engine cycles or flight time and need not be concurrent with the aircraft 's scheduled checks. The combustion section and the turbine blades are the primary concern during these inspections, due to the high stresses and temperatures encountered during service. All defects should be recorded, normally on a chart specific to the engine type, which after completion recorded, normally on a chart specific to the engine type, which after completion constitutes a record of any deterioration taking place within that particular engine. An assessment can then be made as to whether the engine may be allowed to continue in service until the next scheduled inspection, or that it may only continue in service subject to more frequent checks.

Special Inspections
Occasionally , experience gained by frequent endoscope inspections, in-service failures or inspection during overhaul highlights the development of particular defects which can be monitored using endoscopes while the engine continues in service. Normally only one or two access ports need be disturbed because it is only the area detailed by the special inspection which needs assessing. This again enables the engine either to continue in service or to be monitored even more frequently.

NOTE
Engines are often removed after scheduled or special inspections to prevent a primarily minor defect causing secondary damage, possibly leading to engine failure.

Non-scheduled Inspections
Endoscopes can be used to great effect when it is necessary to assess the damage caused by foreign object ingestion or engine surge, diagnose the cause of developed defects, and provide a means of establishing engine serviceability following excursions beyond the normal turbine temperatures or maximum power limits. Together with other basic visual techniques of inspection, the use of endoscopes may, under certain circumstances, provide the necessary evidence to permit an aircraft to fly back to base for repair when it would otherwise require an immediate engine change.

FINAL INSPECTION
On completion of an endoscope inspection, it is essential that all access plugs are refitted correctly and securely. Failure to do so could cause a gas leak and result in a fire warning , shut-down and turn-back or in some cases cause a failure due to blade flutter or loss of cooling air. Access panels must also be correctly refitted.

APPLICATION
Components normally inspected with an endoscope, such as compressors, combustion sections and turbines, are subject to different types of damage and defects ; therefore, actual limits and the specific forms of defects can only be found in the relevant Maintenance Manual.

Compressors

Endoscope inspections after such occurrences as foreign object damage (FOD), bird strikes or surge, must be systematic, not confined to single stages, and always preceded by a comprehensive external visual examination. In addition to the endoscope ports provided, it may be possible to use bleed valve apertures and air-sensing probe points to inspect the compressor.

The most common form of damage to compressors is FOD. Centrifugal compressors have proved to be fairly damage-resistant but axial compressors are not so resistant to FOD and are also subject to surge damage. Inspection of axial compressors and their blades should, therefore, always include a search for evidence of FOD in all its manifestations-nicks, dents, scratches, and the cracks which these defects may produce.

Surge damage may be in the form of trailing edge cracks at the blade root, rubbing marks on the blade platform or blade shroud, with perhaps damage to the spacer plates between the blades. Interference between tips or shrouds and the casing can occur during surge and may bend blade tips, cause cracks, etc. Interference between rotors and stator (clanging) is a more serious defect because of the likelihood of substantial deformation. Engine manufacturers normally know the type of damage which may be caused to their engines during surge, and the Maintenance Manual may, therefore, indicate which particular stage or stages need to be inspected and which defects are particularly indicative of surge damage.

Grime and oil deposits may form on the compressor blades over a period of time. Excessive oil deposits are usually an indication of front bearing oil leakage or general wear in the engine. Where engines are operated in sandy conditions, dust tends to stick on the rear of the compressor if there are oil deposits present, and such engines could benefit from compressor washing procedures.

Compressor blades which have mid-span shrouds (or clappered blades) are sometimes subject to wear at the point where the end of each shroud abuts it neighbour. On 1 stage LP or fan blades this wear is recognized and can be measured by taking up the total free play of the whole stage, by moving half the blades clockwise about their mounting pins and the other half anticlockwise; this leaves a gap between one pair of blades which represents total shroud wear. Of course, this procedure will not be suitable for other than fans or 1 st, and maybe 2 nd, stage LP blades. Inspection of mid-span shroud wear through an endoscope is confined to a close and clear view of abutting shrouds. Shrouds which are wearing may be recognized by :
a.   Metallic streaking from the join.
b.   A wavy, uneven join line.
c.   Hammering (which is where the abutting faces deform, like chisel shafts under the effects of frequent hammer
          blows).

What ever damage is found on compressor blades, its position on the blade will determine its seriousness. It is usual for the inner one-third of the blade to be classified as a 'no damage allowable' area, as are the areas on each side of midspan shrouds.

Combustion Section

High temperature is the reason for most combustion section defects. Burning, cracking, distortion, and erosion of nozzle guide vanes (NGVs) are typical. The combustion section may be inspected with an endoscope either through the designated access ports or through the igniter plug holes or burner apertures. The components visible depend, of course, upon engine design and the position of the access ports, but the flame tubes or liners, burner flares and swirlers, tube interconnectors and the NGV leading edges are normally inspectable.

NOTE
 In the combustion section, all defects must be assessed on the basis of the likelihood of the defect causing a breakaway of material. This could lead to greater damage occurring in the turbine.

Burners

The burners protrude into the forward face of the flame tube\liner through an aperture which is usually flared ; this is sometimes called the burner flare. The burner must be concentric with this flare otherwise a loose flare or burner should be suspected. In an annular combustion chamber, the burners and flares are separated by blank segments, and these must be secure.

The burners may develop carbon deposits, which can be in the form of an irregularly-shaped protuberance from the burner face. In some engines this has a detrimental effect on starting, but when it breaks off it rarely causes any damage because it is usually soft. Hard carbon, however, can block the burner spray nozzle but does not grow large enough to cause break-off damage.

Swirlers (or swirl vanes) should be inspected for security and missing elements. All components should be inspected for cracks.

Flame Tubes \ Liners

Flame tubes (or, in annular combustion chambers, the liners) contain the flame by directing air through holes or slots to the centre of the tube. The whole surface of the tube is peppered with cooling holes of varying sizes arranged in a regular pattern, and these are usually the starting points for cracks and sometimes determine the limits of cracks. For instance, the Maintenance Manual may state that axial cracks which extend rearward beyond the third row of cooling holes are unacceptable. The allowable limits for cracks can depend on both their position and length. To assess their length through an endoscope must at times be a matter of estimation. The engineer should, however, be aware of the general dimensions of the component being inspected (these are sometimes stated in the Maintenance Manual, otherwise familiarity with the components is required); from this a near estimate can be made of crack length. The flame tubes should be inspected for cracks and other damage as follows:

Cracks

These start at holes or edges and may stop when they reach another hole or edge. Circumferential cracks can be more serious than axial cracks as they can result in pieces breaking off under the effect of airflow and flame impingement. Cracks around dilution chutes (scoops or nozzles into the airstream) are usually considered to be serious, since any distortion of the chute may create hot-spots which will accelerate deterioration and may cause torching of the flame onto the air casing.

Distortion

Usually, defined limits give the allowable amount of distortion into the airstream and the length of cracks associated with it. The construction of a flame tube normally includes sections which overlap each other; these overlaps allow cooling air to flow near the surface of the tube. The sections are joined by a 'wigglestrip' (corrugated spacer) which allows air to flow through the overlap. The wigglestrips should be inspected for security because the welds can fail, causing distortion of the strips into the airstream of the tube. Limits for this damage are measured in numbers of adjacent or total wigglestrip pitches affected.

Burning and Hot Streaking

The high temperature materials used for the flame tubes \ Liners sometimes change colour quite dramatically with heat, so coloured areas alone may not indicate serious burning. Burning is caused by the flame approaching the tube/liner and is recognized by the texture of the surface; this becomes rough and pitted, and a reduction of wall thickness is noticeable. Streaks of metallic particles sparkle under the high intensity light of the endoscope and are recognized this way. Edges of lips and overlaps are susceptible to burning and erosion. Burn limits depend upon position and area.

Holes

These can be caused in three ways; (i) pieces breaking off , (ii) cracks allowing a section of metal to be lifted off and (iii) burning through. Holes in a flame tube/liner need not be a reason to reject an engine. However, the turbine should be inspected if the hole was caused other than by burning through. Carbon deposits produced at the burner can sometimes be mistaken for hole as the carbon is an intense black; the angle of view of the suspected hole should be changed if any doubt exists. If the suspected hole is a carbon deposit no detail of the edge of the 'hole' will be visible, neither will any detail through the 'hole'

Nicks and Dents

Inspection should be extended to the NGVs if this damage is found because these are evidence of broken-off particles of FOD.

Nozzle Guide Vanes

The NGVs are subject to very high thermal and mechanical stresses, and only newest of engines do not show physical signs of this when inspected through an endoscope. If viewed from the igniter plug holes, the leading edges and some concave surfaces only will be visible. Access ports are required elsewhere to view the whole surface of NGVs as they are highly cambered. Rows of cooling-air holes are visible on most NGVs and these may be used to identify areas of the vane. Damage can be as follows:

a) **Discoloration**

Slight discoloration is nearly always present and is not necessarily a defect. Heavy discoloration, however, is associated with burning.

b) **Cracks**

These are allowable to a limited extent but if associated with lifting of the surface from the original contour they are not acceptable. Cracks are either axial (from leading edge to trailing edge) or radial (vertical) and their allowable length will depend on their direction ; those which converge or are in convex surfaces may well necessitate engine rejection.

c) **Burning and / or Erosion**

Erosion, although caused separately from burning, is usually found in the same areas as burning and is subject to the same limits. Erosion is the product of abrasion and looks like burning without the discoloration ; that is, roughness and pitting with a noticeable reduction in skin thickness. Burning and erosion are most common on NGV leading edges and concave surfaces. They may penetrate the outer skin and are sometimes allowable, but again subject to position and size of area affected.

d) **Dents and Nicks**

These are caused by FOD and further inspection should be carried out if they are found.

e) **Tearing**

Tearing can occur in trailing edges and is allowable only within defined limits.

Turbine Section

Access for the endoscope inspection of turbine blades is either through the ports provided or sometimes through the igniter plug holes using a flexible endoscope (flexiscope). For this, a holding tool can be made which is fed through the igniter plug hole and fixed. The flexiscope is then inserted and the holding tool guides the tip through the NGVs to view the blades. Methods of identifying blades are explained in above paragraph.

NOTE

When viewing the aerofoil surface of a turbine blade, the end of the probe is located between the blades and must be withdrawn prior to engine rotation to avoid damaging the probe and blades.

Turbine blades are subject to the same types of damage and defects as NGVs. The limits for such damage are, however, more stringent. Blades can have some leading edge damage and cracking but still remain in service; trailing edge cracks, however, can propagate quite quickly due to tearing forces imposed by centrifugal force and the twist of the blade, and these cracks are not normally allowable. Dents on aerofoil surface of hollow turbine blade can initiate cracks on the cooling-air passage wall inside the aerofoil section which can propagate to form quite large internal cracks before breaking through and becoming visible.

Deposits can form on most internal parts of gas turbine engines. When airborne sand is ingested it usually accumulates on the NGV and turbine blade leading edges. It has a sandy colour and becomes baked on by the combustion process, and is not easily removed even at engine overhaul. It can cover some cooling holes but does not usually cover significant NGV or turbine blade defects. Its effect on inspections is therefore minimal., but its overall effect is to shorten engine life.

Record of Damage

When damage is found it must be recorded in the engine records. This is the case whether the inspection was routine or a special one. Increases in crack length, for instance, can then be assessed over a period of time, thus giving time to arrange for repairs or removal. Some operators have introduced inspection sheets for use when carrying out routine and special endoscope inspections. The sheets detail the preparation work necessary before inspections and also include drawings which depict blades or flame tubes ; engineers then mark in observed defects and identify the drawings accordingly. These representations of the internal state of each engine then form part of the engine 's records and can be used in future assessments of damage and the growth of existing damage. Photographic records may also be kept, using a still camera or video tape recording.

The Maintenance Manual will sometimes define a defect as acceptable for a finite number of flying hours or cycles. Engineers should , therefore, ensure that additional entries are made in log books and /or technical log to limit engine operation to the periods allowed. If however, inspection reveals that different defects exist which are related, each with a finite allowable number of flying hours, the engineer should consider certifying such defects as allowable only for a shorter time than the most restrictive of the allowances given.

CHAPTER: 23
NDE : ULTRASONIC FLAW DETECTION AND THICKNESS MEASUREMENT

INTRODUCTION

The methods of crack detection dealt with in last chapters are of considerable value for finding surface defects but are unable to reveal the presence of internal flaws which are distant from the surface. This chapter gives general guidance on the application and scope of ultrasonic sound waves for detecting surface and internal flaws in materials and parts and for the measurement of thickness.

Ultrasonic testing is not a complete substitute for other methods of flaw detection and should generally be regarded as complementary to them. It should be considered an extension to efficient inspection but should not be regarded as a foolproof method without considered trials and its indiscriminate use could be uneconomical and misleading. There are instances, however, particularly in aircraft applications, where ultrasonic testing is the only satisfactory method, e.g. when a distant defect lies parallel with the only available surface of a component. The degree of skill and experience required to use ultrasonic apparatus, and to interpret the indications obtained, varies with the complexity of the parts to be examined, the type of equipment available and the acceptance standards specified. Operators should be properly trained and qualified on the equipment in use.

Cavities, inclusions and cracks in cast metal prior to fabrication by extrusion, rolling, forging, etc., can be found by ultrasonic techniques and automatic scanning devices are often use during the manufacturing process. Large steel or aluminium forgings, components welded by gas, arc or flash butt methods, and a variety of parts such as turbine discs, propeller blades and wing spar booms may all be examined at various stages during manufacture. Ultrasonic methods can also be used for finding fatigue cracks, and other defects arising from operating conditions, during the periodic inspection of airframe and engine and engine parts.

Thickness measurement by ultrasonic methods has some aircraft applications. It provides a satisfactory means of measuring the skin thickness of hollow propeller or turbine blades and for checking tubular members or sheet metal assemblies. Delamination of bonded assemblies can also be checked by similar methods

SOUND WAVES

Ultrasound describes sound at a pitch too high to be detected by the human ear and the frequencies used in ultrasonic testing are normally within the range 500 kHz to 10 MHz.

Sound Energy

Sound is energy produced by a vibrating body, the energy being transferred through a medium by the wave-like motion of the particles making up that medium,. The frequency of the waves is the same as that of the vibrating body and the wavelength is dependent upon the speed of sound in the particular material. This is wavelength is Figure 23.1, the 'y' axis representing the distance of a vibrating particle from its mean position and the 'x' axis its distance from the sound source. The time taken for the sound to travel one wavelength (λ) is the same as the time taken for the vibrating body to execute one complete cycle.

Wave Types

Three main types of waves may be generated. The vibrations in longitudinal (compression) waves are in the same direction as the sound motion and the vibrations in transverse (shear) waves are perpendicular to the sound motion. Waves generated along the surface of a material, known as surface waves, have an eliptical motion. Any of these types of waves may be generated in solids but only longitudinal waves can normally be generated in liquids or gasses. Other types of waves exist and are sometimes used in ultrasonic testing (e.g.. Lamb Waves, which are vibrational waves capable of propagation in thin sheet material).

The speed of sound through any particular material depends on the density and elastic constants of that material. Transverse waves travel at approximately half the speed of longitudinal waves, and surface waves at approximately 90 per cent of the speed of transverse waves.

Beam Characteristics

When sound waves are generated by a flat disc vibrating at ultrasonic frequencies the beam of sound is initially parallel and then, at a distance from the disc related to its diameter and the sound frequency , spreads out and loses intensity, the spread increasing as frequency and disc diameter are reduced. Within the near (parallel) zone variations in sound

intensity occur, and absorption results in a loss of energy with increased distance from the source. A material with a large grain structure or holes associated with porosity absorbs more energy than one with a fine grain structure but, since absorption is also a function of frequency, by decreasing the frequency absorption is also reduced.

Fig. 23.1, Form of Sound Waves

Mode Conversion

When a beam of sound is directed at the boundary between two solid materials at an angle than normal to the interface, both reflection and refraction occur as shown in Figure 23.2. If material 'A' is a liquid, as in ultrasonic testing, only longitudinal waves will be reflected. Adjustment of angle 'a' will enable any of the main types of waves to be injected into material 'B'. Unfortunately mode conversion also produces unwanted reflections from the surface of a component which, due to the different speeds of the various types of waves, may give confusing results.
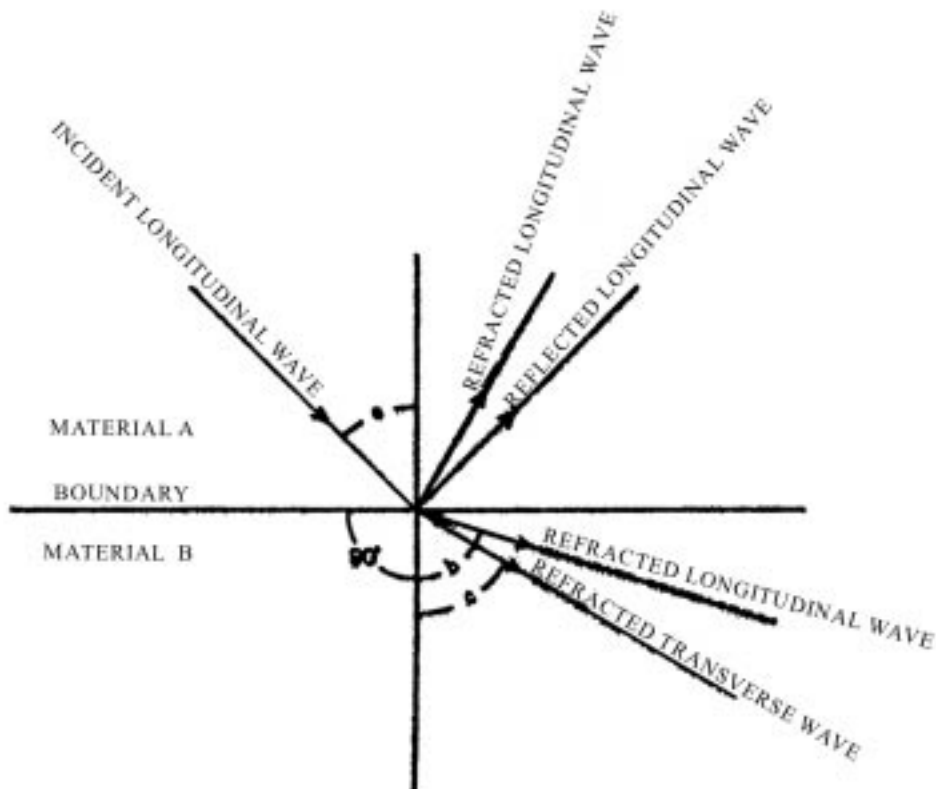
Fig. 23.2, Mode Conversion

GENERATION AND DETECTION OF SOUND WAVES

The sound waves used in ultrasonic testing are produced and detected by means of an electro-mechanical transducer, i.e. . a device which converts electrical energy into mechanical energy and vice versa. The properties of material used in the manufacture of transducers are discussed in the following paragraphs.

Piezoelectric Effect

If a mechanical stress is applied in a specified direction to certain natural crystals such as quartz, an electrical field is produced in which the voltage is proportional to the magnitude of the stress is produced in the crystal. By applying an electrical potential to the faces of an X-cut quartz crystal (i.e. a crystal cut in the form of a disc whose faces are normal to one of the axis) a vibration is produced, the frequency of which depends on the thickness of the crystal. Conversely, when such a crystal is caused to vibrate under the influence of a sound beam an alternating current is produced between the crystal faces.

A similar effect is produced in all electrically insulating materials, and certain ceramic materials such as barium titanate are particularly sensitive in this respect. Transducers made from these materials consist of a large number of tiny crystals fused together, and are permanently polarized during manufacture so as to vibrate in one plane only.

Piezoelectric crystals lose their activity when heated above a particular temperature and this may be a severe limitation for certain uses.

Crystal Frequencies

To achieve maximum efficiency crystals must be operated at their natural frequency (determined by their dimensions and elastic properties). Transducers used in ultrasonic testing are generally used in this way when searching for cracks but for resonance testing different methods are used .

Acoustic Coupling

The amount of energy transferred across a boundary between two materials depends on the Characteristic Impedance of each material, which may be taken as the product of the density and the speed of sound in each material. Good coupling will be provided when the Characteristic Impedance of the two media are closely matched, and the capability of ultrasonic flaw detection depends on these factors. The coupling between metal and air is extremely poor and it follows that if any air is present between a probe and the material being tested very little energy will be transferred across the interface. For this reason a liquid couplant such as water, oil or grease is normally used in ultrasonic testing.

Reflection

If an ultrasonic beam is injected into a material it will continue through that material until it strikes a surface and will then either pass through the interface or be reflected, depending of the factors outlined above. If the beam strikes a discontinuity, crack or void in the material the reflection may be picked up by a suitably placed transducer, the amount of reflected energy depending on the nature of the defect and its orientation. Most of the energy striking an external surface or void will be reflected but in cases such as bolt holes or bushes which have been well lubricated very little reflection may occur.

Probes

A probe consists of a transducer mounted in a damping material and connected electrically to the test set. For any particular application it may be necessary to use a probe of a particular design so that a sound beam is injected into the material at an angle normal to the expected defect. The required angle of the incident beam is achieved by mounting the transducer on a suitably shaped plastic block. Similar blocks are also used for injecting sound waves into a material with a uniformly shaped surface such a tube. In certain applications a wheel probe, consisting of a transducer mounted inside an oil-filled plastic tyre, has been found suitable for high speed automatic scanning.

Display

The most usual method of displaying the information obtained in ultrasonic testing is by means of a cathode ray oscilloscope. A pulsed transmission technique is normally used and is described below ; other methods are described in subsequent paragraphs.

In the cathode ray oscilloscope (Figure 23.3), a triggering device causes both the pulse generator and base control to operate simultaneously. The time base control (connected to the 'X' plates of the oscilloscope) deflects the trace produced by a beam of electrons, so that the trace moves across the screen from left to right in synchronization with the ultrasonic pulse transmissions. Vibration of the transducer result in an electrical signal at the 'Y' plates of the oscilloscope, which deflects the electron beam in the form of a peak (A) in the time base. Any returning echo acts on the receiving transducer to produce a second peak (B), the distance of the flaw from the surface being represented by half the distance between A and B. This distance can be calculated from knowledge of the speed of sound in the

particular material and the time base scale. The time base scale is usually variable, and provision is often made for the attachment of a graticule scale to the oscilloscope screen so that direct measurements may be taken.

Fig. 23.3, Simple Block Diagram of Ultrasonic Set

Transducer crystals are usually damped to reduce the length of the pulse, but a layer (known as the ' dead zone') is left immediately below the surface of the test material in which defects parallel to the surface can only be examined from an opposite face. Increasing the ultrasonic frequency would reduce the depth of this layer but would also result in high absorption and might not be suitable for certain materials.

The pulse repetition frequency is extremely rapid to ensure a good trace on the oscilloscope, but must not be so quick that sound energy is still reflecting within the specimen when the next pulse is initiated.

The presentation described above is known as 'A scan' but the information may also be displayed in the form of a side elevation (B scan) or a plan view (C scan), the latter usually being used in automatically produced paper read-out form from a normal A scan oscilloscope.

METHODS OF OPERATION
Transmission Method
If a transmitting and a receiving probe are placed on opposite sides of a specimen (Figure 23.4), sound waves will be transmitted directly through the material and picked up by the receiving probe. If a flaw in the material interrupts the sound beam, a loss of signal will result and the second peak on the time base will disappear. Longitudinal wave probes are normally used for transmission scanning but angled probes may also be used when only one surface is accessible (Figure 23.5).

Pulse-echo Method
This method relies on reflections from a defect being detected by the receiving probe and either a single transceiver probe or separate transmitting and receiving probes may be used (Figure 23.6).
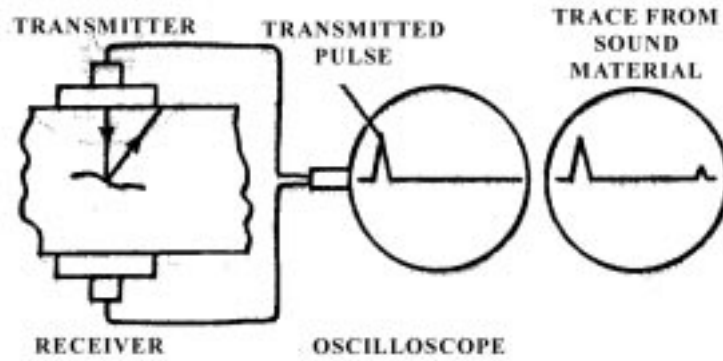
Fig. 23.4, Normal Transmission Technique
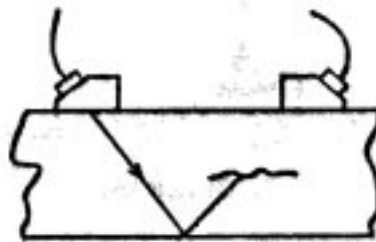
Fig. 23.5, Alternative Transmission Technique
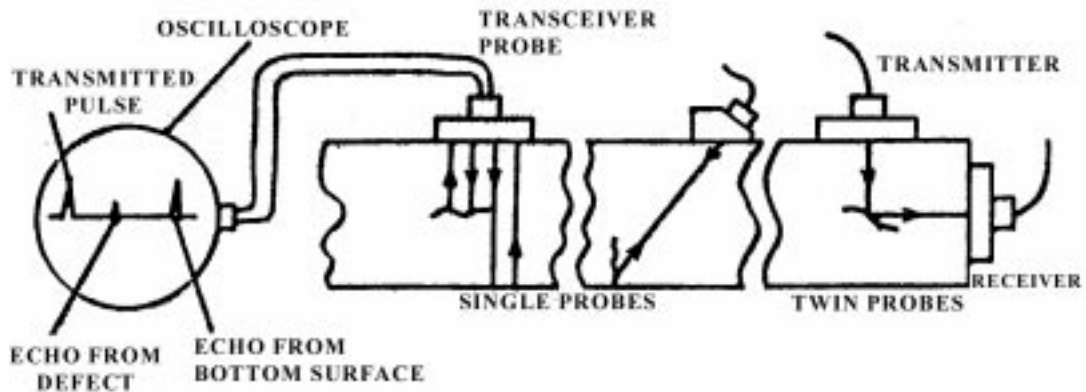
Fig.23.6, Pulse-Echo Techniques

Pulse-echo methods are also used for finding cracks at right angles to a surface. An angled probe is used to inject surface waves into a material , the waves following the surface contour and reflecting back to the probe from any discontinuity (Fig. 23.7)
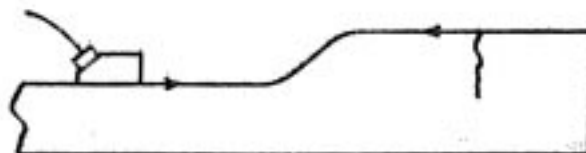
Fig. 23.7, Surface Wave Testing

Immersion Testing

The technique of holding a probe in contact with the specimen is known as 'contact scanning' , but there is also an important method of inspection known as 'immersion scanning', in which the specimen is immersed in a tank of water and a waterproof probe placed in the water, above the specimen (figure 23.8). Pulse-echo techniques are normally used but transmission techniques would also be possible.
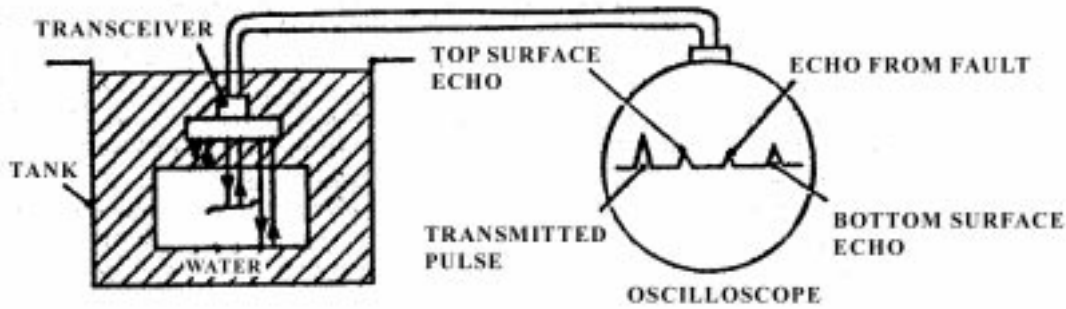
Fig. 23.8, Immersion Testing.

Pulses of ultrasound are emitted by the probe and pass through the water into the specimen. The top and bottom surfaces of the specimen are shown on the oscilloscope, together with indication from the transmitted pulse and any flaws within the material.

The distance between the probe and specimen must be selected so that confusing repeat echoes are avoided, and can also be set to avoid use of the near zone in examining the specimen.

The trace produced by a fault-free specimen will normally produce three peaks, the space between the second and third, i.e., the depth of the specimen, being the only part of interest during inspection. The time base is usually delayed, and its scale expanded, so that indications of defects are more easily seen.

Immersion scanning lends itself to automation and is frequently used for the inspection of parts of simple shape. Parts of complicated geometric shape present difficulties in that expensive electronic circuits would be required to differentiate between surface reflections and internal flaws.

Resonance Technique
If a sheet or plate specimen is caused to vibrate in the direction of its thickness, resonance will occur if the thickness is equal to exactly half the wave length of the inducing vibrations. By using a quartz transducer to vary the frequency of the vibrations, resonance is produced in the specimen and this frequency is displayed to indicate the thickness. A laminar type of defect, or loss of bonding , can also be detected by resonance methods providing that the separation is dry.

General Considerations
A number of factors must be considered before making an ultrasonic inspection and special techniques may have to be developed for a particular situation.

Surface Conditions
There are various surface conditions, such as rust, scale, loose paint etc., which will prevent inspection by ultrasonic methods and these must be removed. The rough surfaces such as are found on cast billets may present difficulties, but the use of grease as a couplant may be effective, or, alternatively, the immersion technique may be used. The shape of the specimen should also be considered so that slipper blocks may be made to provide the best acoustic contact.

Sensitivity
With too great a sensitivity, porosity and large grain size will hide flaws in a material by producing numerous peaks on an oscilloscope. It is important, therefore, that the sensitivity of the test equipment be adjusted so that unimportant features can be disregarded. The amplitude of reflections depends mainly on the size of the flaw and if the maximum acceptable size of defect were specified, then any reflection producing peaks higher than this would be known to be unacceptable.

(i)   For longitudinal wave scans the acceptable size of defect is related to a flat bottomed hole of a particular diameter. Test blocks are used in which holes of various sizes are drilled, and oscilloscope sensitivity is adjusted to give a peak of , say, one inch in height on the reflection from the hole of specified size. Blocks with holes drilled to different distances from the surface may be required to check the effect of attenuation on peak height. During test, defects producing peaks lower than one inch can then be ignored.

(ii)   For transverse wave scanning the acceptable size of defect is related to a hole or saw cut made in a block of the same material and thickness as that to be inspected..

(iii)   Notwithstanding the sensitivity setting of the oscilloscope, some defects, such as cracks, may extend over a considerable distance and therefore be unacceptable. These would be recognized by a constant peak as the

probe was moved in the direction of the cracks.
(iv)   A special test piece has been designed by the International Institute of Welding and may be used for checking ultrasonic equipment in respect of both longitudinal and transverse waves ; oscilloscope scale and resolution can also be verified.

NOTE
Most ultrasonic test sets are now fitted with an attenuators. This is a device which applies calibrated attenuation to the received signal, enabling received signal strength to be measured, in decibels, relative to the signal from a reference standard.

Choice of Frequency
Both absorption and diffraction of sound waves are a function of the frequency used. For any particular test it is necessary to take into account the size and position of possible defects, the nature of the material and the distances to be scanned. With a coarse grained material a low frequency must be used, especially in large specimens, but with a fine grained material a higher frequency may be used, with a consequent increase in sensitivity.

Type of Defect
When preparing a technique for the inspection of a particular item, knowledge of the type of defect which can be expected is of great assistance. For example, if a casting has a known tendency to crack at a particular position during service, sketches can be provided showing the oscilloscope patterns obtained from both sound and faulty castings; inspectors will then not be misled by spurious reflections due to the shape of the castings.

PRACTICAL APPLICATIONS
Testing Ingots, Billets and Heavy Forgings
Large blocks of metal of simple shape are particularly suited to testing by ultrasonic methods, provided that a suitable technique and frequency are used.

Rectangular blocks can be checked by systematically scanning three faces with a longitudinal wave probe. Because it is difficult to detect flaws which are close to the surface it may be advisable to scan all faces, but this not be necessary if surface material is to be subsequently machined off.

Certain cast ingots may have such a coarse grain structure that the ultrasonic beam is scattered to a degree which renders flaw detection difficult or even impossible. If echo techniques prove to be unsuitable, the transmission method should be tried, but if this also is impracticable, it may be necessary to delay the inspection until rolling or forging have been carried out.

Inability to obtain satisfactory results can often be traced to poor acoustic coupling, a difficulty which can be overcome by use of the immersion technique.

It is common practice in industry to use automated ultrasonic techniques on billets, pipes and other similar products. A water jet, passing through a jacket within which the transducer is mounted, acts as the coupling agent, and electronic alarms trigger marking systems which record the position of a defect. An automated immersion technique is also sometimes used on finished size thin wall tubes, using Lamb waves for flaw detection.

Testing Welded Joints
Most types of welds in thick materials can be inspected by ultrasonic methods, but thin sheet metal welds are more satisfactorily checked by the use of X-rays . It is good practice to obtain a separate specimen in the same material, and to drill holes (as shown in Figure 23.9). which will indicate if it is possible to detect flaws at these positions. Experience has shown that this is not possible with all types of material and welding techniques.

But welds made by gas or arc welding methods can be checked by using an angled probe which injects transverse waves towards the weld line. If flaws are present in the weld, the beam will be reflected back to the probe. Experience in the application of scanning methods has made it possible to identify most types of welding defects, although it is not always easy to determine the acceptability of the weld from this information. When doubt exists, the information derived from the ultrasonic test should be correlated with other methods of testing, such as radiography.

Special techniques are required for testing flash butt welds, since they contain no filler metal, and flaws are normally in the plane of the weld. One method of testing is to position two probes as shown in Figure. Scanning is carried out by moving both probes simultaneously in opposite directions so that any flaws are detected by the receiver probe. The probes may, in some instances, be positioned on the same side, and certain specimens are best scanned by fixing the probes in a jig to ensure correct alignment. To determine the best method for inspecting a particular weld, all these methods should be tried until the most consistent results are obtained.
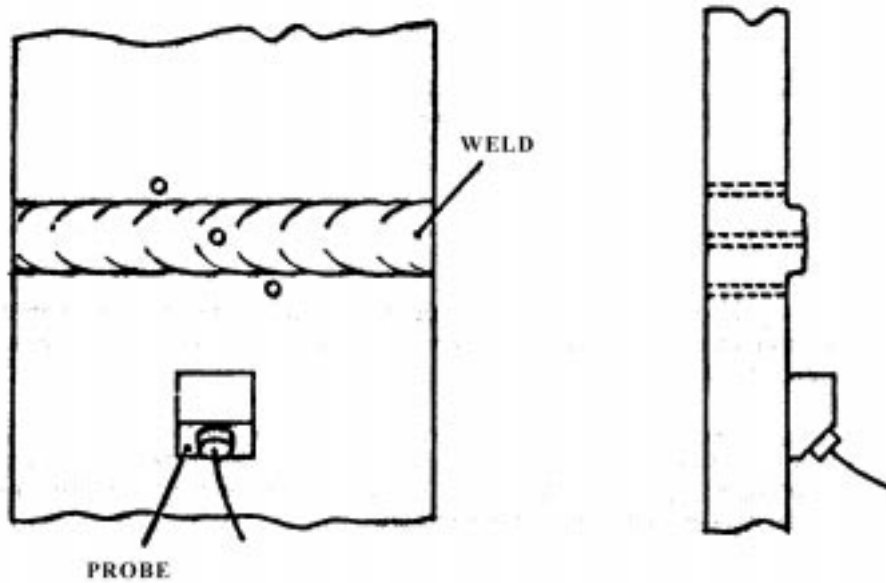
Fig.23.9, Test Holes in Weld Sample
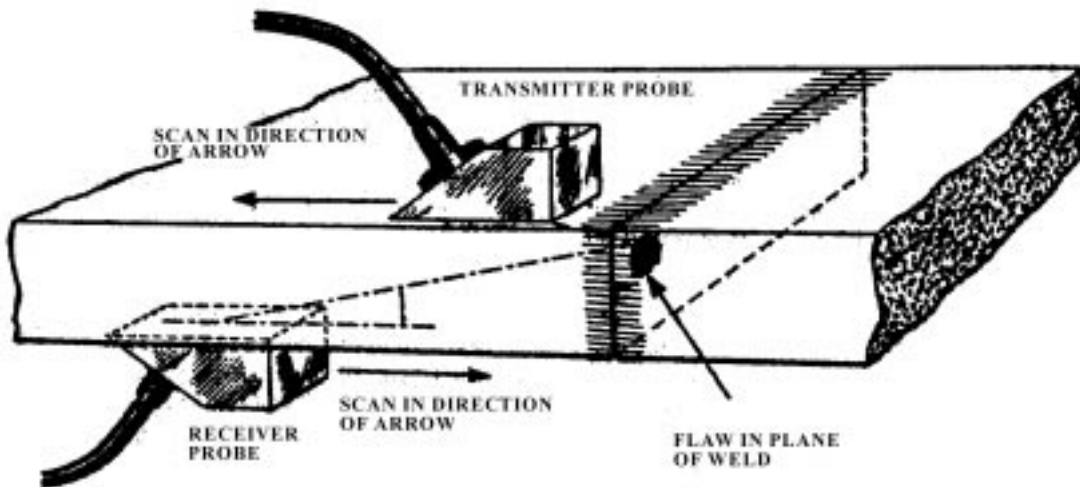
Fig. 23.10, Scanning method for finding flaws in flash butt welds.

THICKNESS MEASUREMENT

Pulse-echo Method

By the choice of suitable probes and the selection of appropriate test frequencies, several types of flaw detectors can be used for measuring thickness, but the accuracy of most is limited when dealing with material of the thin gauges used in aircraft construction. Their main application is, therefore, to the measurement of thick material during machining and manufacturing operations, particularly when the parts concerned would have to be removed from jigs or machines in order to measure them by physical methods. Vertical probes are normally used, and may be either the transceiver type or a probe combining separate transmitting and receiving crystals.

Resonance Method

This method is suitable for the measurement of new aircraft skin, structure and tubing and is normally only used during aircraft manufacture. A quartz crystal is excited by means of a valve oscillator, at a frequency well below the fundamental resonant frequency of the crystal, and held in contact with the specimen. This causes the specimen to vibrate in its thickness direction, and the frequency of the sound wave is increased until the specimen resonates. An increase in

the amplitude of the vibrations results, with a corresponding increase in crystal voltage. If the crystal frequency is further increased resonance recurs (i.e. at the next harmonic), and the fundamental frequency of the material, and hence its thickness, can be determined. Resonances may be shown on a suitably calibrated oscilloscopes screen but more simple methods such as a voltmeter reading or an audible note in earphones are often used.

NOTE: The thickness is equal to an exact number of half-wave lengths, which can be calculated from the speed of sound in the material and the fundamental resonance frequency.

Detection of Lamination
There are several ways of checking materials for internal laminations, and similar methods may also be used to determine the integrity of bounded structures. The pulse-echo technique may be used on plate over 1\2 inch thick but it is unsuitable for thinner sections.

Transmission Method
If a transmitting and a receiving probe are held in alignment on opposite sides of a specimen, any lamination inside the specimen will interfere with the transmission of the ultrasonic waves, and will be shown by a reduction in received signal strength. However, because of the need to have access to both sides of the specimen, this method has limited application in aircraft work.

Resonance Method
It has been explained that resonance occurs at one of the natural frequencies of the material, the thickness being related to an exact number of half-wavelengths of the ultrasonic beam. If a material is laminated, or the bond between two layers is defective, resonance will occur at a different frequency and will result in a change in the shape of the oscilloscope trace. Special test sets have been developed for the inspection of bonded structures, and techniques have been established from which it can be determined whether a bond is satisfactory or not when the bond is dry.

Multiple Echo Method
The time base and sensitivity of an ultrasonic set can be adjusted to give a number of boundary reflections. With a set adjusted in this way, any laminations present in a specimen being scanned will show up as a sudden increase in the number of reflections, e.g., if the specimen is laminated at its centre, the number of peaks on the oscilloscopes screen will be doubled.

'Lamb' Wave Method
Laminations near to the surface of a metal plate are very difficult to detect. However, Lamb waves may be generated in plate which approximates, in thickness, to one wavelength of the sound beam, and any lamination will result in a change in the screen display. The angle of the probe is very important and varies with the thickness of the lamination; it is necessary, therefore, to scan with a variable angle probe.

TECHNIQUES FOR AIRCRAFT PARTS
Ultrasonic testing is widely used on parts removed from aircraft, but is also applicable to the examination of parts in situ where other types of inspection would require extensive disassembly. Techniques are established to ensure consistent results and these are written into the appropriate manuals.

Aircraft structural parts which can be checked by ultrasonic methods include large forgings, wheels, engine bearers, axles etc. Before these parts are installed in aircraft, or at times when they are removed during overhaul, the immersion method of testing will often give good results. Large tanks and automatic testing equipment are not necessary for examining parts of manageable proportions; such parts can be submerged in water in a convenient container, the probe being mounted in a fixture to ensure that the required beam angle is maintained. However, certain parts, such as wheels, lend themselves to automated methods and some aircraft operators have found these to be worthwhile ; their use also permits an electronic record of each inspection to be kept. The essential requirement for any test is a standard of reference and this may be provided by using an identical part of known condition as a specimen. As a check on sensitivity, defects can be introduced in the reference specimen, by drilling small holes or by spark erosion, at positions where defects are likely to occur. Reflections introduced by these artificial defects can be compared with the traces obtained from a part under test.

The chief value of ultrasonic examination in situ, is that defects, and in some individual cases corrosion, can be found in areas not accessible for visual examination. Provided that one smooth surface is accessible to the ultrasonic probe, most forgings, casting and extrusions can be satisfactorily inspected. On some aircraft, spar booms and some similar structural members require periodic examination for fatigue cracks, but the area of suspected weakness may not be accessible for examination by visual or dye-penetrant methods. Ultrasonic testing gives quick results on those defects or dye-penetrant methods. Ultrasonic testing gives quick results on those defects which lend themselves to this form

of testing, i.e., the defect is normal to the directed beam. In this instance radiographic techniques would be quite unsuitable.

When carrying out ultrasonic tests in situ, the surface to be scanned by the probe should be thoroughly cleaned and covered with oil or grease to provide good acoustic contact. If parts are removed for testing, then water may be used as a couplant, but the parts should be thoroughly dried before being put into storage or service.

CHAPTER: 24
RADIOLOGICAL EXAMINATION OF AIRCRAFT STRUCTURES

INTRODUCTION
This chapter gives guidance on the operation of radiological testing apparatus and establishment of satisfactory inspection techniques.

The use of radiography in accordance with an approved technique will often facilitate the inspection of structures during manufacture, overhaul and maintenance, and can be used for the examination of structures which would otherwise be inaccessible. A number of airframe and engine manufacturers, and aircraft operators, have devised techniques for particular inspections, and these are written into the appropriate Maintenance Manuals and Maintenance Schedules or included in a separate Non-destructive Testing (N.D.T.) Manual. General information on radiographic techniques is included in British Standard (BS) M34.

Radiographic methods may also be used to advantage where normal physical methods of measurement are difficult or impractical . It has been shown, for example, that it is extremely difficult to detect eccentricity in items with long bored or counter bored holes and that wall thickness in these cases can be accurately determined by means of a radiograph. Where this type of measurement is considered necessary, the appropriate technique should be quoted on drawings or inspection instructions.

Radiography should be considered as an extension to efficient inspection and is sometimes of value in providing a second opinion where inconclusive results have been obtained by other methods. It should not be regarded as a foolproof method of inspection without considered trails and its indiscriminate use would be both uneconomical and misleading.

The misuse of radiographic equipment could result in the release of physically harmful radiations and it is therefore extremely important that operators should be properly trained and aware of the regulations concerned with safety. The provision of adequate protection is not dealt with in this chapter; it is emphasized however, that the operating procedures and conditions set out in 'The Radioactive Substances Act (1960), and the 'Ionizing Radiations (Sealed Sources) Regulations No. 808 (1969)' must be observed at all times when radiography is used for aircraft inspection.

The importance of proper training is also evident in the interpretation of radiographs. Incorrect conclusions could result in the clearance of unsafe structures or components or, conversely, the scrapping of expensive items which are really sound.

SOURCES OF RADIATION
There are two forms of electro-magnetic radiations which can be used in radiography, namely X-ray and gamma rays. The main difference between the two is in the method of propagation. The radiations are of very short wavelength (0.001 Å to 2Å) and are capable of penetrating solids, the rays passing through a specimen being used to expose a sensitized film. X-rays also cause the fluorescence of certain chemicals and this reaction is sometimes used to produce an image on a phosphor screen; this technique is known as fluoroscopy.

X-Rays
This particular form of electro-magnetic radiation is produced when electrons, travelling at high speed, collide with matter in any form.

The basic requirements for the production of X-rays are a source of electrons, a means of accelerating the electrons to high speed and a target to emit the X-rays. A typical circuit of an X-ray set is shown in Figure 24.1. The X-ray tube is an evacuated chamber in which the electrons are derived from a filament, set in a focusing cup and heated to incandescence by a low voltage current; electrons are released and form a 'space charge' around the filament. When a high potential is applied, electrons accelerate from the filament (the cathode) to the anode and strike the target, which then emits X-rays.

Only approximately 1 % of the electron energy is converted into X-rays the rest being changed into heat and light . For this reason the anode consists of a substantial block of copper, in which the target is set, and is often cooled by the circulation of liquid. The target is made from tungsten to resist the high temperatures produced by the electrons at the focal spot.

X-rays are emitted in all directions from the target but the tube is normally shielded so that a beam is emitted in the shape of a 40 ° cone. However, some X-ray tubes are designed to emit different shaped beams for particular uses.
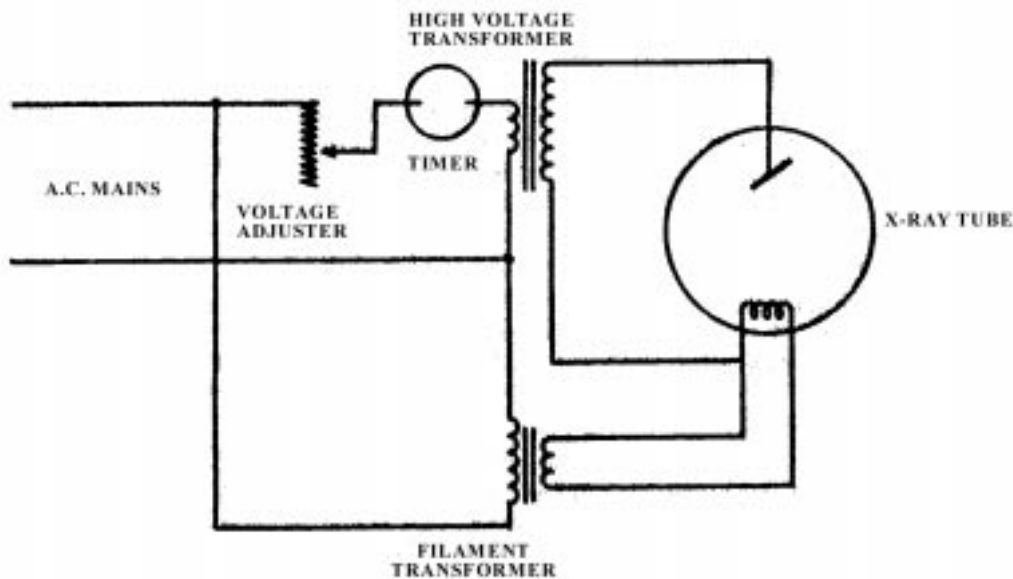
Fig. 24.1, Typical Circuit of An X-ray set

The electrical supply to an X-ray tube is normally from the a.c. mains through a transformer and, since electrons can only flow from the cathode to the anode, a pulsed tube current results. Some X-ray sets use complex electrical circuits to produce a constant potential in the tube, but they are generally very expensive and unsuitable for the type of portable equipment which is generally used on aircraft. The wavelength of the X-rays is inversely proportional to the voltage applied and the X-rays produced will vary in wavelengths down to a minimum value determined by the peak voltage. This is known as a 'continuous spectrum' and is a characteristic of all X-ray tubes. The penetrating power of X-rays increases as the wavelength decreases and high voltages are therefore used when radiographs of dense materials, such as steel, are required.

Penetrating Power
Although penetrating power is related to the voltages of the X-ray tube, it is often indicated by the 'half value layer' (H.V.L) of the beam. This represents the thickness of a given material (usually aluminium or copper) which will reduce the intensity of the beam to half its original value. This method is not completely accurate however, since the longer wavelengths, being less penetrating, are removed first and the quality of the beam is changed. If additional filtration (i.e. thicker aluminium or copper sheets) is provided it will be seen that the H.V.L. increases progressively until a constant beam quality is obtained.

Types of Equipment
X-ray equipment is normally graded according to the voltage range over which it is designed to operate. The portable sets used in aircraft work normally cover voltages between 10 k V and 250 kV, but no single set will cover this whole range. Tubes designed for high voltages possess inherent filtration properties, which, combined with space charge effects, will preclude the emission of an effective X-ray beam at low voltages. Typical ranges covered by portable sets are 10k V to 100k V and 100k V to 250k V.

Gamma Rays
Electromagnetic radiations resulting from the disintegration of radioactive materials are known as gamma rays. The isotopes now used in radiography are artificially produced and emit rays of similar wavelength to those produced in X-rays tubes. Gamma radiation is not in the same form as X-rays however, and consists of one or more discrete wavelengths in what is known as a 'line spectrum'.   The relative intensities of each wavelength are always the same for a particular material. The four most commonly used isotopes are Cobalt 60, Iridium 192, caesium 137 and Thulium 170.

