Aircraft Metallurgy

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

CONTENTS

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UNIT - I
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, rotor*s* 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.

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.3.1The 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.
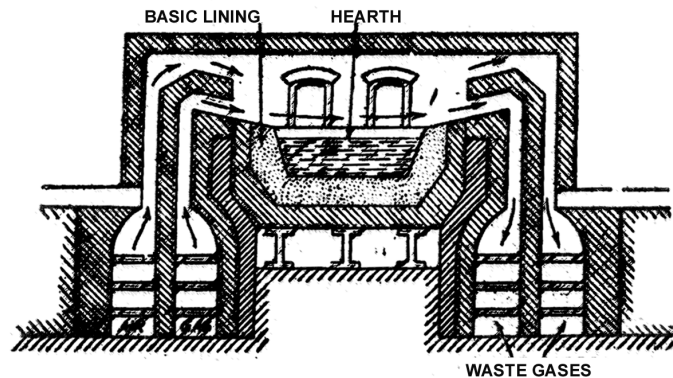

Fig.3.1 An open hearth furnace.

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 typeof 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.
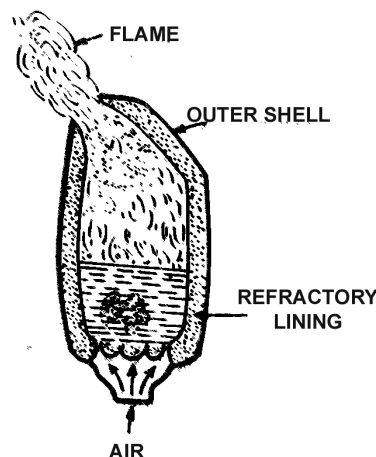

Fig.3.2 A Bessemer Converter

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 $25,00^0C$ 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.
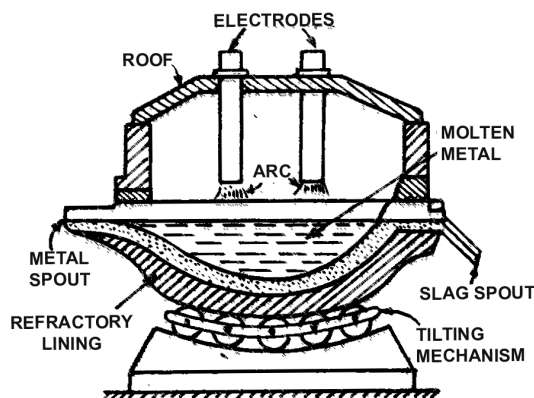

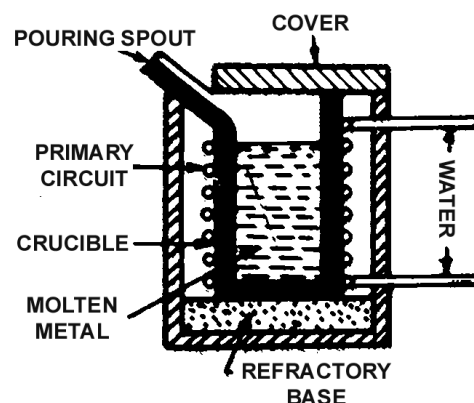Fig. 3.3. A direct arc furnace   Fig.3.4. High frequency

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 2000^0C 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 815^0C. Its yield strength and elongation properties can be substantially enhanced by age-hardening at 480^0C. 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 quenced 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.

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UNIT - II
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 600⁰C. 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% A1 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% A1, 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 700⁰C. 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.

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UNIT - III
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.
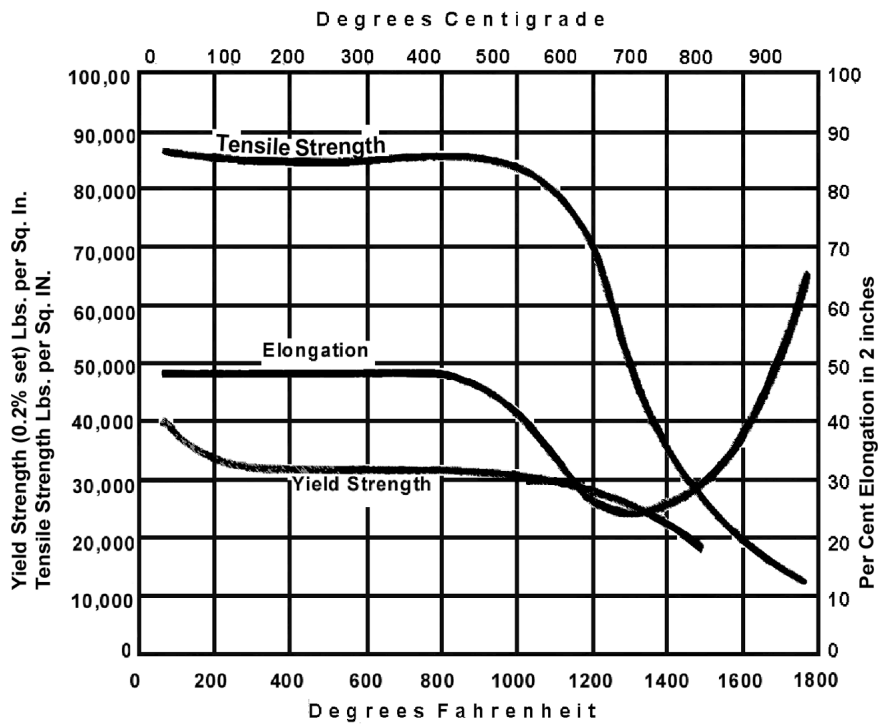
Fig.5.1.High-temperature Properties of Inconel

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 800⁰F to release coiling strains, a necessary treatment if springs are to operate at elevated temperature up to 750⁰F. 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.
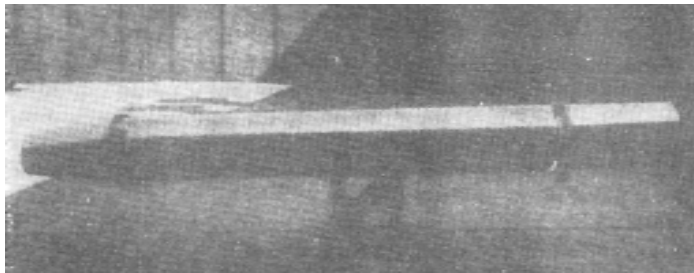
Fig.5.2. Jet Tail Pipe: Inconel.

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.
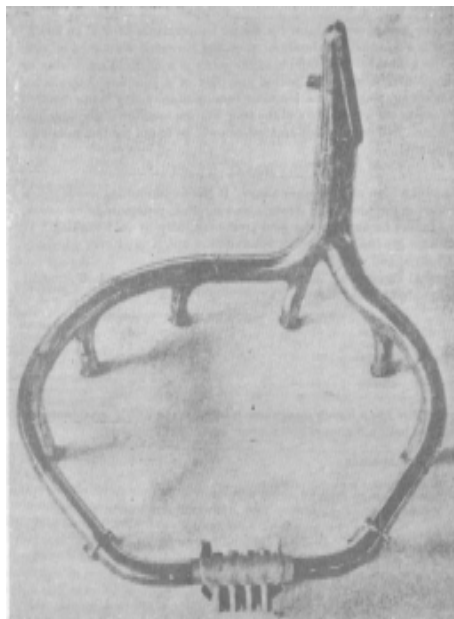
Fig.5.3.Exhaust Collector and Hot Spot ; Inconel

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^{0}F 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.

STRENGTH PROPERTIES

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 ($\frac{1}{8}$ to $\frac{1}{4}$ 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	2400-2460°F.
	(1315-1350°C.)
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.

STRENGTH PROPERTIES

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 :

     1600⁰F.   5 to 10 min.
     1800⁰F.   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. However, 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

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UNIT- IV
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- $\frac{1}{8}$ -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 $\frac{1}{8}$ to 1 $\frac{1}{8}$ inches outside diameter. A wall thickness of 0.035 inch is used up to $\frac{5}{8}$ -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 $\frac{3}{4}$ ”)	80,000 max.		35
Cold-drawn (over $\frac{3}{4}$ ”)	80,000 min.		5
Annealed ($\frac{3}{8}$ to $\frac{3}{4}$ ”)	80,000 max		35
Cold-drawn ($\frac{3}{8}$ to $\frac{3}{4}$ ”)	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
$\frac{1}{4}$ hard	80,000		10
$\frac{1}{4}$ hard, heat-treated	160,000	92,000	5
$\frac{1}{2}$ hard	90,000		5
$\frac{1}{2}$ 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
$\frac{1}{4}$ hard	90,000		5
$\frac{1}{4}$ hard, heat-treated	160,000		3
$\frac{1}{2}$ hard	100,000		2
$\frac{1}{2}$ hard, heat-treated	180,000		1.5

This material is annealed by heating at 1440^0F for $\frac{1}{2}$ 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 1500^0F. 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 (%)

</div>

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 $\frac{1}{2}$ inch	80,000	60,000	12
Over $\frac{1}{2}$ 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.

<div align="center">

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 $\frac{1}{2}$ in	90,000	45,000	15
Over $\frac{1}{2}$ 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 $\frac{1}{2}$ in, under 30 in wide	60,000	24,000	25
Up to $\frac{1}{2}$ in, over 30 in. wide	55,000	22,000	25
Over $\frac{1}{2}$ 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)
$\frac{5}{8}$	72.0	14,000
$\frac{9}{16}$	60.4	11,350

$1/2$	48.8	8,900
$7/16$	38.4	6,800
$3/8$	29.9	5,100
$5/16$	20.0	3,500
$1/4$	13.5	2,500
$7/32$	10.7	2,000
$3/16$	7.3	1,500
$5/32$	5.0	1,000
$1/8$	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.*

■■■

UNIT - V
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 $\frac{1}{3}$ 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 $\frac{1}{4}$ H, $\frac{1}{2}$ H, $\frac{3}{4}$ 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 $\frac{1}{4}$ H, 3S $\frac{1}{2}$ 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.

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.
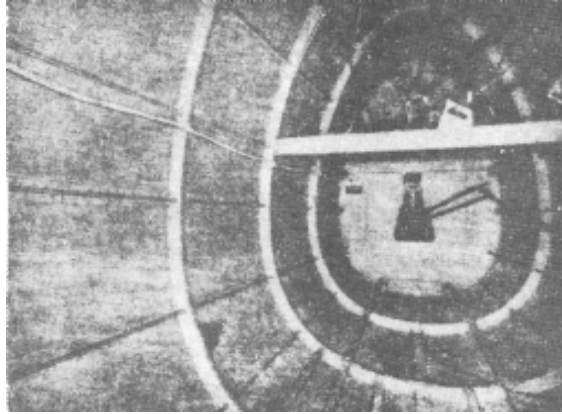
Fig.7.2.Grumman Monocoque Fuselage; R301 and 14ST Clad Aluminum Alloy

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.
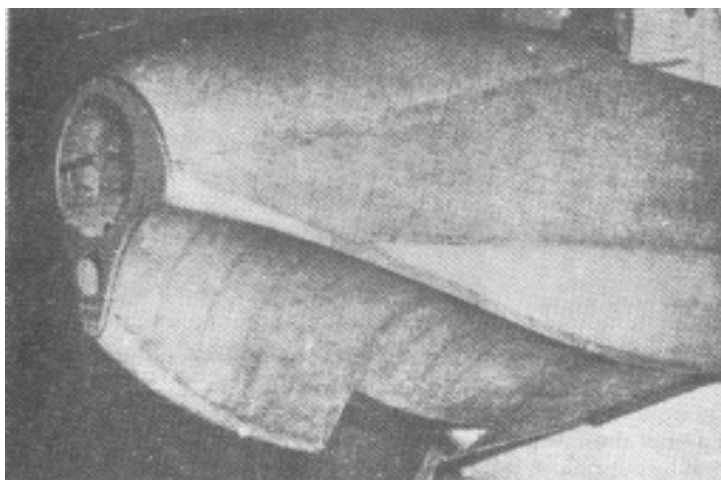
Fig.7.3.Bow of Mallard Hull;1ST (R301) Clad ALuminum Alloy

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; 7½ % 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.

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.
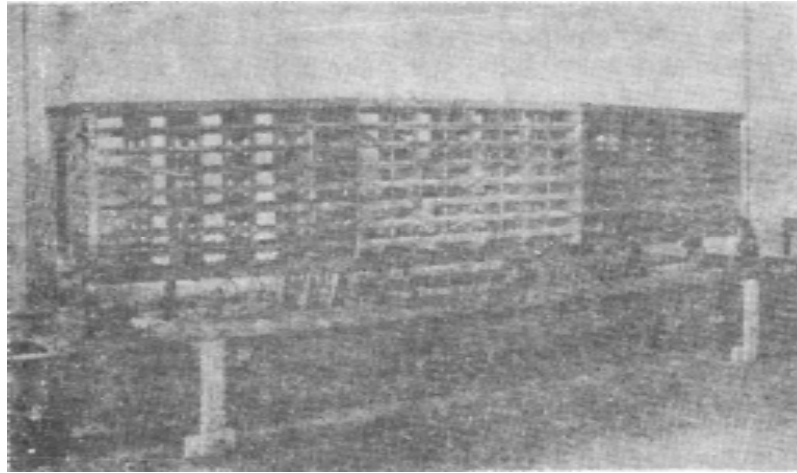
Fig.7.5. Wing Box Beam

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 1/8ˉ 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.