Radioactive Decay
Radioactive elements, whether natural or artificial, are subject to a specific rate of decay i.e. reduction in strength of the radioactivity. This decay is measured in terms of the time over which half the original activity is lost and is called

the 'half life' of the material. The half life of radioactive materials varies considerably, for example, Aluminium 28 has a half life of 2.27 minutes whereas Uranium 238 has a half life of 4.5×10^9 years. Radioactive materials can be used for radiography through several half life periods provided that an adequate working strength remains, and some are capable of re-irradiation in an atomic pile.

Penetrating Power

It is customary to express the penetrating power of gamma rays in terms of the voltage which would be required to generate X-rays of similar penetrating power. The unit used, the mega electron volt (MeV), represents the energy required to accelerate an electron through 1 000 000 volts. The energy emitted by Caesium 137 is 0.66 MeV and this is equivalent in penetrating power to the X-rays generated at 660 k V by an X-ray set. Due to the differences in the radiation spectra of the two sources, however, gamma ray sources, which do not generally emit the longer wavelengths, have a mean penetrating power somewhat higher than X-rays.

Gamma Ray Sources

Radiographic gamma ray sources consist of a circular disc or cylinder of radioactive material encased in a sealed aluminium or stainless steel capsule. The capsule is kept in a container which acts as a storage safe and may also be used as a support during exposure. The container is made of a material, such as lead or depleted (non-radioactive) uranium, which will substantially reduce the emission of gamma trays. High intensity sources are kept in bulky, heavily shielded containers, exposure being achieved by positioning the source opposite a restricting aperture in the container. Some users employ an exposure head connected to the container by guide tubes, the isotope being positioned and controlled by a remote control device. Since gamma rays cannot be turned off, strict regulations have been devised to safeguard both operators and general public during the transportation and use of radioactive sources.

PHOTOGRAPHIC ASPECTS

X-ray Film

The films used in radiography are very similar to those used in photography except that the emulsion covers both sides of the flexible transparent base. The emulsion is sensitive to X-rays, gamma rays and light, and when exposed to those radiations a change takes place in its physical structure. When treated with a developer, a chemical reaction results in the formation of black metallic silver ; it is this silver which, comprises the image . Handling of the undeveloped film is normally carried out in a 'dark room' which is illuminated by subdued yellow light.

Film is supplied in two classes, depending on whether fluorescent intensifying screens are to be used or not. Within these classes, film is available in a wide range of speeds and grain sizes.

Where the high clarity of a normal film is unnecessary, for instance when searching for debris or checking for correct assembly of a component, certain types of photographic paper can be used, with a consequent saving in cost.

Film is normally prepared for exposure by placing in a cassette, which may be either rigid or flexible, or in a light-proof envelope. For many applications films is also prepared in roll from, an example of which would be the film use for taking radiographs of a complete fuselage former. An X-ray tube which emits a $360°$ beam is located in the centre of the fuselage, and a roll of film placed to encircle the fuselage.

Intensifying Screens

It is sometimes necessary to take a radiograph of thick or dense material, necessitating a very long exposure time. This time may be reduced by converting the energy of the X-rays or gamma rays into another form of energy to which the film emulsion is more sensitive.

Phosphor coated screens (known as 'salt' screens) will fluoresce in the presence of X-rays and, if in contact with the X-ray film, will supplement the image formed by X-rays during exposure. The disadvantage of this arrangement is that the screen imparts a granite appearance to the film and detracts from image formed by X-rays during exposure. The disadvantage of this arrangement is that the screen imparts a grainy appearance to the film and detracts from image sharpness. 'Screen' type film must be used in conjunction with fluorescent intensifying screens.

Metal foil screens are usually made of lead and assist the normal X-ray exposure by producing photo-electrons in the presence of X-rays. This intensifying effect is only evident at potentials above 120 k V, but since the lead screens also reduce scattered radiation and are not granular in construction , they are always used in radiography carried out at energies above this value.

It is essential that both types of screen are held in close contact with the film (on both sides), as any gap will result in a spread of light (or photo-electrons) and produce a blurred or fogged image. Absolute cleanliness of the screen is also essential, since any dust or grease between the film and screen will be reproduced on the radiograph.

Sensitivity

The darkness of a radiograph depends on the quantity of radiation penetrating the specimen, the lighter will be the image Defects such as a crack or gas hole will show up as dark areas on the radiograph, since they will give less resistance to the rays. However, the ability to recognize a defect will depend on its size and the quality of the radiograph. The sensitivity of the radiograph is normally measured by an image quality indicator (I.Q.I), also known as a penetrameter (Figure 24.2), but this should not be used as a means of calculating the smallest size of defect which may be detected. The shape of the defect and the plane in which it lies are most important ; if a crack runs in a plane normal to the X-ray beam it will probably not be detected, and this must be taken into account When establishing a technique for a particular inspection.

Ideally I.Q. Is should be made of the same material as the radiographic subject, but in practice mild steel is suitable for all steel specimens, pure aluminium is suitable for all aluminium alloys and copper is suitable for most bronzes and brasses. The I.Q.I. should be placed on the upper surfaces of the area undergoing radiography, i.e. nearest to the beam source, so that it will appear on the radiograph. The thickness of the last detectable step (or wire) should be ascertained and expressed as a percentage of the specimen thickness.

It will be appreciated that the difference in the sizes of the steps or wires in the I.Q.Is shown in Figure 24.2, must be very small for use with aircraft structures. In fact, although the use of I.Q.Is is essential with thick specimens, the very nature of aircraft structures, comprising skins, ribs, stringers, paint, sealant, etc., is an adequate form of I.Q.I. for most radiographic needs.

The step-wedge I.Q.I (Figure 24.2 (a)), consists of a number of steps ranging in thickness from 0.005 in to 0.1 in or greater as required . Each step contains a number of holes, varying in size according to the step thickness, and these are used both for identification of the step and as an indication of image sharpness.

The wire I.Q.I (Figure 24.2 (b)), consists of a series of short lengths of wire in graduated diameters, embedded in thin rubber or plastic sheet. This type of I.Q.I. is sensitive to both sharpness and contrast, particularly in the smaller sizes.

Variations of the standard I.Q.I. are sometimes used for special purposes, e.g., when searching for fatigue cracks an I.Q.I. containing a typical defect could be used (Figure 24.3). The I.Q.I. is placed on the surface of the member being examined and, provided that the simulated defect is clearly visible on the radiograph, it can be assumed that any other crack of similar size and orientation would also be visible.

Geometric Considerations

The sharpness of a radiographic image is influenced by the film characteristics and by geometric effects, which, since they are to a large extent under the control of the radiographer, are very important. The factors involved are the size of the radiation source, the distance between the source and the film, and the distance between the specimen and the film; these factors are illustrated in Figure 24.4.

It is generally accepted that a radiographic image viewed by the naked eye will appear to be sharp if the blurring of edges does not exceed 0.01 inches. The blurring, or sharpness, is caused by the finite size of the radiation source and this is quoted in the specification for the equipment concerned or can be found by experiment. From Figure 4 it can be seen that the closer the film is to the specimen then the sharper will be the image. However, practical considerations may prevent contact between the film and specimen and in this case acceptable sharpness can only be obtained by increasing the source-to-film distance. Alternatively, better coverage of a large or irregularly shaped part may be achieved by taking several radiographs from different angles, thus keeping the object-to-film distance to a minimum.

Exposure Conditions

The quantity of radiation affecting an area of specified size varies inversely as the square of the distance from the source; if the source-to-film distance is increased the exposure time must be increased accordingly. The ideal situation would obtain where the cone of radiation just covered the film area.

The required exposure conditions could be obtained by the use of exposure charts and calculations dependent on film characteristics. However, since a number of variables exist, it is more usual to establish a technique from knowledge of the structure involved, study of the aircraft manufacturing drawings and systematic trial and error methods. Once the geometric considerations have been determined a series of radiographs is usually taken, systematically varying the voltage, exposure time and, occasionally, the tube current or type of film, until an acceptable radiograph is produced; a double film technique is often used to reduce the number of exposures required. The lowest usable kilovoltage gives the highest contrast thus making recorded defects more distinct.

(a) STEP WEDGE TYPE   **(b) WIRE TYPE**
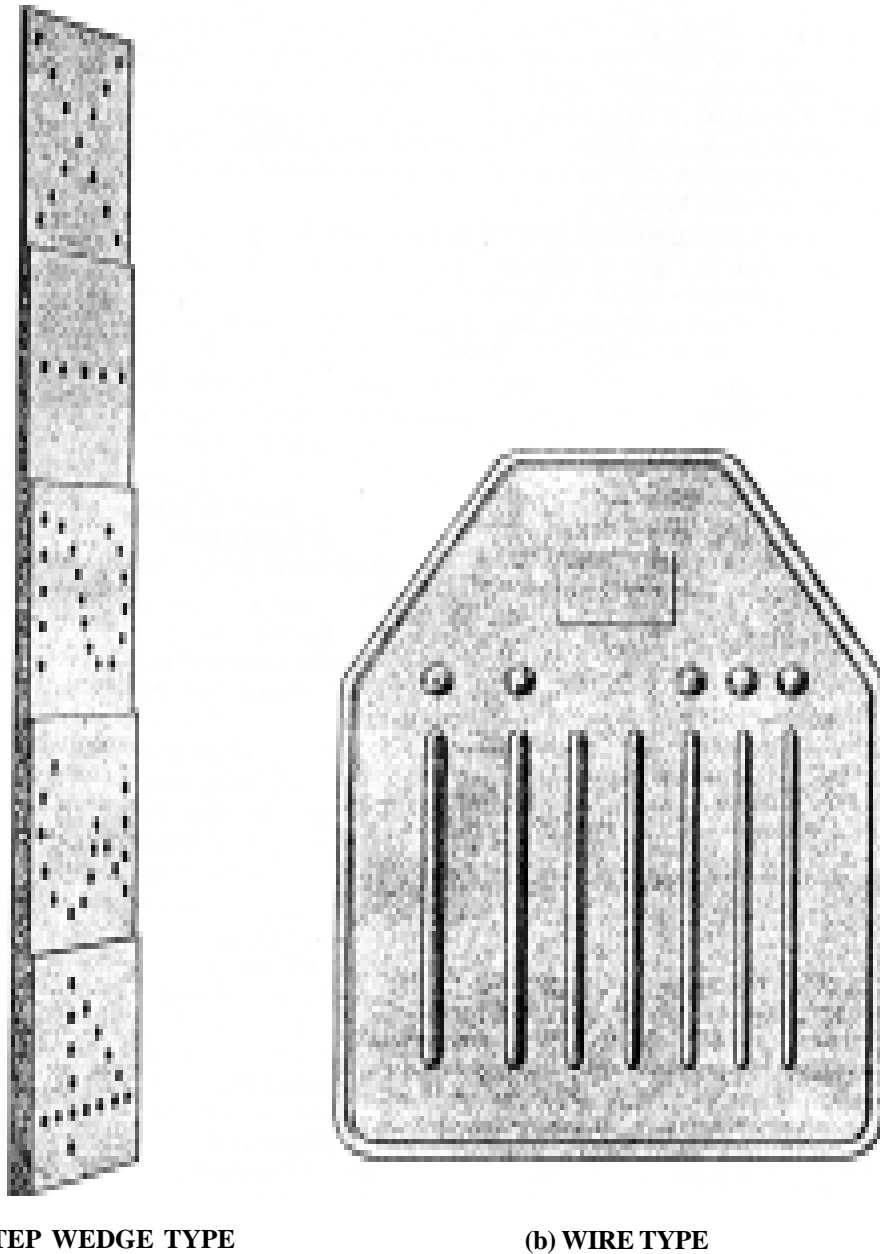
Fig. 24.2, Standard Image Quality Indicators

Filtration

When a beam of radiation passes through a material, some passes directly through (the primary radiation) and some is scattered by collision with the atoms making up the material (the scattered radiation). The primary radiation is the true image forming energy, but the scattered radiation results in a fogging effect on the film, reducing contrast and impairing definition. While scattered radiation is always present, its effects can be reduced by the use of metallic screens, masks or backing.
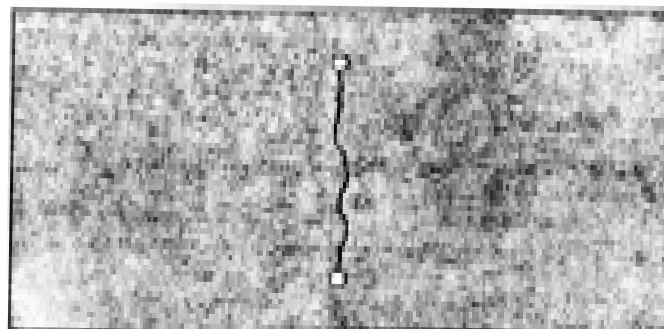
Fig. 24.3, I.Q.I. Simulating a Defect.
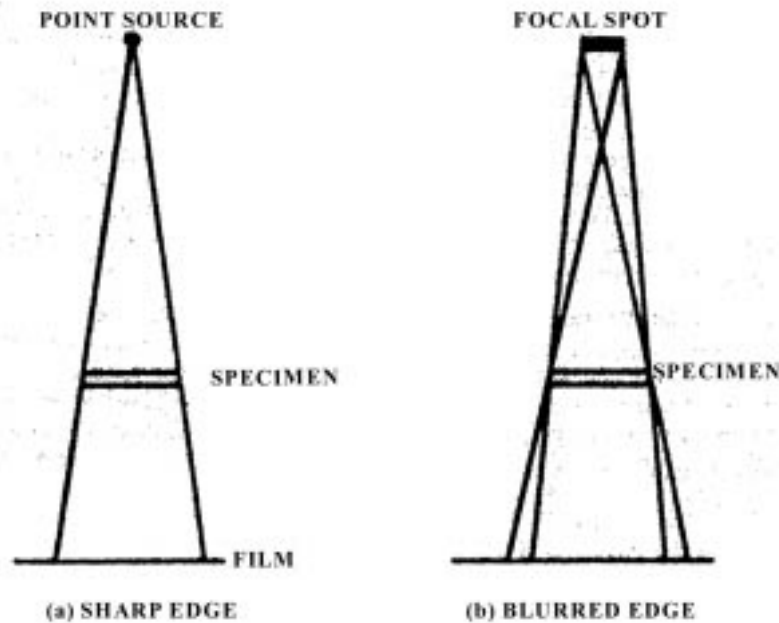
Fig. 24.4, Geometric Unsharpness

Primary Beam Filtration

X-rays consist of a wide band of wavelengths, the shorter of which are the image forming radiations. The longer wavelengths have little penetrating power but are a significant source of scattered radiation, and can normally be eliminated from the X-ray beam by placing a metal filter close to the X-ray source. The thickness of the filter is important since it affects the total material to be penetrated, and it is usually found by experiment; a copper filter 0.1 mm thick would normally be used with a 100kV to 200 kV set.

Scatter Within the Specimen

Some scattered radiation is generated within the specimen, particularly when it consists of a box-like structure, or dense material. This may be reduced by placing a filter, similar to that used for primary beam, immediately above the film. Particular care is necessary to ensure that this filter is clean, since any dirt will show up on the radiograph. In the case of light alloy structures a limitation of 2 minutes exposure time will usually eliminate such scatter.

Makes and Backing

Scattered radiation can be produced from any point within the area of coverage of the radiation beam and will, therefore , be produced by structure situated beside or behind the film. This radiation is reduced by placing lead sheets adjacent to the film and specimen, immediately at the back of the film, and, in permanent radiographic rooms, by covering the floor and table with lead. With irregularly shaped specimens an opaque paste mask is sometimes used.

RADIOGRAPHIC TECHNIQUES

The establishment of completely reliable techniques of examination is essential if confidence is to be placed in the resulting radiographs. It may be necessary to prove their effectiveness initially by dismantling the particular structure to ensure that no defects exist which have not been revealed in the radiographs, and to determine that the radiographs have been correctly interpreted.

The factors outlined in paragraph above should be taken into account in evolving a satisfactory radiographic technique, and a record should be kept of the conditions under which the technique was established. A typical Radiographic Technique sheet, as recommended in British Standard M34, is reproduced in Figure 24.5. This sheet should be given a number for identification purposes and should also include, in the 'Notes' section, such details as items which must be removed (including fuel from the fuel tanks, radiation sensitive items, sealant or paint, etc.), any jacking or trestling necessary and measurements from which the film, X-ray set or isotope may be positioned. A simple isometric drawing may also assist identification of an area under examination and the inclusion of photographs or drawings showing potentially defective items should also be considered.

It may often be necessary to penetrate a widely varying range of thicknesses and, if only a single radiograph is taken this may result in the appearance of greatly contrasting light and dark areas, making accurate interpretation almost impossible. In such circumstances the simultaneous exposure of two or three films without intervening wrapping in

a common cassette or envelope may be employed; if the films and exposure time are carefully selected, each different thickness will be shown at a suitable density on one of the radiographs. The use of a lead screen separating two films is sometimes useful in achieving satisfactory radiographs of different material thicknesses and also gives greater flexibility in the selection of a film pack.

Fig. 24.5, Typical Radiographic Technique Sheet

GAMMA RAYS IN AIRCRAFT RADIOLOGY

In general it may be considered that the majority of radiographs of aircraft structures are taken with an X-ray set. This is due to the unsharpness and lack of contrast normally obtained with gamma sources and the gradual decrease in radiated energy. However, there are occasions when a gamma source is used, mainly due to lack of space or access for X-ray equipment.

Application

By the use of guide tubes or handling rods attached to containers, it is often possible to place isotopes in positions which would be completely inaccessible to X-ray equipment. An example of this is where an internal portion of a structure is to be examined, there being no means of access for the X-ray equipment and the complexity of the structure preluding the taking of X-ray pictures from the outside. Provided it is possible to place the film in position, the isotope can be inserted through a convenient aperture and a direct radiograph of the particular area may be obtained.

Isotopes are also often used for the examination of internal features of turbine engines, such as the main rotor shaft, and provision of access points is sometimes included in the engine design.

Isotopes

The types of isotope used will be determined by the thickness of the subject, the source-to-film distance and the source output in terms of exposure time.

FLUOROSCOPY

The luminescent property of phosphors enables them to transform X-rays into visible light. The effect is most pronounced with low energy x-rays, normal gamma ray sources are therefore unsuitable, being of too short a wavelength.

X-rays are passed through the specimen and impinge on a phosphor coated screen which emits light in proportion to the intensity of the X-radiations falling on it. A positive image is formed on the screen, showing internal details of the specimen in a similar manner to a radiograph.

Viewing cabinets are so constructed that the observer is protected from harmful radiations. Where low energy radiations are used the phosphor screen is viewed directly through a lead glass window but when high energy X-rays are necessary it is usual for an angled mirror to be interposed so that the screen is viewed at an angle tot he primary X-ray beam.

Due to the coarse grain of the phosphor screen and the poor geometric sharpness resulting from the need to place the screen close to the X-ray source, fluoroscopic images are greatly inferior to those produced by radiographs; for this reason fluoroscopy is seldom used in aircraft work. However, one big advantage of fluoroscopy is that there is no film to be developed and the method is suitable for checking the correct assembly of components or inspecting for debris in aircraft. In general engineering fluoroscopy is also used in conjunction with image intensifiers, for the examination of welded tube and other simple structures.

VIEWING CONDITIONS

 In order to recognize all the indications available on a good radiograph, it is essential that suitable viewing conditions are provided.

Ideally, radiographs should be examined in a room set aside for this purpose and situated away from distracting conditions such as a high nose level. The room should be capable of being darkened but, during viewing, should have a low intensity background light which does not reflect on the film.

The viewing of radiographs requires a good deal of concentration. It is recommended that continuous viewing periods should not exceed 90 minutes and should be followed by a period of at least 30 minutes doing associated work away from the viewing area.

The radiograph itself should be placed on a special viewing box where it can be illuminated from the back, preferably by diffused lighting. Any light appearing round the edge of the radiograph should be masked off since it would tend to dazzle the viewer, possibly resulting in fine defects in the denser parts of the radiograph being overlooked. Controllable shutters are usually provide on the viewing box for this purpose. In addition, the masking of light areas of the radiograph while viewing dark areas will increase the apparent contrast of the image. Where the radiograph has areas of widely differing density the provision of a dimming control may assist the viewing of very light areas.

In some instances it may be advisable to make use of a magnifying glass for the examination of fine detail, but a glass with high magnification should not be used.

INTERPRETATION OF RADIOGRAPHS

The accurate interpretation of the defects indicated on a radiograph is a matter which requires considerable skill and experience and, if the maximum benefits are to be obtained from radiography it is essential that the viewer should have an intimate knowledge of the aircraft structure. Without such knowledge it would be possible to overlook faults which would be obvious to an engineer, if radiographs of a sound structure are available as standards, for comparison with radiographs on which defects are recorded. For simple structures on isometric drawing of the area might be suitable. Some of the indications obtained on radiographs are described in the following paragraphs.

Castings and Welds

Metallurgical defects in castings and welds generally produce characteristic patterns which may be recognized by an experienced viewer. Porosity, for example, will reduce the amount of material through which the X-rays or gamma rays must pass and result in dark spots in the film, whereas segregated constituents of alloys, or inclusions, may be light or dark, depending on their relative density.

Cracks in welds may be difficult to detect and knowledge of the defects associated with the particular type of weld is essential. The angle at which the radiograph is taken is of particular importance, since defects in a plane normal to the radiation beam would not result in any significant change of density in the emulsion. Surface blemishes produced by welding are recorded on the radiograph and produce a complex image liable to misinterpretation.

Corrosion

The detection of corrosion is invariably difficult, the difficulties often being aggravated by the presence of paint, jointing compound and surfaces fouling which, by their radiographic density, may compensate for the deficiency of material caused by corrosion or give rise to a suspicion of corrosion which does not exist. However, corrosion normally has an irregular and possibly 'fuzzy' outline, while compounds will usually have a regular and sharply defined one. Intergranular corrosion may not be detectable by radiography until it has reached an advanced state and affects the metal surface.

Under laboratory conditions, where scattered radiation can be effectively reduced and ideal exposure conditions obtained, it is possible to detect very small cavities. However, when radiographs of an aircraft structure are being taken, ideal conditions will not normally exist and the size of detectable cavities may be much larger. For example, fuel tank sealant is particularly dense, and it is doubtful if pitting less than 10 to 15 per cent of the total thickness, including the sealant, would be revealed.

A corrosion pit giving rise to a sudden change of thickness in a given specimen is more readily visible on a radiograph than a pit of the same depth in the form of a saucer-shaped depression. This is due to the fact that a sudden change in the density level on the radiograph is more easily seen than a gradual merging of two areas of different density.

A further difficulty in the detection of corrosion is that the corrosion products often adhere to the surface and the difference in density might be so slight as to be undetectable. In some instances the build up of corrosion products can be detected when the radiograph is taken at an oblique angle to the surface of the metal.

In aircraft structures, stress corrosion often has a characteristic appearance, showing up as lines of spots on the radiograph. With experience this condition can be identified from similar indications caused by debris or poor developing.

Corrosion can sometimes be detected where successive radiographs, taken over a period of time by an identical technique in each instance, reveal a gradual change in density in a particular area.

Cracks

There is a tendency to regard cracks as straight gaps perpendicular to the working surface, but this is not invariably so. Unless appropriate techniques have been used in taking the radiographs, it is possible for fairly large ' dog-leg' cracks particularly in the thicker sections, to remain undetected.

Stress cracks around rivets in aircraft structures often have a characteristic appearance, running along a line of rivets in a series of arcs. In certain circumstances the edge of the jointing compound used during wet assembly of rivets can give the appearance of hair line cracks of this type, but masking down to a very small area will reveal the true nature of the indication.

When cracks are being sought on the tension side of a wing it is sometimes possible to open up the cracks by applying a tension load, normally by jacking. This will result in a more positive indication on the radiograph.

While cracks will normally appear as a darker line on the radiograph, instances may occur when a lighter line is present. This may result from a part, such as a stringer, being cracked right across and overlapping at the point of fracture, thus presenting a thicker section for the rays to penetrate.

Many radiographs of structure bear evidence of what appears to be structural cracking but, when such areas are examined physically, the cracks have been found not in the structure but in the sealing or jointing compound used in the area. Such conditions may occur inside integral fuel tanks, but with experience it is possible to distinguish between the two types of cracks by reason of their distinctive shape. Some sealants are very opaque to X-rays and may completely hide a defect.

Leaded Fuel

It is often necessary to take radiographs where the primary beam of radiation passes through a fuel (e.g. the lower surface of a wing containing integral fuel tanks). Since lead offers considerable resistance to the penetration of X-rays and gamma rays, the presence of even the small percentage of lead contained in most aviation gasoline will restrict the quantity of radiation reaching the film. It is imperative, therefore, that the fuel tanks should be completely drained before the film is exposed. Pools of fuel left in the tanks may also give misleading indications on the radiograph. Less difficulty is experienced with kerosene but some scatter does occur and may impair the quality of the radiograph.

GLOSSARY OF TERMS USED IN RADIOGRAPHY

The following terms and abbreviations are used in radiological non-destructive testing and are taken from a complete list contained in British Standard 3683, part 3.

Ångstrom unit (Å)	Unit of measurement of the wavelength of X-rays and gamma rays. $1\text{Å} = 10^{-8}$ cm.
Anode	The positive electrode of an X-ray tube which carries the target from which the X-rays are emitted.
Cathode	The negative electrode of X-ray tube.
Casette (or cassette)	A light-tight container for holding radiographic film, paper or plates during exposure. Screens may or may not be included.
Contrast	The relative brightness of two adjacent areas on an illuminated radiograph.
Definition	The sharpness of image details on a radiograph.
Density	The degree of blackening of a radiograph.
Focus-to-film distance (f.f.d)	The distance from the focal spot of an X-ray tube to a film set up for exposure.
Gamma (γ) rays	Electromagnetic radiation emitted by radioactive substances during their spontaneous disintegration.
Grain size	The average size of the silver halide particles in a photographic emulsion.
Image Intensifier	A device used to give a brighter image than that produced by X-rays alone upon a fluorescent screen.
Isotopes	Atoms of a particular element which have the same chemical properties and atomic number, but a different mass number from those normally present in the element.
Penumbra (Ug)	Blurring at the edges of a radiographic image due to the radiation source being of finite dimensions.
Quality	The penetrating power of a beam of radiation.
Radiograph	The photographic image produced by a beam of radiations after passing through a material.
Resolution	The smallest distance between recognizable images on a film or screen.
Source-to-film distance (s.f.d.)	The distance from the source of primary radiation to a film set up for exposure.
Tube current	The current passing between the cathode and the anode during the operation of an X-ray tube.
Tube head	A type of X-ray shield which, in addition to the X-ray tube, may contain part of the high voltage generator.

Unsharpness	Image blurring caused by the penumbra, by movement, by grain size, or by light, electron or X-ray scatter.
X-rays	Electromagnetic radiation resulting from the loss of energy of charged particles (i.e. electrons).

CHAPTER: 25
NDE : EDDY CURRENT METHODS

INTRODUCTION

This chapter gives guidance on the use of eddy current equipment for detecting cracks, corrosion or heat damage in aircraft structures, and also shown how the method can be used for the measurement of coating thickness or for sorting materials. Elementary theory of eddy currents is included to show the variables which are being measured and to indicate the interpretation of results which may be necessary for a particular application. Nothing in this chapter should be taken as overriding the information supplied by aircraft or engine manufacturers.

Eddy current methods can detect a large number of physical or chemical changes in a material, and the selection of the required parameter presents the equipment manufacturer with many problems; interpretation of the test indications would be very difficult if un desired parameters were not reduced or nullified. Conversely, equipment set up for a particular purpose is comparatively easy to use when indications are compared with a ' standard' or known defect. Eddy current equipment is normally built to perform only certain types of tests, these falling broadly into the categories of flaw detection, conductivity measurement and thickness measurement.

The main advantages of the use of eddy current methods are that they do not normally require extensive preparation of the surface or removal of the part to be tested, do not interfere with other work being carried out on the aircraft and, with surface defects, offer improved sensitivity over other non-destructive techniques. Small portable sets are battery powered and can easily be used in comparatively inaccessible place in aircraft structures.

Eddy current testing may be subject to certain difficulties, including depth of penetration and the effects of surface coatings and unseen changes in the geometry of the material under test. In addition the results of a test can only be related to the size of signal received, and are not necessarily an indication of the size of defect. Techniques are established after trials have shown a method which gives consistent results.

In aircraft work, eddy current testing is usually of the comparative type, a reference piece or standard in similar material containing an artificial defect, being used to compare indications from the part under test.

PRINCIPLES OF OPERATION

Eddy currents are induced in an electrically conducting material when the material is subjected to a changing magnetic field, and normally flow parallel to the surface of the material (Figure 25.1). In eddy current testing a coil is supplied with alternating current and held in contact with (or in close proximity to) the test specimen. The alternating magnetic field produced around the coil induces an alternating eddy current in the specimen, and the eddy current itself produces an alternating magnetic field which opposes and modifies the original coil field. The resultant magnetic field is the source of information which can be analysed to reveal the presence of flaws in the test specimen.
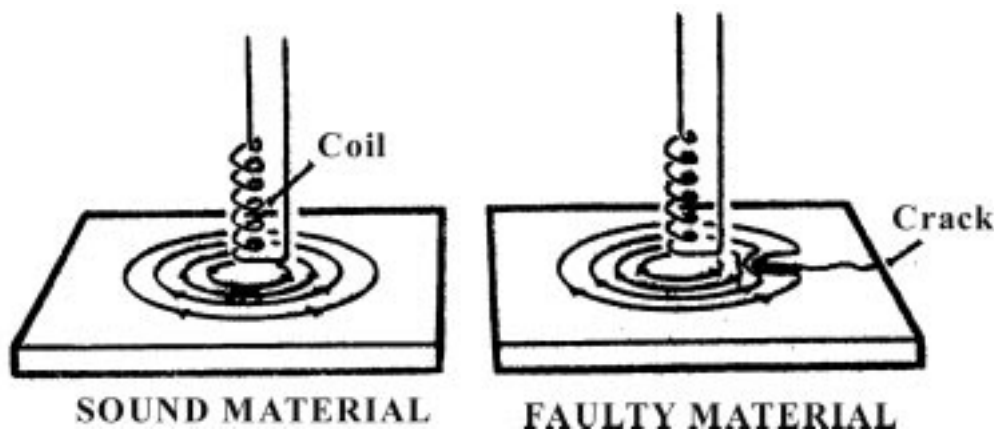
Fig. 25.1, Eddy Current Flow

Permeability

This quality is a measure of the ease with which a material will conduct magnetic lines of force and decides the density of flux which can be induced in that material. Permeability is a function of magnetising force and flux density; air and non-magnetic materials have, for testing purposes, a permeability (μ) of 1, while ferromagnetic materials have a

permeability greater than 1. Permeability is not constant in magnetic materials, and varies with the magnetising force (coil current). Eddy currents are induced by flux changes in a material and are directly related to flux density; as permeability increases so the strength of eddy currents increases. Non-magnetic materials do not generate additional flux densities, but magnetic materials produce high flux densities which can mask all other measurements. During tests on ferromagnetic materials, that is materials with a permeability greater than 1, these effects can be suppressed or made constant by saturation with high D.C.. or AC. fields which, in effect, restore the permeability to 1.

Conductivity

Conductivity (σ) is a measure of the ability of electrons to flow through a material and is one of the main variables in eddy current testing. Each material has a unique value of conductivity and this fact enables changes in chemistry, heat treatment, hardness or homogeneity to be detected simply by comparing the conductivity with a specimen of known properties; increased conductivity gives increased eddy currents (although depth of penetration decreases). Conductivity is measured in either of two ways; it can be compared to a specific grade of high purity copper known as the International Annealed Copper Standard (IACS), which is considered as 100 % or it can be measured in meters per ohm millimetre^2 ($58 \, \text{m}\backslash\Omega \quad \text{mm}^2 = 100 \, \% \, \text{IACS}$).

Effects of Specimen on Test coil

A probe coil placed on the surface of a specimen will posses a particular value of impedance which can be found by measuring the voltage across the coil. The voltages due to resistance and reactance can also be separated and, if required, displayed on a cathode ray tube. Any change in conductivity, permeability or dimensions (d) of the specimen will, through the eddy current field, alter the coil 's impedance, either in magnitude or phase, and , depending on the parameter sought, can be indicated on a meter or cathode ray tube display. Changes affecting apparent conductivity, e.g. a crack, will be 90 ° out of phase with changes affecting permeability or dimensions under certain test conditions.

Geometry

The size and shape of the test specimen may distort the primary magnetic field and mask defects in the affected area (Figure 25.2). The effects of geometry can be overcome by probe design, equipment calibration, frequency selection, or the use of jigs to maintain the probe in a particular relationship to the material surface, but must often be taken into account when conducting tests.
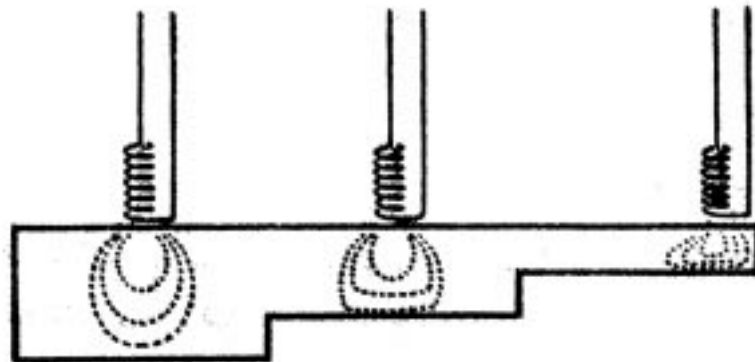
Fig. 25.2, Geometric Effects on primary magnetic field

Penetration

Eddy currents are strongest at the surface of a material and weaken with depth. This effect becomes more pronounced with increased frequency (f) of the alternating magnetic field and is known as 'skin effect'. Increases in permeability (μ) and conductivity (σ) in a material also decrease penetration depth. In practice the depth of penetration (P) of eddy currents is related to a depth where the current is reduced to 1/e (approximately 37 %) of the surface current and

may be calculated from the formula, $\approx \dfrac{\overline{\quad\quad}}{\sqrt{\sigma\mu}}$ where P is in mm, and σ is in m\$\Omega$ mm^2.

Effects of Frequency

Any particular material possesses what is known as a characteristic frequency $\left(\quad \right)$, which depends on its conductivity, permeability and dimensions. a practical use of the characteristic frequency is that samples of different materials tested at the same   ratio will give similar indications for similar defects. Actual test frequency is selected to obtain the

best results from a particular test and depends on the type of defect sought, the depth of penetration required and the geometry of the specimen. When it is necessary to determine the phase of a signal, the frequency should be within the range where phase angle is greatest. When testing for conductivity only, to check hardness, heat treatment, etc., some penetration is required so a low frequency would be used, but when testing for surface cracks greater sensitivity would be obtained at a higher frequency.

In aircraft work testing is often concerned with thin sheet structure in aluminium alloy, and test frequencies between 5 kHz and 4 MHz are used, depending on the defect sought. However, frequencies as low as 50 Hz are used for checking material properties in ferromagnetic materials.

Lift-off

This may be defined as the change in impedance of a coil when the coil is moved away from the surface of the specimen. This produces a large indication on the test equipment . In some equipment the lift-off effect is nullified by applying a compensating current to the probe circuit, thus enabling rapid testing without the need for special jigs, but in other equipment the lift-off effect is analysed to measure, for example, the thickness of a non-conducting coating. This effect, when applied to encircling coils and bar specimens, is known as 'fill factor'.

COIL ARRANGEMENTS

A number of different coil arrangements may be used in eddy current testing, and some of the more common are discussed below. The types shown in Figures 25.3, 25.4 and 25.5 are not generally used during aircraft maintenance operations, but are widely used by material and component manufactures.

Single Primary Coil

Figure 25.3 shows the simplest arrangement. If a sound specimen is placed in the coil the impedance of the coil is modified and if a faulty specimen is placed in the coil the impedance is modified to a different degree.
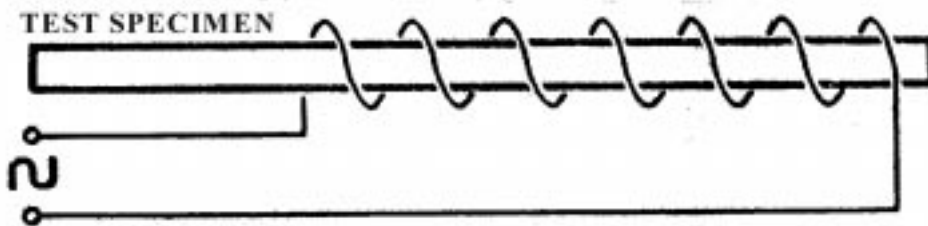
Fig. 25.3, Single primary coil system

Comparative Coil System

Figure 25.4 shows a coil arrangement which has two arms, one containing a flawless reference piece and the other the test specimen. Since the two sets of coils are identical any fault in the test piece will result in voltage across AB.
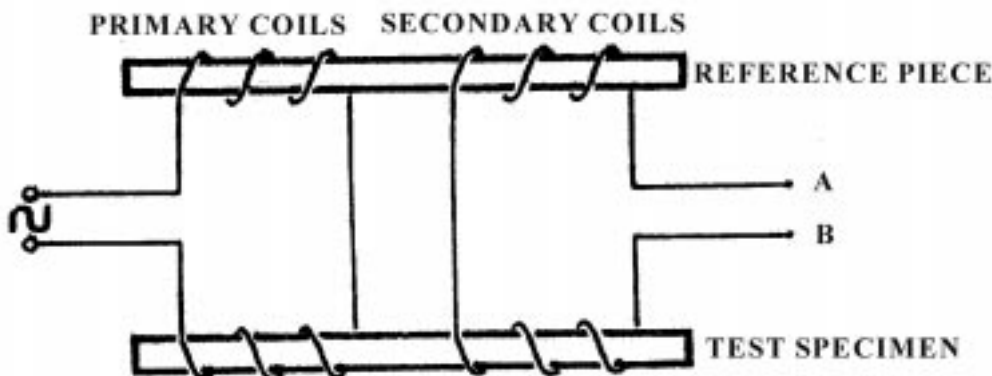
Fig. 25.4, Comparative Coil System

Differential Coil System

Figure 25.5 shows a coil arrangement which is also a comparison method, but in this case adjacent portions of the test specimen are compared with each other . The coil winding are, in effect, identical to the comparative coil system shown in Figure 25.4.
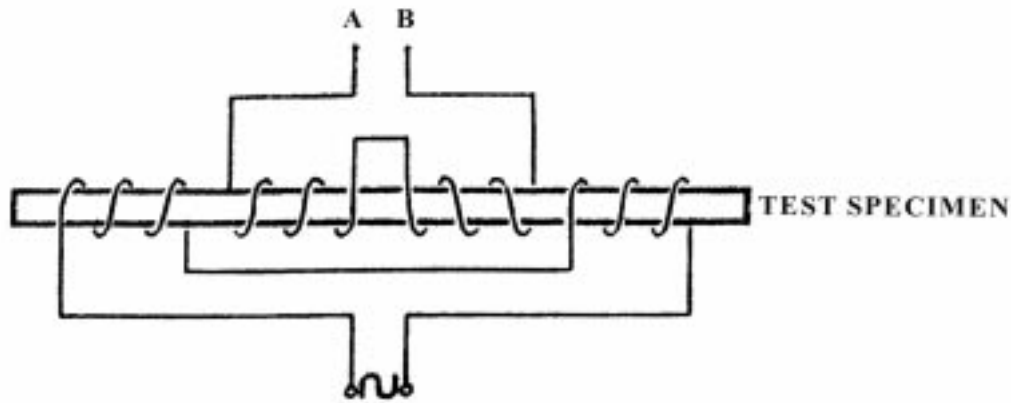
Fig. 25.5, Differential Coil System

Surface Coils

In aircraft work a single coil is generally used, with the axis of the coil normal to the surface being tested (Figure 6). A ferrite core is used to increase sensitivity to small defects, and the arrangement is used for detecting cracks in flat surfaces, curved surfaces or holes, by mounting the coil within a specially shaped probe. Impedance change obtained during a test are compared with those obtained from a defective part or a reference piece.
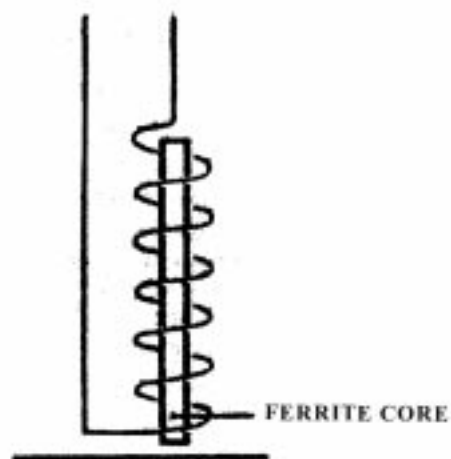
Fig. 25.6, Surface Coil

TYPES OF CIRCUITS

Bridge Circuits

Figure 25.7 shows a bridge circuit, one arm of which consists of two adjustable controls and a coil, and the other arm comprises the reference and test coils. The bridge is balanced initially (meter zeroed by adjustment of the variable resistor and inductor) with probe located on a flawless specimen. In use, any alteration in the impedance of the probe coil (due to faults in the test piece, or to lift-off) will unbalance the bridge and result in a deflection of the meter needle.

Resonant Circuits

The capacitance of a coil is usually small in relation to its inductance. However, if a capacitor is connected in the same circuit as a coil, since inductive reactance increases with frequency and capacitive reactance decreases with frequency, a condition will occur, at some frequency, when the effects are equal and opposite. This condition is known as resonance and circuit then behaves as if it contained only resistance, resulting in a large change in current flow.

Fig. 25.8, shows a typical eddy current circuit which operates on the resonance principle. The probe is a parallel tuned circuit connected to the grid of an oscillator and determines the frequency at which the circuit oscillates. If the flux density (and hence the impedance) of the probe coil is altered (e.g. by placing the probe on a metallic object) the oscillator frequency changes. Consequently, the frequency developed in the anode tuned circuit is no longer the frequency at which that circuit is tuned. This results in a change of impedance, which is recorded on the meter through the secondary windings of the anode coil.

Operation of the circuit shown in Figure 25.8 is dependent upon adjustment of the controls to suppress lift-off. With the probe located on the test specimen the anode circuit is tuned to a frequency in sympathy with the probe circuit

by adjustment of the variable capacitor (i.e. the lift-off control) until the meter reads zero. If the probe is now removed from the specimen a change in impedance will again occur and result in deflection of the meter needle; this deflection can be counteracted by adjustment of the set-zero and lift-off controls. Futher adjustment of these two controls will enable a zero meter reading to be obtained with the probe on or off the specimen. Any change in the specimen (e.g. a defect) will result in a change in the impedance of the probe coil and a deflection of the meter needle, regardless of the presence of, for example, a paint film of uneven thickness.

A different type of resonant circuit is shown in Figure 25.9, the probe coil and capacitor in this case being connected in series. Lift-off is suppressed by the addition of a compensating voltage.
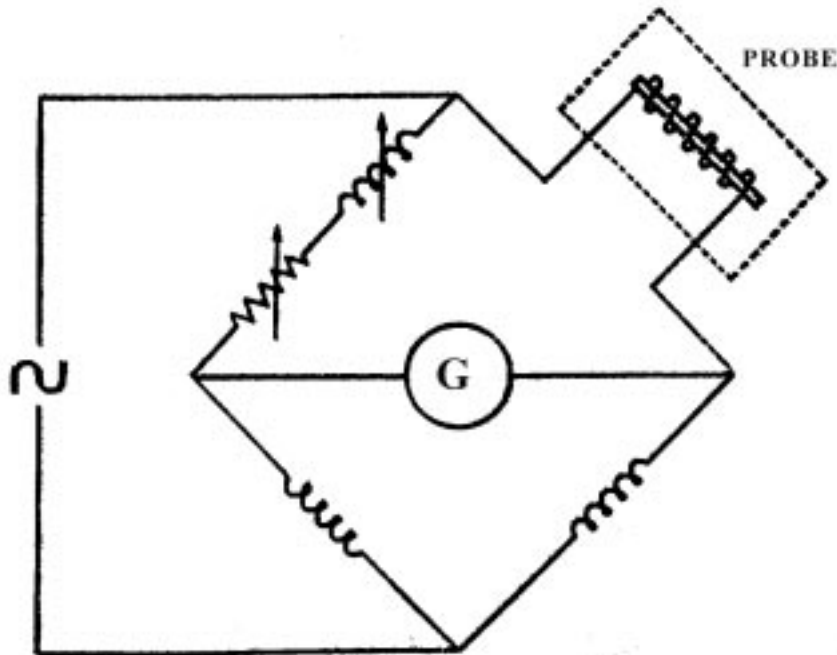
Fig. 25.7, Bridge Circuit
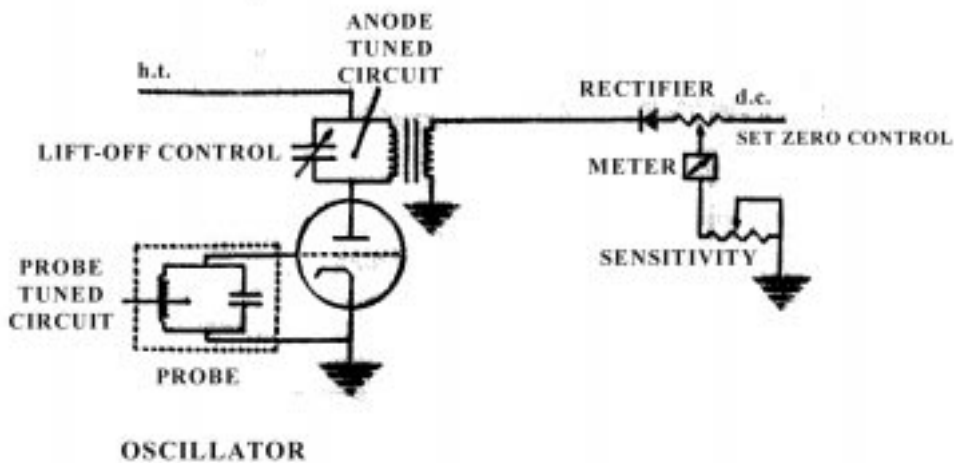
Fig. 25.8, Typical Tuned Circuit
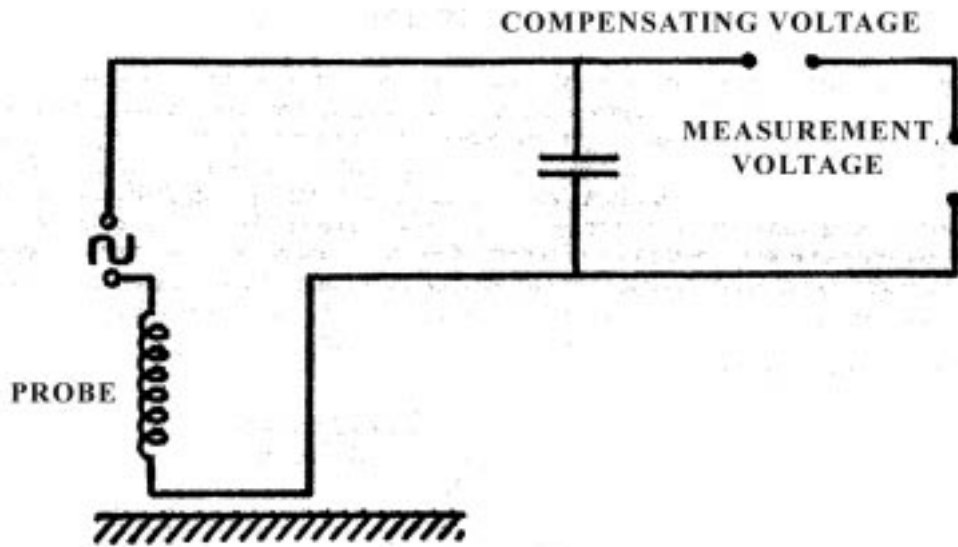
Fig. 25.9, Series Resonant Circuit

PHASE ANALYSIS

Where one of the parameters affecting impedance is required and all others can be assumed to be constant, the measurement of total impedance changes will satisfactorily reveal the presence of a defect or change in the unknown parameter, provided that a suitable reference piece is used for comparison. However, in many cases it is necessary to separate the reactive and resistive components of impedance in order to detect a particular type of defect and more sophisticated equipment becomes necessary.

Figure 25.10 shows the oscilloscope trace of a signal containing two voltages, V_1 and V_2, which are representative of the signal which could be obtained from eddy current equipment under certain test conditions. While the voltages are of the same frequency they can be seen to start at different points of the time scale, the difference resulting from the effects of reactance and being known as a phase change. Eddy current testing based on the use of phase changes is known as phase analysis.
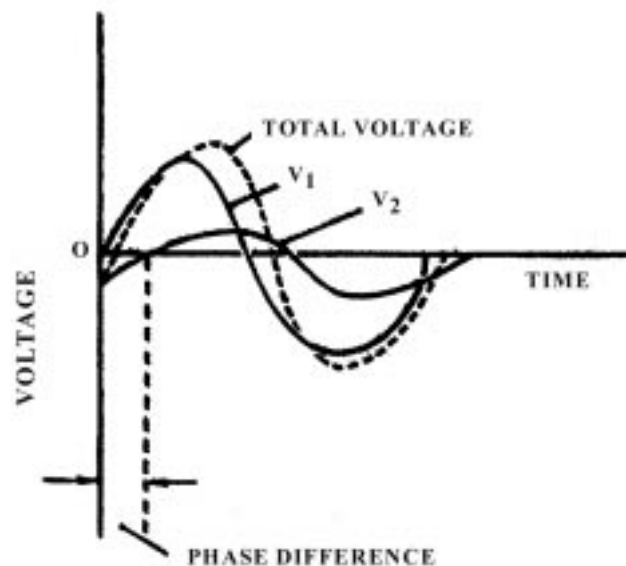
Fig. 25.10, Phase Difference

One method of suppressing the unwanted components of the measurement voltage (i.e. probe coil voltage) and presenting only the parameter required, is to include a phase sensing device in the circuit. This operates on the principle that only those components which are in phase with a reference voltage are passed to the meter. Figure 25.11 show a typical phase sensing circuit in which the measurement voltage is applied to one diagonal of a bridge and a reference voltage to the other. The rectifiers act as switches which pass current during one half of each cycle of the reference

voltage only, but no reference current flows though the meter due to the symmetry of the bridge circuit. The measurement voltage is applied to the meter during those periods when the rectifiers are conducting, and , by varying the phase of the reference voltage, unwanted components of the measurement voltage can be eliminated.
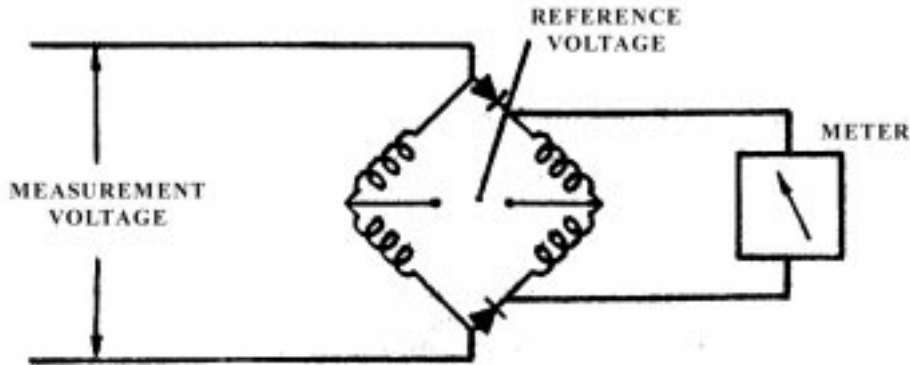
Fig. 25.11, Phase-Sensing Circuit

The resistive and reactive components of the measurement voltage (V_1 and V_2 respectively) can also be separated, fed to separate plates of a cathode ray tube (CRT) and presented as a two-dimensional display on the screen. By suitable phase controls the vertical and horizontal components can be made to represent, for example, conductivity variations and dimensional variations respectively. The most common types of display are the vector point, ellipse and linear time base.

Vector point

A spot is projected on to the screen of the CRT, representing the end of the impedance vector (Z) (Figure 25.12) is adjusted to the centre of the screen when the test piece has the same properties as the reference specimen. Any anomaly in the test piece will result in movement of the spot, the direction of movement being an indication of the cause of the anomaly. If more than one variable is present, since the position of the spot indicates direction and magnitude, the cause can often be determined by vector analysis
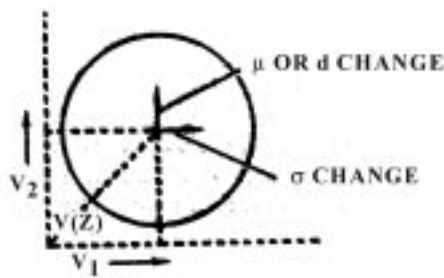
Fig. 25.12, Vector Point

Ellipse Method

A comparative coil arrangement is also used in this method. In the balanced condition a horizontal line is shown on the screen of the CRT whilst an unbalanced condition can be shown in either of two ways. One variable can be displayed by a change in the angle of the line and a second variable by the formation of an ellipse (Figure 25.13). By analysing the position and shape of the ellipse both variables can be evaluated.
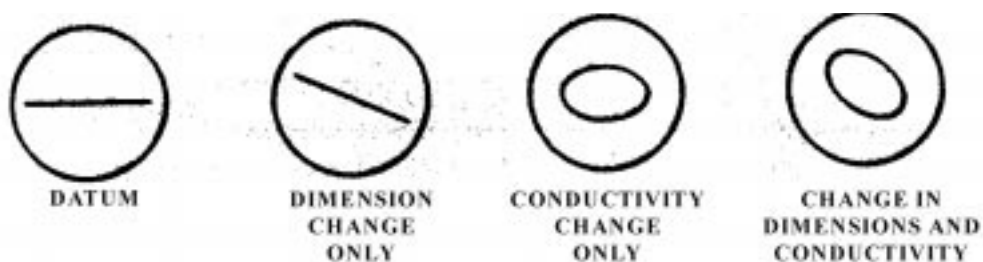
Fig. 25.13, Ellipse Method

Linear Time Base

A spot moving across the screen at a constant rate can be adjusted to show the wave-form of the voltage from a comparative coil system. A change in impedance will alter the wave-form and either of the components of impedance can be measured by adjustment of the phase shift controls. To assist in measuring any changes, the screen is often fitted with a slotted cursor (Figure 25.14).

Fig. 25.14, Linear Time Base

PROBES

Unlike ultrasonic probes, the probes used in eddy current testing, because they are connected to the material by a magnetic field, do not require a coupling fluid, and no surface preparation is necessary other than the removal of any surface condition which would hinder free movement of the probe. Coils are also normally wound on a ferrite core, and this has the effect of concentrating the magnetic field and increasing sensitivity to small defects. Coils are often protected by enclosures in a plastics case, but the ferrite core is often left unprotected when required by particular test conditions. To maintain the coils in close proximity to the work it is often necessary to design a probe for one particular use only; some of the probes commonly used in aircraft work are discussed in below paragraph.

Surface Probes

Figure 25.15 shows two typical surface probes. (A) could be used for detecting surface cracks, and would be connected to a resonant circuit type of test set, whereas (B) could be used for coating thickness measurement or conductivity tests and would be connected in a bridge circuit type of test set. In the case of (A) a simple jig may be necessary to prevent spurious indications due to inadvertent probe angulation.
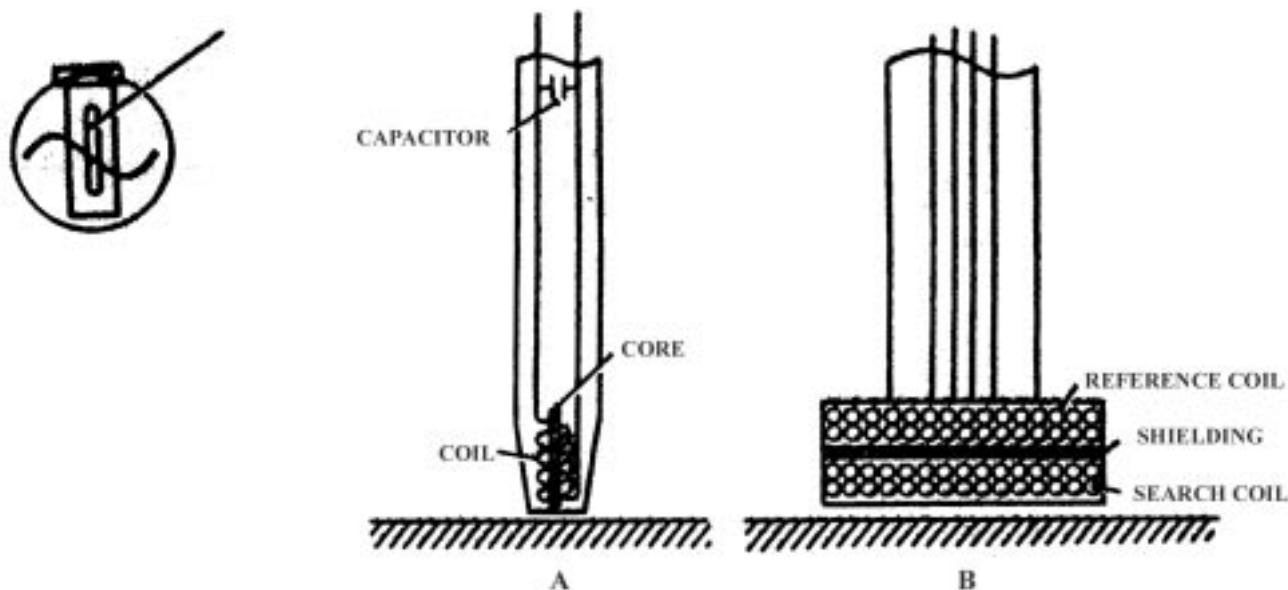
Fig. 25.15, Surface Probes

Hole Probes

Hole probes used during material manufacture would normally consist of a coil, the axis of which would be coincident with the axis of the tube under test, but in aircraft work a hole probe is normally located with the coil diametrically across the hole to achieve greater sensitivity. This type of probe is therefore a surface probe used for testing the surface of a hole. Figure 25.16 shows a typical hole probe of the latter type, the main use for which would be the detection of radial cracks round fastener holes.

The actual position of a crack can be determined by using an offset coil as illustrated, or by shielding one end of the coil.

Fig. 25.16, Hole Probe

Special Probes

Probes may be designed to suit any application, the object being to present a coil at a particular position on a component, so that information can be obtained from changes in the coil's impedance. Examples of the use of special probes would be for the detection of cracks in wheel bead seats, turbine engine compressor or turbine blades, and each of these probes could be connected to a single test set of suitable frequency and complexity. Probes are also designed with a view to eliminating the need for disassembly when carrying out routine maintenance operations.

REFERENCE PIECES

In order to calibrate the equipment, standard reference pieces, manufactured from a material similar to that being tested, are necessary. These pieces should contain defects of known size and shape, so that the change in coil impedance against a known defect could be used as an acceptance limit.

A typical reference piece for surface cracks tests would contain, for example, three cuts of different depths, the depth being marked adjacent to each cut, and the block being marked with the material specification. The test acceptance level could then be related to a signal of the same amplitude as that obtained on a specified cut in the block.

Reference pieces are usually small in size and can be taken to the test location so that quick cross-reference can be made between the reference piece and the test specimen.

NOTE

Since the manufacture of a reference piece involves the removal of metal (by saw cut or spark erosion), the phase and magnitude of the impedance changes will not be identical with those obtained from a natural crack of similar depth. For this reason, actual defective aircraft components are sometimes used to give comparative readings.

TYPICAL APPLICATIONS OF EDDY CURRENTS

The eddy current equipment used in many material manufacturing processes is very sophisticated and completely automatic. Bar, tube and wire materials are normally passed through encircling coils of suitable size, and defects are both displayed on a cathode ray tube and recorded by tape or memory store. Audible warning, marking, and defective component rejection systems, actuated by the defect signal, are also often include. A recent innovation is the use of rotating probes through which bar material can be passed, the advantage of this method being an increase in the sensitivity to surface cracks. In aircraft maintenance work, however, eddy current equipment is usually restricted to conductivity tests and crack detection, mainly by the use of surface probes. Sophisticated equipment such as that described above is not normally required and equipment is usually portable and battery operated. The following paragraphs describe typical eddy current applications.

Checking Fastener Holes for Cracks

A suitable equipment for testing holes would be a simple impedance test set (i.e. not including phase analysing circuits) with lift-off control, and the probe would be similar to that shown in Figure 25.16, adjusted to be a snug fit in the hole. The reference piece should be of similar material to that being tested, and should contain holes of the same size as the probe with natural cracks or artificial notches at various depths in the hole to simulate cracks of maximum acceptable size.

The following procedure should be used when carrying out a test:-
i.   Clean loose paint, dirt, burrs, etc. from inside and around the holes being checked.
ii.   Calibrate instrument and adjust for lift-off in accordance with the manufacturer's instructions.
iii.   Insert probe in hole in reference piece and adjust depth stop to obtain maximum needle deflection from a selected notch or crack. Adjust sensitivity to give the specified scale deflection from the crack.
iv.   Insert probe in hole in test specimen and slowly rotate, noting and marking any holes producing needle deflections greater than that from the reference piece. Re-check probe in reference piece frequently.

NOTE
Any ovality in hole diameter will give a meter deflection which can be confused with the signal from a crack. Generally the indication from ovality shows a much slower change than that from a crack as the probe is rotated.

v.   Repeat (iii) and (iv) at incremental depths to cover the hole surface completely.
vi.   Ream out marked holes as recommended by aircraft manufacturer and repeat test with an appropriate sized probe and reference piece hole.

Checking Heat Damaged Skin
The conductivity of aluminium alloy sheet will increase with exposure to elevated temperatures up to approximately $500\,^{\circ}$ c, and above this temperature obvious sign of damage such as melted or charred metal become apparent. Tests conducted on the surrounding material will show the extent of the area in which the metal is below strength requirements and must be replaced.

The acceptable range of conductivity readings depends on the type of material and its heat treatment condition, and these readings may be stipulated in the appropriate Maintenance Manual. As a rough guide, the conductivity of unclad 7075-t6 material is 31 to 35 % IACS, but the important reading in relation to heat damage is the change in conductivity between sound and defective material

A conductivity meter should be used for this test, and this will normally be an impedance change instrument, with a meter and separate scale graduated in percentage IACS. This equipment is supplied with a surface probe and two test samples, one of high purity copper (with high conductivity) and the other a material of low conductivity, for calibration purposes.

The following procedure should be followed when carrying out the test:-
i.   Thoroughly clean area to be inspected.
ii.   Calibrate instrument in accordance with the manufacturer's instructions.
iii.   Place probe on sound skin of similar material and thickness and remote from the heat affected zone, and adjust scale until meter is zeroed. Compare this reading with the expected conductivity.
iv.   Check conductivity all round the affected area, noting any meter deflection, and marking the skin accordingly. By this means a demarcation line can be drawn round the damaged area, and material removed up to this line.

Detection of Corrosion
Corrosion on hidden surfaces can be detected by eddy current methods using phase sensitive equipment. If a reading at the normal thickness of a sheet material can be taken, since corrosion reduces the thickness of a sheet, when the probe is over corroded area of a different reading will be obtained. The equipment can be set up by noting the readings obtained from a sound material of, say, 90% of the thickness of the test specimen, and a rough estimation of the volume of corrosion beneath the probe can be obtained during a test.

Equipment is available which is specially designed for thickness measurement having a meter graduated in appropriate units, but any equipment operating at a frequency which would give a penetration depth at least equal to the sheet thickness could be used to give an indication of the presence of corrosion. Equipment designed for detecting surface cracks and operating at very high frequency would be unsuitable.

Care is necessary when checking for corrosion to ensure that underlying structure (stringers, frames, etc.), chemically contoured areas, and loose debris, do not cause misinterpretation of results.

Material Sorting
Provided that a known sample is available, eddy current equipment can be used to ensure that a batch of materials is correctly identified, or that a component is made from the correct material. Simple impedance equipment could be used for coarse sorting, but in order to differentiate between materials closely related in composition, equipment with phase sensing circuits is necessary. By placing the known sample in an encircling coil the characteristic trace of that material can be displayed on an oscilloscope and unknown samples accepted or rejected by comparison.

Coating Thickness Measurement
The thickness of conducting or non-conducting coatings on ferrous or non-ferrous bases can be measured using basic eddy current methods; although measurement becomes difficult where the conductivity of the coating and base metal are similar. It is possible to utilise crack detection equipment for measuring thick coatings, by comparing the readings obtained form the test specimen with the lift-off effect obtained when the probe is placed on slips of non-conducting material (e.g. mica) of known thickness. When measuring very thin coatings however (i.e. less than 0.12 mm (0.005 inch)), it is recommended that equipment designed specially for coating thickness measurement should be used.

CHAPTER-26
SELECTION OF MATERIALS

The weight, strength, and reliability of materials used in aircraft construction are extremely important. All materials used must have a good strength/weight ratio in the form used, and must be thoroughly reliable to eliminate any possibility of dangerous, unexpected failures. In addition to these general properties the material selected for a definite application must have specific properties that make it suitable for the purpose. No one material is adaptable for all purposes. A particular part, member, or assembly must be studied from many viewpoints before the best material that can be used in its construction is determinable. In order to make the best choice the designer must have a thorough knowledge of the materials available. In the foregoing pages the author has attempted to describe all the materials and processes used in aircraft work in sufficient detail to enable the reader to choose the proper material for any application. In this chapter the author will enumerate the points to be considered in selecting a material. The materials used in the construction of each part of an airplane at the present time will also be given.

CONSIDERATIONS
The author has arbitrarily divided the points to be considered in selecting a material into economic considerations and engineering considerations. The engineer is apt to neglect the economic considerations, with the result that construction will be very costly because of the cost of the material itself and perhaps also because of delays incident to obtaining the required material and the reworking of jigs and tools.

ECONOMIC
The economic points that should be considered before selecting a material may be itemized as follows :

1. **Availability**
    It is extremely important that any material selected for use in the construction of aircraft should be available in sufficient quantities to satisfy normal and emergency requirements. The material should also be purchasable from a reputable manufacturer who can guarantee a reasonable delivery date. This latter point is particularly important in the construction of an experimental plane when material requirements cannot be anticipated.

2. **Cost**
    The cost per pound should be compared with the cost of other available materials. In making this comparison the savings resulting from a higher strength/weight ratio or better working properties must be considered.

3. **Shop Equipment Required**
    The initial and maintenance cost of shop equipment required for the working of the material selected must be considered. In an established factory the possibility of using jigs and dies on hand is a factor in the choice of a material.

4. **Standardisation of Materials**
    It is advantageous to stock as few materials as possible. In selecting a material for a particular application the possibility of using one already on hand for other purposes should be considered.

5. **Reliability**
    It is essential that the material selected be of consistent high quality. The author has known many instances where a batch of material was received that cracked when bent, or would not take the required heat treatment. The selection of a standard material manufactured by a reputable manufacturer will minimize the likelihood of obtaining a sour lot of material.

6. **Supplementary Operations Required**
    In selecting a material the cost and time necessary for such operations a heat treatment, cleaning, plating, and so on, should be considered. A material that can be used in its natural state has a great advantage from a manufacturing standpoint over one that requires one or more supplementary operations.

ENGINEERING
The engineering considerations that determine the choice of a particular material may be itemized as follows :
1. **Strength**
    The material must be capable of developing the required strength within the limitations imposed by dimensions

and weight. Dimensional limitations are particularly important for external members and for wing beams in shallow wings.

2.   **Weight**
        Weight is usually considered in conjunction with strength. The strength/weight ratio of a material is a fairly reliable indication of its adaptability for structural purposes. In some applications, such as the skin of monocoque structures, bulk is more important than strength. In this instance the material with the lightest weight for a given thickness of sheet is best. Thickness or bulk is necessary to prevent local backling or damage because of careless handling.

3.   **Corrosion**
        Due to the thin sections and small safety factors used in the design of aircraft, it would be dangerous to select a material that is subject to severe corrosion under the conditions in which it is to be used.   For specialized applications, such as seaplane hull construction, the most corrosion-resistant material available should be used. For other general uses an efficient protective coating should be specified if materials subject to corrosion are used.

4.   **Working Properties**
        The ability to form, bend, or machine the material selected to the required shape is important. After the type of material is determined, the proper temper must be chosen to facilitate the mechanical operations that are necessary for the fabrication of the fittings or part.

5.   **Joining Properties**
        The ability to make a structural joint by means of welding or soldering, as well as by mechanical means such as riveting or bolting, is a big help in design and fabrication. When other properties are qual, the material that can be welded has a definite advantage.

6.   **Shock and Fatigue Strength**
        Aircraft are subject to both shock loads and vibrational stresses. It is essential that materials used for critical parts should be resistant to these loads.

SPECIFIC MATERIAL APPLICATIONS

In the following pages the author will enumerate the various parts of an airplane and list the materials that are used at the present time in their construction. Insofar as possible, the major reasons for the choice of a particular material will also be presented. In many instances two or more materials are used for identical parts. This difference of opinion between designers may be due to local operating conditions, the price range of the airplane, or the previous experience of the designer. Many designers are progressive and adopt new materials rapidly, while others are content to lag behind and let the first type break new ground for them. It must be remembered that new developments in the near future may result in many changes in the present type of construction.

In the listing of aircraft parts, the author has taken a standard single-engine tractor airplane and named the parts beginning with the propeller and working aft to the tail. It is hoped by this means to make to reader's task easier in spotting a particular part despite any differences in terminology between him and the author,. General parts such as bolts, bushings, and so forth, are enumerated at the end.

Propeller Blades

Propeller blades are made from aluminum alloy, wood, steel, magnesium, and pressed wood.

25ST aluminum-alloy forgings are most commonly used in this country for propeller blades of high quality. This material is light, strong, uniform, and unaffected by variations in weather. This type of blade is adaptable to adjustable, controllable, and constant-speed propellers.

In this country wooden propellers are used mostly on small commercial planes. They are commonly made from birch, walnut, oak, or mahogany. They are lighter than metal propellers but must be made thicker for strength, and they do not have as high an efficiency.

Hollow chrome-vanadium steel propeller blades welded along the trailing edge have been successfully used in one type of controllable propeller. They have about the same advantages as aluminum-alloy propeller blades.

Magnesium-alloy propeller blades are still in an experimental stage but because of their light weight may some day

supersede aluminum and steel for this purpose. The corrosion of this type blade is somewhat of a problem, particularly when used on seaplanes.

Pressed wood impregnated with resins is being used in the manufacture of large propellers. This type of propeller is relatively light in weight.

Propeller Hubs

Propeller hubs are usually manufactured form forgings of chrome-vanadium steel or chrome-nickel-molybdenum steel. Both these steels machine readily and can be heat treated to 150,000 p.s.i, which is the usual strength required for a hub. In addition, they both have excellent fatigue strength so essential in a part subjected to vibrational stresses.

Cowl Ring

The engine cowl ring is made from aluminum alloy. It has been customary to use 3S½H or 52SO is better because of its greater tensile and fatigue strength. A sheet thickness of 0.040 to 0.050 inch is normally used for ring cowls. 24SO aluminum alloy has been satisfactorily used for spinnings but must be heat treated before installation. 24ST and Alclad 24ST are used frequently for side panels. 61SW is an excellent material for cowling.

3S½H material has been used as a compromise material with good forming and welding characteristics and moderate strength.

52S material is difficult to form in the harder tempers ut can be welded satisfactorily. Its high fatigue strength is ideal for cowling to resist cracking induced by the vibrational stresses imposed by the engine and propeller.

24ST has good fatigue and tensile strength.

Exhaust Collector

Exhaust stacks, manifolds, or collectors are made from 18-8 corrosion-resisting steel, Inconel, and carbon steel. The thickness of the material used for exhaust collectors varies from 0.035 to 0.049 inch. The latter thickness is preferable for high-powered engines using high-octane fuel.

An 18-8 corrosion-resisting steel containing a small amount of columbium or titanium is used. The columbium or titanium reduces the corrosion embrittlement at operating temperatures. This material is available in sheet form and as welded or seamless tubing. After fabrication and welding the finished stacks should be heat treated, or stabilized, to reduce carbide precipitation and corrosion embrittlement.

Inconel is obtainable in sheet from and as welded or seamless tubing. It can be readily fabricated and welded the same as 18-8 steel. Both materials are generally used in the sheet or welded-tubing form for the fabrication of exhaust collectors. Inconel does not require heat treatment after fabrication. It can be heat treated to eliminate internal stresses due to fabrication or welding if desired.

Mild-carbon or chrome-molybdenum steel stacks are sometimes used in small commercial airplanes that do not use high-octane gasoline. This type stack is likely to scale internally and rust externally due to the temperature variations to which it is subjected.

Other types of material have been tried for exhaust stacks but none have served the purpose so well as 18-8 corrosion-resistant steel or Inconel.

Cowling

In general, the material used for engine cowling is the same as that previously described for the ring cowl. The thickness of sheet is somewhat lighter, however, varying from 0.032 to 0.040 inch. In some airplanes 24ST or Alclad 24ST aluminum alloy is used for engine cowling when excessive forming is not necessary. In many cases this material is used for the cowling supports in which strength and rigidity are necessary. 14ST clad or R 301 aluminum alloy are also used for cowling supports.

Engine Mount

Chrome-molybdenum and mild-carbon steel tubing are used for engine mounts. It is customary to weld the entire assembly together, but some mounts are assembled by bolting or riveting.

Firewall

The firewall is usually constructed of a sheet of aluminum alloy either 0.032 or 0.040 inch thick. Some firewalls consist of two sheets of aluminum alloy 0.020 inch thick, with 1/8 inch of asbestos sandwiched between them. Corrosion-resisting steel, Inconel, and terneplate are also used for firewalls.

Oil Tank

Oil tanks are constructed of aluminum or aluminum-alloy sheet, although there are also magnesium-ally tanks. If the tank is welded, either 2S, 3S, or 52S aluminum alloy is used. Riveted tanks are made from these materials or from 24ST or Alclad aluminum alloy. In the construction of oil tanks the thickness of the sheet used varies from 0.040 to 0.065 inch, according to the size of the tank, its shape, and the size of unsupported areas.

Oil Lines

Oil lines are made from any of the following materials ; 52SO aluminum alloy, copper, copper-silicon, various types of flexible tubing. A wall thickness of 0.035 to 0.049 inch is used with the solid tubing. This type of tubing requires a flexible connection, which is made by means of a rubber-hose nipple held with hose clamps. Neoprene hose, a synthetic rubber compound, is commonly used because it is not affected by the hot oil.

Engine Controls

Engine controls, such as push-pull rods, jack-shafts, and bell-cranks, are fabricated from chrome-molybdenum or mild-carbon steel. Push-pull rods that pass close to compasses are made form 24ST aluminum-alloy tubing. Push-pull rod are usually 3/8 inch in diameter and have a wall thickness of 0.035 for steel and 0.058 for aluminum alloy. These sizes may vary somewhat, depending upon the length of the rod and the force transmitted.

Fuel Tanks

The same materials described above for oil tanks are used for fuel tanks, but the thickness of sheet is somewhat greater because of their larger size.

Fuel Lines

The same materials described above for oil lines are used for fuel lines. The sizes of solid lines vary from ½-inch diameter with an 0.035-inch wall for engines under 600 horsepower to 1¼-inch diameter with an 0.049-inch wall for larger engines.

Lamding Gear

Most landig gears are still made of welded chromemolybdenum tubing. Chrome-molybdenum steel forgings are frequently used for fittings on this type of gear. Subassemblies of welded steel landing gears are usually heat treated to 150,

Fuselage

Fuselages are of either welded steel tubing or aluminum-alloy monocoque construction. In rare instances, monocoque fuselages using corrosion-resisting steel or plywood have been manufactured in this country.

Welded steel fuselages are made from either chrome-molybdenum or mild-carbon steel tubing. The diameter of the tubing used varies from ½ inch up to 1½ inches depending upon the loads carried.

Monocoque fuselages differ in detail construction but usually consist of extruded or rolled sections for frames and bulkheads, covered by sheet between 0.025 and 0.065 inch thick. 24ST aluminum alloy, Alclad 24ST, 14S clad (R301), or 75ST clad are used for this purpose.

Hull and Floats

Hulls and floats are very similar to monocoque fuselages in construction and are made with the same materials. Alclad material is preferable because of the severe corrosion conditions that are met.

Several spot-welded corrosion-resistance steel hulls have been manufactured in this country. Their corrosion resisting is excellent, but it is necessary to use much thinner material than is used in aluminum-alloy construction to obtain a comparable weight.

Wings

There are any number of different materials used in the construction of wings. The most common types of wing construction are as follows :
1.   Wood with plywood wing covering.
2.   Wood with fabric covering
3.   Wooden beams with metal ribs, covered with fabric
4.   Metal, including the covering
5.   Metal with fabric covering.

The The choice of a particular type of wing construction depends upon the type of airplane, the manufacturing skill available, and the preference of the designer.

The specific materials used in wing construction are described below under the title of the subassembly.

Wing Leading Edge

The leading edge of a wing forward of the front beam is usually covered with plywood or sheet metal to maintain a perfect

contour in this important region. $\overline{}$ to $\overline{}$ inch plywood is normally used for this purpose on wooden wings. In

metal wing construction the leading-edge covering is usually 24ST, 24ST clad, 14ST clad (R301), or 75ST clad aluminum-alloy sheet from 0.014 to 0.081 inch thick.

Wing Ribs

Wing ribs are made from wood, aluminum alloys, carbon steel, and corrosion-resisting steel.

Wooden ribs are usually made from spruce. The capstips and diagonal are ¼ or 5/16 inch square in teh smaller commercial planes. Plywood gussets glued and tacked in place are used at the joints. The webs of some ribs are made entirely of plywood.

Aluminum-alloy ribs are made from 24ST or 14ST clad (R301) material. They are either stamped in one piece from sheet stock, or bilt up from drawn or rolled sections and riveted at the joints. Material form 0.014 to 0.032 inch thick is commonly used in the manufacture of this type of rib.

Steel and corrosion-resisting steel ribs are made form very light-gage material in a U oer tubular section. Joints ae made by spot welding.

Wing Covering

Wjings are covered with fabric, plywood, or aluminum alloy. This latter covering is either 24ST, 14ST (R301), or 75ST aluminum alloy, or the clad version of one of these materials. When clad material is used for this purpose there is no need to paint the surface for protection agaist corrosion.

Wing-tip Bow

The wing-tip bow is made form ash bent to shape, from a chrome-molybdenum or mild-steel tube, or from an aluminum-alloy tube or formed section. Aluminum-alloy sections formed tot he desired shape are commonly used on metal wings.

Wing Beams

Wing beams are made from spruce, poplar, Douglas fir, steel, corrosion-resisting steel, and aluminum alloys.

Wooden beams are generally made of spruce (although in regions where spruce is scarce or expensive, substitute woods such as fir, poplar, and even white pine have been successfully used). At the present time it is difficult to obtain spruce of aircraft grade in sufficiently long lengths or required cross-sectional dimensions for any but the smaller commercial airplanes.

Aluminum-alloy wing beams are very generally used in this country at the present time. They are made of any one or combination of the following alloys: 24ST, Alclad 24ST, 14ST, 14ST clad (R301), 75ST, or 75ST clad.

Steel spars have been constructed of chrome-molybdenum steel tubing, either round or oval in cross section, welded at the joints. These spars are usually heat treated to develop greater strength. They are difficult to manufacture due to the likelihood of welding cracks and of distortion during the heat treatment operation.

Corrosion-resisting steel beams are fabricated from high-tensile strip or sheet, rolled or drawn to shape and spot welded together. This type of spar is fairly easy to manufacture if spot-welding equipment is available, and it has good strength properties. It works out well for a heavily loaded wing, which permits the use of moderately heavy sheet without penalizing the strength/weight ratio.

Wing Fittings

Wing fittings are made from the high-strength aluminum alloys such as 24ST, 14ST and 75ST and from various types of steel Chrome-molybdenum steel (4130 or 4140) heat treated to 150,000 p.s.i. is very commonly used. Chrome-nickel-molybdenum steel (4340) is used in heat treatments up to 200,000 pounds per square inch.

Wing Supporting Struts

Wing struts are streamline tubing made of 17ST, 24ST, 53ST or 61ST aluminum alloy, or chrome-molybdenum steel. Corrosion-resisting steel streamline struts have recently been developed and may find some applications, particularly for bracing seaplane floats.

Wing Wires

Wing wires of tie-rods are made from 1050 carbon steel and from corrosion-resisting steel. Tie-rods made from corrosion-resisting steel are rapidly displacing carbon steel tie-rods both for exxternal and internal bracing. Their strengths are the same.

Ailerons

Ailerons are usually made from the same materials used in the construction of the wings. Due to the fact that it is necessary to design for static balance of the ailerons, they are usually covered with fabric in order to reduce the weight behind the hinge line. Plywood and metal-covered ailerons have been used to get away from fabric bulging at high speeds.

Wing Flaps

Wing flaps, especially the split type, are constructed with aluminum-alloy sheet backed by stiffeners. The shallow depth of split flaps makes metal construction almost mandatory.

Windshield

Windshields and cabin enclosures are frequently constructed of one of the transparent plastics such as pyralin, plexiglas, lucite, plastecele, Lumarith or Vinylite. A thickness of — to — inch of this material is used.

Nonscatterable glass is used for windshields on most airplanes. A minimum thickness of — inch, preferably ¼ inch, is used in the interest of clear vision.

Windshield frames are made from light steel or aluminum sheet. Inconel strip has also been used successfully.

Instrument Board

Instrument boards are made from magnesium alloy or 24ST aluminum-alloy sheet from — to — inch thick. In some planes the instrument board is made from a molded or laminated plastic. These materials are from — to — inch thick when used for this purpose.

Instrument Tubing

Small-diameter tubing with a light wall is used in conjunction with airspeed meters, oil and fuel pressure gages, primers, and other instruments. This tubing is made form one of the following materials : 52SO aluminum alloys, 2S aluminum, or copper.

Seats

Seats are made form aluminum-alloy or magnesium-alloy sheet and tubing or from light steel tubing. They are usually purchased complete, particularly for commercial planes where padding and tilting devices are desired.

Flooring

Flooring is fabricated form plywood or aluminum-alloy sheet. A composite material made up form plywood and aluminum alloy glued together is also used. Formica or bakelite might work out satisfactorily for flooring in some instances.

Controls

Control parts, such as control sticks, rudder pedals, torsion tubes, push-pull tubes, bell-cranks, and horns are manufactured from aluminum alloys or steel. 17ST or 24ST aluminum-alloy tubing is frequently used for control parts. Because of their nonmagnetic qualities they are particularly good for control sticks and other parts that operate near a compass. When control parts must be wear-resistant and strong as well as nonmagnetic, the use of K Monel will solve the problem.

Chrome-molybdenum steel sheet and tubing are frequently used in the fabrication of control parts. When parts are welded, it is advisable to normalize them or to give them a moderate heat treatment as a precaution against cracks due to vibration.

Aluminum-alloy casting material No. 195-T4 is frequently used for rudder pedals, sockets, horns and other parts. It

is advisable to design these parts 100% overstrength in order to allow for any irregularities in the castings.

Flexible and extra-flexible control cable are both used for the operation of control surfaces. Extra-flexible cable should be used if a marked change in direction is necessary in running the cable.

Tail Surfaces

Tail-surface construction is very similar to wing construction. Fixed surfaces constructed of aluminum alloys are often covered with sheet of the same material from 0.014 to 0.032 inch thick. Movable surfaces such as the elevators and rudder are usually fabric covered to help obtain static balance, although modern high-speed airplanes use metal-covered movable surfaces. Tail surfaces are also built with steel tubing welded at the joints and covered with fabric. In this type of construction about ¼-inch-diameter tubing is used for the rib members and large-diameter tubing for the spar members.

Tail Wheel Structure

Tail-wheel structures are built chiefly form steel tubing and sheet, the same as are used for the main landing gear. In some cases aluminum-alloy forgings are used.

Bushings

Bushings are used in all fittings subjected to reversals of stress. They are held in place by a rive fit and can be replaced when won. They are made form chrome-molybdenum steel tubing or bar stock heat treated to 125,000 or 150,000 p.s.i.

Bearings

Bearings are used in joints that rotate. Ball or roller bearings packed with grease are generally the most satisfactory. Controls and control-surface hinges are ideal places to use ball bearings. In some places where loads are heavy and rotation is slight, such as the joints of a retractable landing gear, bronze bushings are used. These bronze bushings are grooved and the surrounding fittings tapped for a grease fitting to permit thorough lubrication. Chrome-plated hardened-steel bushings are also used in landing-gear joints and similar applications.

Bolts

AN standard bots made form nickel steel (2330) are used for all structural connections. Occasionally it is necessary to position a bolt in place by tack welding the head. For this purpose the bolt is manufactured from chrome-molybdenum steel, since nickel steel cannot be welded satisfactorily. Unless the entire assembly to which the head of the bolt is tack welded is subsequently heat treated, the chrome-molybdenum bolt will not have quite as high strength as the standard nickel-steel bolt. AN standard bolts are all heat treated to 125.000 p.s.i. Special high-strength bolts heat-treated to 200,000 p.s.i.. are made of chrome-nickel-molybdenum steel (X4340).

Rivets

17 ST and 24 ST aluminum-alloy rivets are used for joining structural assemblies. 24 ST rivets are seldom used because of their tendency to crack if not used almost immediately after heat treatment. A17S rivets which do not require heat treatment. A17S rivets which do not require heat treatment just before driving are being used very generally in all but heavily loaded structural assemblies.

Steel rivets are available but are used only in highly loaded joints. High-shear steel rivets are made from 8630 steel rod or equivalent, heat treated to 125,000 p.s.i.

Springs

Flat springs are made from high-carbon steel (1090) sheet stock. Small unimportant coil springs are also made from this material in wire from. Larger coil springs, like those used for engine valve springs and landing-gear oleos, are made form chrome-vanadium steel (6140).

CONCLUSION

The selection of the proper material for a particular part is the first step in good design. It must be remembered, however, that good detail design of the part is equally important if the properties of the material are to be fully realized. Whenever possible that troubles experienced by airplanes in service should be studied in relation the material and design of defective parts. In this way a background can be obtained that will be invaluable in the design of later airplanes.

CHAPTER - 27
SOFT SOLDERING

INTRODUCTION
This chapter gives guidance on the manufacturing processes involving the use of soft solders. Soft soldering is a method of joining metals without intentional fusion of the basis metal, the solders having a lower melting point than the metals being joined. The term "soft soldering" is used to distinguish the process from brazing, which is performed at higher temperatures.

STRENGTH OF SOLDERED JOINTS
The strength of a soldered joint is dependent on the continuity and adhesion of the solder film and the mechanical properties of the solder, and can only be verified by the destruction of the joint. In order to ensure satisfactory joints it is essential that adequate inspection is carried out at various stages throughout the process. In addition, where a large number of similar articles are being soldered, periodic tests can be made by sectioning, or by pulling surfaces apart. In the majority of applications, the solders used are considerably weaker than the materials they join; where the film of solder is too thin the joint will be brittle; conversely, if the film is too thick, the shear strength of the joint will be low.

SCOPE OF PROCESS
Most metals, with the exception of some aluminium alloys, magnesium alloys and zinc-base die-castings, can be soldered, but before applying the process it should be verified that the relevant specifications permit its use. For example, because of the danger of inter crystalline penetration by the molten solder, the soldering of high tensile steel tubes, complying with specifications such as British Standards T 57, T58, T59 and T60, is prohibited, both for jointing and for the attachment of identification labels. The soldering of aluminium with aluminium solder and a suitable flux is possible and is sometimes used for radio and instrument assemblies, but is not normally permitted for other aircraft purposes.

MATERIALS
The solders and fluxes used for aircraft purpose must comply with British standards or DTD specifications. Relevant specifications are given in Table 27.1.

TABLE 27.1
SOLDERING SPECIFICATIONS

Specification	Description
BS 219	Soft Solders
BS 441	Rosin-cored Solder Wire.
DTD 599	Non-corrosive Flux for Soft-Soldering (except high-pressure oxygen equipment).
DEF 34\1	Tinning and Soldering Solution.

Solders
Solder is available in two form, i.e. stick solder with which a separate flux is used, and solder in wire from having a rosin flux core. BS 219 covers a range of antimonial and non-antimonial stick solders, whilst BS 441 is concerned with wire solders having non-corrosive, activated and non-activated flux cores. (See paragraphs below)

General Purpose Solders
The solders which may be used for general soldering work are designated in BS 219 and listed in order of tin content in Table 27.2. Solder manufactured to other specifications may be recommended for particular applications, and an approved proprietary brand of tin \ lead solder containing a small percentage of copper is also available for electrical circuit bit-soldering. It is claimed that the copper content reduces bit erosion without impairing the efficiency of the solder.

TABLE 27.2
GENERAL PURPOSE SOLDERS

Grade	Alloy (%)			Melting Range (°C)	Typical Uses
	Tin	Antimony	Lead		
A	64 to 65	max. 0.6	remainder	183 to 184	Components liable to
K	59 to 60	max. 0.5	remainder	183 to 188	damage by heat, e.g. electrical and instrument assemblies. Nickel and high nickel alloys.
B*	49 to 50	2.5 to 3.0	remainder	185 to 204	General coppersmiths and
F	49 to 50	max. 0.5	remainder	183 to 212	tinsmiths bit-soldering
M*	44 to 45	2.2 to 2.7	remainder	185 to 215	and machine work.
R	44 to 45	max. 0.4	remainder	183 to 224	
C*	39 to 40	2.0 to 2.4	remainder	185 to 227	Blowpipe soldering and
G	39 to 40	max. 0.4	remainder	183 to 234	general fine work.
H	34 to 35	max. 0.3	remainder	183 to 244	Dipping baths.
L*	31 to 32	1.6 to 1.9	remainder	185 to 243	General plumbers' work.
D*	29 to 30	1.5 to 1.8	remainder	185 to 248	
J	29 to 30	max. 0.3	remainder	183 to 255	
V	19 to 20	max. 0.2	remainder	183 to 276	Electric lamps, dipping
N*	18 to 18.5	0.9 to 1.1	remainder	185 to 275	solder.

NOTES
(1)   Grades marked with an asterisk are known as antimonial solders, the antimony being added to increase strength. They should not be used on zinc or galvanized work.
(2)   The two figures quoted in the melting range column represent the completely solid and completely liquid states.

High Temperature Solders
Three types of solders which may be used in high temperature applications are also specified in BS 219. They are used in the manufacture of oil coolers, radiators, etc., where operating temperatures would adversely affect solders with lower melting temperature. High temperature solders may be applied by soldering iron or torch flame

TABLE 27.3
HIGH TEMPERATURE SOLDERS

Grade	Alloy (%)				Melting Range (°C)
	Tin	Antimony	Lead	Silver	
95A	94.5 to 95.5	4.75 to 5.25	max. 0.7	__	236 to 243
5 S	4.75 to 5.25	max. o.1	remainder	1.4 to 1.6	296 to 301
1S	1.0 to 1.5	max. 0.1	remainder	1.4 to 1.6	309 to 310

Wire Solder
Solders of this type, complying with the requirements of BS 441, are of circular cross-section, having one or more continuous cores of activated or non-activated flux. Because wire solders release flux and solder simultaneously when the appropriate temperature is applied, they are generally considered to be more efficient than stick solders. These solders are available in five grades. Information on their properties and uses is given in Table 27.4.

TABLE 27.4
WIRE SOLDERS

Alloy (%)			
Tin	Lead	Melting Range (°C)	Typical Uses
65 max.	remainder	183 to 185	Electrical, radio and instrument assemblies liable to damage by heat or requiring free running solder.
60 max.	remainder	183 to 212	
50 max.	remainder	183 to 212	Electrical, radio and instrument work where slightly higher temperature and some slight loss of penetrating power are permissible. General hand soldering and medium coppersmiths' work.
40 max.	remainder	183 to 234	Tagging components less liable to damage by heat. Tinsmiths' and coppersmiths' light gauge handwork.
20 max.	remainder	183 to 276	Blobbing electric lamp contacts.

General
Care must be taken to ensure that the solder used is of the type specified on the drawing and is the correct type for the work in hand. Apart from the effect on the strength of the joint, the use of incorrect solder may result in other damage, e.g. if solder with too high a melting point is used, damage may result to the surrounding structure from the heat required to melt the solder.

Fluxes
Since solder will only adhere to clean metal, all surfaces to be soldered must be thoroughly cleaned. However, even after cleaning, the oxidation occasioned by heating will prevent the satisfactory adhesion of solder. The use of flux reduces the effect of oxidation, removes oxides and other impurities, helps the molten solder to run freely and results in the production of a stronger joint.

Fluxes complying with Specification DTD 599 are available in rosin, liquid and paste forms, are non-corrosive, and either activated or non-activated. Rosin to this specification is used for the flux in wire solders.

Activated Fluxes
Activated fluxes consist of wood or gum rosin, and contain a small proportion of an agent intended to facilitate the soldering process; such fluxes are usually selected when a more active cleaning agent is required.

Non-Activated Fluxes
These fluxes consist of wood or gum rosin only and are usually selected for the soldering of surfaces where active cleaning is unnecessary.

Test to Distinguish Activated from Non-Activated flux in Wire Solder
The method of conducting this test is described in BS 441. The principle of the test is that a specimen of the solder is melted on a prepared nickle plate. It is essential that the solder should be melted within a period of from two to six seconds, and if the solder on melting wets the nickel and spreads upon its surface, the flux is judged to be activated.

Fluxes for Stainless Steel Soldering
Suitable fluxes, which are all corrosive, are as follows:
(i)   A liquid flux made by dissolving zinc chloride in a solution of equal volumes of hydrochloric acid and water. The solution may be applied with a brush or, if more convenient, the parts may be dipped into the solution.
(ii)   Ortho-phosphoric acid, in its commercial form, which should be applied undiluted.
(iii)   Phosphate-base flux pastes.

Oxygen Equipment

Rosinous fluxes, such as those complying with Specification DTD 599, must not be used for soldering oxygen equipment. A flux complying with DEF 34\1 is suitable.-

Miscellaneous Applications

(i)   For Monel and nickel the rosin types of fluxes are suitable, but for Inconel and the Nimonic alloys, a more vigorous flux, such as killed spirits of salts or lactic acid, is necessary.

(ii)   Parts which cannot be washed after soldering, e.g. radio, electrical and instrument equipment, should be soldered in conjunction with a flux complying with DTD 599.

(iii)   Zinc-plated steel parts, including galvanized wire ropes, should be soldered in conjunction with a flux complying with DTD 599 or with a triethanolamine oleate flux.

(iv)   Where such action is permissible the soldering of identification labels to steel tubes should be in conjunction with a flux complying with DTD 599.

General

Care must be taken to ensure that the flux used is of the type specified on the drawing and is of the correct type for the work in hand . The use of the wrong type of flux may not prevent oxidation of the surfaces to be joined, nor act as an efficient cleaning agent. In addition, it is imperative that a corrosive flux such as that complying with DEF 34\1 is only used on work from which its residues can be readily removed.

Flux Baths

Where a flux bath is used, the bath should be kept in a clean condition, and the contents checked at regular intervals. The acidity of fluxes of the DEF 34\1 type must be carefully controlled.

SURFACE CLEANING

The following methods of cleaning surfaces should be adapted to the material and type of joint.

A high polish is not desirable, since a slightly roughened surface provides the best base for a good joint. Best results will be obtained by mechanical cleaning of the surface with a suitable abrasive, such as a file, sandpaper, or emery cloth; this, however, does not apply to stainless steel . Care should be taken to remove only the surface film and not to reduce the thickness of the material. After such preparation it is necessary to decrease the surface.

Trichloroethane and trichloroethylene are good liquid cleaners and the latter may also be used in a vapor de greasing bath. Neither petrol nor paraffin should be used, since both will leave a film on the metal surface.

Cleaning Stainless Steel

After degreasing, stainless steel may be cleaned by a pickling process followed by washing; suitable processes are given in the following paragraphs.

Anodic treatment in an aqueous solution containing one-third (by volume) of concentrated sulfuric acid and 2.5 per cent (by weight) of potassium dichromate. Current density should be at least 1100 amps per square meter of surface area, and the treatment should be contained until the surface has acquired a light grey color.

Immersion for not more than five minutes in an aqueous solution containing 50 per cent (by volume) of concentrated hydrochloric acid.

After pickling, the parts should be washed in clean water.

General

In order to minimise the detrimental effects of the oxide film which forms rapidly on the surfaces of the parts after cleaning, the interval between the cleaning and soldering operations should be kept to a minimum.

SOLDERING EQUIPMENT

For normal small soldering operations, such as fixing a tag to an electrical cable, a hand soldering iron is the most convenient method of melting the solder. In cases such as fixing identification tags to pipes, where dissipation of heat may prevent the solder from flowing properly, the use of a large iron or blow-lamp may be necessary. Some soldering operations require much more sophisticated heating equipment, however, and in these cases dipping baths, ovens, pre-heating equipment and automated handling methods are often used.

Hand Soldering Irons

A soldering iron consists of a copper 'bit' attached to a suitable handle, and may be heated either by a self-contained

device (electrical elements or gas flame), or by an external source such as a fire or blow-lamp. Irons should be used at a temperature of approximately 60^0 C above the melting point of the solder, and should   not reach a temperature which will result in rapid oxidation . Electric irons are often fitted with a thermostat to maintain ideal working conditions.

Tinning
Before an iron can be used for soldering the bit must be tinned, i.e. a coating of tin or solder applied to all faces. A suitable method of tinning an iron is described below.

(i)   The faces at the tip of the bit should be filed to remove dirt and rough edges, after which the bit should be heated to a temperature sufficient to melt solder. One face of the bit should then be coated with flux rubbed against a stick of solder until a thin film of solder adheres to it. The operation should be repeated until all faces are suitably tinned.

Resistance Tools
With these tools a low voltage electric current is passed into the work to be soldered, by means of a metal or carbon electrode. The resistance between the electrode and the work area causes a rapid local increase in heat which is used to perform soldering functions. The main advantages of this method are that electrical power is only used during the soldering operation and that the electrodes are nearly cold during approach to, and removal from, the work area.

Induction Heating
If a high frequency current is passed through a coil which is held adjacent to a work piece, the work piece will be heated by induction. This method is often used for soldering on a production line basis, but, since a large high frequency generation is required, is not suitable for occasional use.

Ultrasonic Soldering Equipment
Ultrasonic soldering equipment can be used for the jointing of aluminium. Further information of the process and equipment is given in further paragraph   .

PREPARATION FOR SOLDERING
Before the actual soldering operation is begun, preparations should be made taking into account the factors given in the following paragraphs.

The size of a soldering iron should be adequate for the job in hand, and should provide sufficient heat to prevent the solder from solidifying before it has completely melted in a joint. If a large soldering operation is contemplated using a common hand iron, two irons should be available, and used alternately, so that the materials being soldered will not lose heat while one iron is being re-heated.

The parts to be soldered should not be in contact with a material which will cause rapid dissipation of heat, e.g. if the parts are held in a vice, wood should be used for insulation purposes.

When pins are used with soldered joints, the holes should be drilled and the pins inserted before the joint is soldered. Oil must not be used when drilling unless the articles can be de greased before soldering.

Aircraft batteries should be disconnected, as a precaution against fire, when soldering is carried out adjacent to wiring looms or cables.

The clearance between the parts should be in accordance with drawing requirements, a gap of between 0.08 mm to 0.25 (0.003 inch to 0.010 inch) before tinning usually being specified for all materials except aluminium .