HEAT TREATMENT

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 24 hours, and fully complete after four days. 24S develops greater strength than 17S immediately after quenching, ages more rapidly, and is considerably less workable.
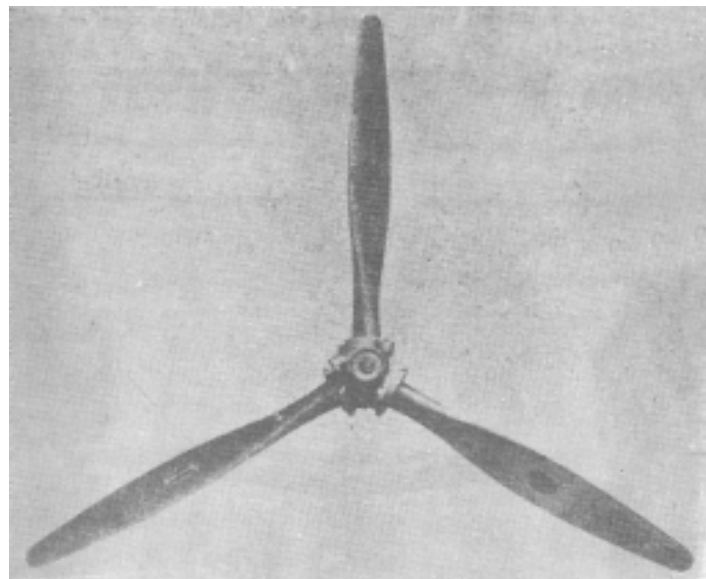
Fig-7.6. Controllable-pitch Propeller;25ST Aluminum-alloy Blades

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 910-930^0F. 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 20-30^0F above their normal heat-treatment range of 930-950^0F. 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.
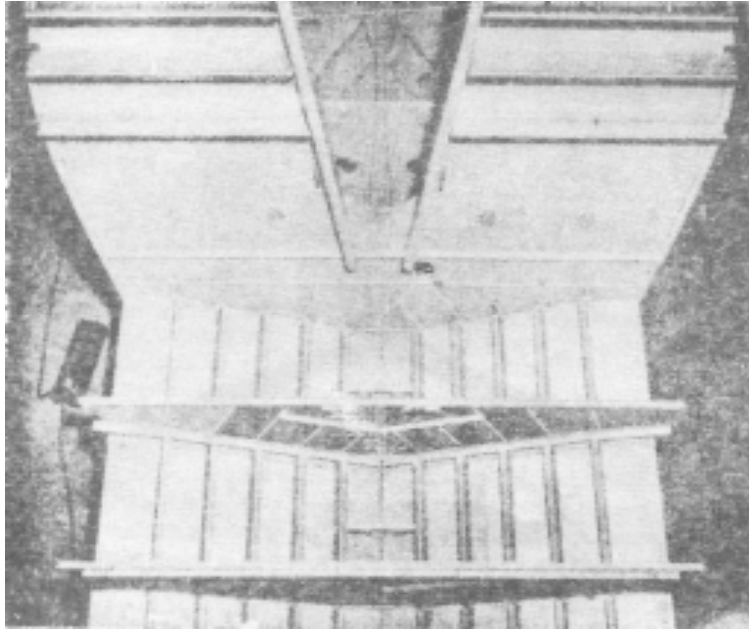
Fig.7.7.Hull Bulkhead and Bottom.

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.

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UNIT - VI
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.

PURE MAGNESIUM

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).

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%.

Table 8.1, Magnesium Alloys- Specifications and Uses

Form	S.A.E.			A.S.T.M.		American Magnesium	Dow. Reverse	General use
	AN aero	No	A.M.S	Designation	Alloy			
Sand castings	AN-QQ-M-56 (A)	50	{4420 4422 4424}	B80-44T	AZ63	AM265	H	General casting use
	AN-QQ-M-56 (B)	500	4434	B80-44T	M1	AM403	M	Weldable-tank flanges
	AN-QQ-M-56 (C)			B80-44T	AZ92	AM260	C	Pressure-tight castings
Permanent-mold Castings		503	4484			AM260	C	Strong-good corrosion characteristics casts well- inferior corrosion
		502				AM240	G	
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	532		B107-44T	AZ80X	AM-C58S	O-1	Highest strength
	AN-M-26	533		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		B91-44T	M1	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 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	$1204°F$
flame temperature	$8760°F.$
Electrical conductivity :	
Volume basis	38 % of copper.
Mass basis	197 % of copper
Mean coefficient of thermal expansion, per inch per degree Fahrenheit	
$(32°-750°F.)$	0.0000166 inches
Modulus of elasticity	6.500.000 p.s.i.

MAGNESIUM ALLOYS

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 $450°$ to $700°$ 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 AN aero	American Magnesium	Dow, Revere	Aluminum	Manganese	Zinc	Tin	Magnesium
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 640^0F 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

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

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.
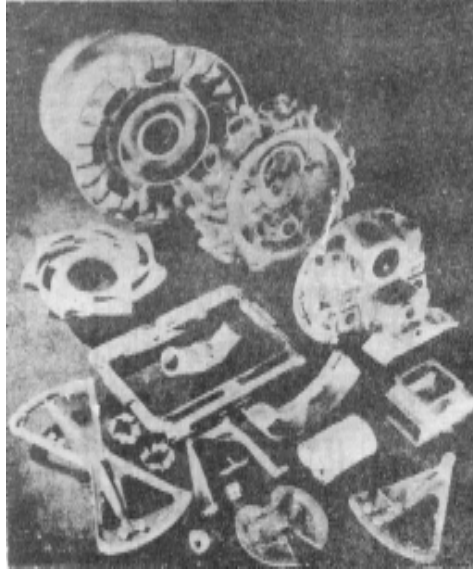
Fig.8.2. Sand-cast Magnesium Parts

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 $1\frac{1}{64}$ 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 $\frac{1}{8}$ inch is obtainable for small areas but $\frac{5}{32}$ inch is more practicable. A nominal tolerance of $\pm\frac{1}{32}$ 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^{0}F. in the solution heat-treated condition. A temperature of 350^{0}F. 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^{0}F. 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 $\dfrac{1}{8}$ inch for small areas nd $\dfrac{5}{32}$ inch for large areas may be obtained in permanent-mold castings.