GENERAL APPLICATION OF SOLDER
After the surfaces have been cleaned, an adequate, but not excessive, amount of the appropriate flux should be applied; the surfaces should then be tinned by hot tinning, dipping in molten solder, or by electrolytic deposition. When a dipping process is used, surplus solder should be removed from the surface by wiping or other convenient means before assembly and final soldering.

NOTE
Electro-tinned surfaces, if allowed to age, may present difficulty in soldering unless the tinning is at least 0.008mm (0.0003 inch) thick.

Where a common soldering iron is used, the bit should be heated in a blue flame. The use of a red or luminous flame is not recommended, since this would result in a deposit of soot on the bit. The bit should not be heated to such an extent that it displays a "rainbow" effect, as this will cause the solder to sputter and detrimentally affect adjacent parts.

Irrespective of the nature of the flame used for heating, some oxides will form on the bit; these should be removed by dipping the tip into a cleaning solution each time it is removed from the flame. A suitable cleaning solution can be made by mixing one pound of melted sal ammoniac with one pint of distilled water.

A mass of material tends to dissipate the heat from the surfaces to be joined, and to obviate its effect it is usually necessary to pre-heat the metal. Care must be taken to prevent the overheating or burning of the parts, since, apart from possible detrimental effects on the material, this will cause the solder to run out of the joint. However, if insufficient heat is applied, the solder will not run evenly into and fill the small space between the faces of the joint, and lack of strength will result.

The use of an excessive amount of solder is un desirable; if the process is correctly applied, a little solder, thoroughly melted, will cover a considerable surface.

When the solder is solidifying, any movement will produce internal fractures in the solder; such fractures are not readily discernible and will considerably weaken the joint. To prevent any such movement, the parts should be firmly clamped during the soldering process.

After soldering, the joints should be wiped clean and thoroughly washed in hot water. Joints soldered with the aid of paste fluxes should, before washing, be cleaned with a spirit solvent such as petrol or industrial methylated spirit. Joints soldered with the aid of zinc-chloride fluxes (e.g. DEF 34\1) should, before washing, be cleaned with a 1 to 2 per cent (by volume) hydrochloric acid solution, preferably with a suitable wetting agent additive.

NOTE
A wetting agent is a substance added to a liquid in order to reduce its surface tension.

Unless otherwise specified, joints which cannot be examined visually, e.g. such as may occur inside containers, etc., should be thoroughly washed with a 2 per cent (by volume) solution of hydrochloric acid, and subsequently swilled for at least two minutes with water. Where paste fluxes are used for such applications, a thorough washing in spirit solvent should precede the acid wash.

BATH SOLDERING
There are a number of methods by which parts may be joined by dipping in molten solder. The simplest method is to dip items into a heated container after fluxing; this method may be suitable for occasional use where attention can be given to the removal of scum or dross immediately before dipping. The presence of dross is a serious matter in production line soldering and the two methods described below have been adopted to overcome this problem.

Rotary Baths
In this method the solder bath is rotated slowly, and dross flows under centrifugal force to the periphery, where it may be easily skimmed off. By this means soldering may be carried out at temperatures of up to 500 °C, at which temperature normal bath operation would not be practical.

Standing Wave Baths
In this method a pump is used to pump molten solder from the bottom of the bath through a slot-shaped hole so that a standing wave of solder appears across the surfaces. Dross forming on the surface is swept to a catchment area where it can be periodically removed. This method is frequently used in the manufacture of printed circuit boards, which are pre-fluxed and drawn across the standing wave. One advantage of this method is that the size of the work is limited only by the width of the bath and not by its length.

General Recommendations
The composition of a bath should be checked at frequent intervals. Particular attention should be given to the copper pick-up, which should not be allowed to exceed 0.4 per cent.

The temperature of the bath should not be allowed to rise too high, as the solubility of copper in the solder increases rapidly with temperature. The formation of a blue film on solder with a high tin content is indicative of an excessive temperature, but this indication will not be found in solders containing less than approximately 40 per cent tin. Pyrometric control of solder baths is strongly recommended.

The bath used should be of adequate size for the work in hand, so that placing a large item in the bath does not result in undue cooling of the solder.

SOLDERING SHEET METAL
The following method of soldering seams in sheet metal is usually employed, to comply with the tinning process referred to in earlier paragraph .

The surface should be cleaned and a suitable flux applied. A heated bit should then be held on the surface until the material reaches the melting point of the solder. Solder should then be applied to the bit so that it will flow from the bit to the surface of the material and spread evenly. The solder may also be applied by dipping or by electrolytic deposition.

The tinned surfaces to be joined should be fluxed, placed together and heated by a bit held on the outside of the joint. The heat transference will be quicker if the bit is applied to the material with a firm steady pressure and moved along the seam slowly. When the materials become sufficiently hot, the solder on the tinned surfaces will melt and flow together to make the joint. Wherever possible, the seams should be soldered in the horizontal position.

The above process is sometimes known as " sweating" and other methods include the use of solder creams, and solder paints, which contain flux and solder, and which are applied to the surfaces of the joint either with a brush, or by dipping, before assembly. The parts are made a close fit, and are manufactured so that they remain in position during heating, or may be held together by a jig.

NOTE
When proprietary types of solder creams or solder paints are used, it is essential that they should be of a type approved for use on aircraft.

SOLDERED ASSEMBLIES MADE OF TINNED STRIP
The methods of soldering described in the following paragraphs are used mainly for the manufacture of heat exchange equipment. Repairs must be strictly in accordance with the manufacture ' instructions.

Honeycomb Structures
The assembly is made up of strip material previously coated with solder, and the component parts are tacked by local heating to hold them in position, after which the completed assembly is placed in a jig. The assembly is then de greased, preferably by trichloroethylene, and allowed to drain, after which it is dipped into a flux bath and again allowed to drain.

Hot air is then blown through the assembly so that the coating melts and forms a soldered joint where the parts are in contact. After soldering, the flow of heated air is replaced by a flow of cold air, which is maintained until the temperature of the assembly drops to room temperature, then the assembly is removed from the jig and washed thoroughly.

As it is not possible visually to check assemblies produced by this method, it is essential that a schedule of operations should be compiled for each type of assembly, the suitability of which has been proved by sectioning and examination of trial assemblies.
A suitable schedule, subject to necessary variations, should include the following:-
(i)   Each component should be thoroughly de greased.
(ii)   After degreasing the assembly should be drained in such a manner as to preclude the formation of pockets of condensate.
(iii)   The assembly should be adequately fluxed and thoroughly drained.
(iv)   The assembly should be positioned in its jig so as to ensure that it is evenly heated or cooled .
(v)   The temperature of the air and the time of blowing should be in accordance with drawing or schedule requirements.
(vi)   After cooling, the assembly should be washed as detailed in earlier paragraph then thoroughly dried.

Fin and Tube Structures
In the production of fin and tube type heat exchangers, thin brass strip is formed into rectangular tubes with a rigid locked seam along one edge. The strip can be pre-tinned with solder, or the tube can be continuously tinned after forming by fluxing and dipping in a solder bath, after which it is cut to the required length.

The tubes are assembled into copper gill-plates punched with rectangular holes to space the tubes evenly apart. The assembly is placed in a jig and is dipped into a bath of flux, usually of the hydrazine type.

After draining, the assembly is baked in an oven, and during this process the solder on the tubes melts and joins the tubes to the gill-plates at their points of contact; at the same time the seam along the edge of each tube is permanently sealed with solder.

Oven temperature must be carefully controlled during the soldering process, and the assembly should be tested with compressed air at the test pressure stated on the drawing to ensure that the solder has effected a perfect seal. A flow test is also essential to ensure that the tubes are not blocked.

CABLE NIPPLES

Nipples and other types of end fittings are normally swagged on to stranded cables, but on some types of aircraft soldered nipples may be used in systems where safety considerations are not of prime importance. To ensure satisfactory attachment of a soldered nipple the following procedure should be adopted (see Figure 27.1).

(i)   Thread the cable through the nipple sufficiently to enable the strands to be splayed apart; the strands should be evenly spaced around the countersink in the nipple and project beyond it.

(ii)   Clean the cable strands and the nipple.

(iii)   After cleaning, pull the cable back so that the splayed strands lie on the counter-sink.

(iv)   Hold the nipple securely in a vice and ensure that the cable is straight and concentric with the hole in the nipple.

(v)   Heat the joint with the soldering bit.

(vi)   Apply a suitable flux solder; the solder should fill the hole in the nipple and envelop the cable and splayed ends. When the solder is set, any projecting ends should be clipped off and filed flush with surface of the nipple.

(vii)   Examine the cable at the point where it enters the nipple, to ensure that there is a clean run of solder on and between the strands.

(viii) Remove all traces of flux from the nipple and cable and apply a coating of rust preventative. When required by the drawing, the assembly should be proof loaded.
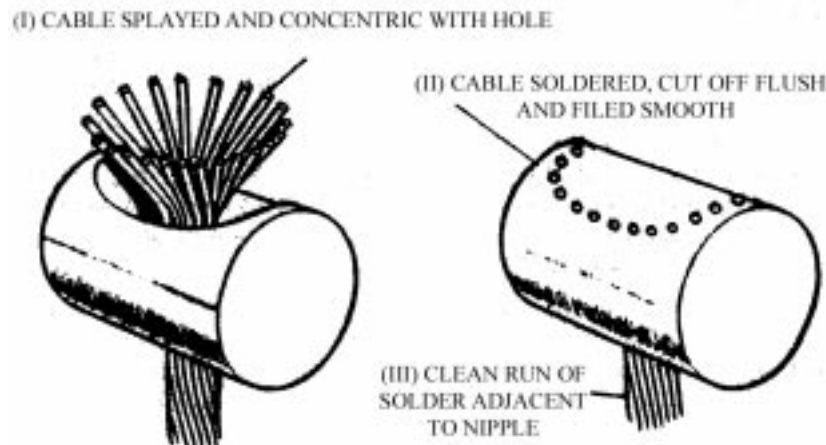
Fig. 27.1, Soldering Nipples to Stranded Cables

SOLDERED ELECTRICAL CONNECTIONS

Electrical cables are usually attached to a terminal or plug by means of a crimped end connector, but on some aircraft, connections may be made by soldering. Crimped end connectors are considered essential in some circuits, e.g. fire detectors, and. in locations where high ambient temperatures may be expected; the connections should not be replaced by soldered connections.

GENERAL CONSIDERATIONS

Cored wire solder complying with BS 441 is generally used for making electrical connections for use in temperatures up to 100 °C, but BS 219 Grade A or K solder and flux complying with DTD 599 are often recommended as an alternative. Grade 5S solder may be used for working temperatures up to 200 °C. Corrosive fluxes are not generally permitted for use on electrical equipment because of the difficulty of removing the residue, and activated fluxes are not recommended for use on very thin wire (i.e. less than 43 s.w.g.) because of the relatively high erosion by the hot flux.

Heat applied by a soldering iron may be conducted along the wire and cause damage to cable insulation or to heat-sensitive components such as transistors. Damage may be prevented by using a "heat-sink", which usually takes the form of close fitting pliers attached to the wire, to conduct heat away from insulation or component. A heat sink may also be used to minimise "wicking" (i.e. the run of solder along the strands by capillary actions), when soldering stranded or braided wire.

When soldering a number of connections in close proximity, a heat shield should be placed between the joint being soldered and adjacent connections. In similar locations the use of neoprene sleeves over completed joints is often specified to prevent short-circuiting.

Soldering Process

A soldered electrical connection must be strong enough to withstand normal handling and vibration, and must also provide the minimum resistance to the flow of electric current. The following procedure should ensure a satisfactory connection.

The cable should be cut to length and the insulation cut back sufficiently to make the connection, care being taken not to nick or damage the wire and to ensure that the remaining insulation does not touch the soldered joint. It is recommended that properly adjusted mechanical strippers or thermal strippers are used for removing unwanted insulation. If the cable is stranded it should be lightly twisted in the direction of lay to eliminate sharp projections.

The end fitting and exposed wire should be cleaned over their contact areas, using a light abrasive paper , then washed in a suitable solvent. The solvent must be compatible with the insulation material, so that any contact between the two will not cause the insulation to deteriorate.

Parts which are not pre-tinned or plated should be tinned by applying flux and solder with a heated iron. The tinning of flexible wires should be restricted to the minimum necessary for making the connection; over-tinning will reduce the flexibility of the wire and may lead to fracture in service.

The wire should be positioned in the end fitting and heat applied by means of a soldering iron until the solder flows through the joint, additional solder or flux being added as necessary. The connection should be made quickly, and held securely in place while the solder solidifies. The wire should be attached in such a way as to provide additional security to the joint, but must not prevent removal if the solder is melted in a future disconnection; if the tag has a hole the wire may be bent 90 $^\circ$ through the hole, but if the tag does not have a hole the wire should be bent 180 $^\circ$ to hook round the tag.

After soldering, the soldered parts should be cleaned with an approved solvent.

Inspection

Inspection of completed soldered connections should include the following:-
(i)   Joints should be clean, smooth, bright and free from sharp projections, and the wire easily discernible through the solder.
(ii)   As far as can be detected visually, the joint should be filled with adhering solder.
(iii)   Insulation should be undamaged (i.e. not burned or affected by solvent).
(iv)   There should be no pitting, corrosion, scale or other evidence of poor work- manship.
(v)   Where electrical tests are specified, the results obtained should be within the prescribed limits.

SOLDERING OF ALUMINIUM

Proprietary brands of cored wire solder are available, which may be used for soldering aluminium and many aluminium alloys, and a method of ultrasonic soldering may also be used.

The normal soldering techniques is similar to that used with other materials but, because of the material's high specific heat and thermal conductivity, a greater heat input is required . An advantage of these properties is that uneven expansion and contraction are avoided, and heating of complex structures is simpler than with other materials. A soldering temperature of 280 ºC to 370 ºC is required, and may be obtained using a hand iron, gas torch, furnace or induction coil. Solder should be pre-positioned or handfed to the edge of the joint, and heat applied adjacent to the joint to bring it quickly to the soldering temperature, so that the solder melts by indirect heating.

As aluminium expands more than most materials, light jigging, which will allow the parts to expand and contract, should be used when necessary. A joint clearance of 0.05 mm to 0.1 mm (0.002 inch to 0.004 inch) will allow the solder to fill the gap by capillary action, and give maximum strength.

Pungent fumes are given off by the flux, and soldering should be carried out in a well-ventilated working area.

Ultrasonic soldering equipment is available in the form of an iron, for normal joints, or a bath, for the quick dip-turning of aluminium wire and small parts.

The working principle of the equipment is that ultrasonic vibrations are imparted to the bit of the iron or, where baths are used , to the vessel containing the solder. When the vibrations are applied to the molten solder on the surface of the material, the effect of the ultrasonic energy is to produce imploding cavitation bubbles in the solder, which remove the oxide film and permit a wetting action by the solder to take place. No flux is required for the process and the solder used should contain 90 percent tin and 10 per cent zinc.

CHAPTER: 28
BRAZING

INTRODUCTION

This chapter gives guidance on the brazing processes applicable to ferrous and non-ferrous metals. For the purpose of this Chapter 'brazing' means the joining of materials by a process in which a molten alloy is drawn by capillary attraction into the space between the adjacent surfaces of the parts to be joined. The parts to be joined are known as the basis, or parent, metals.

Low temperature brazing, also known as silver soldering or hard soldering, is a brazing process which uses filler alloys based mainly on the metals silver and copper, with a melting temperature within the range 600 °C to 850 °C. The strength of a joint brazed with silver brazing alloy, if properly designed, is often equal to the strength of the materials joined.

When brazing is carried out with filler alloys of high melting temperature, grain growth and softening of the parent metal often occur, thus necessitating further heat treatment to restore the required properties.

Where special techniques of brazing are applicable to certain materials, these are described under the heading of the material concerned.

STRENGTH OF JOINTS

The strength and efficiency of brazed joints depend on a number of factors, including the design of the joint, cleanliness of the surfaces to be joined, the method of applying the process, the composition of the materials to be brazed, use of the brazing method and materials specified on the drawing or manual, and the competency of the operator. Primarily the strength of the joint depends on the area of the film which unites the surfaces of the parts forming the joint and, to a lesser extent, on the thickness of the film, a thin film usually producing the strongest joint.

Specific values for the strength of joints can be misleading, since so many factors are involved. For example, most joints made in normal workshop or mass-production conditions contain voids resulting from gas or flux entrapment, or from the formation of shrinkage cavities in the filler alloy during its transition from the liquid to the solid state. Although it is seldom possible to eliminate such faults completely, they can be minimised by careful attention to cleanliness, joint gaps, heating methods and the method of feeding the filler alloy into the joint.

Overheating during brazing can have a serious adverse effect on the strength of a joint. Care is necessary, when using a hand torch, to ensure that the flame is suitable for the work in hand, otherwise grain growth, burning, distortion or melting of the parent metal may result. Particular care is necessary when using oxyacetylene gas, which has a flame temperature in excess of 3000 °C. Overheating of the parent metal may also result from the use of incorrect brazing alloys.

Strength at elevated temperatures depends largely on the type of filler alloy used, and in general terms the silver brazing alloys having the lowest melting temperature are suitable for continuous service at temperatures up to about 250 °C.

When dissimilar metals having different rates of thermal expansion are brazed, the possibility of stresses resulting from differential contraction during cooling is reduced by the use of low temperature filler alloys.

Flux should be removed from parts by washing in hot water but, with assemblies consisting of parts of dissimilar metals or with sudden changes in section, washing should not be carried out while the parts are still hot from brazing. This practice could result in stress cracking or the production of high residual stresses in the component.

SCOPE OF PROCESS

All brazing operations should be performed strictly in accordance with the requirements of the relevant drawings. Material suitable for brazing are listed in BS 1723, and various combinations of these materials may also be joined provided that a suitable technique has been established.

COMPETENCY OF OPERATORS

As stated, the strength and efficiency of brazed joints depend, amongst other factors, on the competency of the operators. It is recommended that the competency of operators responsible for the hand torch brazing of important parts, should be checked regularly by a testing programme such as that described below.

A sample should be selected for testing from the operator's production work wherever possible, but where this is not practicable, a butt, fillet, tube-to-tube, or sheet-to-sheet test piece, as appropriate to the type of work in hand, should be prepared.

The test piece should be submitted for microscopical examination to a laboratory approved for the examination of welded joints, and should show satisfactory penetration into the joint, adhesion and freedom from porosity, freedom from overheating of the parent metal, absence of coarse grain, etc. Further test pieces, to ensure continued competency, should be submitted at intervals not exceeding six months. When an operator fails a competency test he should undergo further practice and \ or training before re submitting a test piece.

An additional competency test should be submitted whenever there is a marked change in the material or types of joints being brazed.

MATERIALS FOR BRAZING
The filler alloys and fluxes used for brazing aircraft parts must conform to the appropriate British Standards or to DTD 900.

Filler Alloys
Details of the composition and melting range of filler alloys or metals which may be used for brazing are contained in BS 1845 in a series of Tables. The basic alloying elements listed in each of Tables 1 to 8 in BS 1845, provide the prefix for the filler type (i.e. AL, aluminium; AG, silver; CP, copper-phosphorous; CU, copper; CZ, brass; NI, nickel; PD, silver-copper-palladium; AU, gold) and a numerical suffix signifies the particular alloy within a group; Table 9 lists the maximum permissible content of impurities in the alloy specified for vacuum brazing.

Filler alloys are generally available in rod, wire and strip, and in some instances in granular form, the choice depending on the brazing method used. Whilst the majority of hand torch operations require the filler alloy to be fed by hand from a rod, wire or strip, better results can sometimes be obtained by placing the brazing alloy in a predetermined position in the joint, and heating the assembly by means of a fixed torch, furnace, or electrical induction or resistance methods. Filler alloy inserts for this purpose usually take the form of wire rings, but, in some cases, foil, washers, or pressing of special shape are used.

A silver brazing alloy in the form of a paste or paint is also available, and consists of finely divided filler alloy, flux and a volatile liquid medium. The proportions of the constituents are so arranged that the paste can be used with any of the various heating methods.

Fluxes
The function of a flux is to dissolve oxides; it also has the effect of reducing the surface tension of the molten filler alloy, thus assisting the alloy to flow readily between the surfaces of a joint.

It is recommended that the flux used in any brazing operations should be agreed with the supplier of the filler alloy, since in certain instances a flux suitable for one filler alloy may not be suitable for another of similar composition, for example, because of the melting range of the alloy. An example of this is borax, which has a higher melting temperature than some of the filler alloys, and , in this case, its use may result in flux entrapments.

Fluxes are normally supplied in powder form, and should be made up in accordance with the manufacturers' instructions. The application of the flux for the various processes is described in the appropriate paragraphs.

BRAZING JIGS
Components which are to be joined by a brazing process are normally specially designed to ensure correct location and filler penetration. In the majority of cases the parts fit naturally together or may be lightly supported in such a way as to permit natural expansion and contraction to take place, but in some instances the use of locating jigs is unavoidable.

Jigs should be so constructed that contact with the parts to be joined is as light as possible, and should be shaped to avoid contact with areas where brazing alloy is required to flow. Jigs should also be designed so that, whenever possible, the capillary flow of filler metal is assisted by gravity.

Where large jigs are necessary, because of the weight of the component, for instance, care should be taken to prevent the absorption of heat from the brazing area. This may be largely avoided by facing the jig with asbestos, fireclay or other ceramic material, and by limiting the size of the areas in contact with the component.

PREPARATION OF JOINTS FOR BRAZING

All scale, grease, dirt, paint, moisture and other foreign matter must be removed from the area to be brazed. Components should first be de greased with trichloroethylene or similar solvent, then cleaned by one of the processes described in the following paragraphs, immediately prior to brazing.

Steel

The methods of cleaning steels vary with the chemical composition of the steel. In general, however, steels may be divided into two main groups, i.e. low alloy steels having a carbon content not in excess of 0.2 per cent, and non-corrodible steels or heat-resisting austenitic stainless steels.

Low Alloy Steels

The area to be brazed may be prepared by sand, shot or alumina-blasting or by brushing with a wire brush. When a blasting. Process is used, the material should he brazed as soon as possible after blasting. If a pickling process is required, a solution of 7.5 per cent (by volume) Sulfuric Acid (S.G. 1.84), maintained at a temperature of 70 °C in a lead or rubber-lined tank, is suitable. An inhibitor should be added to the solution at the rate of 1 oz. per gallon of concentrated acid.

Non-Corrodible and Heat-Resisting Austenitic Stainless Steels

The area to be brazed may be prepared by an alumina-blasting process or by brushing with a brush having stainless steel bristles. The materials should not be prepared for brazing by blasting with crushed steel shot. If a pickling process is required, a solution of the following composition is suitable:-

Hydrofluoric Acid	3.4 to 4.0 per cent (by weight)
Ferric Sulphate	10 to 15 per cent (by weight)
Water	Remainder

The solution should be contained in a lead-lined tank and should be maintained at a temperature of 60 °C.

Nickel Base Materials

The areas to be brazed may be prepared by an alumina blasting process or by brushing with a brush having stainless steel bristles. After mechanical cleaning, the edges to be brazed should be wiped with a suitable solvent. These materials should not be prepared by blasting with crushed steel shot. If pickling is necessary, it must be ascertained that the process used is satisfactory for the material in question, since an inter crystalline attack may result from the use of an incorrect solution.

Aluminium and Aluminium Alloys

The surfaces to be brazed should be prepared either by abrasive blasting with alumina grit or by brushing with a brush having nylon bristles. The use of brushes having copper alloy bristles should be avoided, since, should pieces of bristle become embedded in the surface, there is a danger of bi-metallic corrosion.

If an etching process is required, a solution of the following composition is recommended:-

Sulfuric acid (d=1.84)	150 ml/1
Chromic acid	50 g\1
De-mineralized water	Remainder

The solution should be maintained at 60 °C. Components should be immersed in the solution for 30 minutes, then thoroughly washed in cold water and dried.

Copper and Copper-Based Alloys

The surface may be cleaned by mechanical means such as alumina abrasive blasting or the application of abrasive cloths. Care should be taken to remove only the surface film and not to reduce the thickness of the material when cleaning is effected with abrasive cloth, final cleaning with a solvent being recommended in either case. The parts may also be etched by immersion for two minutes in an aqueous solution containing sulfuric acid (40 ml\1) and sodium dichromate (200 g\1).

BRAZING METHODS

Capillary attraction is the major factor in making a brazed joint, and although, in theory, there is no limit to the extent of penetration by capillary attraction, in practice this is dependent on the dimensions of the joint. The best results are obtained where a joint gap of 0.05 mm to 0.1 mm (0.002 inch to 0.004 inch) is used.

If the optimum joint gap is to be maintained during the heating operation, allowance must be made for the different expansion coefficients of the component metal used in the assembly. However, if the joint gap varies from the ideal, and is, for example, up to 0.2 mm (0.008 inch), an alloy which remains plastic over a greater temperature range should be used, but such an alloy will not have the penetrating power of those normally used for standard gaps.

Heat Application

The methods of applying heat most commonly used in brazing may be classified into four categories, i.e. induction, resistance, furnace and torch, and are described in following paragraphs; flux dip brazing is described in further paragraph.

INDUCTION BRAZING

In this type of heating the parts to be brazed are placed within the influence of the field of a coil which carries high frequency alternating current. The heating effect is rapid and, by careful design of the induction coil, the heat can be closely localized to minimise distortion, grain growth and oxidation. Since the heating effect is influenced by the thermal conductivity and electrical resistance of the component, copper and similar materials will take longer to heat up than materials such as iron or nickel. This method is particularly suitable for high speed brazing of ferrous materials in production line quantities but, because of the high cost of the equipment and the need to design special coils for each particular job, it is not often used for small quantity work.

Induction machines often employ a valve type generator with outputs of up to 15 kVA at frequencies ranging from 100 kHz to 3 MHz, and are usually fitted with timing mechanisms to control the actual heating time. The coils are usually made from copper tube through which water is passed for cooling purpose but solid copper coils may also be used.

In order to take advantage of the speed of induction brazing, paste flux and pre-placed filler alloy are often used, but, in some instances, e.g. when brazing titanium pipe fittings, brazing may be carried out in an argon atmosphere, and no flux is required.

RESISTANCE BRAZING

Resistance brazing is often used where precisely localised heating is required to prevent loss of mechanical properties throughout the parent metal. A high electrical current of low voltage is passed through a resistive circuit so that the heat developed in the circuit raises the temperature in the joint area to the brazing temperature. There are two main methods in use, carbon resistance heating and interface heating.

In carbon resistance heating the electrodes are made from carbon, which has very high resistivity and heats up quickly. The electrodes are in direct contact with the area to be brazed and heat is conducted into the work piece where the temperature is raised sufficiently to melt the brazing alloy and form the joint. Since the temperature of the electrodes is very high, some marking on the surface of the work piece may result, but this can often be alleviated by the use of pulsed current.

In interface resistance heating the electrodes are made from, or faced with, a material of relatively low resistivity. Most of the heat is developed through the resistance to the passage of current at the electrode \ work interface, and some is also developed in the work itself because of its resistivity. The amount of heat in the work piece itself is substantially higher than in the carbon electrode method.

With resistance brazing direct heating is often used, the work piece being gripped between the electrodes at the position where heating is required. In some cases, however, indirect heating may be used, both electrodes being located on one side of the largest component and the smallest component being heated by conduction.

FURNACE BRAZING

The main advantages of using a furnace for brazing are that high rates of output can be achieved, uniform results obtained and an inert or reducing atmosphere used to prevent oxidation. This method is particularly suitable for large batches of small articles which are self-locating or easily jigged, or for parts likely to distort through uneven heating.

Steel or nickel alloys can be successfully furnace brazed using a copper or bronze filler alloy. Brazing is usually carried out in a controlled atmosphere of cracked ammonia, town gas or hydrogen, and flux is not normally required although it may be recommended in some cases.

Furnace brazing of aluminium and aluminium alloy is widely used. Brazed joints may be made between aluminium and aluminium alloy parts either by the use of inserts of aluminium brazing alloys, or by using sheets with an integral coating of brazing alloy. The use of a suitable flux is essential. Since the difference in melting temperature between the filler and the basis metal is very small, close control of the furnace temperature is most important.

TORCH BRAZING

The brazing methods previously mentioned all require a high initial outlay or are only suitable for specialised tasks; they are, therefore, mainly used for large quantity brazing. Brazing by means of a hand torch, although requiring a skilled operator, is inexpensive and is widely used for all types of work.

A wide variety of gas mixtures is suitable for brazing. Oxygen may be combined with acetylene, hydrogen, propane or coal gas; air with propane, butane or methane; or compressed air with coal gas. Of these the most commonly used are oxygen \ acetylene and compressed air \ coal gas.

The selection of a gas for a particular job depends on the size of the component, the temperature required and the rate of heating required, but account must also be taken of the likelihood of overheating, with consequent excessive oxidation and the possible loss of physical properties in the component.

A mixture of compressed air and coal gas burns at approximately 1000°C and is especially suitable for preheating components and for brazing components of light construction, while and oxygen \ acetylene mixture burns at temperatures up to 3000°, and is used where high rates of heating are required.

Brazing Process

It is recommended that before heating is commenced, flux should be applied in the form of an aqueous paste, both to the joint area of the assembly and to the filler alloy. Where the duration of heating or the size of the joint makes it necessary to add flux during the brazing operation, such additions are best made by dipping the hot end of the filler rod or strip into dry flux. If the overlap of a joint exceeds 4 3\4 mm (3\16 inch) the surfaces should be coated with flux prior to assembly.

In all cases rapid heating of the joint is essential, and the flame must be adequate for this purpose, but care must be taken to avoid overheating. When an oxy-acetylene flame is used, a large jet should be employed than that used for the welding of similar material of similar thicknesses. The envelope of the flame should be kept constantly on the move over as large a portion of the joint as possible, since a static flame is likely to cause local overheating and loss of heat control.

Heating should be started with the torch held several inches from the work so that the outer flame envelope spreads over a large area of the joint. Where parts of unequal thickness are brazed, the flame should be concentrated on the heavier part to ensure uniform heating.

(i)   As heating is continued, the flux first bubbles then settles down to a thin clear liquid. When this stage is reached, the work is approaching the correct temperature for application of the brazing alloy.

(ii)   The brazing filler strip or rod should then be placed in contact with the joint, but if the filler does not melt on contact with the work, it should be removed and the heating continued until the correct temperature is reached. The filler must not be melted by the flame and so allowed to drop on the work; heat should be applied to the work, and the heat from the work used to melt the filler.

When the brazing alloy melts in contact with the assembly, the feeding in of the strip should be continued until the joint is slightly over filled to allow for shrinkage on solidification. When this stage is reached and the molten filler has had time to penetrate the joint fully, heating should be discontinued. Unless the work has sudden changes of section, or is an assembly of metals of widely different expansion characteristics, and if there is no specific instruction on the drawing, it is usual to quench in water after the filler has set.

Oxyacetylene Flame

A neutral flame should be used in all instance, except when copper-zinc, copper-zinc-silicon or copper-zinc-nickel-silicon filler alloys are employed, when a slightly oxidising flame is necessary.

(i)   An oxidising flame is produced by excess oxygen giving a considerably smaller inner flame than that obtained in the neutral condition.

(ii)   A neutral flame is composed of an equal amount of both oxygen and acetylene, giving a clearly-defined inner flame.

(iii)   A reducing, or carburizing, flame is produced by an excess of acetylene in proportion to oxygen, giving a furry edge to the inner flame.

The appearance of the various flames is shown in Figure 28.1.
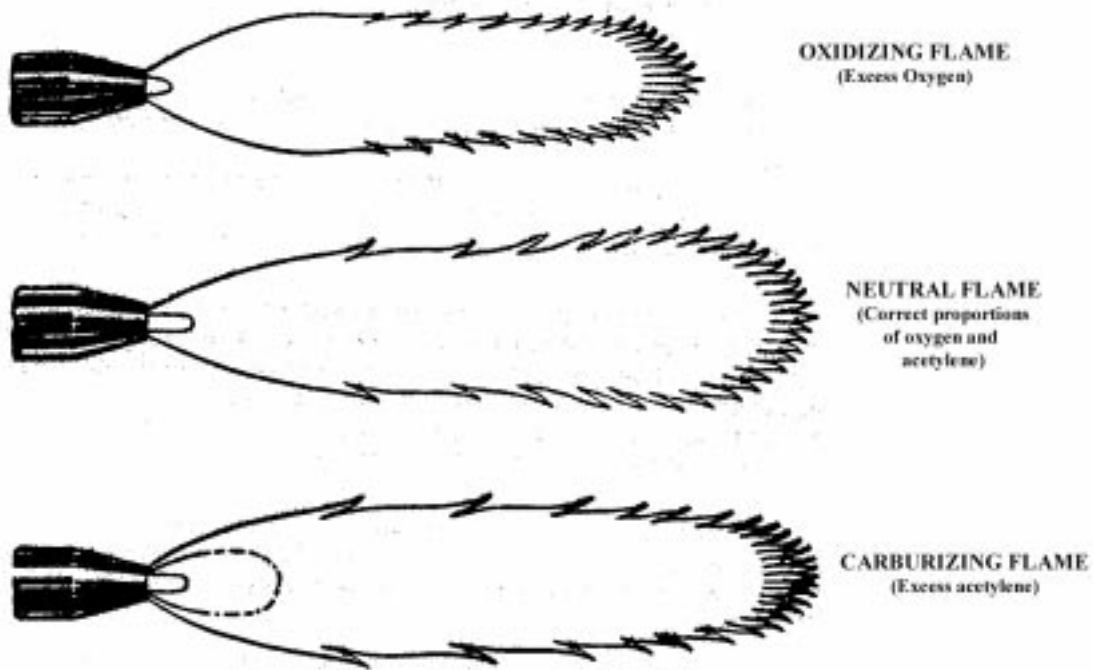
Fig. 28.1, Flame Adjustment

Torches

Brazing torches vary in design according to the gas used. When oxyacetylene is employed, a welding torch, together with the normal welding equipment, is used, the flame being adjusted to suit the brazing work in hand.

There are several types of torches available for brazing with coal gas and air. Brazing torches are designed for lightness and balance to avoid physical strain on the operator. Flame control is obtained by various means, such as two adjustable levers, knurled knobs or, in some instances, a spring loaded trigger-type of levers.

A typical brazing or braze welding hand torch embodies the following features: (a) quick action valves with conveniently place thumb control for the gas and air supplies; (b) a built-in economizer that cuts off the gas and air supply when the operator's grip is relaxed, and restores the flame when the torch is again grasped; this same control enables a soft warming-up flame to be obtained by partial operation of the lever; (c) a pilot flame adjustable to suit different gas pressures; (d) several interchangeable flame units to provide various flame characteristics to suit a wide range of work and gas combinations.

Air is supplied by an electric blower, a foot operated bellows, a compressed air bottle, or the normal factory supply suitably regulated to the required pressure.

Fixed Torches

A logical development of the hand torch is to use fixed burners stationed around a turntable, conveyor belt or similar equipment. Conventional torches are used, but special burners have been developed for this purpose. Compressed air and coal gas are fed to the burner, which comprises a series of fine jets. This produces a flame which does not 'bounce' and has a good depth of heating. These arrangements are commonly fitted with electric timers.

BRAZEWELDING

Braze welding, also known as bronze welding, is a process suitable for use with metals of high melting temperature, in which the main strength of the joint is obtained by building up a fillet alloy. No fusion of the basis metal takes place, but some penetration of the filler alloy into the joint gaps may occur through capillary action.

Filler rods for braze welding are specified in BS 1724, and are basically a copper\zinc alloy, but may contain quantities of nickel, manganese, silicon or tin, depending on the metals being joined.

Fluxes

Proprietary types of fluxes are used, usually on the recommendation of the manufacturer of the braze welding rod. Fluxes should only be applied after the joint has been suitably prepared.

Torches

Because of the high temperatures required for braze welding, an oxyacetylene torch is normally used.

FLUX REMOVAL

Flux residue is likely to promote corrosion when exposed to atmospheric moisture. The residue cannot be neutralized and should be removed from brazed joints by either chemical or mechanical means, removal being facilitated by the use of adequate amounts of flux and by the avoidance of overheating or prolonged heating during the brazing operation.

Aluminium and Aluminium Alloys

The following procedure may be used for removing flux residue from joints in aluminium or aluminium alloy assemblies:-

(i)　　Wash in boiling water for 10 to 60 minutes according to the complexity of the assembly, preferably in a bath through which their is a continuous flow of water.

(ii)　　Rinse in clean hot water.

(iii)　　Wash in a solution of 10 per cent nitric acid in water at a temperature of 65 $^\circ$C for 20 minutes.

(iv)　　Rinse in water and inspect visually for signs of flux residue.

If flux residue is still present, continue as follows:-

(v)　　Immerse for up to 30 minutes in a second nitric acid bath to which 1 to 5 per cent sodium dichromate may be added.

(vi)　　Rinse in clean hot water, drain and dry.

(vii)　　Inspect for flux residue and, if necessary, repeat operations (v) and (vi).

Materials Other than Aluminium

Where no harmful effects can occur, flux removal is assisted by quenching the work in water as soon as the filler has solidified, but where the component parts of an assembly are of dissimilar materials or have sudden change in section, they should be allowed to cool before washing. The parts should then be thoroughly dried to avoid the possibility of corrosion.

Fluoride Fluxes

Washing in water, followed by brushing with a wire brush, will generally remove the residue of fluoride fluxes, especially if hot or boiling water is used. In difficult cases, soaking in a cold solution of 5 per cent (by volume) of sulfuric acid (SG 1.84) in water, followed by a thorough washing in water and subsequent brushing, will facilitate flux removal, but it will be necessary first to ensure that such an operation will not prove harmful to the finished work, e.g. by entrapment of the solution.

Borax Fluxes

Residues of these fluxes are only slowly soluble in water; they may be removable by the methods specified in above paragraph but mechanical methods such as shot or grit blasting are sometimes necessary. In instances where mechanical methods are impractical the manufacturer may recommend that residues be dissolved in a hot caustic soda solution.

BRAZING ALUMINIUM AND ITS ALLOYS

There is a distinction between brazing aluminium and brazing of other metals. For aluminium and its alloys, the filler metal is of the aluminium-silicon type with a melting point only slightly lower than that of the basis metal. Consequently there is a much smaller margin (compared with the brazing of other materials) between the melting point of the filler and the temperature at which overheating and collapse of the basis metal can occur; accurate control of temperature is therefore most important.

BS 1845 gives a list of the filler materials which are suitable for brazing aluminium and its alloys. Some of the basis metals which can be brazed easily are the various grades of pure aluminium, and some of the alloys of aluminium and magnesium or aluminium, magnesium and silicon. The brazing of alloys containing more than 2 per cent magnesium is not recommended because of the difficulty of removing the oxide film.

Many types of proprietary fluxes are available for brazing aluminium and its alloys; these are generally of the alkali halide type, and the recommendations of the manufacturer of the filler material, regarding their use, should be observed. A standard aluminium brazing flux containing chlorides of sodium, potassium and lithium gives satisfactory results when used with aluminium which has been chemically cleaned.

Most fluxes for aluminium and its alloys absorb moisture very rapidly, and their efficiency is reduced accordingly. It is essential, therefore, that fluxes should be stored in airtight containers. Containers manufactured from aluminium or glass are suitable for this purpose, but steel or brass should not be used, since these materials causes contamination.

Brazing Process
The three main methods of brazing aluminium and aluminium alloys are : torch or flame brazing, furnace brazing and flux dip brazing.

Torch Brazing
In torch brazing, actylene and hydrogen are the preferred fuel gases, although other gases, e.g. coal gas, are used; all these gases are often used with oxygen.
(i) A brazing torch, which is often a standard welding torch, is suitable for most aluminium brazing work. The flame must be maintained in a neutral condition, but should this prove difficult, a slightly reducing flame is preferable to an oxidizing flame (see Figure 28.1).
(ii) When using oxy-acetylene the possibility of overheating must be kept in mind. The melting point of the filler alloy must occur before the temperature of the joint causes sagging or plasticity of the basis metal.

Furnace Brazing
Furnace brazing requires a temperature control of $+5\,°C$. $-0\,°C$. over a range of $540\,°C$ ti $650\,°C$, according to the material being brazed. The general requirements for brazing aluminium are, a rapid rise in temperature, a short period at the brazing temperature, and a rapid cooling to below the solidifying temperature of the brazing alloy. Any heat-treatment furnace giving such conditions, and having its linings protected from attack by flux, is suitable.
(i) A high rate of heat input ensures that the work is raised to the brazing temperature rapidly and so prevents excessive alloying between the filler metal and the basis metal. An even distribution of the heat throughout the chamber is a definite advantage. No useful purpose is served by having an inert or reducing atmosphere in the furnace.
(ii) As a general guide to timing, light gauge sheets take 2 to 6 minutes from the time the brazing temperature is reached until the filler metal has filled the joint area, and 4 to 15 minutes for complete furnace treatment, havier sections may take up to half-an-hour for the complete furnace treatment.
(iii) Heat-treatable alloys must be reheated and quenched at the appropriate temperature to restore their properties, although quenching from the brazing temperature results in partial restoration. Quenching also loosens and partly removes the residual flux, thereby simplifying the final cleaning process. Thin gauge materials may become distorted if quenched by immersion, and water sprays may be used to minimize this by ensuring that all parts are cooled simultaneously.

Flux Dip Brazing
Flux dip brazing is used largely in the quantity production of assemblies having a large area of jointing in relation to their size, for example, heat exchanger or radiators, and is useful for the brazing of parts in an inaccessible position which cannot be brazed by other methods. This process is suitable for any aluminium alloy that is suitable for furnace brazing.
(i) Components should be cleaned, assembled with pre-placed filler material and heated in a furnace to a temperature just below the melting point of the filler alloy.
(ii) Assemblies should then be transferred to a bath containing molten flux at a temperature high enough to melt the filler, but not the parent metal ; they should be removed as soon as the filler has had time to flow freely through the joints. Overlong immersion may result in flux attack and allow excessive diffusion between the filler and parent metal.
(iii) Heat-treatable assemblies should then be quenched or re-heated as described in paragraph (iii) under furnace brazing.

Flux Removal
The quick removal of flux after brazing is essential ; immediately the assembly can be handled, it should be treated as described in previous paragraph.

Properties of Brazed Aluminium Joints
As the brazing temperature is higher than the recrystallization temperature of aluminium and aluminium alloys, annealing takes place during brazing.

Brazed assemblies made of non heat-treatable alloy have their design strength based on the strength of the annealed material.

Suitable assemblies made of heat-treated alloy of the aluminium-magnesium-silicon type may be strengthened after brazing by quenching, followed by natural or artificial ageing according to the requirements of the specification.

Alternatively, assemblies may be re-heat-treated to restore the full strength of the basis material.

Aluminium filler alloy does not show a significant increase in strength after heat-treatment and limits the design strength of a brazed assembly.

HIGH NICKEL ALLOYS
These alloys are usually specified for their heat and corrosion resistant properties.

Most of the high nickel alloys can be readily joined by silver brazing, but may be subject to inter crystalline penetration by the filler alloy if brazed in a state of stress. When high melting point filler alloys are used all stresses are relieved during the brazing process but, if low melting point filler alloys are used on heavily worked components, stress cracking may result if the components are not stress-relieved prior to brazing. Nickel alloy should normally be brazed in the annealed condition.

Cleanliness
Cleanliness is essential, and it is particularly important that all foreign matter which might contain sulphur or lead is removed before any heating takes place, as all nickel alloys are subject to some degree of attack by inter crystalline penetration by these elements, resulting in embrittlement. Possible sources of such contamination are: oil, grease, paint, marking pencils and cutting lubricants. Cleaning should be carried out just before the actual brazing operation. The tenacious oxide film requires vigorous treatment for its removal, particularly on the chromium-containing alloys, and especially after long storage. Mechanical methods, such as grinding, buffing, etc., are generally used, but chemical cleaning may also be employed.

Brazing Materials
Sliver brazing alloys complying with the AG series of filler alloys in BS 1845 are readily available and are recommended for use with nickel alloys. The flux should be of a type recommended by the manufacturer of the filler alloy; borax is not a satisfactory flux for this material. The flux is generally mixed with water and applied with a brush but, alternatively, the parts may be coated with flux and assembled whilst wet. Flux residue must be removed.

Heating
Any of the methods of heating previously described may be used with nickel alloys. The hand torch method may be applied to most work, but particular care is necessary when using an oxyacetylene torch, as the flame can easily produce temperatures well above those required for silver soldering and may overheat the basis metal.

HIGH TEMPERATURE BRAZING
Where joints are required to retain their strength and corrosion resistance at elevated temperatures, high temperature brazing may be used.

Brazing alloys containing palladium or nickel are widely used for joining the Nimonic and Inconel types of alloys; these brazing alloys make joints which combine good mechanical properties at high temperatures with a high resistance to oxidation.

Brazing Methods
Brazing is usually carried out in a vacuum furnace or in a furnace containing an atmosphere of cracked ammonia or hydrogen, but salt bath or induction heating may also be used. Except when vacuum brazing, a flux should normally be used, but if, because of the difficulty of removing the residue, the use of a flux is undesirable, components are sometimes electroplated with nickel before being brazed.

BRAZING STAINLESS STEEL
Stainless steel parts are often joined by brazing. The method is adaptable to repetitive techniques and provides a simple means of making joints which are often as strong as the parent metal.

The success of the brazing operation depends on the use of a suitable stainless steel alloy and on the selection of a suitable filler and flux.

When stainless steels are heated, the formation of chromium carbide within the metal reduces the amount of chromium available and may decrease its resistance to corrosion. This effect is known as weld decay and has been largely overcome by the use of 'stabilised' steels containing titanium or niobium. If it becomes necessary to braze un stabilised stainless steels the effects of carbide precipitation may be minimised by keeping the brazing temperature and heating time to a minimum.

Joints in nickel-free stainless steel often suffer from a defect known as crevice corrosion when subjected to conditions of high humidity. Sliver brazing alloys are generally employed where this type of corrosion is likely.

Nickel brazing alloys and alloys containing palladium and gold have been found particularly suitable for furnace brazing in a protective atmosphere, the resulting joints being resistant to chemical attack and crevice corrosion. Bronze filler alloys may also be used but are less resistant to chemical attack.

Fluoride fluxes are normally used when brazing with silver brazing alloys, but special fluxes with improved wetting properties are often recommended for use with stainless steel because of the formation, during, of a thin film of residue which is insoluble in normal flux.

Flux residues should be removed after brazing.

SAFETY PRECAUTIONS

All brazing operations involve the use of flame or heat and the handling of metals at high temperatures ; it is necessary, therefore, that certain simple safety precautions are observed. Additional precautions are necessary because of the use of alloys or fluxes, which may have toxic properties under certain conditions.

General Precautions

Components may retain their heat for a considerable period after brazing and should always be handled with care. Unless asbestos gloves are worn, unquenched parts should always be handled with pliers or tongs.

Torches should always be pointed away from the operator when being lit and should be lit either from the side or from below. If possible, hand torches should be fitted with a switch hook, in which a pilot jet and hook are connected to a valve in the gas supply. When the torch is hung from the hook, its weight cuts off the main gas supply but when it is picked up the flame relights.

Controlled atmosphere furnaces often have a curtain of burning gases at the entry and exit doors. These flames are often nearly invisible under certain light conditions and particular care may be necessary when inserting or removing components.

Hand torch brazing should always be carried out in a location shielded from flammable materials by refractory bricks or asbestos.

Induction Brazing

Metal articles heat up very quickly when placed within an induction coil. For this reason the hands should not be placed in a coil if a ring, watch or bracelet is worn, as severe burns could result.

Salt Baths

Molten salts splashed from a salt bath may cause very severe burns; protective clothing, including overall, gloves and goggles, should always be worn when working with a salt bath. Components must be completely dry before being immersed in the bath and must be lowered very slowly into the salts to prevent splashing. Salt residue should always be scrubbed from the hands before handling food.

Brazing Alloys

Most silver brazing alloys contain zinc or cadmium which, if overheated, give off fumes which may be irritating and injurious to health. Adequate ventilation must be provided when brazing with these alloys and overheating must be avoided.

Fluxes

Most brazing fluxes cause skin irritation, and physical contact should be avoided whenever possible. The hands should be washed frequently and a barrier cream used. In the event of flux being swallowed, medical attention should be sought immediately.

INSPECTION

In order to obtain the most successful brazed joints, close control of all operations is essential. The design, manufacture and cleaning of the component parts of the joint, the brazing alloy and flux used, the heating process selected, the method of removing flux residues and the application of any necessary heat treatment, should all be in accordance with proven methods and substantiated by the manufacture and testing of sample joints.

Adequate control of the heating method is essential, particularly for induction heating, resistance heating and furnace heating, and staff should be competent to ensure that consistent results are obtained. Hand torch operators should have their work checked at frequent intervals.

At specified intervals a completed assembly should be selected and subjected to strength tests and sectioning to ensure that the complete brazing operation remains satisfactory.

The following points should be checked when visually inspecting a finished joint:-

(i)   The joint and surrounding surfaces should be free from pitting, corrosion, scale, flux residue and other evidence of bad workmanship.

(ii)   The filler alloy must have penetrated throughout the joint. In the case of pipe joints an examination should be made for excessive penetration which may partially obstruct the pipe bore.

(iii)   Fillets of filler alloy should be smooth and continuous.

(iv)   The dimensions of the assembly should be in accordance with the appropriate drawing.

A visual examination may sometimes be insufficient to establish that the filler alloy has penetrated through the joint. In these cases, X-ray, ultrasonic or eddy current inspections may be required.

In some instances, brazed joints which have been found unsatisfactory, may be re-brazed under suitably controlled conditions. Care is necessary to prevent the build up of an excessive amount of filler alloys, particularly in the case of pipe joints .

INTENTIONALLY BLANK

CHAPTER: 36
ADVANCED COMPOSITE MATERIALS

INTRODUCTION

Because the improper use and handling of composite materials may have serious health effects, this chapter begin with a brief overview of some of the steps that must be taken by the technician to avoid potential health hazards.

During the manufacturing and repair of composites, the curing process releases solvents and volatiles. Chemicals are also used in the cleaning and preparation process. These chemicals can create problems for unprotected humans. The material safety data sheets ($MSDS_s$), that are supplied with the chemicals give the necessary information needed to protect the technician from harm.

Personal protection equipment (PPE) in the form of safety glasses, respirators, dust masks, and chemical resistant gloves should be used when handling any chemical substance. Chemical exposure orientation should be reported to the work-area supervisor for immediate attention.

Eating , drinking, and smoking should be avoided until the hands have been washed, because some chemical used in composite fabrication can easily be transferred to mucous membranes. Chemical ingestion works with some materials. The technician may not notice any detrimental effects initially, but they may appear years later if the proper precautions are not taken.

Vacuum downdraft tables, power tools with vacuum attachments, and portable vacuum systems should be used when drilling and trimming operations are performed on cured composites. Dust is created during composite processing that could cause respiratory problems that may not manifest themselves for years.

Using compressed air to blow composite dust should be avoided. Blowing the dust may result in the dust mixing with the air being breathed, resulting in ingestion of the materials through the lungs. Do not use compressed air to clean dust from body or clothing. This may force dust particles into the pores of the skin.

DEVELOPMENT OF METAL BONDING AND COMPOSITE MATERIALS

The first aircraft with movable flight controls to fly was the Wright Flyer at Kitty Hawk, N.C., in 1903. This aircraft was constructed of wood with cotton fabric glued to the frame. This combination of materials is known as a composite. In its simplest form, a composite is a combination of two or more materials joined permanently together so that the strength of the combined materials is greater than any of the component material.

As the structural demands placed upon aircraft increased with greater speeds and payloads, alternative materials and assembly techniques were developed. As technology progressed, aircraft were assembled using mechanical fasteners to connect aluminium skins to structural members. Aluminium is lightweight and offers greater structural integrity than wood and fabric. Mechanical fasteners provide an easily accessible mean of transferring the loads associated with the aircraft's structure.

However, the use of mechanical fasteners, such as screws, bolts, and rivets, as a means of transferring the aircraft's structural loads required that holes be drilled or punched into sturctural members and skins this process leads to a number of minute cracks, which create stress risers. These cracks grow in size, eventually resulting in failure. In addition use of mechanical fasteners increases parasitic drag when they are placed in the airstream. The use of mechanical fasteners also results in increasing the weight of the entire structure.

Aircraft engineers needed to find materials and assembly processes that would eliminate or reduce the effects of mechanical fasteners in order to further reduce the aircraft's weight and drag, thus increasing the aircraft's speed and payload. Combining their efforts with those of chemical engineers, the aircraft engineers developed methods for bonding metal structures together. A bonded structure eliminates stress concentrations due to the creation of holes and evenly distributes the load along the entire surface of the assembly.

BONDED STRUCTURES

A bonded structure is an assembly that is "glued " together and does not use mechanical fasteners to give the assembly its strength. This process of construction uses specially formulated adhesives that are exothermically cured. Curing is a process that prepares, preserves, or finishes material by a chemical or physical process. Proper curing of aircraft

bonded materials is necessary to ensure that the resultant joint possesses the anticipated strength. Materials are exothermically cured when the chemicals involved in the process combine in a manner such that the heat produced is a result of the chemical reaction between the agents and not from an external source. The temperature involved in the process is critical in providing the proper bond characteristics.

This exothermic bonding techniques have improved the joining process, the structural limitations of the aluminium skins, such as the potential for corrosion and fatigue failure, still remain. Hence aerospace and material engineers continued their efforts to find new materials that provide structural integrity and increases in the useful life. Composite imbedded in a resin matrix were developed in the quest for lighter, stronger materials.
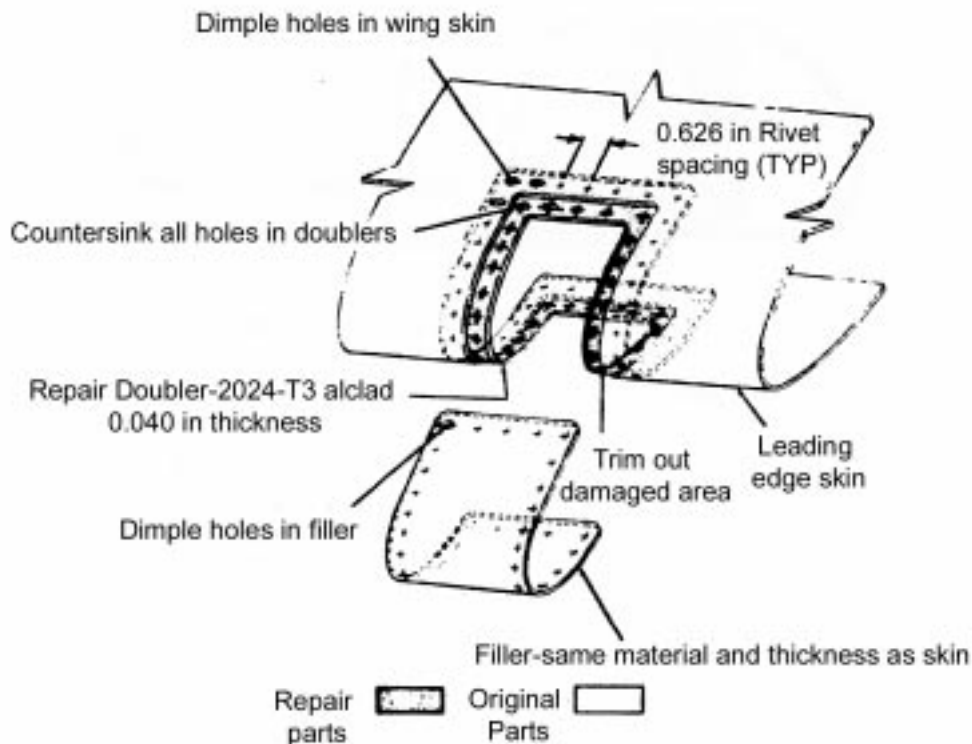
Fig. 36.1, Leading edge repair

TYPICAL REPAIRS TO BONDED METAL STRUCTURES
Repair of bonded metal skin, as with all repairs, should follow the instructions found in the manufacturer's manuals. If specific instructions are not found in these manuals, the technician may follow the standard practices set forth in AC 43.13-1A & 2A describing riveted repairs . The rivets are countersunk and then smoothed over with an epoxy filler, which ;is sanded smooth . The final finish is urethane enamel. A typical repair for the leading edge of a wing on a bonded metal airplane is shown in Fig. 36.1. Repair instruction are as follows:
1.   Trim out the damaged area in a rectangular pattern and deburr.
2.   Place the repair doubler beneath the wing skin, as shown in Fig. 36.2. Note that the doubler is 2024-T3 Alclad aluminium. (Note: Dimensions given are typical.)
3.   Holding the repair doubler in place, drill 1\8 in (3.18 mm) dimple holes through the wing skin, spacing the holes 5\8 in (15.88 mm) apart, center to center. (Note : This repair can be completed in the area of wing ribs by installing the doubler in two places, one on each side of the rib flange.)
4.   Secure the doubler to the wing leading edge with 1\8 in (3.18 mm) diameter countersunk Cherry rivets (CR 162) or equivalent. If bucked rivets are used, exercise caution to prevent nearby bond damage, (Cherry rivets are blind rivets described later in this section.)
5.   Place the preformed filler flush with the skin over the doubler. The filler must be the same material and thickness as the skin.
6.   Hold the filler in place, drill dimple holes through filler, spacing holes 5\8 in (15.88 mm) apart, center to center.
7.   Secure the filler to the doubler as directed in step 4.
8.   Use an epoxy filler and sand smooth. Finish to match aircraft.

A wing rib repair as specified in a manufacturer's manual is shown in Fig. 36.2.
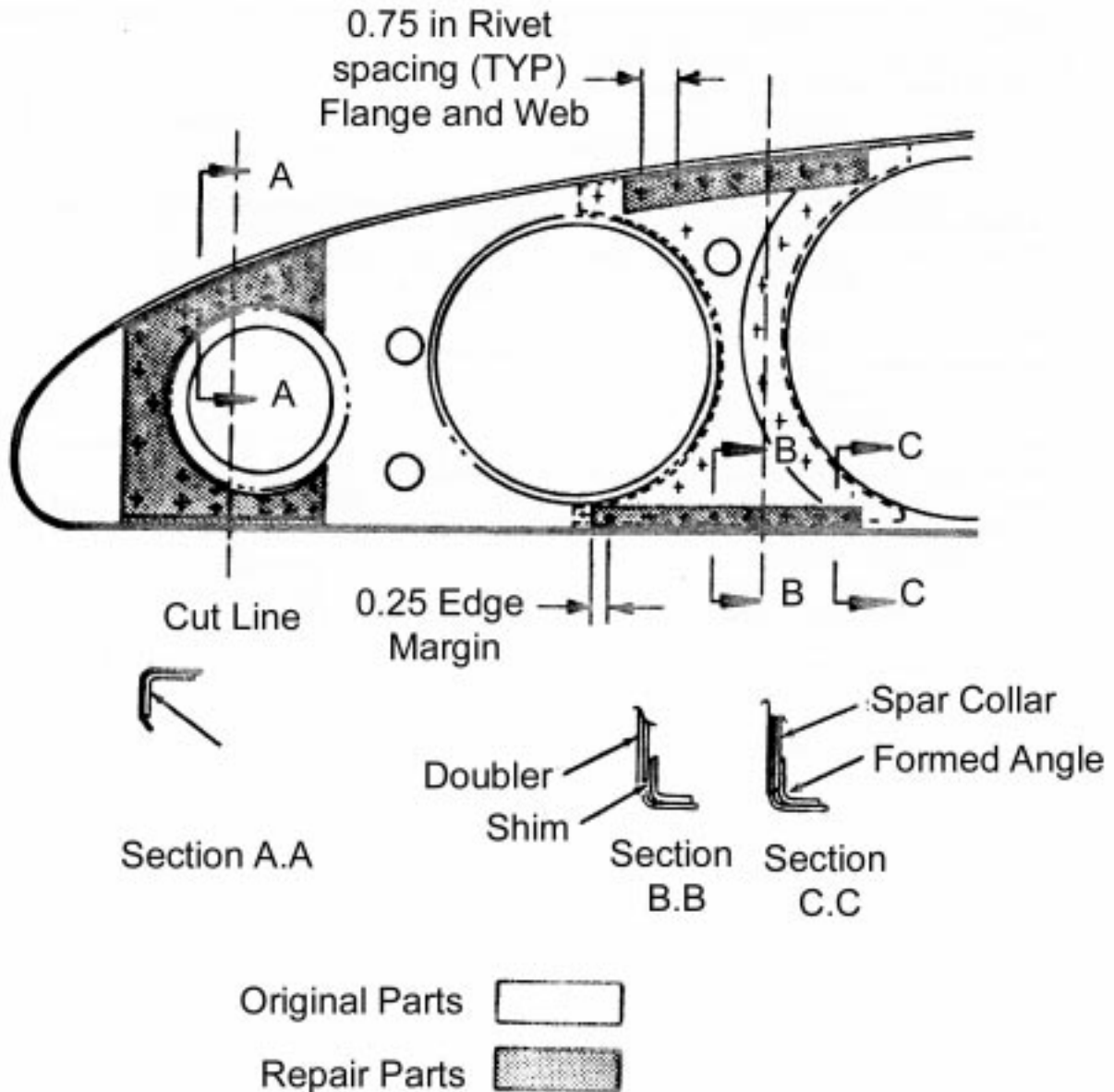
Fig. 36.2, Wing rib repair

In cases where ribs are damaged extensively, it is usually best to replace the entire rib. The technician must exercise judgement in determining whether a repair can be made satisfactorily and economically.

Instructions for the repair shown in Fig. 36.2 are as follows:

1. If the rib damage consists of a crack, stop-drill the crack if it does not extend to the edge of the part and add a reinforcement plate to carry the stress across the damaged portion and to stiffen the joints.
2. If the area is to be repaired is damaged extensively, trim out the damaged area and deburr.
3. Make repair parts from 6061 - T6 aluminium alloy or equivalent.
4. Hold the doubler, 0.032 in (0.81 mm) thick, in place against the damaged area on the rib structure. If extra support is needed, place a formed angle against the inside portion of the rib nested under the flange; place a doubler on the opposite side of the rib against the damaged area.
5. With repair parts held in place, drill 1\8 in (3.18 mm) diameter holes through repair parts and rib structure, spacing holes 3\4 in (19.05 mm) apart, center to center, Holes drilled at the ends of the formed angle should be placed 1\4 in (6.35 mm) from the edge.
6. Install all rivets, 1\8-in—(3.18-mm-) diameter Cherry rivets CR 162, CR 163, or equivalent, with wet zinc chromate primer. If bucked rivets are used , exercise caution to prevent nearby bond damage.
7. After the repair is completed, coat the repaired area with zinc chromate primer.

It should be understood that the repairs just covered for bonded repairs are not the same as repairs for composite or honeycomb structures.

COMPOSITES

Composite materials are not as new as most people think . Composite materials and bonded structures have been in use for many years., Adobe bricks are appropriately considered composite materials because they are made from a mixture of straw and mud bonded together. Reinforced concrete used in driveways and roads is a composite material because it is made from a combination of cement and reinforcing rods.

The use of composite materials in aerospace applications evolved from research done in England by the Royal Aeronautical Establishment. The U.S. military and NASA have continued their development. The first fibrous-glass-rein-force plastic (FRP) winged aircraft flew at Wright-Patterson Air Force Based in the mid-1940s.   This type of structural fabrication was not placed in common use because tests revealed that even though it exhibited high specific strength, the glass reinforcement material had marginal rigidity compared to metallic structures.

Expanding on the abbreviated definition of a composite given earlier, a composite is an in homogeneous material that has been created by the synthetic assembly of two or more materials to obtain specific characteristics or properties. Unlike metal alloys, which are homogeneous, the component parts of a composite retain their identities. That otherwise merge completely into each other, even though they do act as one. Normally, the components can be physically identified after assembly and continue to exhibit an interface between themselves.

An example of a material in common use that is not a composite by definition is a two-part-mixture epoxy adhesive. When the two parts are mixed together, they form a third material that becomes a very tough, useful adhesive. Each individual part can no longer be identified. The previous examples of the adobe bricks and the reinforced concrete are composites because the individual components can still be identified after compilation into a new material.

GENERAL CHARACTERISTICS OF COMPOSITES

Composite structures are those aircraft components that are manufactured using fibrous materials combined with a specially formulated medium called a matrix. The matrix supports the fibres, as shown in Fig. 36.3.
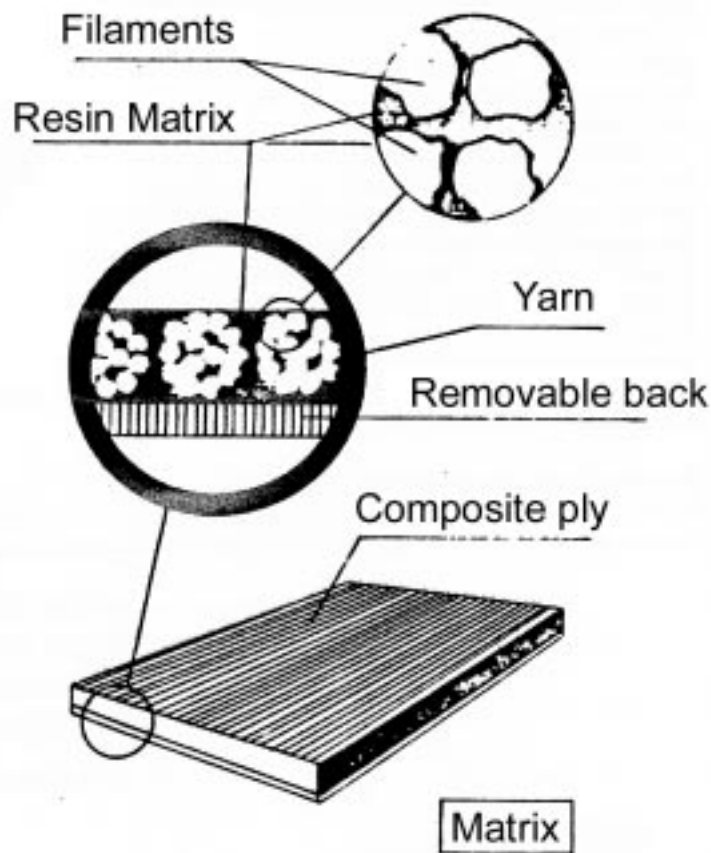
Fig. 36.3, Fibrous material encapsulate in a matrix

The original composite materials used in aircraft components were limited to fibreglass fibres combined with thermoset polyester resins as the matrix and were not used in critical applications. A thermoset resin is a type of resin that, once cured, cannot return to the uncured, or soft, state.

Improved thermostat adhesives, such as epoxies and vinyl-ester resins, bismaleimides, and thermoplastic adhesive, such as poly -ether-ether-keytones (PEEK) , as well as new fiber-reinforcement materials have been developed for resins may be repeatedly softened with heat, even after they are originally cured.

Both thermosetting resins and thermoplastics increase the workability of a material. In addition, thermosetting resins may be added to the material before the component-fabrication process begins. When a matrix is added to the fibrous material as part of a material's manufacturing material is commonly called pre-preg and is discussed in more detail later in this chapter.

The most critical properties of a composite, which are controlled by the direction of the reinforcement fibers and the ability of the matrix to transfer loads from one fiber to another, are called transverse properties. The load-carrying properties of a fibrous composite are greatest when the load applied runs in the same direction as the fibers . Loads that do not run parallel to the reinforcement fibers must, at least in part, be transferred through the matrix, which typically has the lowest load-carrying capability. Therefore, to a point, the greater the ratio of reinforcement fibers to matrix, the greater the strength of the composite.

Kevlar , a Du Pont trade name, carbon fiber, commonly referred to as graphite (even though it is not a mined material), boron, tungsten, quartz, silicon carbide, ceramics, and SPECTRA , a trade name of Allied Signal Corporation, are commonly used composite materials. Collectively they are referred to as advanced composite materials.

In 1969, Grumman aircraft, in conjunction with the U.S. Navy, fabricated the world's first primary flight-critical structure made of advanced composites for a production aircraft. This was a boron-epoxy combination horizontal stabilizer for the F-14 TOMCAT fighter.

As the demand for the use of composites increased, additional development in the areas of specialised fiber-reinforcement materials, adhesives, and processes have taken place. These developments have made the use of composite material in aircraft more economical and structurally compatible. As a result, bonded and composite structures can be found in a great many parts of today's aircraft. Landing-gear doors, flaps, vertical and horizontal tail structures, propellers, internal turbine engine parts, helicopter rotor blades, and flight-control surfaces are just a few places where these structures are found. The advantages of the high material strength-to-weight ratio coupled with corrosion and fatigue resistance frequently makes fibrous reinforced composite materials the first choice of aircraft designers and manufacturers.

When compared to conventional sheet-metal structures, composites have a low sensitivity to sonic vibrations (good vibration resistance). There are also lower assembly costs and parts in a particular assembly . In addition, there are other advantages such as reduced weight, high corrosion resistance, high deterioration resistance, and the capability of achieving a smooth surface, thereby reducing aerodynamic and parasitic drag.
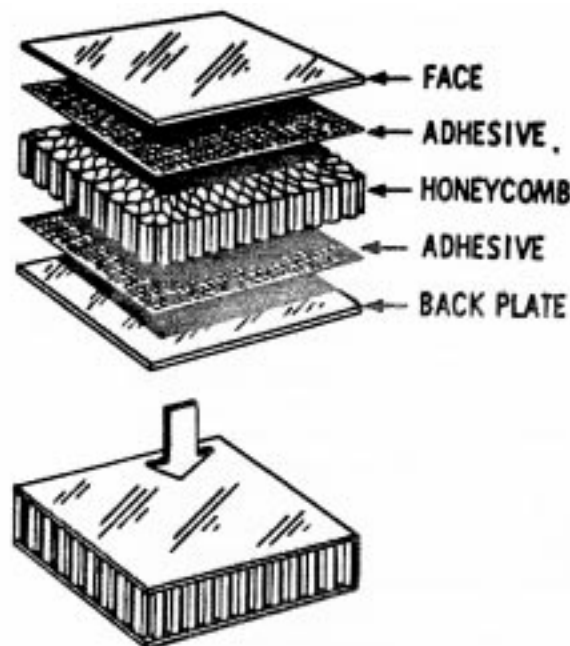
Fig. 36.4, Honey comb sandwhich construction.

TYPES OF COMPOSITE STRUCTURES

Composite structures can either be a solid laminate or a honeycomb \ ringed foam sandwich construction. A solid laminate is made by bonding together several layers of reinforcing fiber materials that have been impregnated with the resin matrix.(Fig. 36.5).
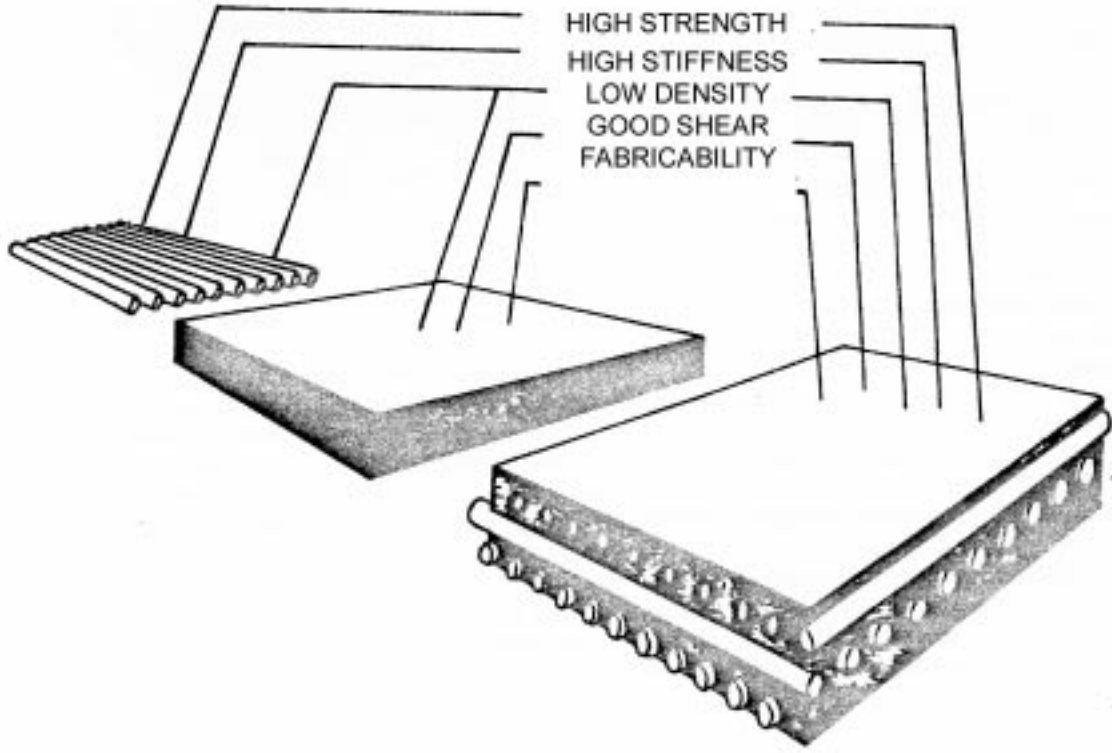
Fig. 36.5, Solid laminate using reinforced fibers.
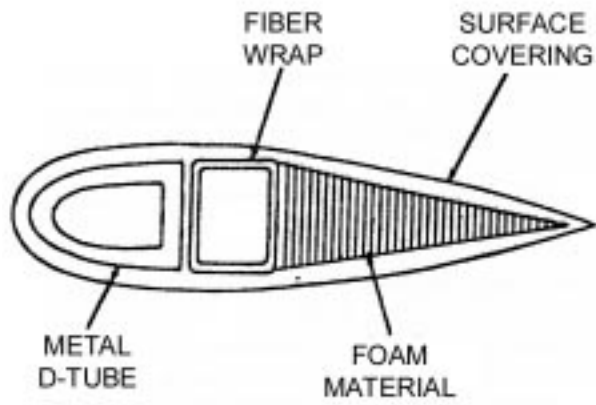
Fig. 36.6, An assembly using composite components

A sandwich assembly is made by taking a high-density laminate or solid face and back plate and sandwiching a low-density filler (core) between them. This filler can be honeycomb (see Fig. 36.4), which may be fabricated from reinforced paper, Nomex, fiberglass, aluminium, or carbon; a rigid foam (for example, high-temperature polyurethane), as illustrated in Fig. 36.6 or balsa wood (using a low -temperature curing matrix). The sandwich arrangement creates an improved structural performance and high strength-to-weight ratio.

Laminates depend more on the combination of the assembly material than sandwich assemblies for their strength and durability.   In sandwich applications the core material is often constructed using mechanical principles in order to

produce additional strength, such as the inherent strength of a honeycomb design compared to a simple square pattern. The selection of materials used for the face, core, and back materials as well as the design configuration of the core material are varied by the design engineer, depending upon application anticipated for the component part.

REINFORCEMENT MATERIALS FOR COMPOSITES

Reinforcement fibers are produced in several forms using various materials. Fiberglass material is the most widely used in aircraft. It is manufactured in either S-glass fiber (structural) or E-glass fiber (electrical) forms for aircraft applications. Glass can be found as chopped strands, woven roving,, woven fabrics, continuous-strand mats, chopped-strand mats, and milled fibers. Fig. 36.7 shows some of the configurations of glass.
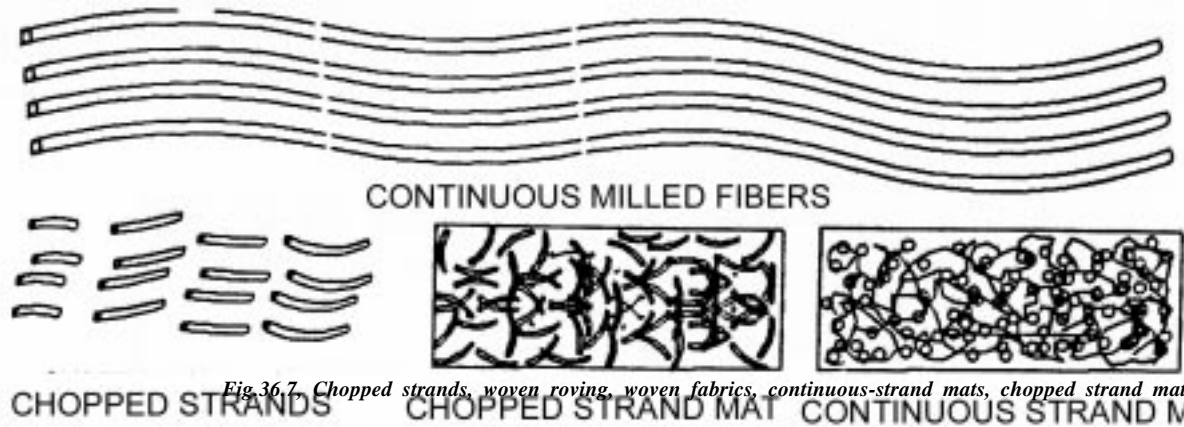
Fig. 36.7, Chopped strands, woven roving, woven fabrics, continuous-strand mats, chopped strand mat and milled fibers

As stated, carbon, Kevlar, boron, tungsten, quartz, and ceramics and collectively known as high-strength advanced composites. They are produced in the form of particles, flakes, fillers, and fibers of various lengths. A detailed analysis of all composite forms is beyond the scope of this text. However, due to the common use of fiber-form composites in the aviation industry, further discussion of fiber forms is appropriate.
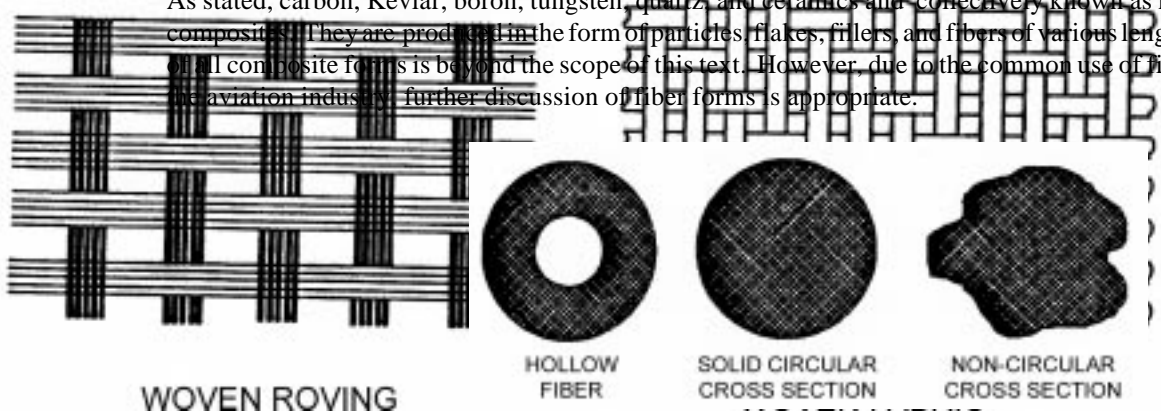
Fig.36.8, Hollow fibers, of non-circular cross section, and solid, circular cross-sectional fibers.

Even in the fiber form, there are a number of variations. There are hollow fibers, fibers of non circular cross section, and solid, circular cross-sectional fibers, as shown in Fig. 36.8. The most common of these are solid-circular cross-sectional fibers, which are commonly found in general and commercial aviation applications.

FIBERS AT 0°

FIBERS AT 0°, 90°
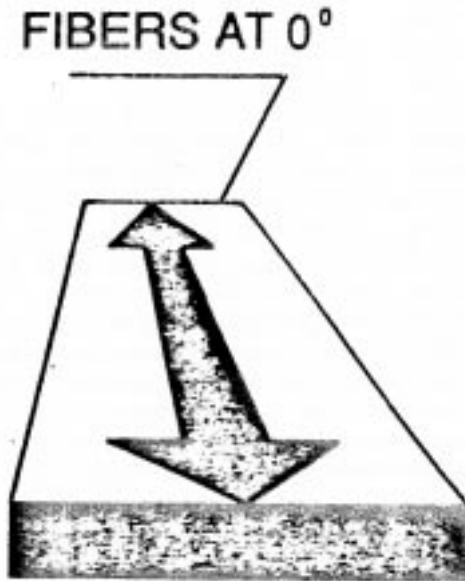
Fig. 36.9, Bidirectional weave
(woven at right angles to each other)
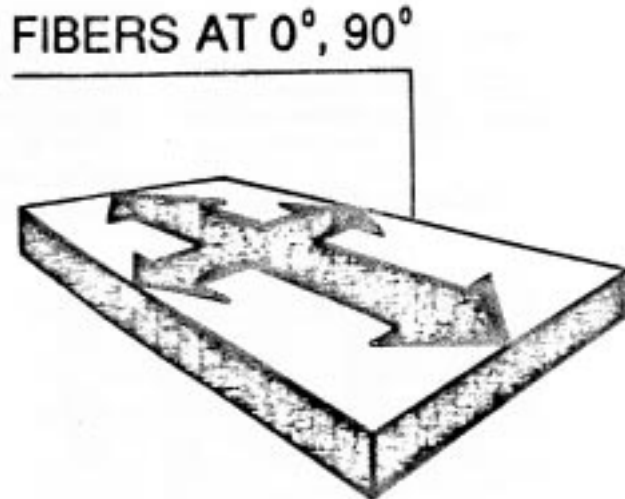
Fig. 36.10, Unidrectional weave
(woven in a continuous straight line)

These solid-circular cross-sectional fibers are combined with strong, stiff, heat-resistant, synthetic resin matrices to form a composite material. The engineering performance of a fiber-matrix combination depends upon the fibers' orientation, length, shape, and composition. The mechanical properties of a composite are directly proportional to the amount of fiber that is oriented by volume in a particular direction.

Since fiber length has a bearing on the process-ability of the composite, this consideration is of major concern during part fabrication. Continuous fibers are much easier to handle than short ones, but the former are sometimes more limited in their ability to make compound curved shapes, particularly boron.

Continuous fibers can either be woven into fabrics that are bidirectional, woven at right angles to each other (Fig. 36.10), or unidirectional, woven in a continuous straight line (Fig. 36.9). Filament winding consists of resin-impregnated continuous fibers wrapped on a mandrel simulating the shape of the part (Fig. 36.11), using one continuous strand, as applied in the manufacture of helicopter rotor blades. Short fibers are utilized in flat and irregular-shaped parts using either open-or closed-mould processes, discussed later in this chapter.
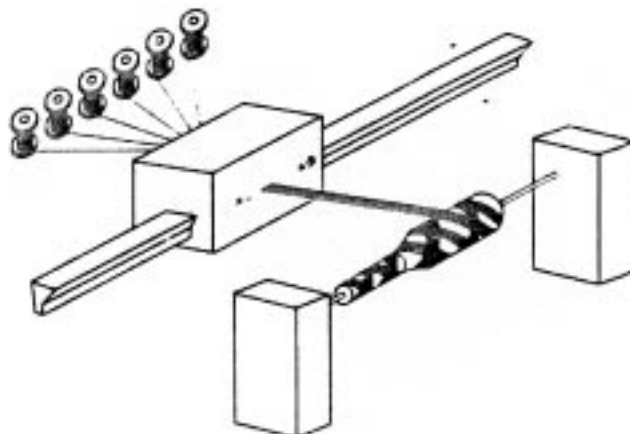
Fig.36.11, Filament winding consists of resin impregnated continuous fibers, wrapped on a mandrel the shape of the part.

The fibers are manufactured by first creating individual filaments. These filaments are then assembled into tows, as shown in Fig. 36.12 Tows can have as many as 160 000 filaments. Tapes are processed directly from the tow. In the case of fabric, the tows are then twisted together in bundles to form yarns, and the yarns are then processed into fabrics.
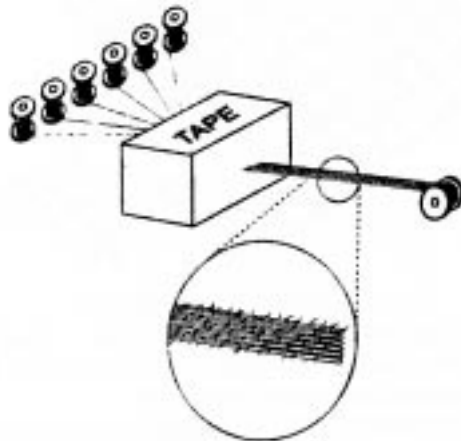
Fig. 36.12, Tows to yarn and tape.

A weave (see Fig. 36.13) consists of warp yarn, fill yarn, and selvage. The warp yarn is the yarn that runs parallel to the sewn or manufactured edge of the roll and is usually made up of the longest threads. The fill yarn is the yarn woven perpendicular to the manufactured edge. Fill yarn is weave pattern. Selvage is a closely woven pattern used to prevent the edges of the cloth from unravelling during handling. Selvage is typically removed form the fabric during the composite-manufacturing process. To help the technician identify the warp yarn direction during the usage of the cloth., warp tracers, which are warp fibers of the same composition but dyed a different color, are woven into the fabric.
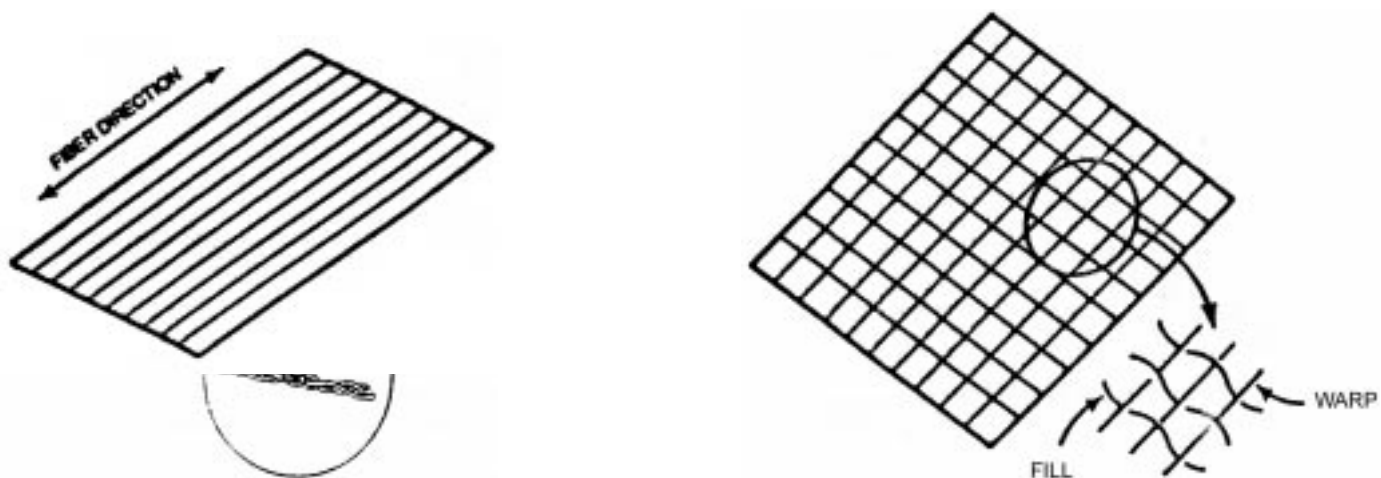
Fig. 36.13, Weave Definition.

Bidirectional fabrics are available with various weave patterns, yarns per inch, and ounce per yard weight. A plain-weave (Fig.36.14) fabric pattern has an individual warp yarn woven over one individual fill yarn and under the next. A plain weave is considered the most stable weave pattern, providing both openness in the weave (for even resin flow) and weave stability (reducing slippage and draping during the part lay-up). Uniform strength is achieved in both directions.

Satin weaves (Fig.36.15) are manufactured when the warp yarns are woven over several successive fill yarns and then under one fill yarn. When the warp yarns are woven over three fill yarns and under one fill yarn, the pattern is called a five-hardness satin-weave pattern.

An eight-hardness satin-weave pattern is identified by the warp yarns having been woven over seven fill yarns first and their under one fill yarn. The satin weaves are more pliable than the plain-weave pattern and therefore conform more easily to complex shapes. These bidirectional weave patterns allow the material to retain high strength in both directions.

Unidirectional fabrics are fabricated with all structural fibers laying in the same lengthwise direction on the roll. Unidirectional fabrics use a few fibers loosely woven at right angles to the warp yarn together in a flat shape.

Fig. 36.14, Plain weave

COMPOSITE MATRICES

A composite matrix is the plastic-based medium that encapsulates , or surrounds, the reinforcement fibers to protect them and help transmit the stress forces between the fibers. These matrices can either be thermosetting or thermoplastic in makeup. They can be a two-part liquid mixture that has a room temperature cure of 70°F $(21^\circ$C$)$ or a factory-mixed and frozen system that requires an accurately controlled elevated temperature cure cycle up of 700 $^\circ$F $(371^\circ$C$)$. Epoxy matrix is normally cured at either 250°F$(121^\circ$C$)$ or 350^0F$(177^\circ$C$)$ range but require temperatures as high as 600 $^\circ$F$(316^\circ$C$)$. Bismaleimide adhesives cure in the 350 $^\circ$F$(177^\circ$C$)$ range but require higher postcure temperatures of up to 700 $^\circ$F $(371^\circ$C$)$. A postcure requires additional time at elevated temperatures to ensure the completeness of the bonding process. Postcures may also be used to increase strength and relieve stress.

5 HARNESS SATIN WEAVE   8 HARNESS SATIN WEAVE   CROWFOOT SATIN WEAVE
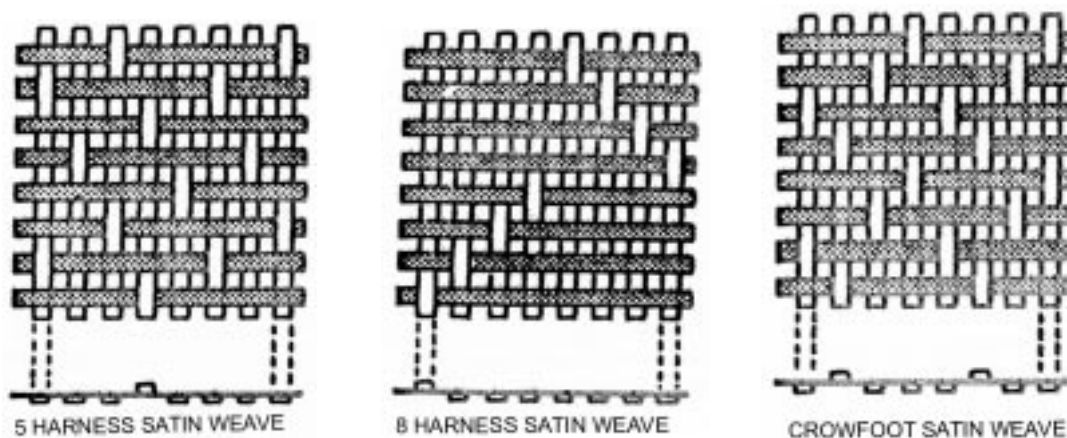
Fig. 36.15, Satin weave

The matrices can have metal flakes added to them during the manufacturing process. In this combination the matrix provides an impermeable barrier between the atmosphere and the metal flakes and giving the part thermal and electrical conductivity. Stainless steel wire whiskers are added to some matrices to give them additional impact strength, heat-distortion points, and lightning strike protection.

Resin matrices are available to the technician in many forms, including as one-part polymer, two-part liquid mixture, sheet-film adhesive, and pre impregnated reinforcement fibers. The term wet lay-up is frequently used to describe the process of applying the two-part liquid mixture.

In the two-part liquid mixture, the technician must accurately proportionate , by weight or volumes (depending upon the manufacture's instructions), the two liquid components and mix them thoroughly before applying the mixture to the fiber-reinforcement materials. This stage of the resin-curing process, in the liquid form, is said to be in the A stage (it is in a runny liquid stage-the beginning stage). This method is common for simple manufacturing or repair situations where accuracy of the fiber-to-matrix ratio is not critical. The individual matrix components have a maximum storage life prior to use, called a shelf life, that must be controlled. After the components have been thoroughly mixed, the combinations then has a pot life, Which is the maximum time it can be applied prior to gelling.

Another form of matrix application is a sheet-film adhesive, which must be stored at low temperatures. It has a maximum shelf life of 6 months. This stage of the resin-curing process, in stiff sheet form, is known as the B stage it's not a liquid or a cured solid-an intermediate stage). A sheet-film foaming adhesive is used when bonding together section of honeycomb. The foaming adhesive expands during the cure cycle to fill voids (a pocket that lacks adhesive) that may occur due to improper fit of the core pieces.

A more accurate method of matrix application involves using fiber reinforcement materials that have been pre impregnated (pre-preg) with matrix at the material manufacturer. It is during this stage in the resin-curing process that the resin is blended with the reinforcement material and kept frozen in the Stage B condition.

The technician must enssure that pre-preg materials are stored and used properly. Pre-preg materials must be kept at $0\,^\circ F$ ($-18\,^\circ C$) or below until ready for use. There is a maximum out time (accumulative time that the pre-preg roll is out of the freezer) that must be controlled to assure " freshness "of the adhesive. The material must be checked by a chemical engineer for usability . The pre-preg materials must be handled in a clean room environment (temperature and humidity-controlled without dust and dirt). This does present a handling problem but helps assure a good bond.
When the pre-preg material has been cured using the controlled, elevated-temperature curing system, the resin is said to be in the c stage (fully cured).

When using the wet lay-up method, the technician can get a ratio of approximately 40 percent resin to 60 percent fiber reinforcement, which is sufficient for most aerospace application. When using the pre-preg method, accuracies of 30 percent resin to 70 percent fiber can be achieved. Remember that to a point, the more the reinforcement fiber volume, the more strength the final assembly will have.

Solid microspheres, or solid beads of plastic, are often added to matrices to increase strength while controlling costs. When solid beads of plastic are introduced to the resin mixture, the mixture is often called syntactic foam. Syntactic foams are non-gas blown. Not only does this mixture increase the matrix resin strength, but it also helps to solve problems in shrinkage and warpage during the cure cycles. This mixture may be used on the edges of honeycomb core as a potting compound prior to shaping in order to prevent core crush.

When hollow microspheres (microballoons) of glass are introduced to the resin mixture, the glass spheres have a tendency to disperse throughout the part being manufactured, resulting in stronger edges and corners. Microballoons are used as a filler to assure uniform shrinkage without causing possible internal stresses during curing.

Matrices with solid microspheres or hollow microspheres added are isotropic, which means that they have no specific orientation. The improved strength characteristics of both process typically occurs with an overall improved strength-to-weight ratio, because the microspheres have less density than the matrix.

COREMATERIALS

Core material is the central member of an assembly. When bonded between two thin face sheets, it provides a rigid, lightweight component. Composite structures manufactured in this manner are sometimes referred to as a sandwich construction.
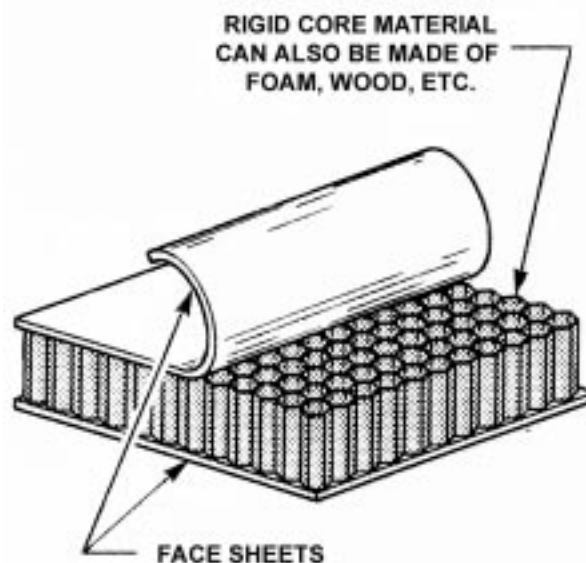
Fig. 36.16, The use of a core material can dramatically increase the strength of a structure without adding significant weight.

The core material gives a great deal of compressive strength to a structure. As an example, the sheet metal skin on a rotor blade has a tendency to flex in flight as stress is applied. This constant flexing causes metal fatigue. A composite blade with a central foam , or honeycomb, core will eliminate most flexing of the skin, because the core is uniformly stiff throughout the blade.

If made of sheet metal with metal ribs, the skins will twist and flex in the areas where there is no support. The solid core resists the bending and flexing of the skin, greatly increasing the life of the skin. This core could be of a honeycomb or a foam construction, and the result would be about the same.

(A) METAL SKINS WILL BEND AND FLEX WHEN FORCE APPLIED IN FLIGHT

(B) COMPOSITES KEEP THE STRUCTURE FROM FLEXING IN FLIGHT, ELIMINATING FATIGUE
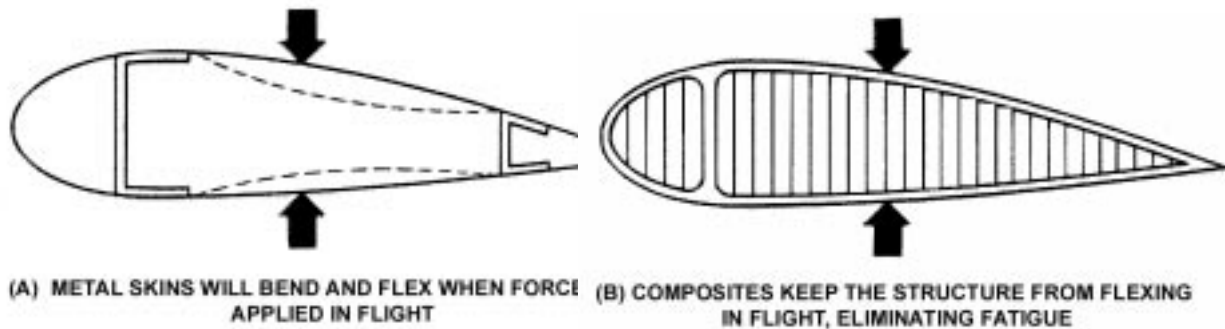
Fig. 36.17, (A) Metal skins will bend and flex when forces are applied in flight.
(B) Composites keep the structure from flexing in flight, eliminating fatigue.

HONEY COMB CONSTRUCTION VS "I" BEAM CONSTRUCTION
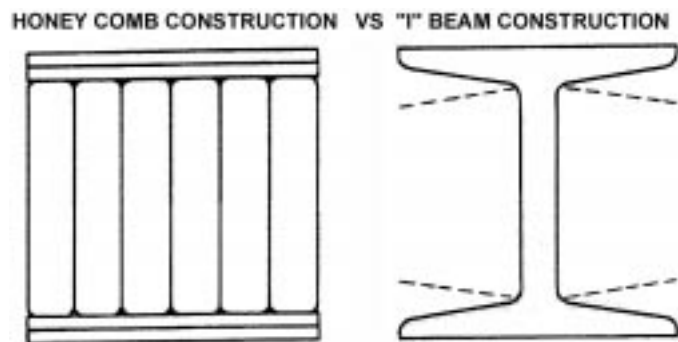
Fig.36.18, this concept can also be shown using a spar I-beam example. The flanges of the I-beam will bend and flex; however, with a solid core material, the tendency to bend is eliminated.

Two popular core structures are foram and honeycomb. Core materials may also come in wood. Honeycomb has the greatest strength-to-weight ratio, but foam is usually more forgiving. If a foam core is damaged, It has a memory and will return to about 80% of its original strength. Most honeycomb cores have little resiliency.

HONEYCOMB

this type of core structure has the shape of natural honeycomb and has a very high strength-to-weight ratio. Honeycomb cores may be constructed of aluminum, Kevlar®, carbon, fiberglass, paper, Nomex, or steel. Nomex is a trade name of DuPont and is widely used as an advanced composite core material. Nomex is a paper impregnated material.

It is common to find these honeycomb cores laminated with a variety of composite or metal skins.