Dimensional tolerances as low as 0.01 inch can be held, but $\pm\dfrac{1}{64}$ 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. 8.4, Magnesium-alloy Castings-Mechanical Properties

| Form | Specification | | | Tension | | | Compression yield(p.s.i.) | Brinell hardness (500Kg./10mm.) | Shear (p.s.i.) | Fatigue (p.s.i.) | Impact Izod (ft./ib) | Condition |
	AN aero	American Magnesium	Dow	U.t.s. (p.s.i)	Yield (p.s.i)	Elongation (%)						
	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		55		11,000		As cast-stabilized
	A-HT	AM265-T4	H-HT	32,000	10,000	7	14,000	73	19,000	14,000	5	Solution heat treated
	A-HTA	AM365-T6	H-HTA	34,000	16,000	3	19,000	59	20,000	13,000	2	Heat treated-aged
	A-HTS	AM265-T7	H-HTS	34,000	13,000	4				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.
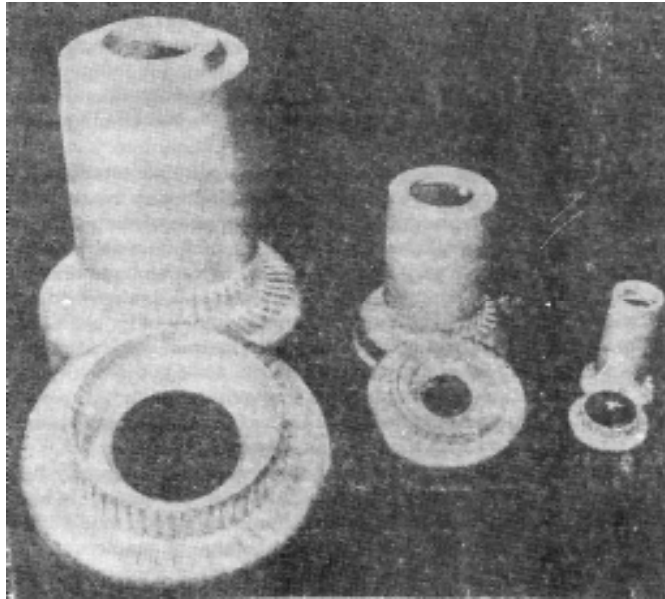
Fig.8.3. Permanent-mold Cast Magnesium Aircraft Wheels

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 $\frac{1}{16}$ to $\frac{3}{16}$ inch are best from casting considerations and to obtain maximum mechanical strength.

Walls as thin as $\frac{1}{32}$ inch are possible for areas of 10 square inches or less. A maximum wall thickness of $\frac{1}{2}$ 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 $\pm$ 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.

WROUGHT MAGNESIUM ALLOYS

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 700^0F. 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 $\frac{1}{16}$ inch in 5 feet.
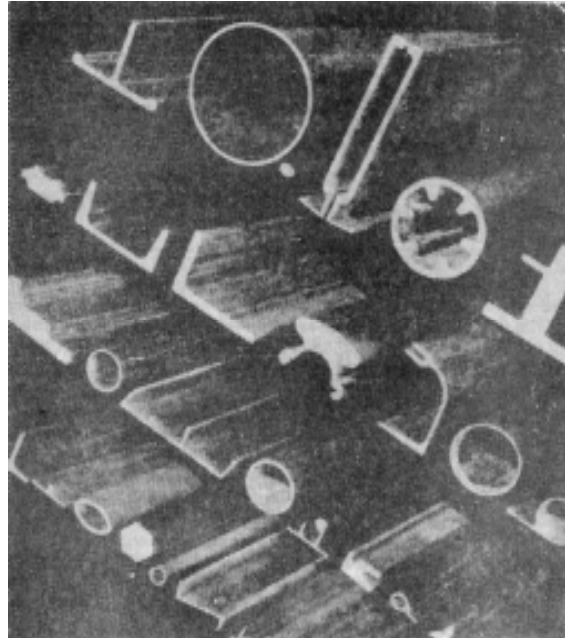
Fig.8.4. Miscellaneous Magnesium Extruded Shapes

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 400^0F. 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.

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

Table 8.5, Magnesium-alloy Extrusions-Mechanical Properties

| Form | Specification | | | Tension | | | Compression yield (p.s.i.) | Brinell hardness (500 kg./10 mm.) | Shear (p.s.i.) | Fatigue 500×10⁶ cycles (p.s.i.) |
	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 8.6, 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.)	Elorgation (%)				
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 HT A mean heat treated and aged after forgings; T5 after alloy means forged and aged.

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 1/8 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 $\pm$ 1/32 inch for small forgings and $\pm 1/16$ inch for large forgings is required.
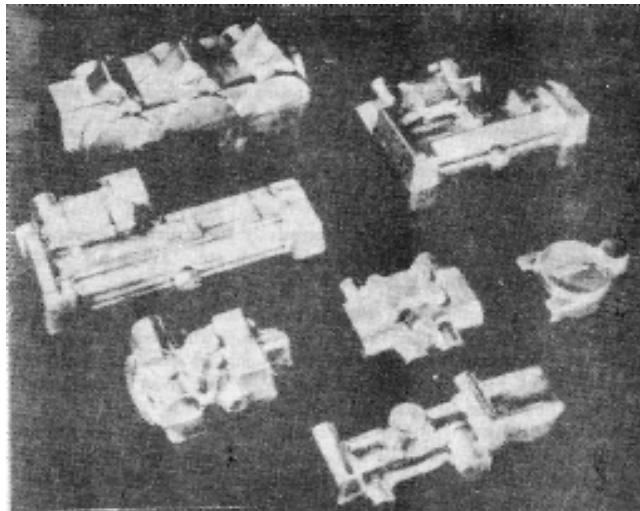
Fig.8.5. Press-forged Magnesium Hydraulic Parts

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.
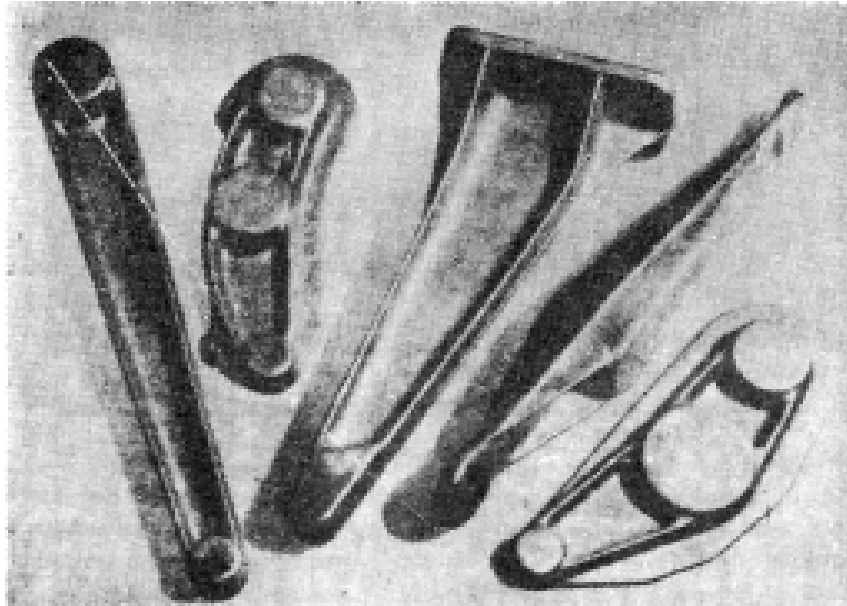
Fig.8.6. Hammer and Press-forged Magnesium Control Parts

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.