Honeycomb cores are made by crimping the core material into place. The pattern has what is known as a ribbon direction. The ribbon direction can be found by tearing along one side of the honeycomb. The direction of the tear is parallel to the direction of the ribbon. The honeycomb will not tear except in the ribbon direction. It is important when doing a repair to line up the ribbon direction of the replacement honeycomb core with the ribbon direction of the original part.

Honeycomb can be joined together with a foam adhesive. The foam adhesive used to join honeycomb together comes in the form of a tape. The foam adhesive is laid between the parts to be joined and heated to cure. During the curing process, the foam expands into the crevices of the honeycomb.
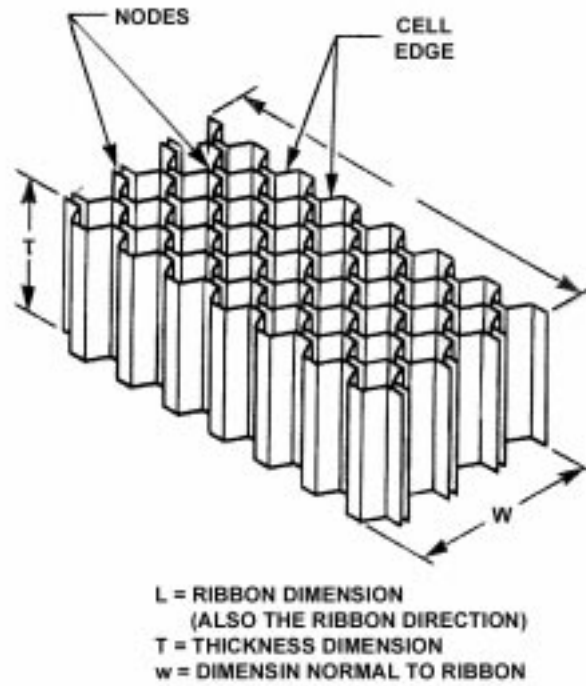
Fig.36.19, Honeycomb comes in a variety of core configurations, some may be bent to form a curve, some honeycombs are more flexible than others.

FOAMS

There are many different types of foams available depending on the specific application. There are different densities and types of foams for high heat applications, fire resistance, repair foams, structural foams, etc. When using foams in the repair operation it is important what the proper type, in the proper density, is used.
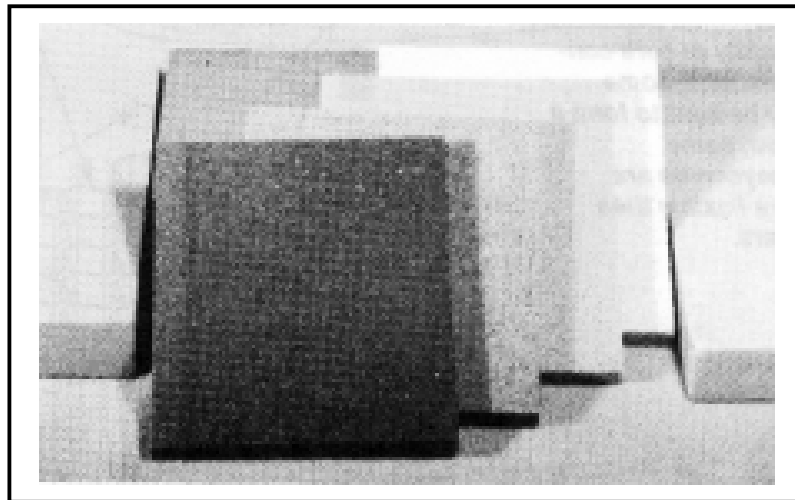
Fig.36.20. Foam cores for sandwich construction can be styrofoam, urethane, poly vinyl chloride, or strux (cellulose acetate). While easily shaped, foam construction can provide much greater strength and stiffness over plain laminates.

In figure 36.21 , the advantages of a sandwich structure can be shown by comparing four layers of solid fiberglass laminate to a foam core sandwich structure that is four times as thick. This part has two layers of fiberglass on top and two layers of fiberglass on the bottom of the foam. The part becomes 37 times stiffer than the laminate and ten times stronger, with only a six percent increase in weight. This is not an excessive amount of weight to be added in exchange for the amount of strength and stiffness which are gained by using the foam core.

Fig. 36.21, Strength to weight advantages of sandwich construction.

STYROFOAM

Styrofoam is used commonly on home-built aircraft and should be used with epoxy resin only. Polyester resin will dissolve the Styrofoam. Do not confuse aircraft quality Styrofoam with the type of Styrofoam used to make Styrofoam cups. The Styrofoam in cups have a large cell configuration and can not be used structurally. The type of Styrofoam which is used in aircraft is much stronger. Styrofoam can be cut with a hot wire cutter to form the desired shape. A hot wire cutter is a tool that, as it's name implies, has a wire that is heated to cut through foam. The tool is typically homemade to be used when making a home-built aircraft. A template is attached to each end of the foam to be cut. The wire is then heated and run around the template. Smooth curved surfaces can be fabricated with the hot wire cutter.

URETHANE

This foam can be used with either epoxy or polyester resin. Urethane cannot be cut with a hot wire cutter in the way Styrofoam is cut because a hazardous gas is created when urethane is subjected to high temperatures. Instead of using a hot wire cutter, urethane can be cut with a number of common tools. Knives can be used to get the rough shape, which can be then sanded with another piece of foam to the desired size and shape.

POLY VINYL CHLORIDE (PVC)

Poly Vinyl Chloride foam is used with either polyester or epoxy resins. It can be cut with a hot wire cutter.

STRUX

(Also known as cellular, cellulose acetate)

Strux foam material is used to build up ribs or other structural supports.

WOOD CORES

Balsa wood or laminations of hard wood bonded to laminates of high strength materials are being used for some composite construction.

FABRICATION TECHNIQUES FOR COMPOSITES

From previous discussions, it is clear that composite parts may be fabricated into a variety of configurations, depending upon the design needs determined by the aircraft engineer. The fabrication may be accomplished by the use of moulds or dies. Since this text deals primarily with maintenance-related activities the discussion is limited to fabrication techniques using moulds.

Forming these configurations is accomplished by combining the fibers and matrix over a form, called a mould. A mould is a tool that confirms to the desired shape of the finished product. Moulds may be either open or closed moulds.

Open moulds, often referred to as a bond form or lay-up tool, allow easy access to the composite materials during the fabrication process and depend upon gravity and atmospheric pressure or externally applied pressure to mould the composite material against the mould until the curing process is complete. Closed moulds are designed in a matched male-female configuration. Forcing the two mould halves together ensures that the composite material takes the shape of the mould . Gravity from the weight on the top mould half or externally applied pressure may be used to ensure the proper mating of the mould.

One important consideration in the design of moulds for close-tolerance composite parts is the coefficient of thermal expansion of all the related materials. As previously discussed, the process typically involves the generation of or the use of externally applied heat. The use of materials with the same or similar coefficients of expansion for moulds is preferred. If a mould is fabricated using materials with coefficients of expansion different than those of the composite materials, adaptations for the different expansion rates must be included in the mould design.

The first step in mould design, when using materials with different coefficients of thermal expansion, is to determine how the finished-part dimensions change at the curing temperature. For example, a composite part that has a dimension of 10 in (25.4 cm) at room temperature might measure 10 1\32 in (25.479 cm) at the elevated curing temperature. Therefore; for the part to be at the 10-in (25.4 cm) finished dimension at room temperature, it must be 10 1\32 in (25.479 cm) at curing temperature.

The mould must also be at the expanded dimension at the elevated curing temperature. However, if the coefficient of thermal expansion of the mould material is different than that of the finished part, the dimensions of the mould will be different at room temperature. Continuing the preceding example, the mould must have a dimension of 10 1\32 in (25.479 cm) at elevated temperature. When cooled to room temperature the mould will have different dimensions. For example, assume that the coefficient of thermal expansion for the mould material was half that of the part material. The mould cooled dimension, which when heated to the elevated curing temperature, would result in a mould dimension equal to the dimension of the part at the curing temperature.
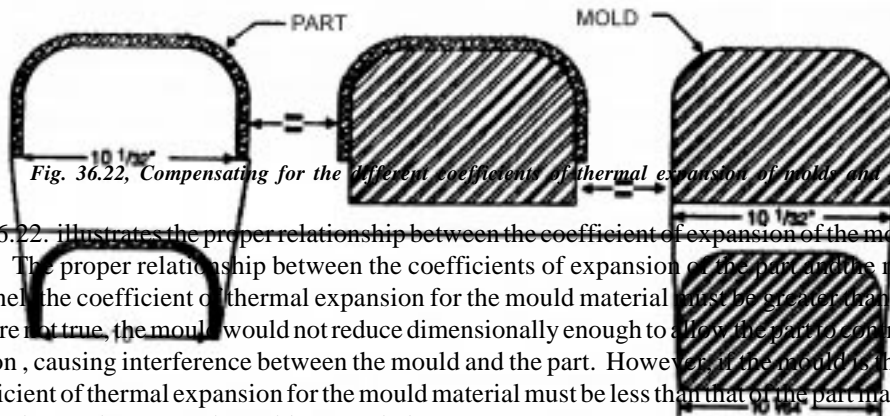
Fig. 36.22, Compensating for the different coefficients of thermal expansion of molds and parts material.

Figure 36.22. illustrates the proper relationship between the coefficient of expansion of the mould material and the part material. The proper relationship between the coefficients of expansion of the part and the mould form is the inside the channel the coefficient of thermal expansion for the mould material must be greater than that of the part material. If this were not true, the mould would not reduce dimensionally enough to allow the part to contract to the proper finished dimension, causing interference between the mould and the part. However, if the mould is the outside the U channel, the coefficient of thermal expansion for the mould material must be less than that of the part material or interference will again develop as the part and mould are cooled to room temperature.

The removal of the composite materials from the moulds can result in damage to the part if the moulds are not properly prepared with a damage to the part if the moulds are not properly prepared with a release agent, or release film, which is used to prevent the bonding of the matrix to the mould itself. The type of releasing media used is determined by the type of matrix form used, the heat of the curing process, and the material from which the mould is fabricated.

In low-volume production process and repairs, a vacuum bag. Which is a plastic bag surrounding the part material from which air has been evacuated, and a separate heat source may be used. Common heat sources include controlled ovens, portable "hot bonds", and heat blankets. The resin-matrix cures and the fiber-reinforcement materials are bonded in close proximity to each other. The strength of the lay-up depends on the volume of the fibers and their orientation.

High volume and critical composite structures are often heated using an autoclave, which is an oven that heats the material while it is under pressure.

WARP-ORIENTATION TECHNIQUES
As previously mentioned The strength or load-carrying properties of a fibrous composite are greatest when the load

applied runs in the same direction as the fibers. Loads that do not run parallel to the reinforcement fibers must at least in part be transferred through the matrix, which typically has the lowest load-carrying capability.

When designing a composite part, the engineer considers the relation of the design load to an arbitrarily selected orientation line on the part. The reinforcing fibers in a composite material will usually be designed to run parallel to the load. It is, therefore, important that the fibers to the design of the part. To do this the engineer will specify a $0°$ plane as an alignment indicator. The orientation of the warp fibers as a fabric is rolled off the bolt is defined as the $0°$ position for the fabric.

Because the alignment indictor is not always in the same plane as the design loads, the engineer may specify a warp orientation in terms of degrees relative to the reference , or $0°$ plane. This is frequently done in the form of a warp clock (see Fig.36.23), which is a circle divided into four quadrants. Which quadrant has a plus or minus orientation, which reflects the direction of rotation required of the warp fibers if they were to be positioned parallel to the alignment line. Clockwise is usually plus. Counter clock wise is usually negative.

A warp clock is typically included as part of the manufacturing drawing or in the text of the manufactures' specification sheets for the particular aircraft. Generally, most manufacturers use the same orientation for warp clock as just discussed, but the technician should always consult the particular manufacturer's information sheets before building a part or making repairs.
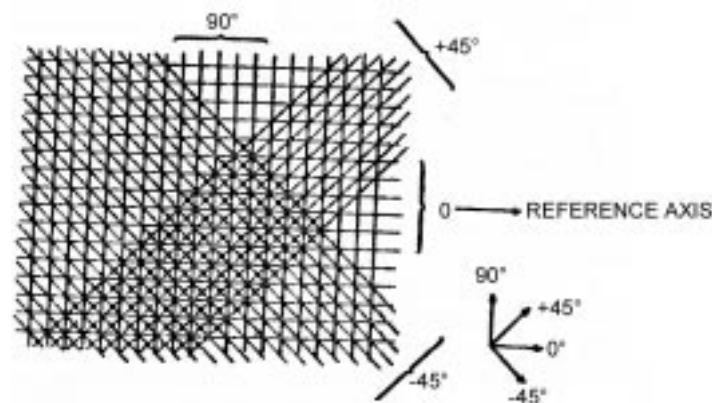
Fig. 36.23, Warp orientation.

If the warp fibers are positioned in such a manner that they lay in only one direction, they are said to be unidirectional, or anisotropic , in stress design. Quasi-isotropic stress design refers to design capabilities that are capable of carrying loads in more than one direction but not in all directions. For example, if the warp fibers are laid perpendicular to each other-that is , at a $0°$ and a $90°$ point-they are said to be bidirectional because the stress design is in two intersecting directions; they are also considered quasi isotropic. If the warp fibers are placed in such a way that they fall at a point of $o°$ and $45°$ to the alignment point ($0°$ on the lay-up tool), the lay-up is again said to be quasi isotropic. When the warp fibers are assembled in a laminate with the fibers heading in the $0°$, $45°$, $90°$, and $-45°$ positions the lay-up is said to be a cross-ply stress design. This multidirectional pattern is sometimes referred to as isotropic, because the stress design is in all directions typically specified on the warp-orientation indicator. Isotropic refers to the capability of a material to bear loads in all directions, so technically cross-ply applications are not truly isotropic.

TRIMMING AND DRILLING OF COMPOSITES
Since composites are usually an assembly consisting of laminated layered materials , they are subjected to delamination. In delamination the layers of material s, they are subjected to delamination. In delamination the layers of material are forced apart and are no longer bonded together. Therefore, care must be taken during trimming and drilling to avoid delamination.

Drilling and trimming of composite materials is difficult because standard tool steels will rapidly dull in the process. Problems can occur because of the way drills are shaped and sharpened. As a drill dulls, it tends to push against the material rather than cut, causing layer separation. The drill bit should be shaped in a spade form (Fig.36.24) or a long tapered form sometimes referred to as a dagger drill (Fig. 36.24). Fig. 36.25. depicts a series of commercially available composite toolings. Diamond-tipped equipment will allow more cuts to be taken per tool. When drilling carbon products, it is best to use a high-speed, low-feed combination with the drill motor.

Kevlar and fiberglass are highly fibrous materials, and using a drill that is diamond- dust coated will only aggravate the situation. The fibers will grab at the drill bit and pull the diamond from the base metal or fill the voids in the dust pattern with material. These composite materials should be drilled with a specially ground drill bit that causes the material to be sheared during the drilling process. This point will also reduce the fuzziness of the drill hole typically found after drilling.

Honeycomb structures are best cut with a cutting wheel or a saw tipped with carbide or diamond materials, with the teeth of the saw shaped like a bread knife. When routing out fiberglass or Nomex core, use a coarse router bit, because a fine one will not cut material. A diamond-coated router bit is also too fine to be effective.
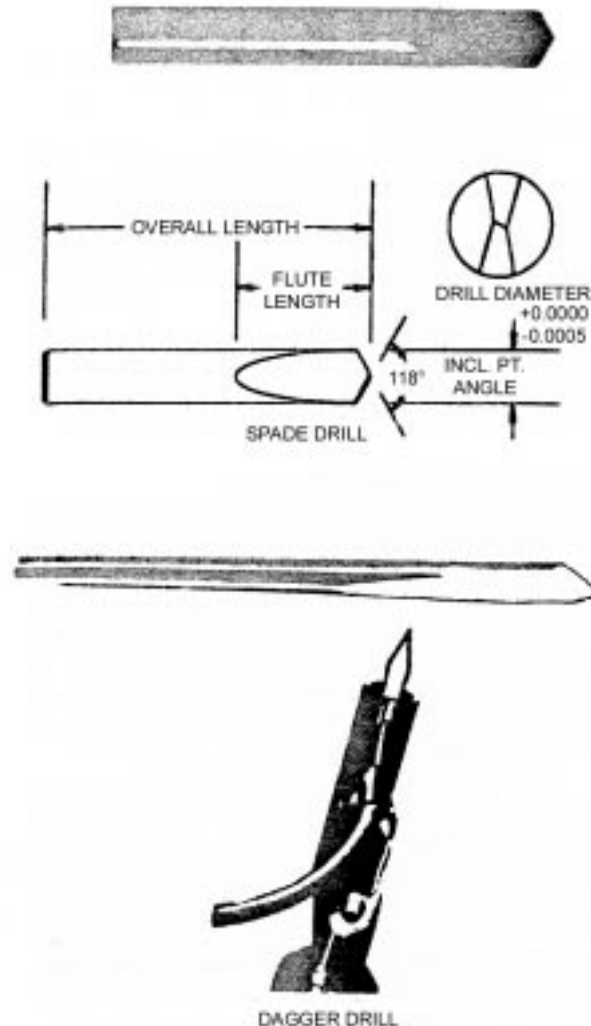
Fig. 36.24, Spade and dagger drills. (Federal mogul, Metal Remover Division.)

Edges of composites can be finished with sanding disks and sandpaper with a grit of 80 or finer. Be careful in dealing with KEVLAR structures because the fuzzy nature of the material will cause it to grab at the surface of high-speed tools and pull the sanding disks or cutter from the power tool's jaws, throwing the tool.

COMPOSITE INSPECTION

The specific inspection method used for a composite structure varies with the composite material used and the using organisation's experience with inspection methods. Acoustic emission, holography, ultrasonics, X and γ (Gamma) rays, thermography, and ring tests are some of the non destructive inspection (NDI) techniques currently in use. The information presented here is a summary of the methods commonly used. However, the aviation maintenance technician should always consult the manufacturer's maintenance manual for specific testing and repair procedures as they apply to a particular aircraft.

A ring test can be used to detect voids (no matrix between the fibers and delaminations (separations) between the layers. A 1-oz hammer, a quarter, or other lightweight metal-tapping device is used to tap on the bonded areas. If the bonding is intact, the tapping gives a solid "ring". If there is a void or delamination under the surface, the tapping results in a dull sound. If a separation is located, the extent of the separation has to be evaluated by other inspection methods to be assured that there really is a problem.

When performing the ring test, the sound may change due to a transition to a different internal structure, the technicians striking the part at a slightly different angle, and\or pressure. Variations in the sound during the ring test may be caused by factors other than internal damage. This test is quite quick but "unscientific" and is more a cause for continued inspection using other techniques than a true indication of component failure. An example of a change in internal configuration that would change tones would be where a laminate changes to sandwich area. The honeycomb will give a different sound than the solid sheet.

An ultrasonic tester can be used to transmit a sound wave signal into a solid laminate panel. The sensors of the analyser send and receive the sound signal and evaluate the speed at which it moves through the structure. The analyser then displays the signal time on a cathode-ray tube. A trained operator can evaluate the display and determine the location, depth, and extent of voids, delaminations, inclusions (debris), resin richness or starvation, and other damage as the sending \ receiving probe is positioned on different part of the structure. A couplant, or thin coating, of petroleum jelly, oil, or water is used between the sensing unit and the material surface as a sound-transmission medium. The couplant provide an airtight bond between the material being tested and the signal pick-up device.

Radiology can be accomplished using X-ray and   -ray signals . These can be used to locate moisture and corrosion in honeycomb, delaminations, and separations of the core from the skin. The use of radiology is a complex operation that requires the services of specially trained technicians to operate the equipment and interpret the exposed films.

Acoustic emission monitoring is used to detect corrosion and dis bonding of the adhesive bond. This system also relies on the transmission of sound waves through a material. This inspection method employs a very sensitive microphone and amplifier. The microphone is placed on the surface of a bonded structure. The active corrosion activity can be detected as a hissing sound. If the panel being inspected is heated to about 150 °F (82 °C), dis-bonding of the adhesive will be indicated by a crackling sound.

Fig. 36.25, Various types of composite tooling. (Federal Mogul, Metal Remover division)

REPAIRING COMPOSITE MATERIALS

The classification of damage and the repair methods for composite materials have not been standardised in the aviation industry. Each manufacturer has developed a method of classifying damage and establishing an appropriate repair

procedure. The specific repair data should be consulted prior to repair attempts. The repair procedures presented here are intended to give the technician a general understanding of some of the procedures.

Damage to one laminated skin surface with no damage to the core can be repaired by the installation of a surfaced patch. Prior to the installation of the patch, the surface is cleaned. Topcoat and undercoat paint materials are removed to expose the skin itself around the damaged area. Note that cleaning and paint removal should be accomplished using abrasive. The use of chemicals for cleaning and paint removal may lead to weakening of the composite structure.

The damaged area is either tapered (sanded) or stepped (routed) using a small disk sander or a microstop suitable air-powered grinder to remove each layer. The damaged area is removed with ascending concentric circles of material in 1\2 in increments (the area should look like a shooting target with the bulls-eye in the center of the damaged area). Circular patches of repair material. are cut corresponding to the diameters of the removed material. The repair material must be of the same type as the original or an approved substitute. If three layers of the fabric have to be cut back, then four patches are cut, as shown in Fig. 36.26. The first patch is the size of the material removed from the innermost portion of the tapered area (the bull's -eye). The next two patch are the size of the next two correspondingly enlarging layers that were cut back. The fourth patch is large enough to over-lap the sanded area by 1 in on all sides. If a liquid wet lay-up adhesive is to be used, it is mixed and the time is noted so that the mixture pot life will not be exceeded. A thin coat of adhesive is then applied over the cleaned and prepared area. Each patch is saturated (impregnated) with adhesive. The patches are stacked sequentially, from smallest to largest, and placed (usually symmetrically) over the damaged area. The warp fibers of the repair patches must align with the warp direction of the original parent material.
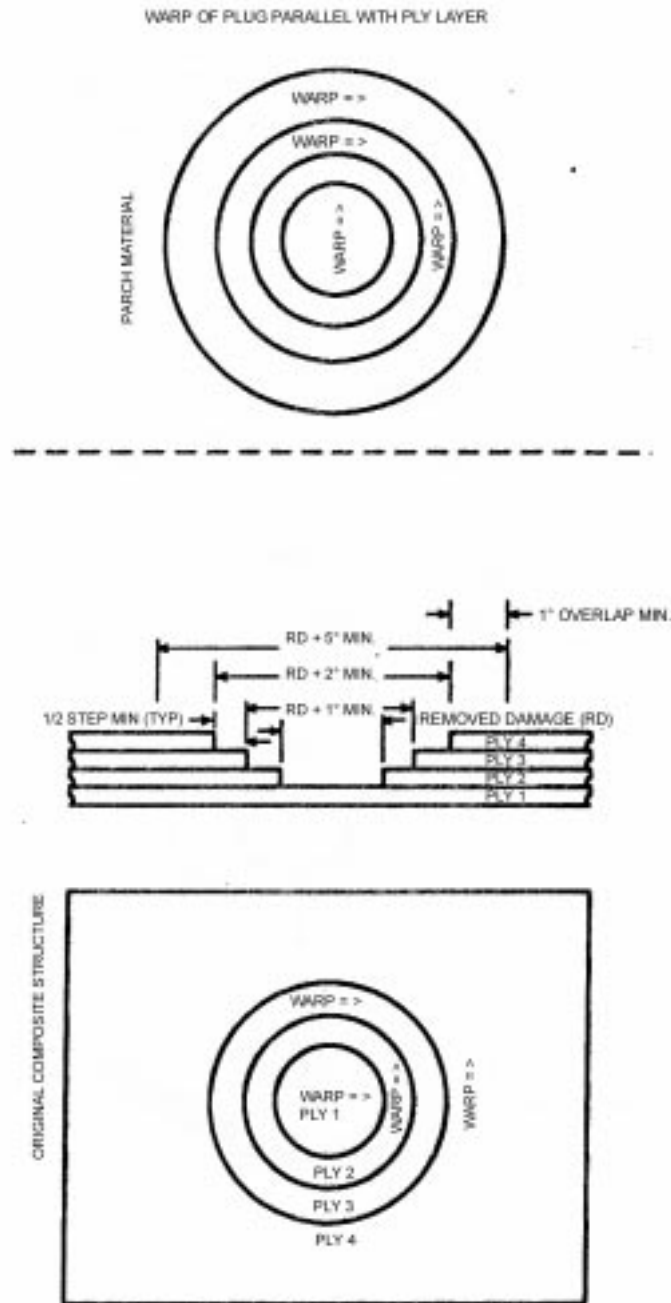
Fig. 36.26, Layout of a three-layer cut-back composite repair.

If pre-preg materials are used, patches are simply cut from specified materials and laid with the same warp direction as the original parent material; the repair is then cured. Pre-Preg materials must be carefully handled to avoid contamination. After the lay-up has been accomplished, the repair is sealed in a vacuum bag with thermocouples (temperature sensors) attached to a temperature controller. The repair can be cooked with an oven, autoclave, or a portable hot bounder and the appropriate cure cycle. The temperature rise, soak, and drop-off during the cure cycle are as specified.

When using a vacuum-bag process (which can be used with either the wet lay-up process or the pre-preg lay-up pair patches have been put into place, a layer of release film is placed directly over the patch. This material normally a porous film because excess resin needs to be bled from the lay-up and the solvents and volatiles need to be vented. If smooth, finish is required then this bagging layer is a smooth, high-temperature nylon release film, if the repair surface is to be painted, then a high-temperature, coarse-weave, nonporous (peel-ply) material is the first bagging layer over the repair patch peeled from the repair patch after cure, leaving a rough surface so that the paint will adhere. If the painted surface is to be smooth, the area will require "filling" before painting. When preparing the surface for filling and painting, care should be taken not to damage the fabric filaments.

Next a breather-bleeder material, such as felt, is placed on top of the release film. This material provides a path for the air, volatiles, and solvents to flow through during the curing process. It also absorbs excess resin that has been worked to the edges. Once the release film and breathener of the lay-up area (it is not placed on the patch itself), with a piece of breather-bleeder material under it (to protect it from the resins and aid in air flow from the lay-up). The patch area is then covered with a heavy piece of high-temperature nylon plastic bagging film and sealed airtight. It should create a vacuum attachment. The source should create a vacuum at least 23 in Hg (at sea level) and the plastic over the patch should compress free of wrinkles. The complete repair arrangement is shown in Fig. 36.27.

Fig. 36.27, Vacuum bag repair arrangement

If the repair is a wet lay-up process, the excess resin matrix in the patch can now be worked out with a plastic squeeger. Then squeeger should be flexible and have rounded edges (to preclude tearing the plastic bagging film). All the air bubbles should be worked toward the edge of the patch and into the breather-bleeder material. The squeeger is used until the excess resin can no longer be moved away from the patch. Care must be taken not to remove too much matrix, as this will render the patch dry and "unairworthy". The time should be monitored when working the wet lay-up process in order that the pot life of the matrix is not exceeded. The matrix should not be worked past its pot life.

If a pre-preg patch is used, the repair area is heated using the available heating equipment after the vacuum has been applied (cure cycle). The amount of heat applied should be held constant by monitoring the surface temperature of the repair with the thermocouple. Special heat-monitoring units are available that will automatically turn the heat source on and off to keep the temperature of the patch at the desired value. Care should be taken not to apply too much heat initially as the initial out-gasing of the matrix may cause air bubbles to appear in the patch. Pre-preg material manufactures have developed specific cure cycles for their products, which must be followed.

Heat lamps and hand-held guns are not recommended because of the difficulty in maintaining a constant and controlled level of heat on the patch for the required curing period. When it is necessary to apply heat to a limited area, heating blankets with the proper temperature-controlling equipment may be used. The use of an oven is not recommended unless the complete part can be placed in the oven while fixed in bondform or fabrication fixture. The component could warp during the heating process.

In some aircraft repair manuals , there is a provision for an emergency, temporary, surface patch (commonly called a scab patch) that can be riveted in place using blind pull rivets, as shown in Fig. 36.28. Still other aircraft manufactures may allow the use of a microsphere impregnated potting compound to repair small defects in a skin surface.

 If damage penetrates the skin surface and the core material, then all the damaged material must be removed. This can be done by the use of a router and template, as shown in Fig. 36.29 a, hole saw, or a fly cutter. The router cuts out the damaged core using a template as a guide for the movement of the router. The shape of the cleaned-out area can be circular ,oval, or rectangular. The depth of the routing operation is shown in Fig. 36.30.   If the damage is on a sloping surface, bridges must be used under the router to allow it to cut parallel with the undamaged surface, as shown in Fig. 36.31.

If a syntactic foam is used to fill the core, the core material should be undercut beyond the edges of the surface opening to anchor the foam within the structure. The routed out area should be cleaned with a reagent solvent, a solvent that has been chemically purified. The repair area is then air dried thoroughly to assure that the core has not retained any liquid. If liquid is still present, the adhesive could break down.

pair,

Fig. 36.29, Router, support assembly, and template.

Fig. 36.30, Areas routed out prior to repair
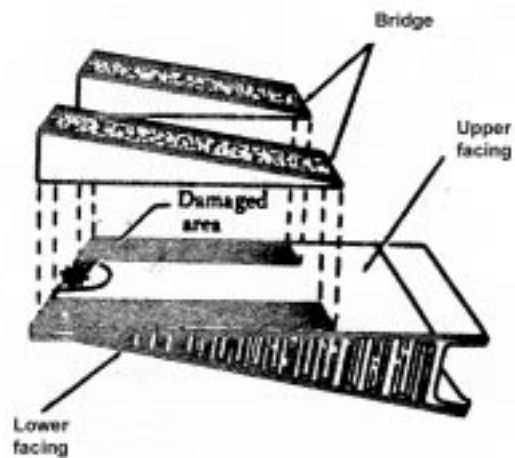
Fig. 36.31, Bridges used for router support.

There are several basic techniques used to repair damage. If the damage penetrates only one skin and is barely into the core, syntactic foam can be used to fill the cavity if the damage is no more than 1 in. in diameter. A piece of plastic is placed over the repair opening, as shown in Fig. 36.32. A Duxseal sealing compound is forced into the opening of

the repair cavity until the damaged area is full and air pockets are eliminated. The repair should be vacuum bagged with a thin coat of pure resin coated over the trimmed foam prior to the outer patch application. The resin is then allowed to cure. This prevents trapped air from being drawn up through the foam material and into the patch during its cure period, rendering the patch unairworthy.

Fig. 36.32, A potted repair to the core and skin

If more extensive damage occurs to the core material, a replacement piece of core material is needed as well as a replacement skin patch. The damaged area is prepared by scarfing or stepping the outer skin and removing the damaged core with a router. If a wet lay-up is to be used, the sides of the replacement core plug are coated, or "buttered", with liquid adhesive mixture (viscous slurry) and the core is pushed into place. The replacement plies of the skin are impregnated with the liquid resin and stacked over the core in the same orientation as the parent material.

Glass cloth
laminates

Fiber glass
honeycomb
core

2.0"
Max. (typ.)

2.0" Max

Butter edges and
bottom of prepared
hole with potting
compound before
installing honeycomb core.

Butter edges of honeycomb
core with potting compound
before installing core in
repair area.
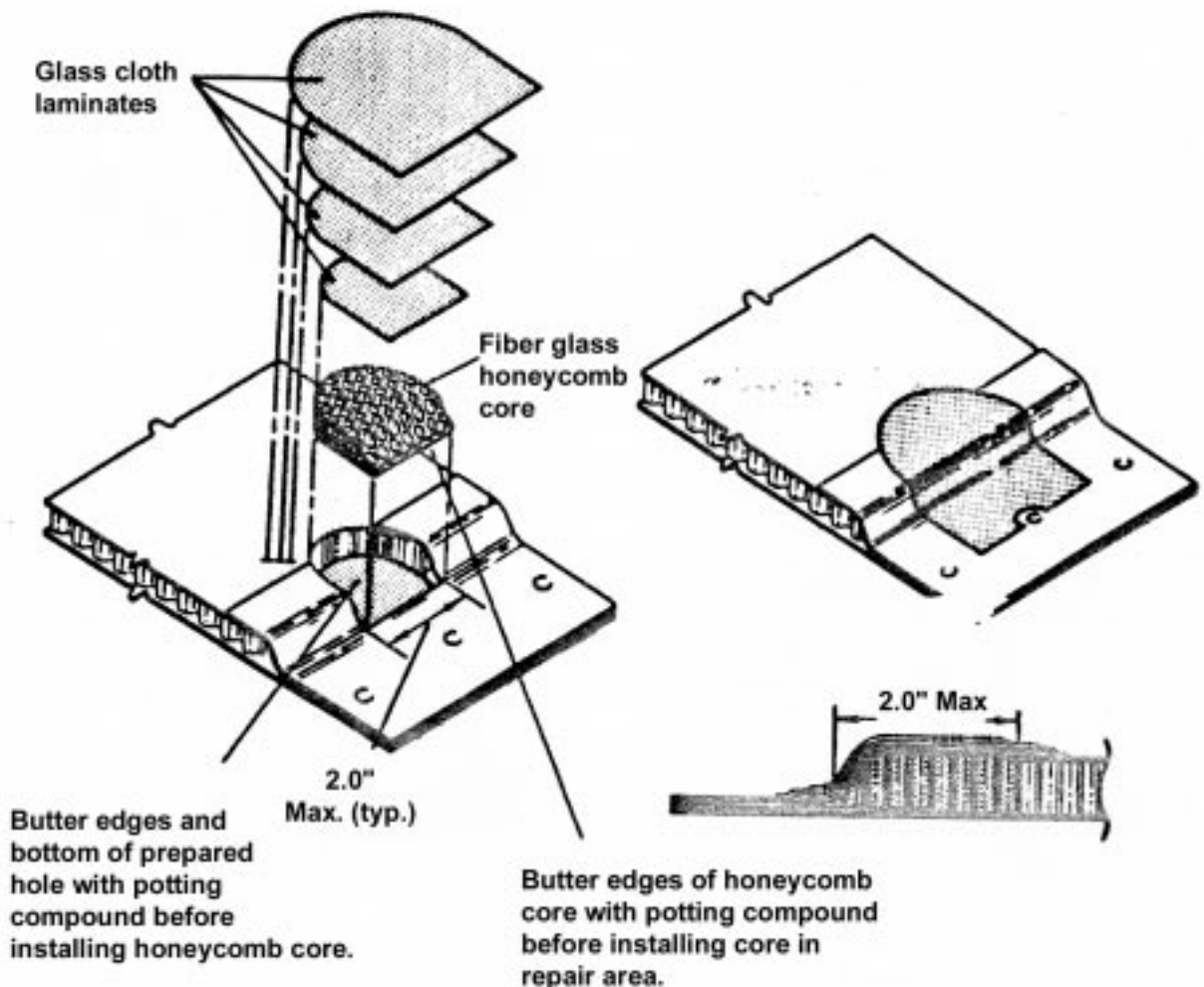
Fig. 36.33, A plug repair on an edge.

If pre-preg materials are used for the repair, than a sheet foaming adhesive is used to install the core. The adhesive is removed from the freezer, cut into strips, and wrapped around the core before it is placed into the cavity. A layer of sheet adhesive (nonfoaming) is placed into the cavity. A layer on which the core sits. If a pre-preg material is used for the skin, the properly identified material roll is removed from the freezer and allowed to thaw in the sealed storage bag in which the material is stored. This allows the material to come up to room temperature without having condensation form on the material surface. Monitor the out-time record to make sure the storage and out-life limits have not been exceeded. The replacement plies are cut to shape after the material has thawed and are then placed over the core in the proper orientation. Some manufactures also recommend the application of adhesive between the plies of the pre-pregged layers. Remember to use clean gloves to protect the material from oils in your skin. This procedure is shown in fig. 36.33. The repair is vacuum bagged and cured. Once the adhesives have set, the repair is smoothed and finished.
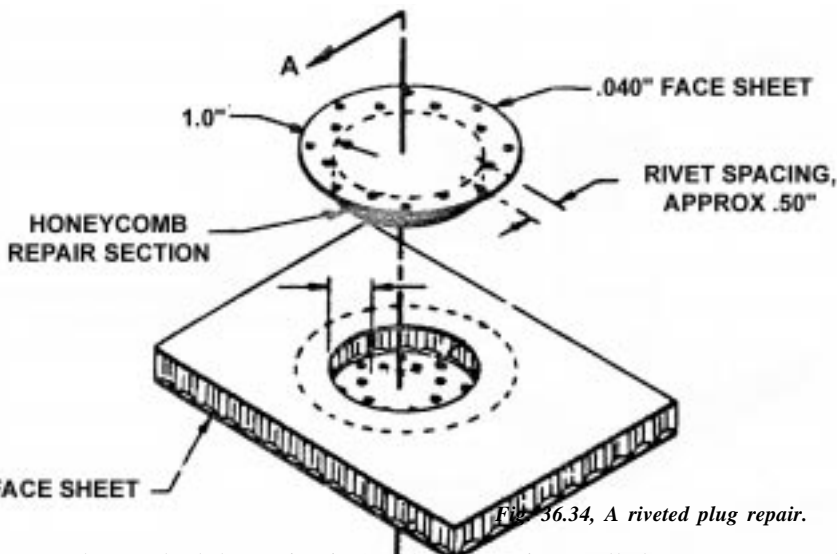
Fig. 36.34, A riveted plug repair.

Another method shown in Fig.36.34., is sometimes called a temporary repair, or riveted repair. In this illustration all the core material in the original structure has been removed . The core plug is inserted and an external plate is blind pull riveted into place. If damage penetrates both skins, the hole is routed out through the entire panel. Plug and surface patches are prepared, and the pieces are assembled, as shown in Fig. 36.35. A similar riveted repair is shown in Fig.36.36. If you have a choice, the surface patch should be of the same material as the parent skin. If that material is not available, aluminium face sheet should be used. An air hammer and bucking bar should not be used to install solid rivets in composite structures because the pounding will delaminate more of the skin areas.

Although some of the repairs illustrated in this chapter shown the trimmed surface openings without any tapering or stepping, most manufactures require that the skin surface be tapered or stepped and the patch be composed of materials similar to those of the parent skin.

Remember, this chapter describes generic repairs. Always consult the manufacturer's repair manual for specific information

SECTION A-A
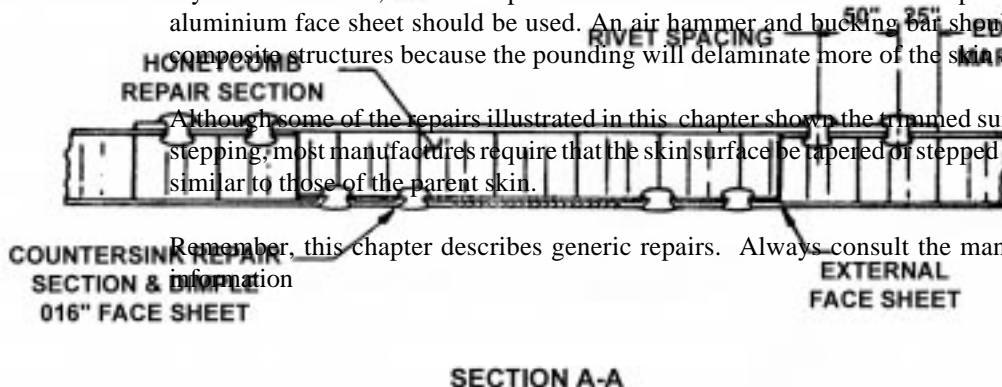
CHAPTER-37
COMPOSITE SAFETY

Safety is always around and aircraft. When working with any composite material, proper safety precautions must be observed to prevent personal or aircraft injury. Many accidents have occured with composite materials because of improper usage and handling.

MATERIAL SAFETY DATA SHEETS
Before working with composite resins and solvents, it is important to know exactly what type of material you are working with. Obtain the *Material Safety Data Sheet* (MSDS) for the mateial you are working with. The MSDS contains information on healthprecautions, flammability of material, vantilation requirements, and information for health professional in case of an accident. Know where the MSDS sheets are kept in the shop. Resins come with instructions on mixing, and with the MSDS sheets.

As a technician, you may not come directly involved with the MSDS sheets when the material is delivered. These may be kept in the tool crib area, the doctors or nurses office of the company, or your boss or secretary may have them.

It is a law that all hazardous materials used in the shop have the MSDS sheets available to the prople working with the materials.

Know where they are. If something should happen to you while working with these chemicals it is important that you take the MSDS sheet to the doctor with you. A doctor cannot be expected to know every chemical. If you bring an MSDS with you, the docor will know what type of material you came in contact with, and can treat you appropriately, and in many cases quicker.

PERSONAL SAFETY WITH CHEMICALS AND MATRICES
Skin Protection
Some materials can cause allergic reactions when in contact with the skin. Some people are more sensitive to these materials than others. The most effective way to provide skin protection with these chemicals is through the use of rubber gloves. These gloves should be replaced after heavy use.

Shop coats should be worn to prevent clothing contamination and subsequent eventual skin contact. Colthes saturated with expoxy resins should be removed without delay. If contaminated clothing is allowed to stay next to your skin, it can be very irritating.

Remove any splashed resin from your skin immediately. Wash hands thoroughtly before and after work, before eating or smoking and before putting on gloves.

Always wash your hands brofre using the restroom. Many of the chemicals are *potential carcinogens* and may cause serious irritation and possible cancer, not only in the technician, but also with his sex partner

There are special types of epoxy cleaners available that will break down the resins without drying out the skin. Don't use excessively strong solvents to clean your skin, they will dry out the natural oils in your skin and cause allergic reactions that may cause your skin to peel (a form of dermatitis).

Respiration And Ingestion
When working with any resins or solvents, proper ventilation is required. Some resins are sufficiently toxic as to require that youwear a respirator when working with them. Some shops may provide a ventilated mixing booth. However, once the chemicals have been mixed, it is often necessary to apply the resin in an unventilated area, or otherwise expose yourself to the chemical fumes. In such instances, it is important that respirators be used once the mixed resins are removed from the mixing booth.Keep contaminated hands, gloves, clothing or material away from your hands and mouth. *Some of these materials have no known antidote. If you drink it, you are as good as dead.*

MATERIAL SAFETY DATA SHEET

Manufasturers name and address will be found here.	AB9174 REVISION : 01 09/09/09 934 NA HMIS CODE : H F R P
PHONE : (000) 000 - 0000	2 1 1 C

Information contained herein is believed to be true and accurate. Compliance with applicable Federal, State and local laws and regulations are the responsibility of the user. This data relates only to the specific product designated on the Material Safety Data Sheet, and is not for use in connection with any other material or product.

It is not to be expected that this Material Safety Data Sheet can address all possible individual situations. In order that the Material Safety Data Sheet serve its intended purpose as an effective means of hazard communication, the health and safety information on the form must be provided and its importance emphasized to all those who handle or use the product by developing work practice guidelines and employee instructional programs for the individual operation.

The user has the responsibility to provide a safe workplace by examining all aspects of an individual operation to determine if, or where, precautions, in addition to those described herein, are necessary.

*N.A.	=	Not Applicable	HMIS : Hazardous Materials Identification System, National Paint and Coatings Association Rating applies to product "as packaged" (i.e. ambient temperature)
N.E.	=	Not Established	
0	=	Insignificant	H = Health F = Flammability R = Reactivity P = Protective Equipment
1	=	Slight	
2	=	Moderate	CARC : Carcinogen or Potential Carcinogen
3	=	High	NTP : National Taxicology Program
4	=	Extreme	IARC : International Agency for Research on Cancer

OSHA : Occupational Safety and Health Administration

SECTION I - NOMENCLATURE

TRADE NAME AND SYNONYMS

943 PART B

SECTION II - HAZARDOUS INGREDIENTS

HAZARDOUS INGREDIENTS	OSHA PEL	ACGIH TLV	CAS NBR	PCT	CARC
Expoxy Resin System	N.A.	N.A.	N.A.	N.A.	NO
Diethylenetriamine	N.A.	N.A.	111 - 40 - 0	<15	NO
Triethylenetetramine	N.A.	N.A.	112-24-3	<10	NO

SECTION III - PHYSICAL DATA

BOILING PT (DEG.F)	405	SPECIFIC GRAVITY 0.951	
VAPOR PRESSURE (MM HG)	0.37 mm	PCT VOLATILE BY VOL N.A.	
VAPOR DENSITY (AIR = 1)	3.48	EVAPORATION RATE Nil	

SOLUBILITY IN WATER 100%
APPEARANCE AND ODOR - Amber liquid with a ammoniacal odor

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PART B	PAGE : 1 OF 3

Fig. 37.1, Sample Material Safety Data Sheet.

SECTION IV - FIRE AND EXPLOSION HAZARD DATA   AB9174...CONTINUED ...

FLASH POINT (DEG.F)   >200   METHOD USED T.C.C.

LOWER EXPLOSION LIMIT   N.A.   UPPER LIMIT   N.A.

EXTINGUISHING MEDIA -
Dry chemical or Halon fire extinguisher, or water spray, foam or fog.

SPECIAL FIRE AND EXPLOSION HAZARDS -
Dense smoke and toxic gasses may be liberated.

SECTION V - HEALTH HAZARD DATA

HEALTH HAZARDS (ACUTE AND CHRONIC) -
Material is corrosive to skin. May cause chemical burn to eyes and skin. Repeat contact may cause sensitization. Vapors irritating and may cause chest discomfort and bronchitis symptoms.

ROUTE(S) OF ENTRY - Inhalation, Skin, Ingestion

SIGNS AND SYMPTOMS OF EXPOSURE -
Possible burns to eyes and skin; irritation and possible sensitization to skin. Irritation to upper respiratory tract.

MEDICAL CONDITIONS GENERALLY AGGRAVATED BY EXPOSURE - N.A.

EMERGENCY AND FIRST AID PROCEDURE
Flush skin and eye contact with plenty of water. Wash thoroughly with soap and water, rubbing alcohol or hand cleaner. Do not use solvents. Remove soiled clothing and wash before refuse. If irritation persists, see physician.

NOTES TO PHYSICIANS - N.A.

SECTION VI - REACTIVITY DATA

STABILITY   STABLE
        CONDITIONS TO AVOID - N.A.

INCOMPATIBILITY (MATERIALS TO AVOID) -
Strong oxidizing agents, strong Lewis or mineral acids.

HAZARDOUS DECOMPOSITION PRODUCTS -
CO, NOx, aldehydes, acids and undetermined organics.

HAZARDOUS POLYMERIZATION -
May occur

CONDITIONS TO AVOID -
Avoid mixing resin and curing agent in batches greater that 1 poind total. Do not heat mixed adhesive unless curing surfaces to be bonded. Failure to observe caution ay result in excessive heat build-up with the release of toxic gases.

SECTION VII - SPILL OR LEAK PROCEDURES

STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED -
Wear protective clothing, gloves and safety glasses. Scrape up and transfer to metal container. Wipe up remaining residue with solvents, observing solvent flammability cautions.

WASTE DISPOSAL METHOD -
Dispose of as hazardous waste according to DOT hazard class. If not regulated by DOT, dispose of as ORM-E.

PRECAUTIONS TO BE TAKEN IN HANDLING -
Keep cool in accordance with label instructions.

MFG. NAME   DATE : 10/10/90
PART B   PAGE : 2 OF 3

Fig. 37.1, Sample Material Safety Data Sheet.

SECTION VII - SPILL OR LEAK PROCEDURES   AB 174 .... CONTINUED ....

OTHER PRECAUTIONS -
Follow recommended curing schedule.

STORAGE -
Store at room emperature (77 deg. F) for 12 months.

SECTION VIII - SPECIAL PROTECTION INFORMATION

RESPIRATORY PROECTION (SPECIFY TYPE) -
Not needed with good industrial ventilation.

VENTILATION -
Local exhaust recommended.

PROTECTIVE GLOVES -
Impervious plastic or rubber.

EYE PROTECTION -
Safety glasses or goggles.

OTHER PROTECTIVE EQUIPMENT -
As needed to protect skin and clothing.

SECTION IX - SPECIAL PRECAUTIONS

PRECAUTIONS TO BE TAKEN IN STORAGE AND HANDLING -
Keep cool in accordance with label instructions.

OTHER PRECAUTIONS -
Follow recommended curing schedule.

SECTION X - TRANSPORATATION AND LABELING

DOT PROPER SHIPPING NAME -
Alkaline Liquid, N.O.S.

DOT HAZARD CLASS -
Corrosive Material

UN/NA HAZARD ID NUMBER -
NA 1719

DOT LABEL -
Corrosive

WARNING LABEL -
Danger ! May cause severe eye or skin burns. Prolonged or repeated exposure may cause allergic skin reactions. Part B contains diethylenetriamine. Use only in a well ventilated area. Do not get on skin or clothing. Do not handle or use until the MSDS has been read and understood.

FIRST AID -
In case of contact, immediately flush eyes with plenty of water for at least 15 minutes. Wash skin with soap and water at once. Seek medical attention.Remove contaminated clothing and thoroughly clean before reuse.

IATA PROPER SHIPPING NAME -
Alkylamines, N.O.S.(Diethylenetriamine)

IATA LABEL -
Corrosive.

IATA PACKING GROUP -
Group II

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Fig. 37.1, Sample Material Safety Data Sheet.

Fig. 37.2, Personal hygiene and careful material handling become even more important than normal when working with composites. Remember, Everything is hazardous.

Eye And Face Protection

Some of the solvents and matrix components can cause permanent blindness within a few seconds after contact with the eye. Goggles provide complete eye protection against front and side impact hazards, chemical liquid splashes and dust. If you should splash any epoxy resin or solvents in your eye, rinse the eye out immediately, report your accident to your supervisor, and seek medical help.
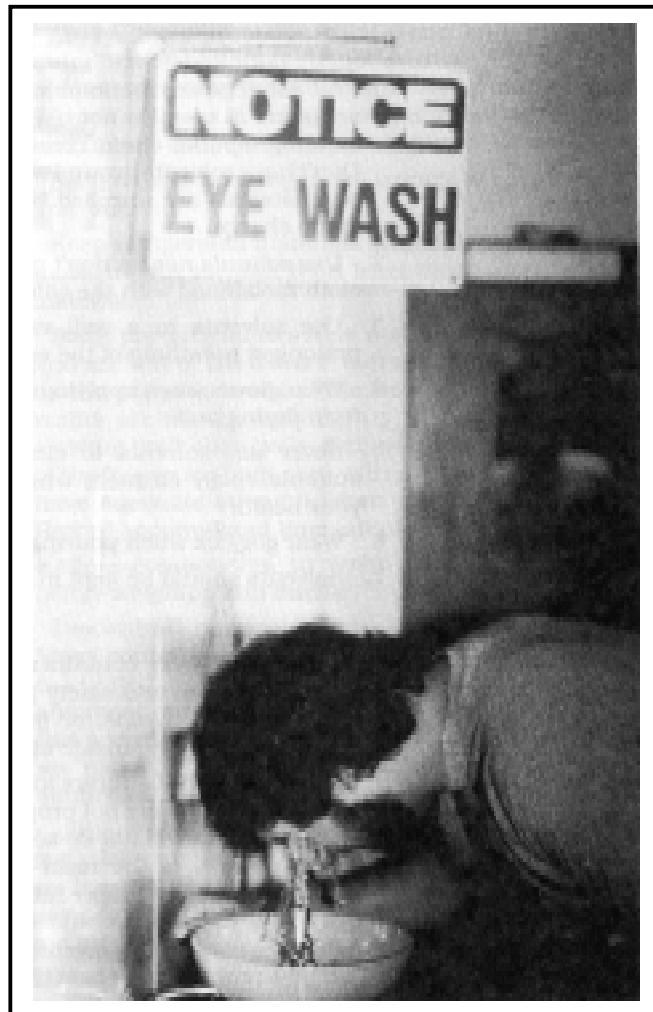
Fig. 37.3, An OSHA approved eyewash station is not only required, but extremely important! They should be cleaned and maintained regularly. All approaches to the station should always be unobstructed.

Goggles are worn in combination with prescription glasses or alone. Very serious eye accidents have occurred when people didn't take the warning seriously. If you get any substance in your eye, do not wait to seek medical attention. If the substance is left in the ye for a prolonged period of time, or overnight, the damage to the eye can become more severe. Don't take chances. Tell your supervisor and seek medical help immediately. Some resins, hardeners and solvents may make you go blind. Face shields are a good protection when working with resins, however, if you have a up-draft table, face shields should not be used. Up-draft tables, as their name implies, pulls fumes up through an exhaust vent, If a face shield is being worn, the fumes will be pulled up under the shield and have no place to exit, and may cause respiratory problems.

CAUTION

Plastic contact lenses may craze from resin fumes. Crazing is when plastic cornes in contact witht he fumes of solvents or resins and causes white lines on the suface. Wear glasses if possible. Goggles are a must.

Solvents: Usage And Safety

Many types of solvents are used when working with or repairing composites. Some of the most common slovents used with composites include :
MEK or Methyl-Ethyl-Keytone--
Used for cleaning dust, grease and mold release agents from composite components.

Acetone

Used for general cleanup of tools, equipment, and is used to clean the composite parts after sanding as a prebond prep.These safety guidelines should be followed with all solvens and Matrices :
1.   All solvents are flammable. NO SMOKING when solvents are in use. Don not use solvents in the vicinity of sanding; sparks could create a potential fire hazard. Don't have solvents around when bagging films and peel ply materials are unrolled because they may create a static charge.
2.   Use solvents neatly,don't pour it onto the part. A soft cloth moistened with the solvent is usually adequate.
3.   Use solvents in a well ventilated area, and avoid prolonged breathing of the vapors.
4.   Wear gloves when applying solvents to protect the skin from drying out.
5.   Never use solvents to clean skin. There are more suitable epoxy cleaners which are less dangerous to your health.
6.   Wear goggles when pouring solvents.
7.   Solvents should be kept in the original containers.

USE & STORAGE OF MATRIX MATERIALS

Read the labels on containers for all information on handling, storage, and safety precautions. If improperly stored adhesives, resins, or pre-pregs are used, it may result in structurally unsafe aircraft components.
1.   Follow all manufacturers instructions for mixing components. If resins are not properly mixed, the maximum cured strength will not be achieved.
      The two parts of the resin system must be weighed properly to get the proper mixture. A scale can be used to mix to the proper ratio desired. Some resins and adhesives may come conveniently packaged and already have the proper amounts in the two parts of the package.
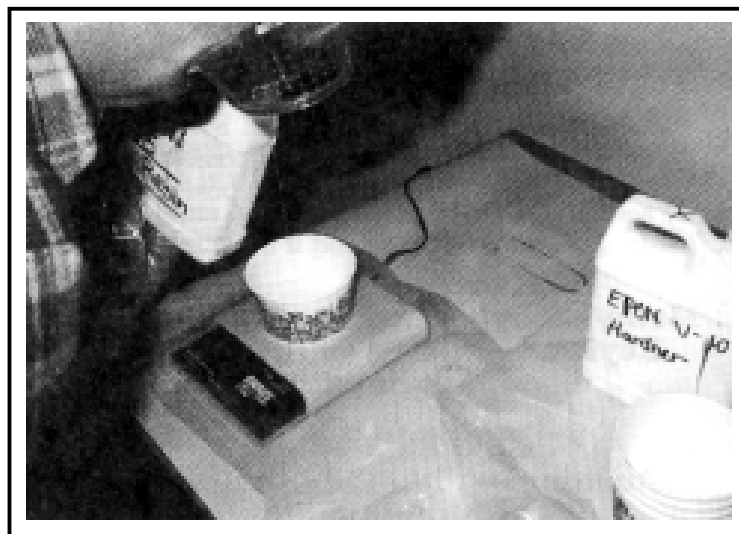
Fig. 37.4, All instructions supplied by the manufacturer of the materials used MUST be followed exactly. This includes mixing, as well as safety instructions. Any materials you are not familiar with, you should also consult the MSDS.

2.   Always store properly. Some resins and catalysts require special storage temperatures. Three storage temperature ranges are common. Room temperature of 75 to 80 degrees F, refrigeration of about 40 degrees F, and freezer temperatures of 0 degrees F or less.

3.   Keep records on refrigerated storage to ensure first-in, first-out.

4.   Keep refrigerated materials sealed to prevent entry of moisture. An identification label must accompany the material.

5.   Some pre-preg fabrics have an "in freezer" storage life, and an "out of the freezer" storage life. This is because as the pre-preg is out of the freezer while cutting, the resins are slowly warming up to room temperature, starting their cure cycle. If they are allowed to stay out of the freezer too long, they will cure too much and won't have adequate strength when you need to use them. Record accumulated time out of refrigerated storage.

6.   Allow components to warm to room temperature before weighing and mixing.

7.   Discard all materials that exceed their storage life. Many containers will have a "limitation date", which is calculated from the date of manufacture or date of shipment receipt (whichever is applicable). If an item has a manufacturing or shipment date of 1/89, and a six month storage life, its "limitation date" may be stamped 7/89, and should not be used after this date.

        To discard the materials properly, consult the MSDS sheet. Many materials may not be just thrown away. They may have to be mixed and cured before throwing them away because by themselves they may be considered as toxic waste.

8.   Handle materials with gloves to maintain cleanliness.

9.   Don't use brushes contaminated with another type of resin.

10.   Store dry fabric and bagging materials in a clean, dry area. Care should be taken not to distort the fabric weave.

11.   Do not allow protective hand creams to come in contact with the resins or bond lines. They may create an unbondable surface.

12.   Do not remove the backing on pre-preg materials until the material is used.

13.   Store honeycomb and foams in the original packing box.

14.   Clean rooms are not required for making composite repairs, however, it is nice if you have a separate area for sanding and one for laying up the patches. This will help keep any dust particles from the sanding operation from getting into the repair.

Not all shops have separate areas to do the composite repair work. In this case, clean the area very thoroughly and vaccum up any dust, followed by a solvent wash, before attempting to bond patches.

FIRE HAZARD MINIMIZATION

Many of the solvents and resin materials used are flammable. Keep away from heta and open flame. to minimize or elimanate the danger of fire, the following requirements should be met :

1   Elimanate all flames, smoking, spaarks, and other sources of ignition from areas where solvents are used.

2.   USe nonspark producing tools.

3.   Ensure that all thye electrical equipment meets the applicable electrical and fire codes.

4.   Keep flammanle solvents in closed containers.

5.   Provide adequate ventilation to prevent buildup of vapors.

6.   Statically ground the aircraft and any repair carts.

7.   Never unroll bagging films or peel ply around solvents.They may produce static electrically.

8.   Never have solvents in the area when sanding. The possibility of sparks during the sanding operation is a fire hazard when silvent fumes are present.
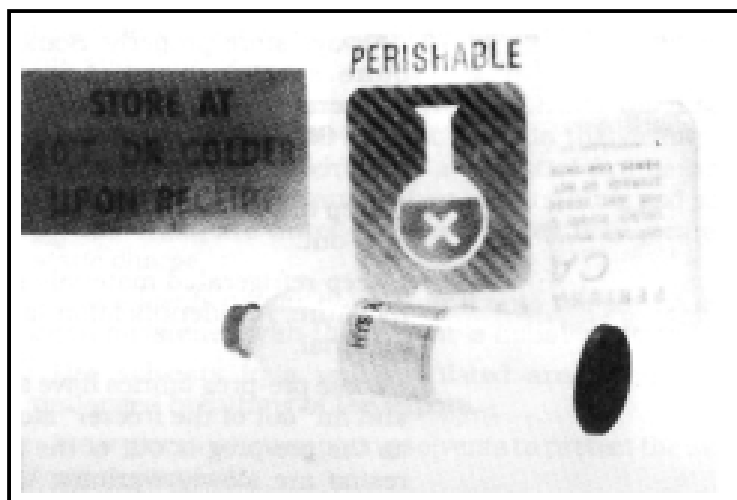
Fig. 37.5, Storage of inventory and materials for work-in-process have definite requirements. Again, follow the manufacturers instructions.

PERSONAL SAFETY WHILE MACHINING

While sanding, drilling, or trimming composite structures, very fine dust particles contaminate the air. Respirators must be worn. A dust collector or downdraft table is very desirable to use while sanding, to pull the fine particles out of the air. A dust collector or downdraft table alone should not be solely relied on. Use such equipment in conjunction with a respirator.

Some composites decompose when being trimmed or drilled at high speeds. Because of the friction generated, you are burning away various materials creating toxic fumes. Composites vary in their toxicity, so you should consider all composites equally hazardous and should observe appropriate safety precautions while working with any of them.

To minimize the possibility of particles entering the pores of the skin, wear protective clothing, such as a shop coat that doesn't have loose fitting sleeves.

After working with composite, take a shower at the end of the day to flush particles from he skin and hair.

TOOL SAFETY

Tools should be disconnected from the air supply before changing cutters. Never hold small parts in your hands while drilling, always use a backup.

Because carbon chips may be corrosive to aluminum parts and hazardous to electrical components, carbon composites may hve to be removed from the aircraft prior to being worked on.

Point the exhaust from pneumatic power tools away from other people. Safety goggles are a must when drilling, sanding, routing or grinding.

Never use compressed air to blow dust from a part that has been sanded. The excessive air pressure couls cause an area of the laminate to disbond, causing further damage. To remove the dust, a vacuum should be used, followed by a solvent wash.

WORKING ENVIRONMENT

Good housekeeping is an important aspect of t he profession you are working in. It directly impacts an individuals; safety and general work. Due to the materials used in composite repair, good housekeeping is a must :
1. Do not block access to any safety equipment.
2. Keep storage areas neat and orderly.
3. Properly dispose of mixing containers.
4. Keep fabric remnants swept up.
5. Wipe up any spills, keep tools clean.
6. Container labeling should be legible and lids intact.
7. Trash receptacle emptied.
8. Bagging materials kept on rolls, covered storage.
9. Keep sanding away from lay-up area.
10. Down draft or dust collectors should be used while sanding.
11. Adequate ventilation must be available while working with resins.

CHAPTER-38
METHODS OF APPLYING PRESSURE DURING CURING OF COMPOSITES

Pressure should be applied to the surface during the curing operation, whenever possible until it is fully cured. The purpose of mechanical pressure is to :
1.   Remove excess resin to get the proper ratio of resin to fiber reinforcement. As the resins cure, they will start to flow. The pressure will squeeze out some of this excess resin as it begins to flow.
2.   Remove trapped air between layers.
3.   Maintain the contour of the repair relative to the original part.
4.   Hold the repair securely to prevent any shifting of the patches during the curing process.
5.   Compact the fiber layers together.

Various types of tools and equipment are used to apply mechanical pressure. Vacuum bagging is probably the most widely used and recognised method of applying pressure for use on advanced composites. If vacuum bagging materials and equipment are not available, there are other methods to provide pressure which can some-times be used.

Fig. 38.1, On a contoured part, the repair plies should keep the same shape of the part. The pressure should also hold the patches in place during the curling process so they don't shift.

SHOT BAGS
This method is effective when used on large contoured surfaces which cannot be clamped. To prevent the shot bags from sticking to the repair, a plastic sheet film should be used to separate the repair from the shot bags. Unfortunately, because of the laws of gravity, shot bags cannot apply pressure to the underside of the curve of a leading edge, or to the underside of any other part on the aircraft. The part must be removed from the aircraft and turned upside down to apply this type of pressure.

CLECOS
Clecos are used in conjunction with preshaped caul plates to support the back side of a repair. Clecos should be coated with mold release to prevent adhesion. Unfortunately the holes may cause problems and will have to be filled. These holes could cause as much damage to the part as the damage itself. This type of pressure is not recommended.

SPRING CLAMPS
When using spring clamps, a caul plate should be used to distribute pressure evenly over the area. The use of "C-clamps" is not recommended, because as the resin flows during the cure, the clamps will not compensate to hold a constant pressure. If C-clamps are used, they must be continuously tightened, thus increasing the chance that compression damage might occur on the part.

PEEL PLY
Peel ply is nylon fabric that is usually used during the vacuum bagging process to facilitate the removal of the bleeder material, vacuum bagging plastic, etc., from the repair area. However, if peel ply is applied over a patch and the resin is worked into it, peel ply will remove excess resin and air bubbles, as well as prevent shifting and create a "feather-in" of surrounding surfaces. Peel ply is used to apply pressure in places that are inaccessible to vacuum bagging or have varied contour or shape. Peel ply may also be used in conjunction with other pressure methods.

SHOT BAG
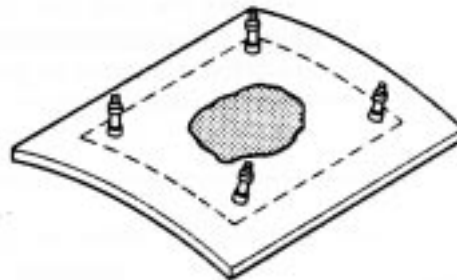
CLECOS
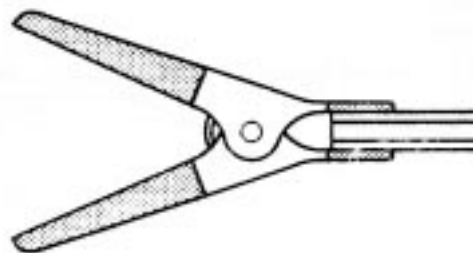
SPRING CLAMP

Fig. 38.2, Various types of pressure devices.

VACUUMBAGGING

Vacuum bagging is probably the most effective method to apply pressure to a repair. It is recommended for use whenever possible. If you are working in an area with high humidity, vacuum bagging should be used. High humidity may effect the cure of the resins and the vacuum bag system evacuates the air and the humidity.

Vacuum bagging works by using atmospheric pressure to provide an even pressure over the surface of the repair. The pressure of the surrounding atmosphere is greater at lower elevations that it is at high elevations. Consequently, the amount of pressure created during a vacuum bagging repair at sea level will be greater than the pressure created during a repair at a high mountain airport.

The amount of pressure will vary according to the effectiveness of the vacuum seal, the amount of vacuum drawn by the equipment used and the altitude at which the repair is done.

Surface bagging is used on larger surfaces and for most repair work. On penetration repairs, the back side of the damaged area must be sealed to prevent air from flowing through the repair being made to the other side. In this case, the puncture is sealed on one side with vacuum bagging material while the repair is vacuum bagged on the other side where the patches are curing. When one side of the puncture has cured, the other side of the repair can be completed. This repair is often done in separate steps.

Self-enclosed bagging material is used on small parts. Self-enclosed bagging material is a plastic tube that can be sealed on the ends. The self-enclosed tube vacuum bag may be used on a repair when the part is removed from the aircraft and is mall enough to be placed inside the tube. Atmospheric pressure will be on all surfaces of the part. If the part is hollow, the atmospheric pressure may cause the part to collapse, especially in the area of the repair since it is not yet cured. An internal as well as external bagging should be used.

SELF-ENCLOSED BAG

SURFACE BAG

VACUUM BAG ARRANGEMENT

BLEEDER/
BREATHER   BAGGING
                FILM   SEALING
                            TAPE

                PEEL
                PLY

PATCH   ORIGINAL
                            STRUCTURE
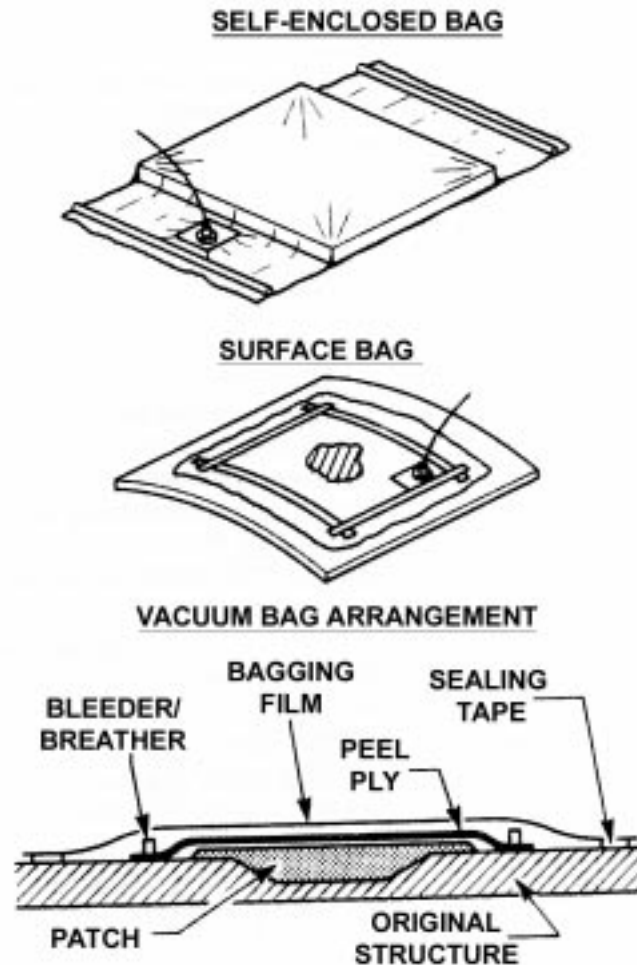
Fig. 38.3, Surface bags and self-enclosed bags are basically the same in function. With a surface bag, the part to be repired serves as one side of the bag.

VACUUM BAGGING PROCESS

Once the repair is made and the patches are in place, the area is covered with a parting film or a parting fabric (peel ply). This allows the excess matrix to flow through to the upper surface and the bleeder material. Parting film is easily removed after the cure is completed and it prevents other materials, such as bleeder material, from sticking to the repair. The parting film or parting fabric also "feathers" in a seam or overlap of fabric to produce a smooth surface.

Some release fabrics can be used instead of a parting film to provide a final rough surface (slightly etched) suitable for painting. Instead of using a peel ply, some manufacturers recommend the use of a perforated release film. This is a plastic that is used over the wet repair surface, but has small holes to allow the resins to flow through the holes to the bleeder.

A bleeder material is an absorbent material that is either placed around the edges or on top of the repair to absorb the excess matrix.

A breather material is placed to one side of the repair to allow air to flow through it and up through the vacuum valve. Bleeders and breathers can be made of the same material and be used interchangeably in many cases. In such a case, the manufacturer may refer to it as a bleeder/breather.

The vacuum valve is placed on top of the breather material, to remove the air from inside the vacuum bag. Later, the vacuum valve will be attached to a vacuum hose which connects to the vacuum pump.

A sealant tape is attached around the edges of the repair. Sealant tape, in conjunction with the vacuum bagging film, is designed to produce an airtight seal which can be removed from the aircraft surface after the repair is made, without taking the paint off. Sealant tape comes on a roll with paper backing on one side. As the tape is laid onto the surface, the paper is left on the tape so that it can later be pushed down onto the surface without sticking to your fingers. The paper on the sealant tape also helps to prevent the bag from sticking to the surface prematurely. Sealant tape should be applied in straight lines to prevent air leakage on a curve. The four sides to box in a repair should be overlapped on the corners to eliminate air leaks.
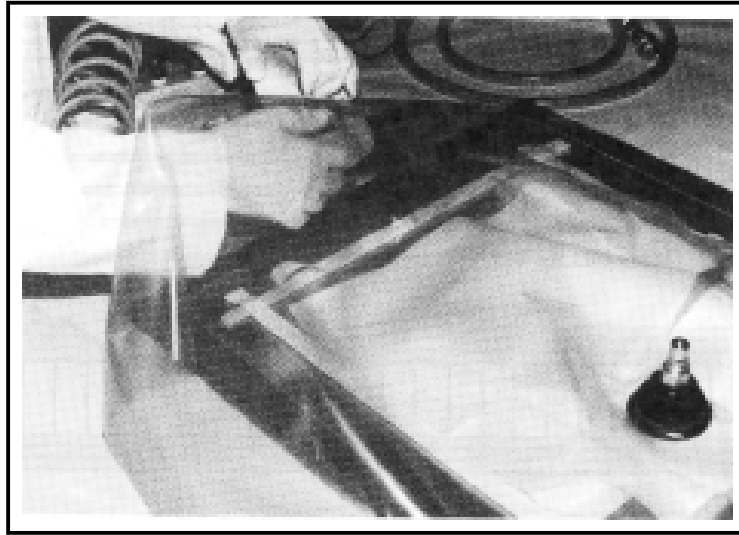
Fig. 38.5, Selant tape being applied to the edge of the repair area.

If a thermocouple or temperature sensing device is used, it should be laid next to the repair area and be sealed into the sealant tape by putting another small strip of tape over the thermocouple wire. This will prevent air from leaking around the thermocouple wire.

If a heat blanket is used to cure the repair, a parting film should be laid over the repair to prevent the heat blanket from sticking to the repair. The parting film used in this case can be a non-perforated release film, or piece of vacuum bagging material. In any case, it should be able to withstand the temperature of the cure since it will be directly in contact with the heat blanket. The heat blanket should be placed over the parting film. Make sure the heat blanket covers the thermocouple wire. If the heat blanket has two wires, they should be split apart, and another strip of sealant tape should be put over the two wires to reduce the chance of air leakage.

Vacuum bagging film is laid over the repair and the edges are worked into the sealant tape to produce an airtight seal. The bagging films which are most commonly used are usually mad of nylon. They resist tears and punctures, and are rated at different temperatures. The most effective way to create a seal with the bagging material is to take the paper off the sealant tape on one side and lightly press the bagging film into the sealant tape. This should be done one side at a time so the bagging film won't stick to the sealant tape.
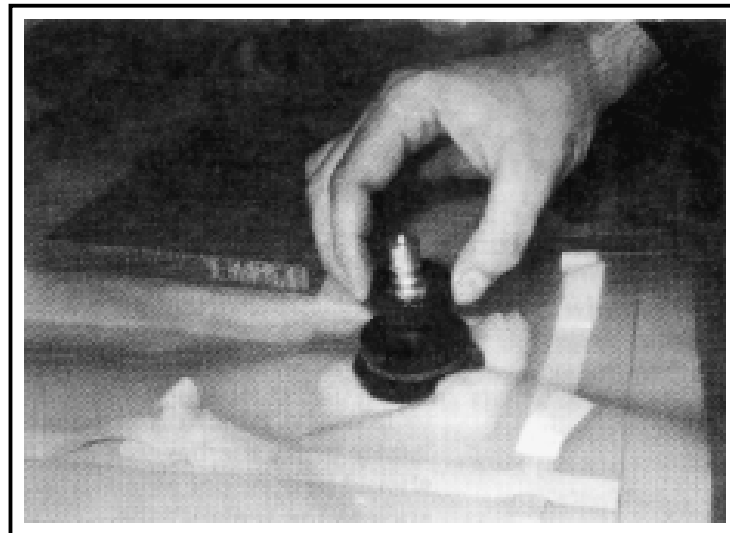
Fig. 38.6, The valve being installed into the X-shaped cut that is made in the vacuum bag material.

On a part that is contoured, pleats may be needed to allow extra bagging film to conform to the shape of the part. The pleats are made form small pieces of sealant tape and folded together. These pieces are than positioned in the sealant tape which lies around the edges of the repair. When the bagging film is applied, it is attached to all surfaces of the sealant tape, producing a pleat in the bagging film.

The bagging film should be lightly pressed into the tape until it has been determined that the film forms an airtight seal that covers the part. If it is necessary to readjust the bagging film, it can be picked up and repositioned. If the film is stuck to the tape too firmly, it is difficult to reposition. Once the film is positioned correctly, it can then be pushed firmly into the tape to produce an airtight seal.

An X is cut into the bagging film over the vacuum valve. Don't make the hole (X) too big, or air will leak through it. The film should go all the way down past the threads to the base of the valve. The area around the vacuum valve must then be sealed airtight. The rubber grommet goes over the valve to seal it, followed by the pressure plate and then a check nut. Wrinkles are seen they should be worked smooth. The valve is then attached to a vacuum hose.

The vacuum source is connected to the vacuum hose and turned on. Check to see if there are any leaks in the bagging film, which will produce a hissing sound. These areas of the bagging film which have the hissing sound should be pushed down harder into the sealant tape until there is no hissing. Leaks usually occur where the tapes overlap, at pleats, or where wires pass through the sealant tape. An acoustical leak tester can be used at this point. Perform a vacuum leak test.

Vacuum Leak Check

A vacuum leak check is done to make sure that the bag sealed properly. The vacuum to the part is shut off after about two minutes of operation. With a vacuum gauge attached to the part, the amount of mercury drop is noted. Depending on the manufacturer's instructions, an allowable drop may be one to four inches of mercury.

After the curing process, all the layers of bagging film, sealant tapes, bleeders, breathers, and peel plies or release films, are removed from the part and are disposed of. The peel ply layer may be kept on the part until it is painted to keep the surface clean.
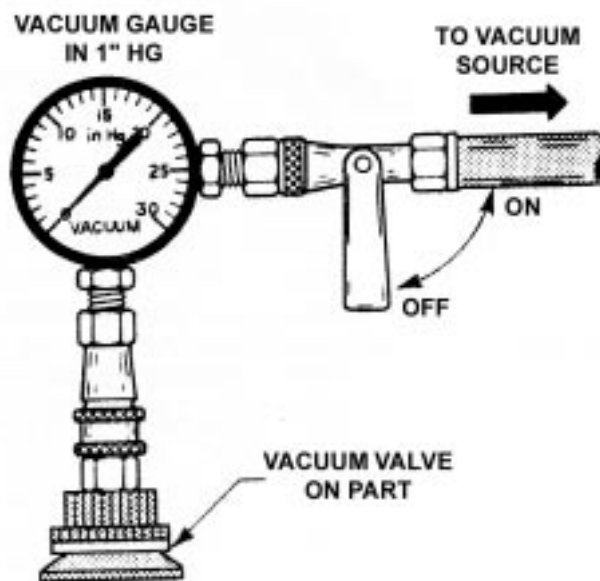
Fig. 38.7, The valve with vacuum gauge, ON/OFF valve, and hose attached.

The rough surface of the peel ply is like a slight etch that allows the paint to adhere to the part better. If a parting film or plastic was used, the surface must be scuff sanded to allow the paint to adhere. If the part is scuff sanded, caution should be used while sanding to avoid sanding through the fabric.

Vacuum bagging can be used for parts which are cured in autoclaves, ovens, hot bonding units, heat blankets, heat guns and heat lamps. The vacuum bagging process is used in manufacturing as well as in the repair process.

VACUUM BAGGING MATERIALS

The materials which are commonly used for vacuum bagging come in a number of types, depending on the manufacturer. Some of the more commonly used materials for composite repair are listed here.

Vacuum Bagging Films

Vacuum bagging films, are used to cover the component and seal out any air. They must be made with absolutely no voids or pin holes of any size. If there are small holes in the film, air will leak through and less pressure will be applied to the part while curing. Bagging films come in a variety of temperature ranges from room temperature up to 750 degrees

F. It is important to use the correct temperature rating for the required cure temperature. The vacuum bagging film should remain flexible at high temperature cures, especially around highly contoured shapes. If the bagging film becomes brittle, it may develop air leaks, which decreases the amount of atmospheric pressure to the part.

The selection of the appropriate bagging film depends on the method by which the part is cured, and on the required temperature of the cure. Bagging film is hydrophilic, or water sensitive material. Moisture acts as a plasticizer. The higher the moisture content of the film, the more flexible and rubbery it becomes. During the vacuum bagging process, it is important to have the film be as flexible as possible so that the film can be formed around any contoured shape.

In storing this film it is extremely important to maintain the moisture content. When the material is shipped, it should be enclosed in a plastic wrap. Only the amount to be used should be cut from the roll. The rest of the roll should be stored in the original plastic wrapper. This is specially important in dry climates and during the winter months when the moisture content may dry out and cause the film to become brittle.

Sealant Tapes

Sealant tapes are used to maintain a positive seal between the surface of the original part and the bagging films. This seal must be leak proof, to ensure maximum atmospheric pressure is held on the part. Most sealant tapes have a limited shelf life, so storage and labeling is required. If the shelf life is exceeded, the seal will not be as good, and the sealant tape may not clean off of the surface easily.

The tape should hold tight, even if the bagging film shrinks during the curing process. The sealant tape should be able to withstand the temperatures of the cure. These tapes are usually not available in lots smaller than a case, however, some manufacturers or distributors may break a case if the tape is sued only occasionally.

Pleats, or ears, are made with sealant tape to provide extra bagging film over the part if it has contours. To make the pleats, a three-to four-inch piece of sealant tape is cut. The middle of the sealant tape is pinched together, and the ends are attached to the sealant tape which has been placed around the part.

When pleats are used, the pleat should be placed even with any edge or sharp contour to allow for the extra plastic where it is needed to provide a good seal. No more than half of the backing paper on he sealant tape should be removed prior to attaching the bagging film.

Pleats allow for extra room in the bagging film to conform to the shape of the part and achieve a good seal. If extra vacuum bagging material is not available in some places, a bridging effect may take place. Bridging is when extra bagging film does not conform to the shape of the part, and the excess resin flows into these areas during the curing process. If enough pleats are added around the vacuum bagging area, the excess material should easily conform to the shape of the part when the vacuum is applied.

Release Fabrics And Films

Release fabrics and films are used when a barrier is needed between the wet patches and the other vacuum bagging materials. Release fabrics are also used when the resins are expected to flow up through the material and into a bleeder.

Peel Plies

A nylon or polyester release fabric may be used next to the wet resin during the curing operation. It is used to transfer excess resin to the bleeder material without sticking to the part. After curing, the peel ply is peeled off the part, and will cause a slightly rough surface. This is important if the part is to be repainted. Peel plies are extremely helpful over seams or where layers of fabric overlap. They will "feather-in" the layers and eliminate the need for sanding. These come in different finishes, some are very smooth, others are more coarse. Some peel plies may be treated with mold release, corona treated, or Teflon coated to release better.

Release Films

Release films come in two forms. Perforated release film is a plastic film which has been perforated. These holes in the film allow excess resin to flow through the holes and into a bleeder. If a non-perforated film is used, the excess resin will not flow out and will create a brittle, heavy repair or part because of the excess resin.

The non-perforated release films are used when a barrier is needed between other parts of the vacuum bagging process. These non-perforated release films are often used under a heat blanket, over the bleeder material. This prevents the bleeder material and resins from coming in contact with the heat blanket.

Before painting a surface that was cured with a release film, the glaze should be removed by hand sanding, otherwise the paint may not adhere to the structure. Carefully sand the glaze off, do not sand into the fiber material.
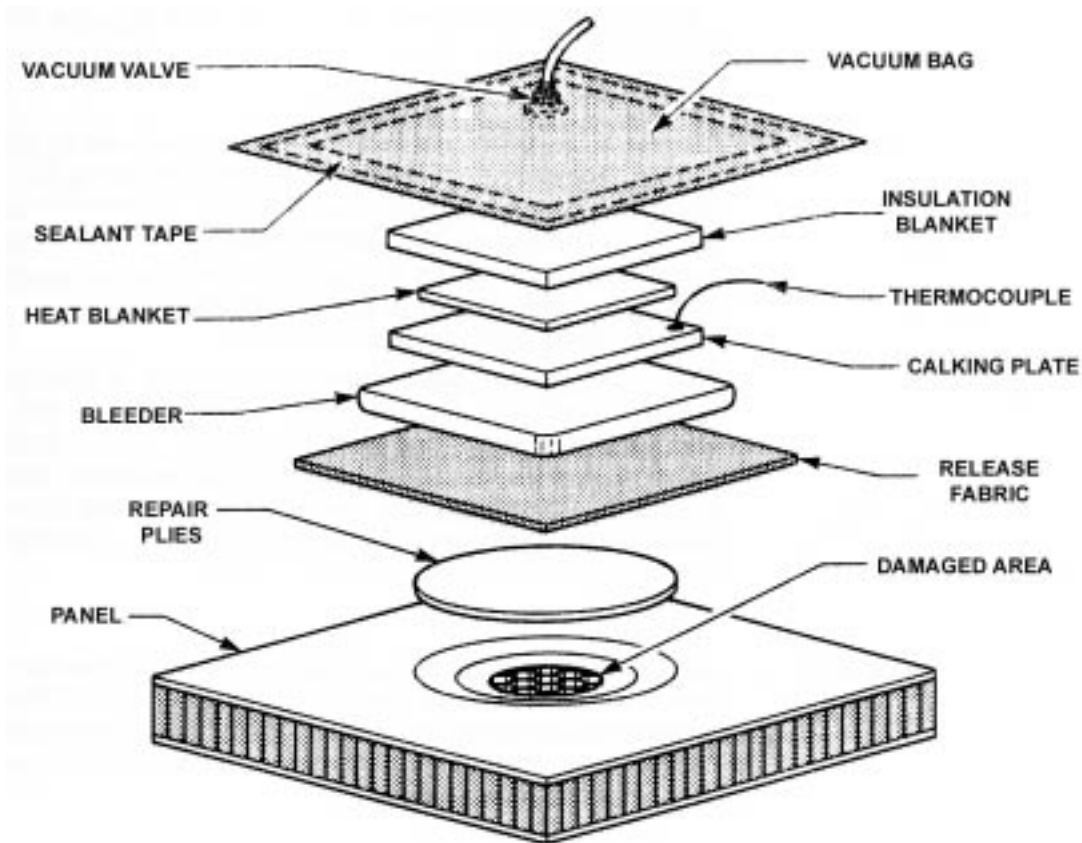
Fig. 38.8, a typical stack-up for a heated vacuum bag surface repair.

Bleeders

Bleeders are absorbent materials which are used to soak up the excess reins. Some companies will use a felt or other absorbent material. Do not use the bleeder in contact with the repair. This bleeder material will become a permanent part of the aircraft if a peel ply or release material is not used. Always use in conjunction with a release fabric, peel ply or release film.

There are different thicknesses and weights of bleeders. The type used will depend on the type of lay-up used. If the patches were impregnated by hand, a heavier bleeder will probably be used to soak up the excess resin. Some people, however, will have a very dry lay-up, and should use a thinner bleeder. If a pre-preg is used, usually a thinner type of bleeder material is used.

Breathers

Breathers are a cottony type material used to allow air to flow through a valve or over the surface of a part. This is typically the same material as a bleeder, and in some cases a bleeder is called a bleeder/breather, when it can be used as a combination material.

Calking Plate

In some instances, a calking plate or pressure plate is used to add extra pressure and smooth the contour of the part that is being cured. This is usually an optional piece made of wood, aluminum, or copper.

Insulation Plies

Insulation may be added under the vacuum bagging film and over the heat blanket. This is used to hold the heat in and to minimize the amount of heat loss during the cure process. The insulation may be a few layers of fiberglass or a sewn blanket with many layers.

The vacuum bagging operation can be done around a corner or over an edge as illustrated in Figure 38.9. Trailing edges can also be vacuum bagged in this manner. If the repair is done to both sides of the edge, a calking plate should be used in the vacuum bag to prevent the repair plies from bending up or down as the air is evacuated from the repair.
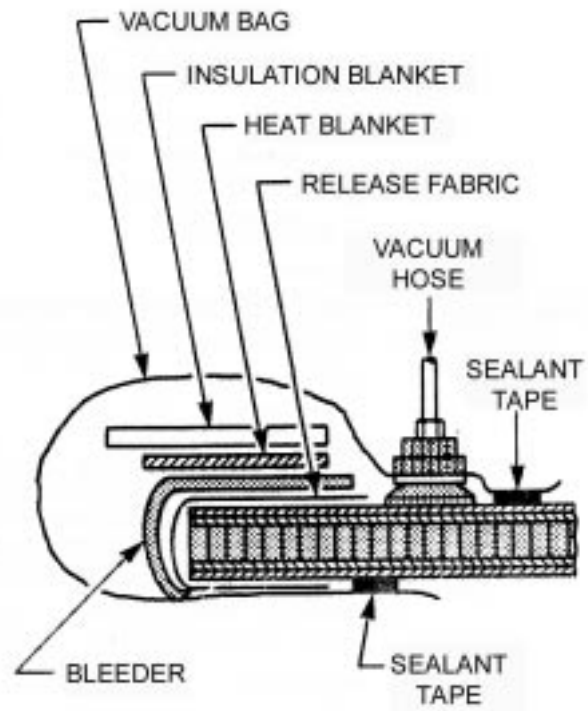
Fig. 38.9, Stack-up of heat being applied to the edge of a piece of honeycomb panel.

CHAPTER-39
METHODS OF CURING OF COMPOSITES.

Composite matrix systems cure by chemical reaction. There are room temperature cure systems which will cure at room temperature, but can be accelerated by the use of applying external heat. There are some matrix systems which require heat to cure the composite to achieve the maximum strength.

Failure to follow the proper curing requirements, or improper usage of curing equipment, can cause defects which are cause to reject the repair. Proper curing or handling during the cure has a direct effect on the strength of the repair. During the curing process, humidity may cause a problem unless the repair is vacuum bagged.

ROOM TEMPERATURE CURE
Some repairs may be cured at room temperature (65- 80 ^{0}F) over a time span of 8-24 hours, depending on the type of resin system used. The curing process can be accelerated by the application of low heat to some room temperature resin systems. Low heat is considered to be about 140 to 160 ^{0}F. Check the applicable cure time for the specific material used.

Full cure strength is usually not achieved until after five to seven days. If the repair calls for a resin system that can be cured at room temperature, it would be for parts which are used in areas where there is no exposure to high operating temperatures (usually above 160 ^{0}F).

Such room temperature cures are usually used with composite parts that are used in lightly loaded, or non-structural parts.

HEAT CURING
The most widely accepted method of curing structural composites employs the use of resins which cure at higher temperatures. These adhesives and resins require elevated temperatures during their cure in order to develop full strength and reduce the brittleness of the cured resin. Heat will also reduce the curing time.

When a part is manufactured at a high temperature, the repair patches which are used in its repair may have to be cured at the manufacturing temperature in order to restore the original strength. These resins usually cure at a temperature of 250 to 750 ^{0}F. The amount of heat applied should be held constant by monitoring the surface temperature of the repair. Although curing by applying heat in some instances produces a stronger repair, over-heating can cause extensive damage to the component. If too much heat is applied, the vaporisation, or "gassing" of the matrix may cause bubbles to form on the surface. A dry area is also an indication of excessive heat.

Although the fibers will withstand higher temperatures than the matrix, the recommended curing temperature should not be exceeded in order to avoid material disintegration or further delamination of the existing structure around the repair.

When a part is to be cured with heat, it is not enough to simply apply heat at the final cure temperature. It is important that the resins be allowed enough time to flow properly before they go through their process. If this is not allowed, a resin rich area may result.

It is also important to allow a repair to cool at the proper rate. Composites gain much of their cure strength in the cooling down process. A slow rate of temperature rise and a gradually cooling process is desirable, but not usually possible, unless a monitor or controller is available. A monitor, or controller, is a device that is used to regulate the temperature in a specific way.

The "*step cure*" and "*ramp and soak*" are probably the most commonly used with composite repair. They will ensure a slow rate of temperature rise and decline.

STEP CURING
Step curing is used when a manually operated controller is used. It requires that the technician make the adjustments manually at specific time intervals. Step curing is the process of bringing up the temperature slowly by raising the temperature to one point and holding it there, then bringing it up again and holding it there, until the cure temperature is reached. This allows the slow heating process which is critical in the curing of the composite.

After the cure time has elapsed, the temperature can be stepped down by reducing the temperature slightly and holding it there, then bringing it down slowly again and holding it there until room temperature is reached. This slow cooling down will give a stronger final cure to the component.
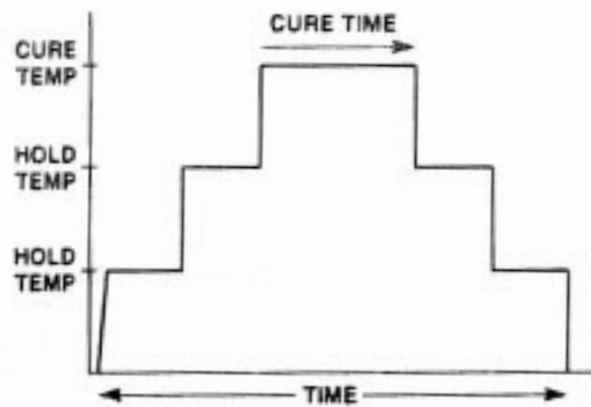
Fig. 39.1, Step curing is normally used where a manually operated controller is hand adjusted by the technician. Time and temperature must be watched closely.

RAMP AND SOAK CURING

A more sophisticated and accurate curing may be done with a programmable controller. A controller may be programmed in a "ramp and soak" mode, which is used to heat or cool a repair at a specific rate. For example (fig 39-2) a structural repair manual may specify that a repair be heated to a temperature of 400 ^{0}F and that the temperature be reached at a slow, constant rate of change from room temperature at eight degrees per minute. If room temperature was 70 degrees, it will take approximately 41 minutes to reach the 400 degree mark ($400^0 - 70^0 = 330^0, 330^0 + 8^0$ each minutes $= 41.25$ minutes). This heating process is called the "ramp".

Once the repair has been heated to 400 ^{0}F, the structural repair manual may require that this temperature be held for a specific amount of time; in this example, for two hours. The mode which the controller operates during these two hours is referred to as the "soak"
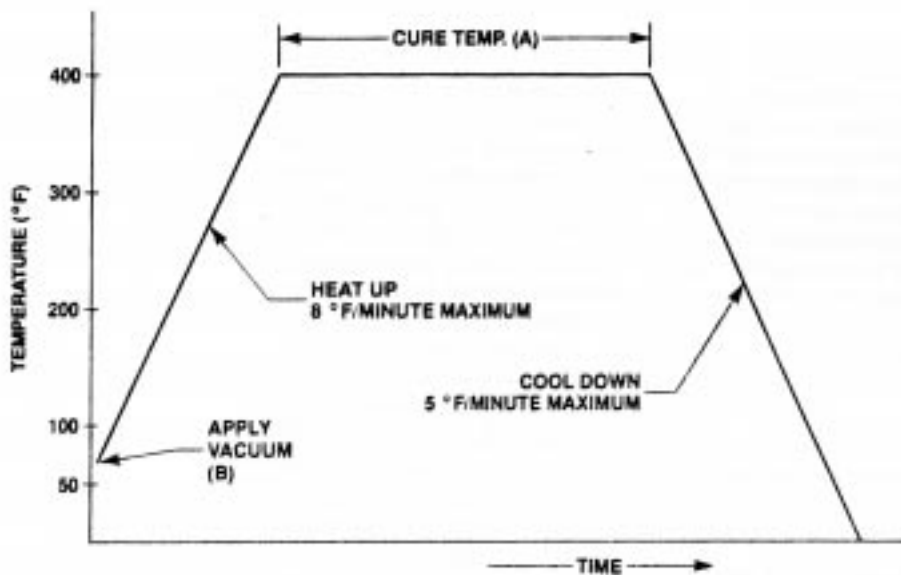
... nperature be ramped down to room temperature
... rate will take an hour and six minutes

CURE CYCLE FOR REPAIR PLIES

(A) REFER TO THE SPECIFIC COMPONENT REPAIR FOR THE REQUIRED CURE
    TEMPERATURE AND TIME.   EXAMPLES:
    *CURE AT 200 ^{0}F ±10 AND HOLD FOR 220 MINUTES MINIMUM
    *CURE AT 250 ^{0}F ±10 AND HOLD FOR 120 MINUTES MINIMUM
    *CURE AT 300 ^{0}F ±10 AND HOLD FOR 130 MINUTES MINIMUM
    *CURE AT 350 ^{0}F ±10 AND HOLD FOR 155 MINUTES MINIMUM

(B) MAINTAIN 22 INCHES VACUUM MINIMUM DURING ENTIRE CURE CYCLE.

Fig. 39.2, Profile for a ramp and soak cure.

(400^0 - 70^0 = 330^0, 330^0+5^0 each minute = 66 minutes). The entire heating and cooling cycle are combined graphically to depict a ramp and soak profile. Figure 39-2 is an example of a ramp and soak profile.

Structural Repair Manuals typically will not give the ramp up and down times. This is because the starting temperatures may not always be the same. If, for example (Figure 39-3), you are working outside in a cold climate and the temperature is 30 ^{0}F, and the final cure temperature is 250 ^{0}F, the ramp up will be a longer period of time. The same can be said for a climate which is very warm. If the outside temperatures is 105 ^{0}F, and the final cure temperature is 250 ^{0}F, the time it takes to ramp up will be substantially shorter to achieve the same final cure temperature (fig 39-4).
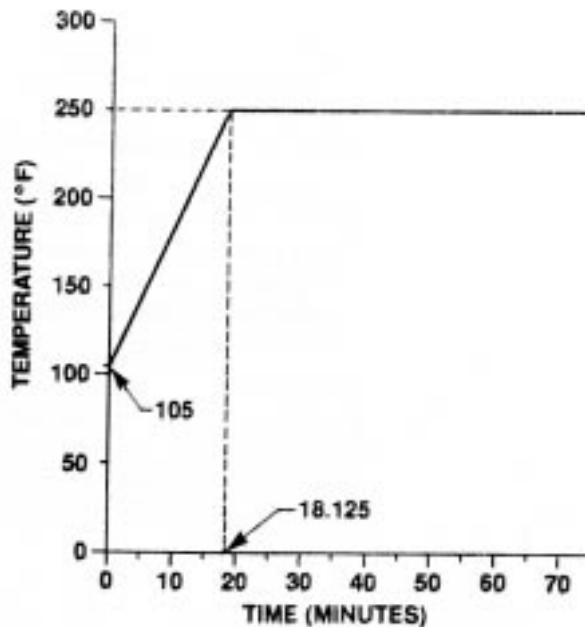
Fig. 39.4, Warm Climate. If the cure is to be done in a warm climate where the temperature outdoors is 105° F, the cure ramp up time is to be at eight degrees per minute. 250° - 105° = 145° + 8° = 18.125 minutes to climb to the cure temperature of 250 degrees at a rate of eight degrees per minute.

HEATING EQUIPMENT
Heat Lamps

The use of heat lamps to cure composite parts is *not* recommended. The temparature cannot be accurately controlled, and the heat may localise in one spot. Scorching or blistering of the part may occur if the heat lamp is too close, or is left on too long. Heat lamps generate high surface temperatures, which have a tendency to cure a repair too rapidly.

Fig. 39.5, Heat lamps are NOT recommended. They tend to overheat and heat only localized spots.

Drafts in the work area can also affect the amount of heat. The light of the heat lamp must hit all areas of the part. If there is a shadow on any area, it will not cure at the same rate as a part with the light shining on it.

A *templestik* or other temperature monitoring device can be used, but it must be monitored constantly. A templestick is a temperature sensitive crayon that will melt at the temperature at which it is rated,. Another temperature sensing device is a strip with temperature sensitive ink on it that will change colors when the heat reaches a certain temperature.

If nothing else is available, heat lamps may be used for accelerating the cure of room temperature resins. They should not be used on resins that need to be cured at a higher manufacturing temperature.

Heat Guns
When a heat gun is used to cure a composite part, it must be controlled with a monitor. A typical heat gun can generate temperatures of 500 to 750°F when it is left on constantly. If the cure temperature is 350°F and a heat gun is used to cure the component, the heat gun should be monitored with a controller to maintain a constant temperature.

To control a heat gun, a thermocouple is used with the controlling unit to keep the temperature constant. The controller will allow the heat gun to get up to the desired temperature, then the thermocouple senses that it is at the set temperature and will shut off the heat gun. The heat gun cycles on and off around this temperature to hold the temperature fairly constant.

Problems may occur if the heat gun is focused in one place on the repair. If a heat gun should shift position during the curing cycle, excessive evaporation of the resins in one spot amy leave dry areas which will be cause to reject the repair.

A heat gun is often used to cure repairs when the contour of the part will not allow the use of a heat blanket. On composite components with very contoured shapes, heat blankets sometimes lack enough flexibility to conform to the shape of some parts.