■■■

UNIT - VII
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.*
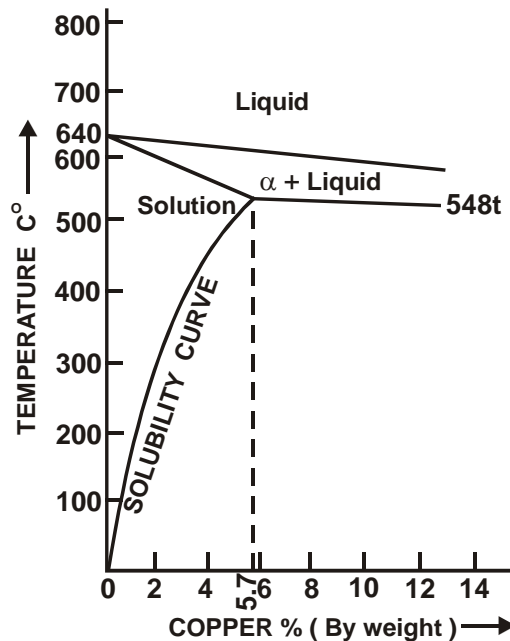
Fig. 11.1, Phase diagram of an aluminium-copper alloy.

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 548^0C 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 α 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 θ phase. It is an unsatble condition needing diffusion. To achieve that, it is reheated to between 150^0C to 200^0C 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.
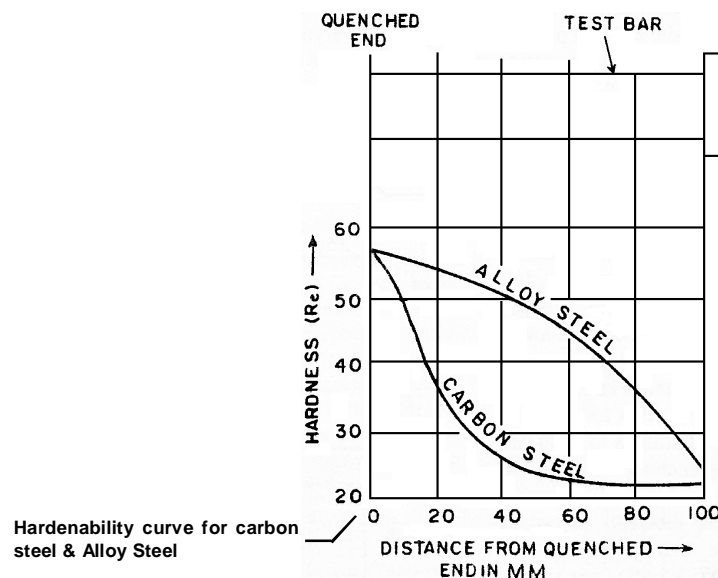
Fig. 11.2, Graph of hardness values of two Jominy test bars in Jominy hardenability tests conducted on test bars made of carbon steel and alloy steel.

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.

ALUMINUM ALLOYS
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 32^0F., the beginning of the aging process is delayed for several hours, while dry ice(-50^0F. to - 100^0F.) 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 250^0F. to 375^0F. They should be controlled within a very narrow range (plus or minus 5^0) 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. Alloy 2024 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.

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UNIT - VIII
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.

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UNIT - IX
MECHANICAL TESTING OF METALS

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 machines carry different replaceable accessories and attachments to enable counductance of different tests on the same machine.
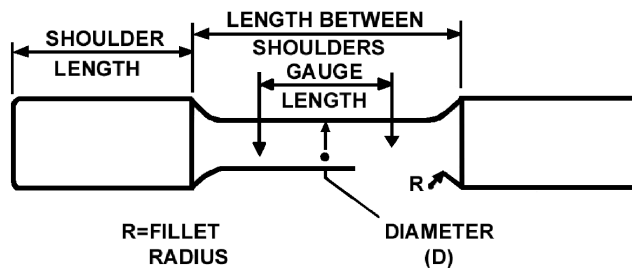
Fig.13.2 Main parameters of tensile test specimen with plain ends

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.
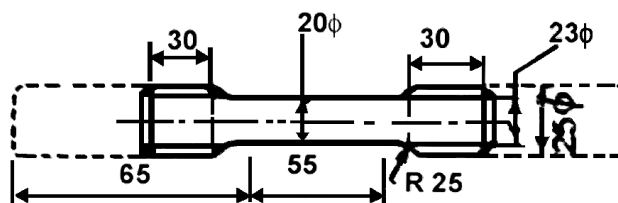
Machining tolerance in dia = $\pm$ 0.5
All dimensions are in mm

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.
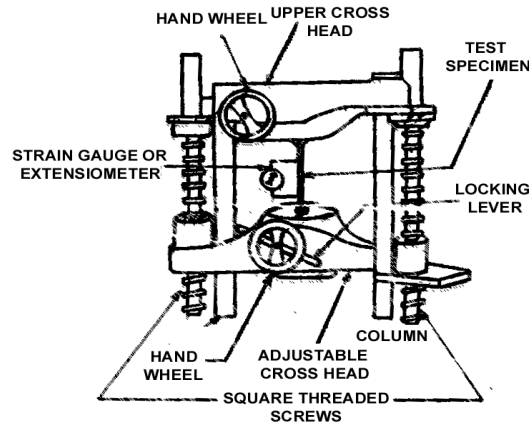
Fig.13.4. Schematic setup of a U.T.M., showing the test specimen gripped between the two cross heads.

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.
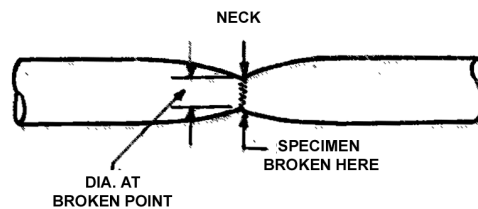
Fig 13.5. Broken pieces of specimen joined together for final measurements.

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 :

$$\text{Elastic limit} = \frac{\text{Maximum load within the elastic limit}}{\text{Original area of the specimen}}$$

$$\text{Yield strength} = \frac{\text{Load at the yield point}}{\text{Original area of the specimen}}$$

$$\text{Ultimate tensile strength} = \frac{\text{Ultimate load}}{\text{Original area of the specimen}}$$

$$\text{Young's modulus of elasticity } (E) = \frac{\text{Stress at a given point within elastic limit}}{\text{Strain at that particular point}}$$

$$\text{Percentage elongation} = \frac{\text{final guage length - Original guage length}}{\text{Original guage length}} \times 100$$

$$\text{Percentage reduction in area} = \frac{\text{Original area of specimen} - \text{Final area at broken point}}{\text{Original area of specimen}} \times 100$$

$$\text{Breaking strength} = \frac{\text{Breaking load}}{\text{Original area of specimen}}$$

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.
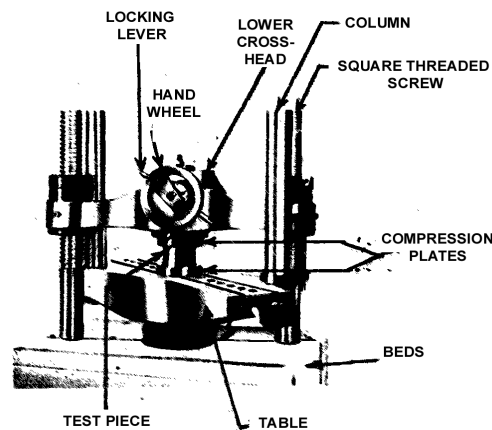
Fig.13.6. Setup for a compression test on a universal testing machine.