In this case, a tent around the part can be fabricated to hold the hot air within a confined area. The tent can be made of vacuum bagging film and attached to the part with sealant tape. To prevent excessive curing, be sure the heat gun is not pointed at the part. If the cure temperature of the part is 250°F, the bagging film used for the tent should be able to withstand a high heat range.

Another alternative to using bagging film as a tent is to use a cardboard box, or anything which will hold the heat in. Heat guns may present a fire hazard and should never be left unattended during the cure process.

If a tent-like structure is used with a heat gun, a shaded area is not a problem as it was with the heat lamps. The heat will reach all areas of the part.

Over Curing
Ovens offer controlled, uniform temperature over all surfaces. Some ovens have vacuum ports installed to provide

vacuum pressure while curing. Oven curing is frequently used by manufacturers. When using an oven for repair work, the part must be removed from the aircraft, and the part must be small enough to fit into the oven.

When an aircraft part has metal hardware attached, it should not be cured in an oven, because the metal will heat up at a faster rate than the composite. This uneven heating or high temperature may deteriorate the adhesives under the metal, causing failure of the bond.

Ovens may also present a problem by heating up the whole part, not just the repair area. The areas which are not being repaired are subjected to very high temperatures and may deteriorate the existing bond. Ovens which are used to cure composites must be certified for that purposed.

Autoclaves.
Autoclaves are usually used in the manufacture of composites and are not usually used in the repair procedures unless the part must be remanufactured. Autoclaves ay be used to remanufacture a part if the damage in very large and it is necessary to put the part into the original mold, and cure it with high heat and high pressure. In this case, the part is vacuum bagged and is heated to the curing temperature at a controlled rate, while additional pressure is applied within the autoclave. Normally, parts that are vacuum bagged are subject to one atmosphere of pressure, but an autoclave can apply substantially more pressure to a part. Two or three atmospheres of additional pressure may be added while the part is being manufactured, or cured, in an autoclave.

If the damage is large and extensive enough, it may be sent to a remanufacturing facility. Large manufacturing facilities have the molds and capabilities to repair large damaged surfaces. If an extensively damaged component is not cured with the molds and high heat and pressure, the part may not regain its original strength.

Caution should be taken when operating any autoclave. They can be very dangerous if not operated properly.
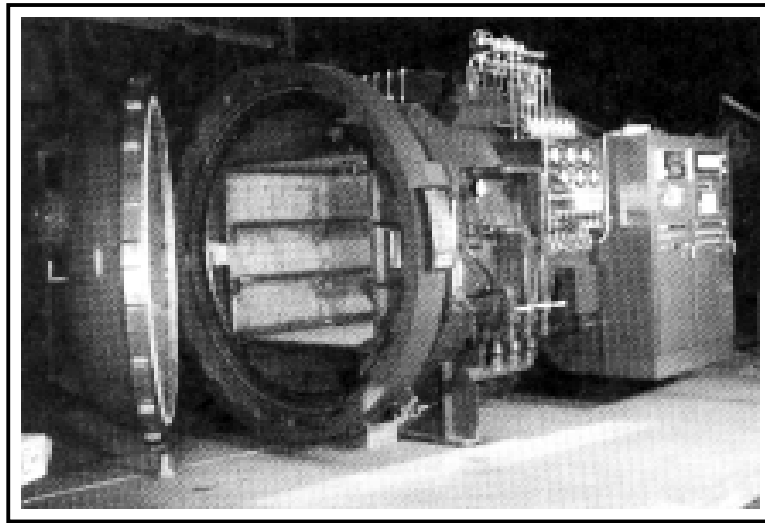
Fig. 39.6, An autoclave provides both heat and pressure under extremely controlled conditions. They are normally used for manufacturing.

Heating Blankets
Heating blankets are probably the most widely accepted form of applying heat to a composite component for repair work. They will uniformly heat the repair area without heating a larger area than necessary. They are usually used with a controller, or hot patch bonding machine, which means the accuracy of the cure is higher. They can be used with vacuum bagging to hold the heat directly into the surface.

Heat blankets are made of a flexible silicon and come in a variety of forms and sizes. Heating coils within the blanket are powered by a controller regulating unit. A thermocouple is used with the blanket it monitor the heat and to control the temperature.

Most manufacturers recommend the use of a heating blanket for curing repairs because of its ability to evenly heat the part. The ramp and soak method of heating is easily accomplished with the heat blanket method, and results in a stronger cure. The heat blanket must cover the repair completely, and usually is an inch or two larger than the largest size patch. However, if the heat blanket is too large, the heat may damage surrounding areas of the part.

The heat blanket is vacuum bagged into the repair area so that no matter where the repair is being done, the heat blanket will be next to the patches to be cured. For example, if the underside of a wing is to be repaired, the vacuum bagging film with vacuum applied will hold the heat blanket tightly to the patches as they are being cured.

Some heat blanket are very flexible, to bend around curved surfaces, yet others are made for flat use only. A flat heat blanket should not be used on a curved surface, as this may break the wires in the heat blanket. Flexible heat blankets are available to go around a curve, such as a leading edge.

If the part is sharply contoured, customized heat blankets made to the shape of a specific part can be used. This would most commonly be used if the same type and size of part is repaired repeatedly.

A typical bagging operation with the use of a heat blanket is shown in figure 39.7.
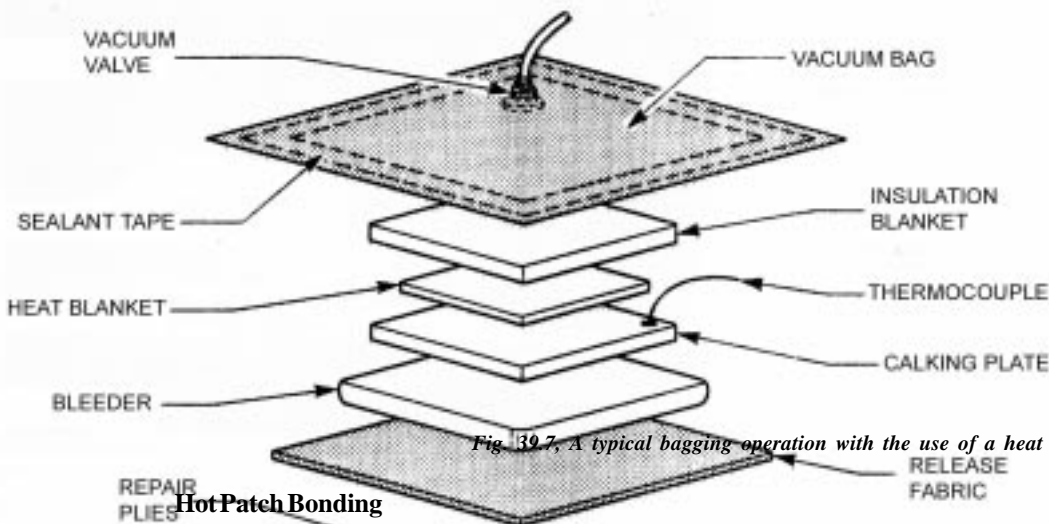
Fig. 39.7, A typical bagging operation with the use of a heat blanket.

Hot Patch Bonding

Simply stated, a hot patch bonding machine performs two functions :
1.   It applies atmospheric pressure by means of a vacuum pump.
2.   It applies heat, usually in the form of a heat blanket. Hot patch bonding makes use of heat blankets which have electrical coils bonded into a rubber pad or blanket. The heat blankets can heat up quickly, unless they have a monitoring unit to control the rate of temperature rise and to set the temperature.

If the shape of the part to be cured is sharply contoured, instead of using a heat blanket with the hot bonding machine, in some instances a heat gun may be used. A tent of bagging film is attached to the part to hold the heat in around the part. The heat gun is monitored with a thermocouple and the controller of the hot bonding unit.

The monitor or controller is a device which will maintain a constant temperature, or will change the temperature at a specific rate. In working with composites, the temperature must be controlled both at a constant and at a specific rate of change. It is critical to perform these functions with a minimum of effort and a maximum of efficiency in order to achieve professional results. The simplest function the controller will do is to maintain a specified temperature for the repair.
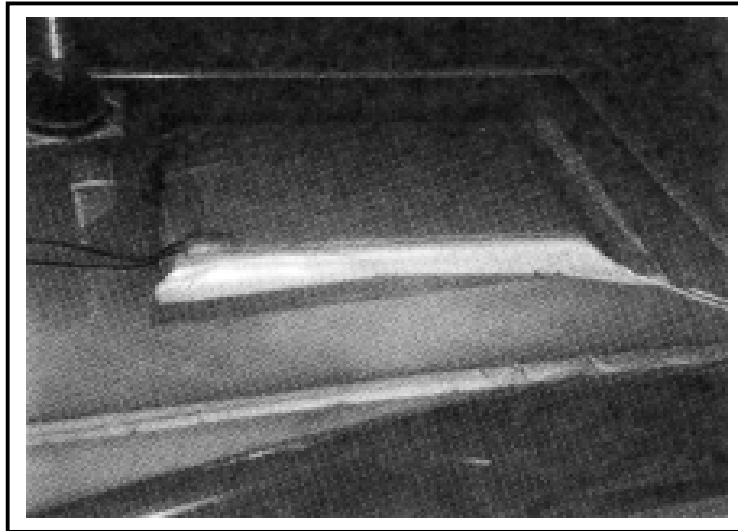
2Fig. 39.8, Hot patch bonding is accomplished with a heat blanket, and is normally used in conjunction with a vacuum bag. Controller devices are used and the temperatures and times should be recorded.

The specified temperature is called the "setpoint" of the repair and when the controller is working in this mode it is called a setpoint controller.

Another function the controller may be able to perform is the "ramp and soak." The controller allows the temperature to slowly rise at a specific rate, then hold the temperature constant, then allows a slow decline of temperature at a specific rate.

Recording the temperatures of the curing process can be accomplished using hot bonding units which are equipped with a temperature recording unit. Such controllers may use a recorder that is included in the control unit, or as a separate unit. In any case, some manufacturers require that permanent records of the cure cycle be included in the log of the aircraft repairs. A note of warning : Don't become dependent on the recording record as an assurance that the part was repaired correctly. There are many aspects of a repair that need close monitoring. Just because the repair was cured at the proper temperature does not mean that the repair is airworthy.

To use a controller, a thermocouple is placed beside the repaired area, under a heat blanket, and under the bagging film to sense what temperature is being delivered to the part. The thermocouple sends the temperature information to the controller. The controller adds heat or stops heating depending on how the controller is set.
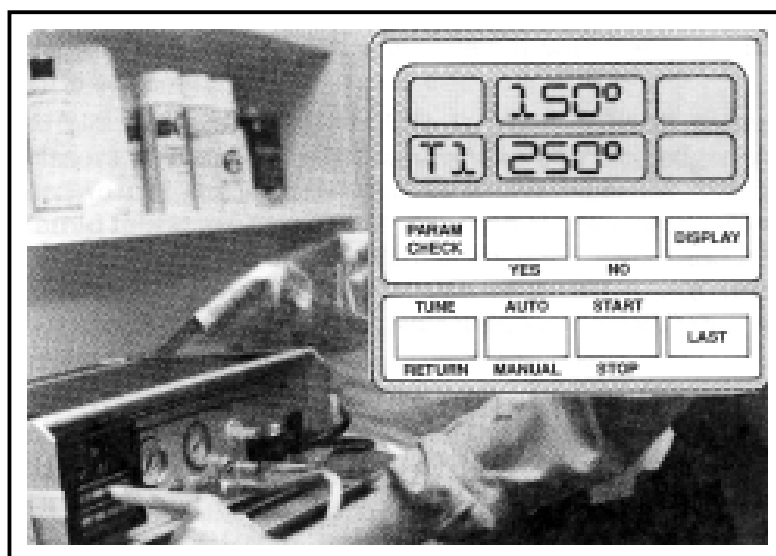
Fig. 39.9, controllers are actually fairly simple in their operation. Settings are straightforward, indicators are clearly represented, and programming is not complicated.

In the illustration of the controller face, the set pint is 250°F. If the thermocouple is only sensing 150°F, the controller will apply heat to the blanket or gun until the thermocouple senses 250°F. If the set point during the cooling down process is 150°F and the controller had previously been curing at 250°F, then the controller will not apply heat until the temperature dips slightly below 150°F.

To initially apply heat at the final cure temperature will not allow the resins enough time to flow properly before they go through their curing process. This may result in a resin rich area. For example, if 250°F is the final cure temperature and the controller applies heat, it will reach the 250°F is the final cure temperature and the controller applies heat, it will reach the 250°F mark as soon as it possibly can (usually within 30 seconds). The resin and catalyst mixtures need time to slowly start their chemical reaction before the final cure temperatures is reached.

It is also important to not turn off the heat and allow the part to cool too quickly, because composites gain much of their strength during the cooling down process which will also prevent the part from becoming brittle. A slow rate of temperature rise and decline is desirable, but can usually be achieved only if a monitor or controller is available.

A graph of the controller operating as a setpoint controller might look like figure 8 - 10. Here, the temperature climbs quickly from room temperature (T1) to a specified temperature (T2). There are many different ways in which a controller can be used.
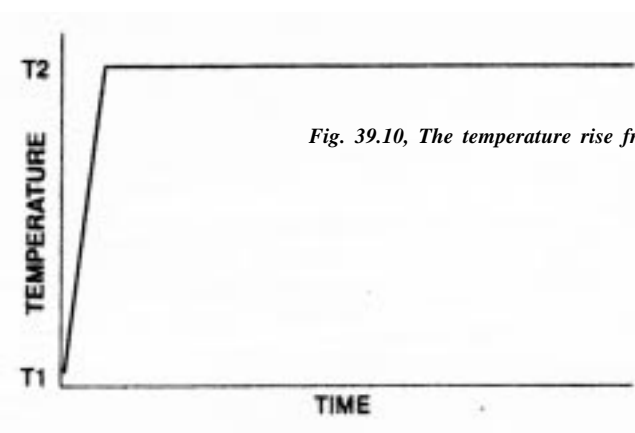
Fig. 39.10, The temperature rise from T1 (room temperature) to T2 (set point) would look like this graph.

CHAPTER-40
TYPE OF DAMAGES OF COMPOSITE AND THE METHODS OF INSPECTION.

COSMETIC DEFECTS

A cosmetic defect is a defect on the outer surface skin that does not involve damage of the structural reinforcing fibers. It may be caused by chipping or scratching during handling, does not usually affect the strength of the part, and is usually repaired for esthetic reasons. On some structural components made of either aramid or carbon/graphite, their top layer may be of fiberglass. If damage is to the fiberglass, it many times would e considered negligible or cosmetic damage.

IMPACT DAMAGE

Impact damage may occur if struck by a foreign object. The degree of damage may range from slightly to quite severe. Probably the most common cause of impact damage results from careless handling during transportation, storage, or by standing parts on their edge without adequate protection.

Because of the thin face sheets on a sandwich panel, they are susceptible to impact damage. An area which has been subjected to impact damage should also be inspected for delamination around the impacted area.

Nicking, chipping, cracking or breaking away pieces of the edge or corner can also be caused from improper handling.

DELAMINATION

Delamination is the separation of layers of material in a laminate. another type of delamination to a sandwich construction would be a separation of the skin to the core structure. Delamination can occur with no visible indications. To compound the problem, delamination often accompanies other types of damage, particularly impact damage. As figure 40.1 shows, delamination occurs when the discrete layers of reinforcing fibers separate from each other in a laminate, or from the core material in a sandwich structure. This can occur as the result of several causes among which are impact, moisture in the fabric or lightening strikes.

SEPARATION
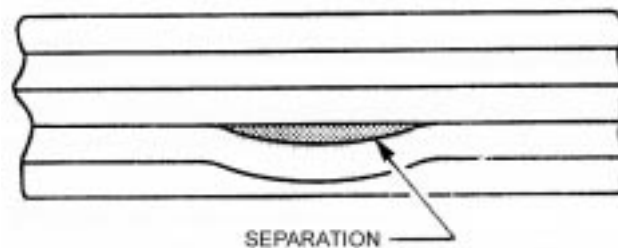
Fig. 40.1, Delamination of fabric layers

In those instances where visible damage has occurred, it is best to assume that the damage has radiated around the visual damage into areas which exhibit no visual damage. An air pocket between layers of fabric may also be the result of improper bonding of the composite. This may occur during manufacturing, or more often during a repair operation. If this is the case, it may have been caused by any of the following :

1.   Improper resin/catalyst
2.   Improper mixing or weighing of the two matrix components
3.   Inadequate amount of pressure or heat during the cure cycle.
4.   Improper cleaning of dirt, grease or foreign materials on the surface which is to be bonded.

CRACKS

Cracks can occur in advanced composite structures, just as in metallic ones. Sometimes they can be detected visually, other times they may require more advanced methods of NDI. A crack may be just in the top paint or matrix layer, and not penetrate into the fiber material at all. A crack may also extend into the fiber material and into the core, but appear to be just in the top surface. A thorough inspection should be made to determine the extent of each crack.

HOLE DAMAGE

Hole damage may occur from impact damage, over-torquing fasteners or as a result of fastener pull-through. Holes drilled in the wrong location, wrong size, or wrong number of holes can also be classified as hole damage.

Damage due to lighting strike may burn off resins, leaving bare cloth.

INSPECTION METHODOLOGY

Areas on the aircraft which are subject to damage, such as leading edges made of thin face sheets over a honeycomb panel, should be inspected more often than areas which are more protected by design, such as the vertical stabilizer. Visual inspection to these areas should be accomplished periodically, more in depth inspection should be done at regular overhaul intervals.

Many times the inspection method requires that the component be removed from the aircraft in order to be inspected correctly. This type of inspection is usually accomplished at the time of the aircraft's overhaul. Between overhaul inspections, visual inspection is usually adequate.

VISUAL INSPECTION

Visual inspection is used to detect cracks, surface irregularities (from an internal flaw), and surface defects such as delamination and blistering. A visual inspection will usually detect surface flaws. A light and magnifying glass are useful in detecting cracked or broken fibers. A small microscope is helpful in determining whether the fibers in a cracked surface are broken, or if the crack affects only the resin.

Delaminations may sometimes be found by visual inspection, if the are is examined at an angle with a bright light shown on the surface. The delaminated area may appear to be a bubble, or an indentation in the surface. A coin tap test should be used if you suspect an area of delamination.

COIN TAP TEST

To detect internal flws, or areas suspected of delaminations, a coin tap test is used. Coin tap lightly along a bond line or area suspected of having delaminations. Listen for variations in the tapping sound. a sharp solid sound indicates a good bond. A dull thud indicates bond separation. However, changes in the thickness of the part, reinforcements, fasteners, and previous repairs may give flase readings. Whenever damage is found visually, coin tap around the area to find damage such as a delamiantion that cannot be seen visually. Much of the time if there is a hole, crack, or other damage, there is also delamination around the area.
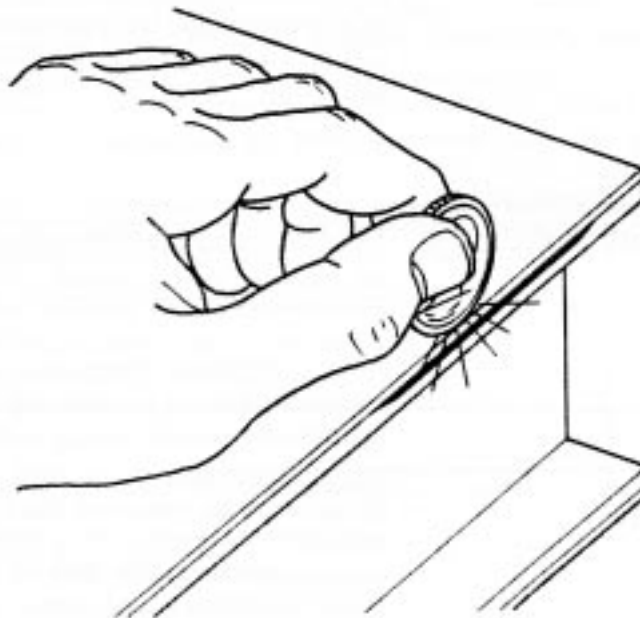
Fig. 40.2, Coin tap test.

ULTRASONIC INSPECTION

For internal damage inspection an ultrasonic tester may be used. Ultrasonic testing uses a high frequency sound wave as a means of detecting flaws in a part. This is done by beaming a high frequency wave through the part and viewing the echo pattern on an oscilloscope. By examining the variations of a given response, delaminations, flaws or other

conditions are detected. A newer type of ultrasonic machine has been recently developed to detect flaws in honeycomb cores. Ultrasonic equipment may be ineffective for detecting some types of damage on some composite structures.
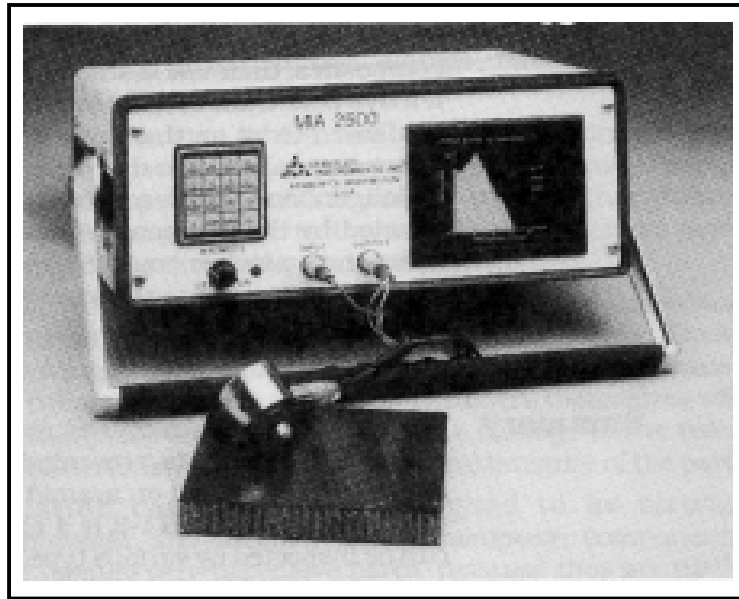
Fig. 40.3, Ultrasonic tester for composite use. (Stavely Instruments).

THERMOGRAPHY

Thermography locates flaws by temperature variations at the surface of a damaged part. Heat is applied to the part, then the temperature gradients are measured using an infrared camera or film. Thermography requires a knowledge of the thermal conductivity of the test specimen and a reference standard for comparison purposes.

LASER HOLOGRAPHY

This process calls for the suspect part to be heated and then photographed using a laser light source and a special camera system. It is used to detect disbonds or water in honeycomb and impact damage.

RADIOGRAPHY

Radiography can be used to detect cracks in the surface as well as internal cracks that cannot be visually detected. Radiography will also detect water inside the honeycomb core cells. It is useful in detecting the extent of the damage that cannot be visually detected.

HARDNESS TESTING

After a repair has cured, a hardness tester, such as the Barcol, could be used to determine whether the resins have reached their proper strength. A special chart is used to interpret the results for different types of resins and pre-pregs. Hardness testing does not test the strength of the composite, but only the matrix strength.

DYE PENETRANT

Dye penetrant has been used successfully for detecting cracks in metallic surfaces, however, with the advanced composites, their use is still questioned. The reason is that if a dye penetrant is used on the composite structure and is allowed to sit on the surface, the wicking action of the fibers may take in the dye penetrant and then they would no longer bond to new material. The entire area which was affected by the dye penetrant would have to be removed before new patches could be applied. This in effect could extend the damage to the size which would make the part non-repairable.

SUMMARY

Carbon/graphite structures are easier to inspect with some of the methods presented. Ultra sound and x-ray may not be as useful on aramid or honeycomb composite components. Figure 40.5 is a chart showing defects that can be inspected by various types of inspection equipment.

Fig. 40.4, Defects that can be located by various types of inspection equipment.

INSPECTION	SERVICE-INCURRED DEFECTS						
	IMPACT	DELAMINATIONS/ (DISBONDS)	CRACKS	HOLE DAMAGE	WATER	LIGHTNING STRIKE	BURNS/ OVERHEATING
VISUAL	X		X	X		X	X
X-RAY	X		X	X	X	X	
ULTRASONIC		X	X				

CHAPTER-41
LIGHTNING PROTECTION OF COMPOSITE STRUCTURES

No matter whether an aircraft is aluminum or composite when lightning hits an aircraft it needs a path for the electricity to flow through. Aircraft require electrical contact between all metallic and composite parts in order to prevent arcing or fiber damage. Aluminum is used to provide a conductive path for the dissipation of the electrical energy. This path is usually provided to static wicks.

Since composites do not conduct electricity, lightning protection has to be built into the component. If there is no lightning protection in the composite and the lightning exits through the composite component, the resins in the composite will evaporate, leaving bare cloth. This is why it is so important during the repair procedure to replace any lightning protection that may have been removed during the repair operation.

Refer to the section on manufacturing that spells out the types of lightning protection which is used on many composite aircraft.

Whatever type of lightning protection is used, when a repair is made the part must be restored to provide a path for the dissipation of an electrical charge.

If the aluminum wires are woven into the top layer or if a fine aluminum screen is used under the top layer, the repair is accomplished by laying in all the repair plies into the sanded area until the ply is reached which has the aluminum protection. A fine screen of aluminum is then placed on top of the repair plies before proceeding.

Care should be take to line up the wires so that the new aluminum wires contact the wires in the original part. If the wires don't contact each other, there will not be a path for the electrical charge to follow and the charge will exit out the repair. Once the aluminum screen patch is installed, the fiber patch is put into the repair, and cured into place.

After curing, a test should be made to see if there is continuity. This can be accomplished by scratching the surface of the original part and inserting an ohmmeter probe. The repair area is also scratched and the other probe of the ohmmeter is placed on it. There should be a good conductance between these areas. If there is good continuity between these areas, the lightning charge will be able to flow through the structure and out to a static port.

There may be a problem in attempting to bond a thin aluminum film, rather than a screen, to the repair area. The resins cannot flow through the aluminum sheet, and the bottom repair plies may be resin rich. This type of aluminum should be installed after the part has completely cured and is bonded on with an adhesive. If the part was originally flame sprayed with aluminum or painted with aluminised paint, it should be applied following manufacturer's instructions.

PAINTING THE COMPOSITE PART
After completing a repair, the part should be painted. For most aircraft, the same type of paint that is used for the metal portions of the aircraft is suitable for use on the composites. Some companies, such as Boeing, use a layer of Tedlar® on the composite before painting. Tedlar is a plastic coating which serves as a moisture barrier.

Gel Coats
A gel coat is a polyester resin which is used during the manufacturing of the part. The manufacturing mold is coated with a color coat of polyester resin. The plies are laid down onto the surface of the colored gel coat and impregnated with an epoxy resin.

After curing, the gel coat is on the outside surface and provides a smooth finish. The plies of fibers which are embedded with the epoxy are the structural part of the aircraft. The gel coating is not structural, it is more like a paint coat. Gel coats were used on gliders extensively in the 1970s.

The problem with gel coats is that because they are made of polyester resin, they are not very strong, or flexible. If the aircraft is parked outside in the sun and weather, the gel coat may crack. The aircraft must be inspected to see if the fibers themselves are cracked, and not just the gel coat. If only the gel coat is cracked, there is no structural damage. However, if the fibers are cracked, the structure will have to be repaired.

Gel coats cannot be rejuvenated as dope on fabric can. The gel coat must be sanded off and reapplied. Many aircraft owners who have had problems with the gel coat will sand off the gel coat surface and paint the surface with one of

the new generation of paints that are very flexible and can take the weather. Care should be taken when sanding the coat off, because the fibers were manufactured into the wet gel coat and the gel coat thickness will not be perfectly even. Do not sand through the fibers.

Fill primers can sometimes be used over the repair, but again, don't add too much weight to the repair, or you will just be ruining the whole idea of using composite parts on the aircraft in the first place. Light weight and high strength are the key to doing proper composite repair work.

RECORDING YOUR WORK

A log entry or FAA Form 337 must be prepared to show conformance to the recommended repair procedure. These items should be included in your records :
1.   Par and serial number.
2.   Steps taken to restore the item to a serviceable condition.
3.   Cross-reference to the manufacturing record.
4.   Time, temperature, and pressure used in the repair cure cycle.
5.   Type of fabric material, type of matrix and adhesives used, and type of core material used.

QUALITY CONTROL

Quality control is exercised to ensure that during the repair operations, the proper steps are followed and that the final repair will meet the requirements of the manufacturer.
1.   Remove and discard all peel ply, release film, bleeder, breather, sealant tape, and bagging film from the repair area once the repair has been cured.
2.   Check to see if the repair has cured properly (hardness testing).
3.   Any delamination of the skin to core is cause for rejection of the repair.
4.   Voids may be cause for rejection.
5.   Check for any white areas which would indicate that excessive heat may have caused the resins to bleed out, leaving only fabric.
6.   Check that there is not excessive foreign material in the repair. Many manufacturers will give a maximum amount of foreign material that can be included and still be an airworthy repair.
7.   Check for excessive resin on the edges. This is usually not allowed.
8.   Blisters or white areas could be an indication of moisture in the composite during cure.
9.   If lightning protection was installed during the lay-up, there should be good electrical continuity (check with ohmmeter).
10.   Check for brown sport on the part, which would indicate oil or grease contamination.
11.   All repairs should be inspected to the requirements of the manufacturer, which may or may not included NDT inspections.
12.   Lightly sand the edges to produce a feathered edge before painting.
13.   Clean the part and prepare the surface for painting.
14.   Paint the structure with the original type of paint, in accordance with manufacturers specification.
15.   If this is a control surface, it must be rebalanced.

There are a number of other composite repairs for specific aircraft parts, which can be found in the appropriate structural repair manual for different aircraft. The repairs discussed in this chapter were only a sampling of the most common repairs, and many repairs were simplified for training purposes. In any repair situation, the structural repair manual for each aircraft should be consulted before performing any repair. This book is intended to familiarize the technician with basic repair techniques, terminology, tools and materials frequently used in composite repair. After being properly trained, a technician should be able to easily translate the manufacturer's instructions into airworthy repairs using skills and knowledge gained.

CHAPTER-42
COMPOSITE TERMINOLOGY

Accelerator A chemical additive that quickens cure, or a chemical reaction.

Adhesive A substance which is applied to two mating surfaces to bond them together by surface attachment.

Adhesive Film Premixed adhesives cast onto a thin plastic film. Requires refrigerated storage.

Advanced Composites A fibrous material embedded in a resin matrix. The term "advanced" applies to those materials which have superior strength and stiffness and the process in which they are manufactured.

Alloy A blend of polymers or copolymers with other polymers or elastomers. Also called polymer blend.

Areal Weight The weight of a fiber reinforcement per unit area (width × length) of tape or fabric.

Aspect Ratio The ratio of length to diameter of a reinforcing fiber.

Autoclave A large vessel used to cure laminates and bonded parts, using pressure, vacuum and heat in an inert atmosphere.

Bagging applying an impermeable layer of film over an uncured part and sealing the edges so that a vacuum can be drawn.

Bag side The side of a part that is cured against the vacuum bag.

Balanced Design In filament-wounding, a winding pattern so designed that the stresses in all filaments are equal.

Balanced Laminate See Symmetrical Laminate.

Basket Weave In this type of woven reinforcement, two or more warp threads go over and under two or more filling threads in a repeat pattern. The basket weave is less stable than the plain weave but produces a flatter and stronger fabric. It is also a more pliable fabric than the plain weave and maintains a certain degree of porosity without too much sleaziness, although not as much as the plain weave.

Batch (or Lot) Material that was made with the same process at the same time having identical characteristics throughout.

Bearing Area The cross-section area of the bearing load member on the sample.

Bearing strain The ratio of the deformation of the bearing hole, in the direction of the applied force, to the pin diameter.

Bearing Stress the applied load in pounds divided by the bearing area

Bias A 45-degree angle to the warp threads. Fabric can be formed into contoured shapes by suing the bias.

Bidirectional Cloth a cloth in which the fibers run in various directions. Usually woven together in two directions.

Bleed An escape passage at the parting line of a mold (like a vent, but deeper), which allows material to escape, or bleed out.

Bleeder A layer of material used during the manufacture or repair of a part to allow entrapped air and resin to escape. It is removed after curing. It also serves as a vacuum valve contact with the part.

Blister   Undesirable rounded elevation of the surface of a plastic, and somewhat resembling in shape a blister on the human skin.

Bond Ply   The ply or fabric patch which comes in contact with the honeycomb core.

Boron Filament   A strong, lightweight fiber used as a reinforcement. Has a high strength to weight ratio.

Braiding   Weaving of fibers into a tubular shape instead of a flat fabric.

Breakout   When drilling or cutting the edges of a composite part, the fibers may separate or break.

Breather   A loosely woven fabric used to provide venting and pressure uniformly under a vacuum cure. Breather material is used under the vacuum valve to allow the air to be evacuated inside the vacuum bagged part. Removed after curing.

Bridging   This term can refer to plies of fabric over a curved edge that don't come in full contact with the core material. It is also used to describe excess resin that has formed on edges during the curing process.

Buckle Line   On a honeycomb core, it is a line of collapsed cells with undistorted cells on either side. It usually is found on the inside of the radius on a formed core.

Carbon Fiber   Produced by placing carbon (an element) in an inert atmosphere at temperatures above 1,800 degrees F. Used as a reinforcing material.

Carbon/Graphite Fiber or Fabric   A fiber used in advanced composites comprised of carbon filaments which may be woven together. The terms carbon and graphite have been used interchangeably for years. The Americans prefer the term graphite, while the Europeans prefer carbon. Depending on the manufacturer of the aircraft, different terms may be used. The term Carbon/Graphite is used throughout this book to include both terms.

Catalyst   A substance which initiates a chemical reaction.

Catalyzed Resin   A term used to describe the resin mixture after it has been mixed with the catalyst or hardener. It may still be in the workable state.

Caul Plates   Smooth plates used during the cure process to apply pressure in a uniform manner.

Coefficient of Expansion   A measure of the change in length of volume accompanying a unit change of temperature.

Coefficient of Thermal Expansion   The change in unit of length of volume accompanying a unit change of temperature.

Cohesion   The tendency of a single substance to adhere to itself. The force holding a single substance together.

Coin Tap   The use of a coin to tap a laminate in different spots to detect a change in sound, which would indicate the presence of a defect.

Composite   Two or more substances which are combined to produce material properties not present when either substance is used alone.

Contaminant   An impurity or foreign substance present in a material or environment that affects one of more properties of the material, particularly adhesion.

Core   The central member of a part (usually foam or honeycomb). Produces a lightweight, high strength component when laminated with face sheets.

Core Crush   Compression damage of the core.

Core Depression   A gouge or indentation in the core material.

Core Orientation   On a honeycomb core to line up the ribbon direction, thickness of the cell depth, cell size, and transverse direction.

Core Separation   A breaking of the honeycomb core cells.

Core Splicing   Region of ultrafine cracks, which may extend in a network on or under the surface of a resin or plastic material.

Crazing   Region of ultrafine cracks, which may extend in a network on or under the surface of a resin or plastic material.

Critical Strain   The strain at the yield point.

Cross Linking   With thermosetting and certain thermoplastic polymers, the setting up of chemical links between the molecular chains.

Cross-ply Laminate   A laminate with plies usually oriented at 0° and 90° only.

Cure   To change the physical properties of a material by chemical reaction, by the application of catalysts, heat and pressure, alone or in combination.

Curing Agent   a catalytic or reactive agent that causes cross linking. Also called a hardener.

Delaminate   The separation of layers due to adhesive failure. This also includes the separation of the layers of fabric to a core structure. A delamination may be associated with bridging, drilling, and trimming.

Doubler Plies   A patch that extends over the sanded out area to the existing structure.

Drape   The ability of a fabric or pre-preg to conform to a contoured surface.

Dry Fiber   A condition in which fibers are not fully encapsulated by resin during pultrusion.

Dry Laminate   A laminate containing insufficient resin for complete bonding of the reinforcement.

Eight-harness Satin   A type of fabric weave. The fabric has a seven-by-one weave pattern in which a filling thread floats over seven warp threads and then under one. Like the crowfoot weave, it looks different on one side than on the other. This weave is more pliable than any of the others and is especially adaptable to forming around compound curves, such as on radomes.

Environmental Stress Cracking (ESC)   The susceptibility of a resin to cracking or crazing when in the presence of surface-active chemicals.

Epoxy Plastic   An important matrix resin in reinforced composites and in structural adhesives.

Epoxy Resin   A common thermoset material used in aircraft construction. Used as the bonding matrix to distribute the stresses to the fibers, and hold the fibers together. When mixed with a catalyst, they are adhesive, resistant to chemicals, are water resistant and are unaffected by heat or cold. One part of a two-part system, which combines the resin and the catalyst to form the bonding matrix. In composites, the term "resin" is often used to describe the two parts mixed together.

Fabric   Individual fibers woven together to produce cloth. Unidirectional or matted fibers may be included in this classification.

Fabric Warp Face   That side of a woven fabric on which the greatest number of yarns are parallel to the selvage.

Faying Surface   The surfaces of materials in contact with each other and joined or about to be joined.

Fiber   A single strand of material, used as reinforcement because of its high strength and stiffness.

Fiber Bridging	Reinforcing fiber material that bridges an inside-radius of a pultruded product. This condition is caused by shrinkage stresses around such a radius during cure.
Fiber Content	The amount of fiber in a composite expressed as a ratio to the matrix. The most desirable fiber content is a 60:40 ratio. This means there is 60% fiber and 40% matrix material.
Fiber Direction	The orientation of the fibers in a laminate.
Fiber Reinforced Plastics FRP	Term used interchangeable for advanced composites.
Fiberglass	A glass fiber produced by spinning molten glass into long continuous fibers, used as a fiber reinforcement.
Fiberglass Reinforcement	Major material used to reinforce plastic.
Filament	The smallest unit of a fibrous material.
Filament Winding	A long continuous fiber wound around a mandrel to produce a structure.
Fill Threads	Also known as the Weft. These are the crosswise fibers woven at 90 degrees to the warp fibers.
Filler	Material added to the mixed resin to increase viscosity, improve appearance, lower the density and cost.
Filler Ply	An additional patch to fill in a depression in the repair, or to buildup an edge.
Film	Sheeting having a nominal thickness not greater than 0.25 mm (0.010 in.).'
Film Adhesive	A synthetic resin adhesive, usually of the thermosetting type, in the form of a thin, dry film of resin.
Fish Eye	A small, globular mass that has not completely blended into the surrounding pultruded material.
Four-harness Satin	A fabric weave, also called crowfoot sating because the weaving pattern resembles the imprint of a crow's foot. In this type of weave there is three-by-one interlacing.
Gel Coat	A Coating of resin, generally pigmented, applied to the mold or part to produce a smooth finish. Considered as a nonstructural finish.
Gel Time	The period of time from the initial mixing of the reactants of a liquid material composition to the point in time when gelation occurs, as defined by a specific test method.
Glass Cloth	See Fiberglass.
Graphite	A carbonised fiber used as reinforcement. See Carbon Fiber and Carbon/Graphite Fiber.
Hand Lay-Up	Assembling layers of reinforcement by hand. This many tines also includes the working in to the resin yourself, as opposed to using a pre-preg fabric.
Hardener	See Catalyst.
Harness Satin	A weaving pattern producing a satin appearance. See also eight-harness satin and four-harness satin.
Honeycomb	A core material resembling natural honeycomb to produce a lightweight, high strength component.
Hot Bond Repair	a repair made using a hot patch bonding machine to cure and monitor the curing operation. Hot bonding equipment typically includes both the heat source and the vacuum source.

Hybrid   The combination of two or more types of reinforcing materials into the composite structure.

Impregnate   In reinforcing plastics, to saturate the reinforcement with a resin.

Inclusion   A physical and mechanical discontinuity occurring within a material or part.

Kevlar   Trademark of DuPont. A strong, lightweight aramid fiber used as a reinforcement fiber.

Laminate   A structure made by bonding together two or more layers of material with resin. It contains no cor material.

Laminate Orientation   The geometric configuration of a cross-plied composite laminate.

Laminate Ply   One fabric-resin or fiber-resin layer that is bonded to adjacent layers in the curing process.

Lap Joint   A joint made by placing one adherend partly over another and bonding the overlapped portions.

Lay-up   Reinforcing material that is placed in position in the mold.

Matrix   The material that bonds the fibers together, and distributes the stress to the fibers. Typically in advanced composites, the matrix is a resin, more specifically an epoxy resin. There are new advancements being developed using metal as the matrix material.

Microballoons   Very small glass or phenolic spheres used as a filler.

Moisture Absorption.   The pickup of water vapor from air by a material, in reference to vapor withdrawn from the air only, as distinguished form water absorption, which is the gain in weight due to the absorption of water by immersion.

Mold   The hollow form used to give shape to a laminate part while curing.

Mold Release Agent   A lubricant used to prevent the part from sticking to the mold.

Nomex   Trademark of DuPont. A nylon paper treated material that is made into a honey comb core material.

Nondestructive Testing (NDT)   Broadly considered synonymous with non-destructive inspection (NDI).

Nylon   The generic name, by common usage, for all synthetic polyamides.

Orientation   The alignment of the crystalline structure in polymeric materials to produce a highly aligned structure.

Out Time   The time a pre-preg is exposed to ambient temperature, namely, the total amount of time the pre-preg is out of the freezer.

Parallel Laminate   a laminate of woven fabric in which the plies are aligned in the same position as they were on the fabric roll.

Parting Agent   See mold release agent.

Parting Film   A layer of thin plastic to prevent bagging materials form sticking to the part. It ma be perforated to vent excess resin. It is removed after cure. May be used instead of Peel Ply.

Peel Ply   A layer of fabric used in manufacturing to vent excess resin, and prevent bagging materials from sticking to the part. it is removed after cure.

Phenolic Resin   a thermosetting resin produced by the condensation of an aromatic alcohol with an aldehyde, particularly of phenol with formaldehyde.

Pin Holes   Small holes caused by the mold used.

Plain Weave   A weaving pattern in which the warp and fill fibers alternate; that is, the repeat pattern is warp/fill/warp/fill.

Ply   One layer of reinforcement in a laminate.

Polyvinyl Chloride (PVC) A thermoplastic material composed of polymers of vinyl chloride. It is widely used for commercial cable and wire coverings and in the manufacture of protective garments.

Porosity   A condition of trapped pockets of air, gas, or vacuum within a solid material.

Pot-Life   The length of time that the resin, mixed with catalyst, will be in a workable state.

Preform   A preshaped fibrous reinforcement of mat or cloth formed to the desired shape on a mandrel or mock-up before being placed in a mold press.

Preimpregnation   The practice of mixing resin and reinforcement and effecting partial cure before use of shipment to the user. See also pre-preg.

Pre-Preg   Reinforcing material that is pre-impregnated with resin. Usually requires refrigerated storage.

Process Control Record   A record of the materials and processes used in making the repair.

Puckers   Local areas on pre-preg material where the material has blistered and pulled away from the separator film or release paper.

Puncture   A break in the skin that may or may not go through to the core material, or completely through the part.

Reinforcement   Material used to strengthen the matrix. Fiber reinforced plastic is an example. Fibers are used to reinforce the plastic material.

Release Film   See Parting Film.

Resin   A type of Matrix system used when mixed with a hardener or catalyst. The term resin is sometimes used to describe the matrix.

Resin Rich   An area which has an excess amount of matrix. A resin rich laminate usually is more brittle and weighs more than laminates with the proper amount of resin.

Resin Ridge   A ridge of excess resin that contains only resin.

Resin Starved   An area which is deficient in resin.

Resin System   A mixture of resin and ingredients required for the intended processing method and final product.

Ribbon Direction   On a honeycomb core, the way the honeycomb can be separated. The direction of one continuous ribbon.

Sandwich Structure   A thick, low density, core between thin faces of high strength material.

Satin   A type of finish having a satin or velvety appearance, specified for plastics or composites.

Scarf joint   A joint made by cutting away similar angular segments on two adherends and bonding the adherends with the cut areas fitted together.

Sealant   a material applied to a joint in paste or liquid form that hardens or cures in place, forming a seal.

Secondary Structure   In aircraft and aerospace applications, a structure that is not critical to flight safety.

Selvage Edge   A manufactured woven edge on fabric. It is removed for all fabrication and repair work.

Separator   A permeable layer that also acts as a release film. Porous Teflon ®-coated fiberglass is an example. Often placed between lay-up and bleeder to facilitate bleeder systems removal from laminate after cure.

S-glass   A magnesium aluminosilicate composition that is especially designed to provided very high tensile strength glass filaments.

Shear   An action or stress resulting from applied forces that causes or tends to cause two contiguous parts of a body to slide relative to each other.

Shelf Life   The time span that a product will remain useful. This should be listed on the label. Temperature during storage will affect the shelf life.

Slashing   Cutting or slicing the core material.

Solvent   A liquid used for dissolving and cleaning materials.

Starved Area   An area in a plastic part that has an insufficient amount of resin tow wet out the reinforcement completely.

Starved Joint   An adhesive joint that has been deprived of the proper film thickness of adhesive due to insufficient adhesive spreading or to the application of excessive pressure during the lamination process.

Stiffness   The relationship of load and deformation. The ratio between the applied stress and resulting strain.

Storage Life   The period of time during which a liquid resin, packaged adhesive, or pre-preg can be stored under specified temperature conditions and remain suitable for use. Also called shelf life.

Strain   In tensile testing, the ratio of the elongation of the test specimen, that is, the change in length per unit of original length. Strain is a nondimensional quantity, but is frequently expressed in inches per inch, meters per meter, or percent.

Strand   Normally, an untwisted bundle or assembly of continuous filaments used as a unit. Sometimes a single fiber or filament is called strand.

Stress Concentration The magnification of the level of an applied stress in the region of a notch, void, hole, or inclusion.

Stress corrosion   Preferential attack of areas under stress in a corrosive environment, where such an environment alone would not have caused corrosion.

Stress Crack   External or internal cracks in a plastic caused by tensile stresses less than that of its short-time mechanical strength. The stresses that cause cracking may be present internally or externally or may be combinations of these stresses.

Structural Adhesive   Adhesive used for transferring required loads between adherends exposed to service environments typical for the structure involved.

Structural Bond   A bond that joins basic load-bearing parts of an assembly. The load may be either static or dynamic.

Strux   A foam like material used to form structural sections for stiffening.

Substrate   A material upon the surface of which an adhesive-containing substance is spread fro any purpose, such as bonding or coating.

Surface Treatment   A material (size or finish) applied to fibrous material during the forming operation or in subsequent processes. For carbon fiber surface treatment, the process used to enhance bonding capability of fiber to resin.

Symmetrical Laminate A laminate in which the stacking sequence of plies below its midplane is a mirror image of the stacking sequence of plies below its midplane is a mirror image of the stacking sequence above the midplane.

Tack   Stickiness of an adhesive or filament reinforced resin pre-preg material.

Tedlar   a material used on the surface as a waterproof barrier.

Telegraphing   Dimpling of the repair plies into the honeycomb core.

Tensile Strength   The pulling stress required to break a given specimen.

Thermal Stress Cracking The crazing and cracking of some thermoplastic resins from overexposure to elevated temperatures.

Thermocouple   a wire assembly used with a control device to sense temperature readings.

Thermoplastic   a plastic material used in advanced composites as a matrix material. Heat is used during the forming operation. It is not a permanent shape, however, if heated again it will soften and flow to form another shape (Plexiglass windshield).

Thermoset   a plastic material used in advanced composites as a matrix material. Heat is used to form and set the part permanently. Once cured, it cannot be reformed by applying heat. Most composite structural components are made of thermoset plastics.

Thixotropic   In respect to materials, gel-like at rest, but fluid when agitated. Having high static shear strength and low dynamic shear strength at the same time. Losing viscosity under stress.

Toughness   A measure of the ability of a material to absorb energy.

Tracer   A fiber, tow, or yarn added to a pre-preg for verifying fiber alignment for distinguishing warp fibers from fill fibers.

Unidirectional   A fabric with all the major fibers running in one direction, giving strength in that direction.

Vacuum Bagging   A means of applying atmospheric pressure to a part while curing.

Viscosity   The property of resistance to flow exhibited within the body of a material.

Void   An empty area in the composite. The term void may be used in place of delamination.

Volatile Content   The percent of volatiles that are driven off as a vapor from a plastic or an impregnated reinforcement.

Volatiles   Materials, such as water and alcohol, in a sizing or resin formulation, that are capable of being driven off as a vapor at room temperature or at slightly elevated temperature.

Warpage   Dimensional distortion in a plastic object.

Warp Direction   The threads running the length of the fabric as it comes off the bolt. Parallel to the selvage edge.

Warp Face   The side of the fabric where the greatest number of yarns are parallel to the selvage edge.

Water Absorption   The ratio of the weight of water absorbed by a material to the weight of the dry material.

Water Break Test   Spraying water on a part to be bonded to assure there is no oil or grease contamination on the surface.

Weave   The particular manner in which a fabric is formed by interlacing yarns. Usually assigned a style number.

Weft Direction   Fibers that are perpendicular to the warp fibers. Sometimes referred to as the fill.

Wet lay-up   A method of making a reinforced product by applying the resin system as a liquid when the reinforcement is put in place.

Wet-Out   The condition of an impregnated roving or yarn in which substantially all voids between the sized strands and filaments are filled with resin.

Whisker   A short single-crystal fiber of filament used as a reinforcement in a matrix.

Wire Mesh   A fine wire screen sued to dissipate an electrical charge from lightning.

Working Life   The period of time during which a liquid resin or adhesive, after mixing with catalyst, solvent, or other compounding ingredients, remains usable.

Woven Fabric   A material constructed by interlacing yarns, fibers, or filaments to form fabric patterns.

Wrinkle   A surface imperfection in laminated plastics that has the appearance of a crease of fold in one or more outer sheets of the paper, fabric, or other base. Also occurs in vacuum bag molding when the bag is improperly placed, causing a crease.

Yarn   An assemblage of twisted filaments, fibers, or stands, either natural or manufactured, to form a continuous length that is suitable for use in weaving into textile materials.

Zero Bleed   A laminate fabrication procedure that does not allow loss of resin during cure.

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