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.) :
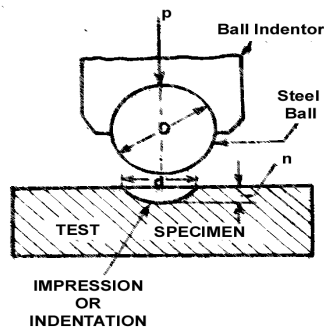
Fig 13.7. Important parameters of a Brinell hardness test.

$$BHN = \frac{\text{Load on ball (in kg.)}}{\text{Area of the ball impression in mm}^2}$$

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* : $R = 100 - 500\,t$
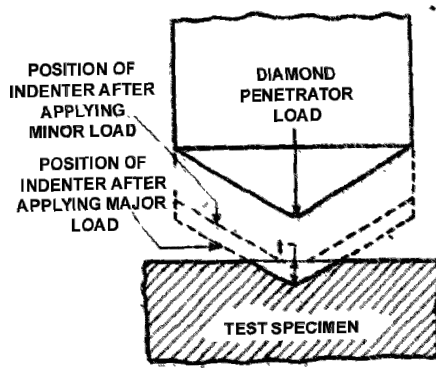
Fig.13.8. Principle of Rockwell testing
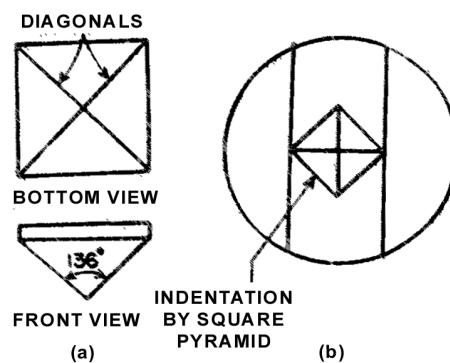
Fig 13.9. Details of square pyramid and indentation produced during Vickers hardness test.

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	Major load	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 :

$$VHN = DPN = \frac{Load}{Area\ of\ the\ impression}$$

$$= \frac{P}{d^2/2\sin(\theta/2)} = \frac{2P\sin\theta/2}{d^2}$$

or

$$= 1.8544\ \frac{P}{d^2}$$

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.
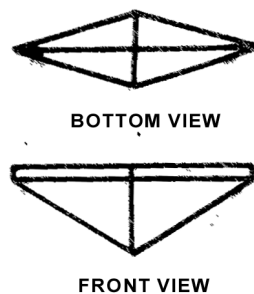
Fig.13.10.Diamond Knoop indenter used in Knoop hardness test

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.
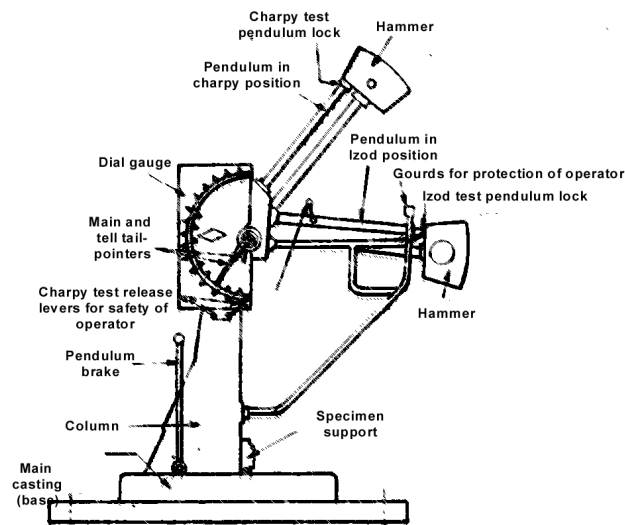
Fig 13.11.A pendulum type Impact testing machine.   *Fig.13.12. Standard dimensions of an Izod impact*
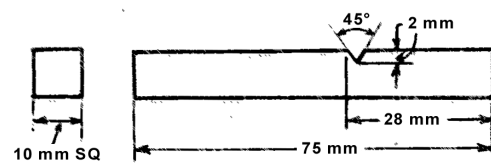
The test specimen used for **Izod impact test** is held in the support in a cantilever position, as shown in Fig .13.13. dimensions of the specimen are shown in Fig.13.12. For breaking the specimen during the test the swinging load strikes it near its upper end as shown in the diagram

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 :
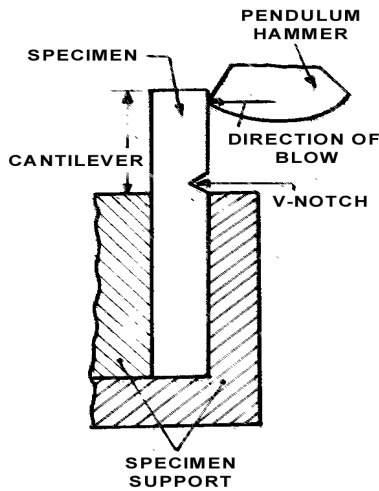
Fig 13.13 The test specimen held in contilever position for Izod impact test.
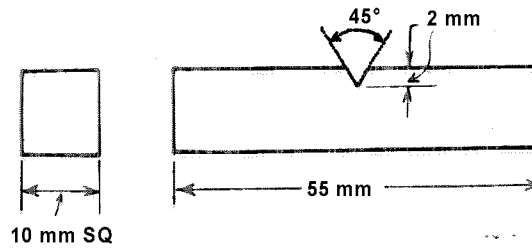
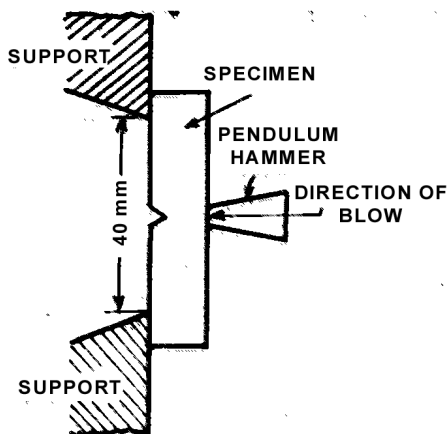Fig 13.14. Principal dimensions of a charpy Impact test specimen

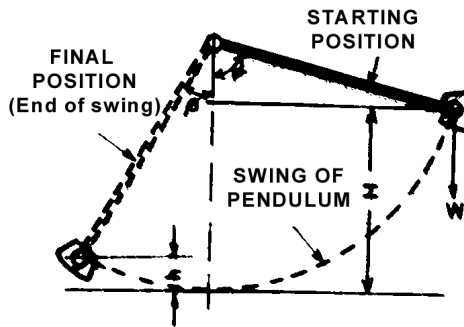Fig.13.15.Charpy test specimen held in supports in proper position for test.

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 fracture.	=	Kinetic energy spent in carrying the fracture pendulum weight to a vertical height 'h' after
	=	Wh
$\therefore$ 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.
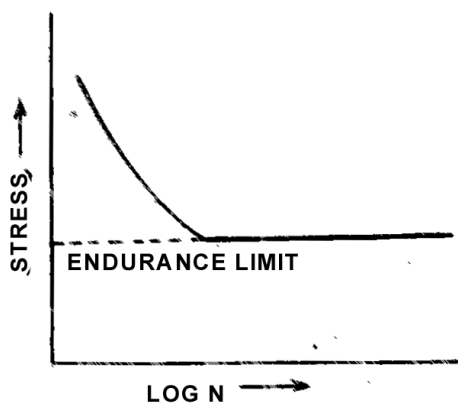
| *Fig 13.17. Fatigue (S-N) curve for mild steel* | *Fig.13.18. S-N curve for Aluminium* |
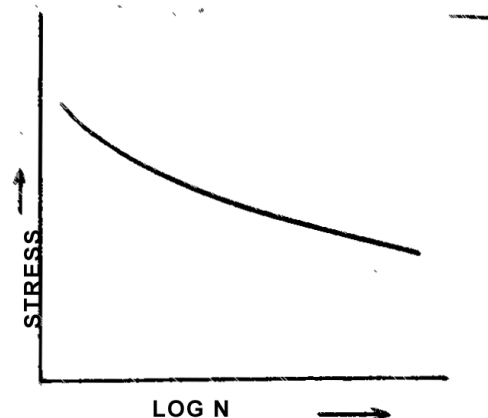
The number of cycles to be used, *i.e.* the number of rotations required to be made by the specimen, until fatigue failure occurs, will depend upon the magnitude of the applied stress. Greater the magnitude of the applied stress smaller will be the number of cycles required and vice versa. Depending 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.
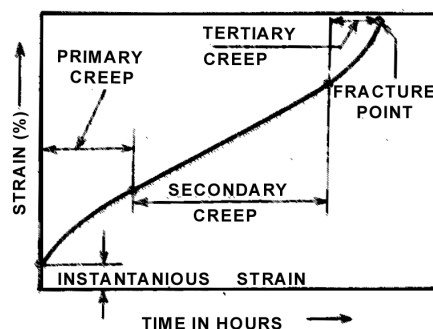
Fig.13.19. A typical creep curve showing different stages of creep

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.

■■■

UNIT - X
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 ° 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^oC (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 Deoxidine 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.

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UNIT - XI
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.

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UNIT - XII
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 70°C., 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 :

Teepol	5 per cent		
Cresylic Acid	5 per cent	$\leftarrow$	by volume
Water	90 per cent		

The solution should be maintained at a temperature of between 70° C. to 80^{0}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.

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UNIT - XIII
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°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)
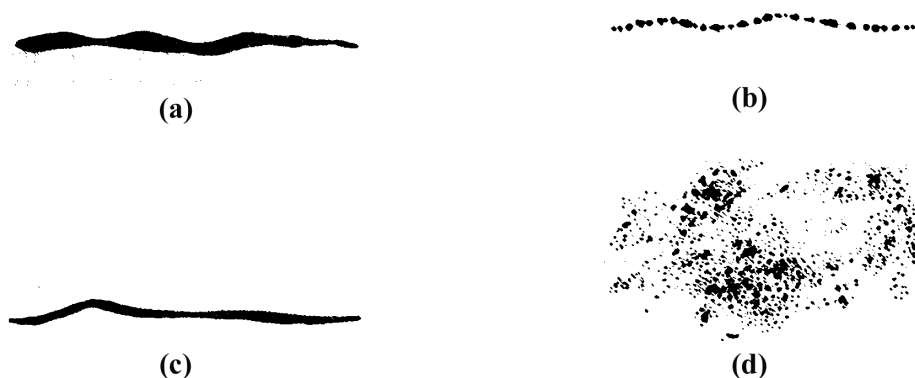
Fig. 19.1, Indications Given by Defects

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.

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UNIT - XIV
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.
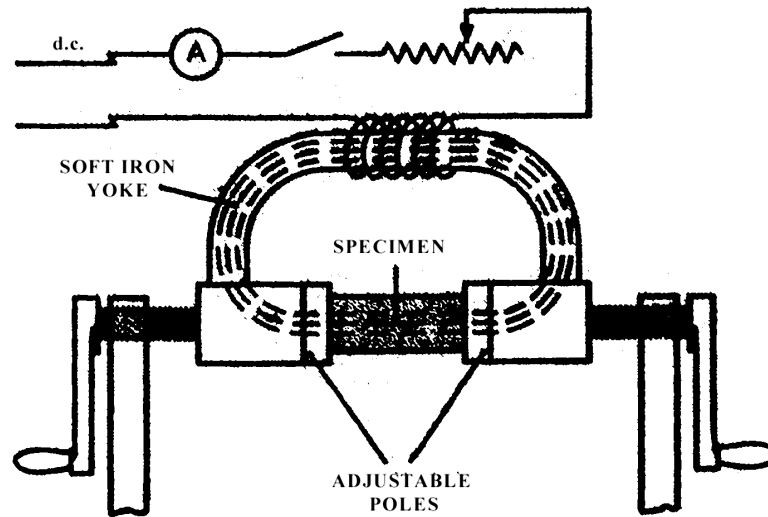
Fig. 20.1, Magnetic Flow Machine

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.
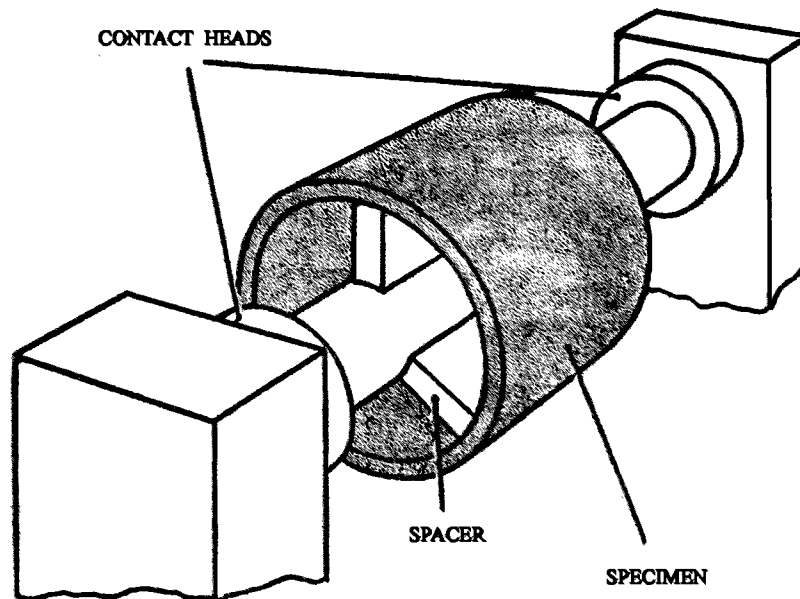
Fig. 20.2, Threading Bar Method

(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.
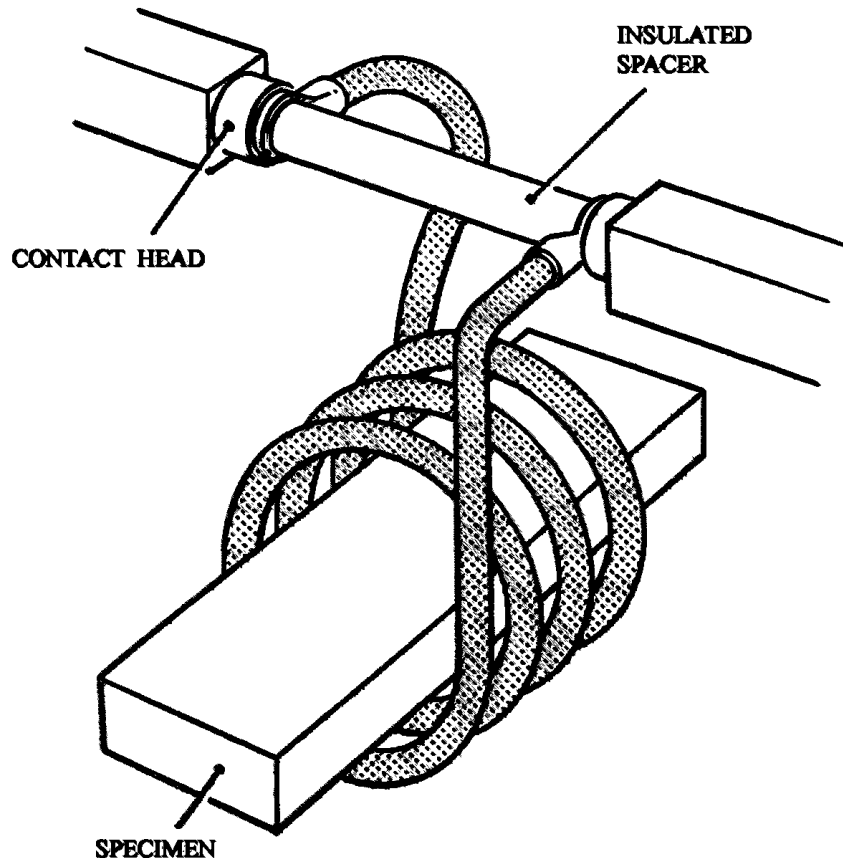
Fig. 20.3, Magnetising Coil Method

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.
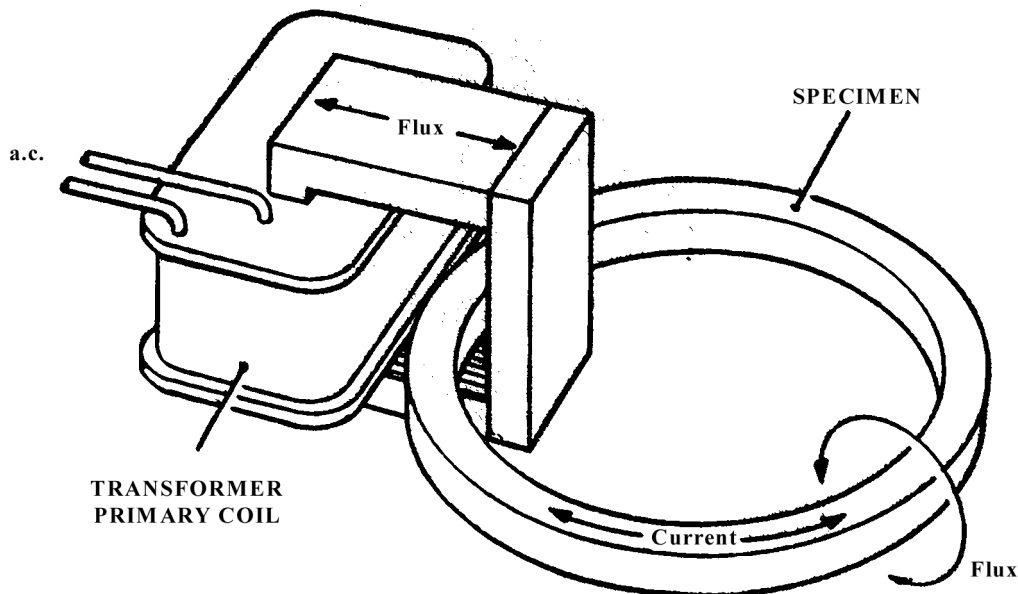
Fig. 20.4, Induced Current Flow Method

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.

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UNIT - XV
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.
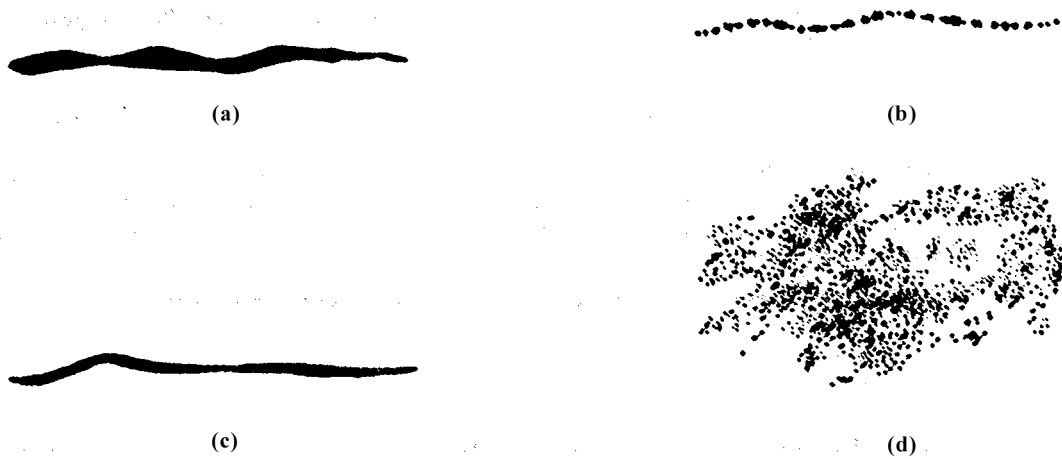
Fig. 21.1, Indications given by Defects.

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.

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UNIT - XVI
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.
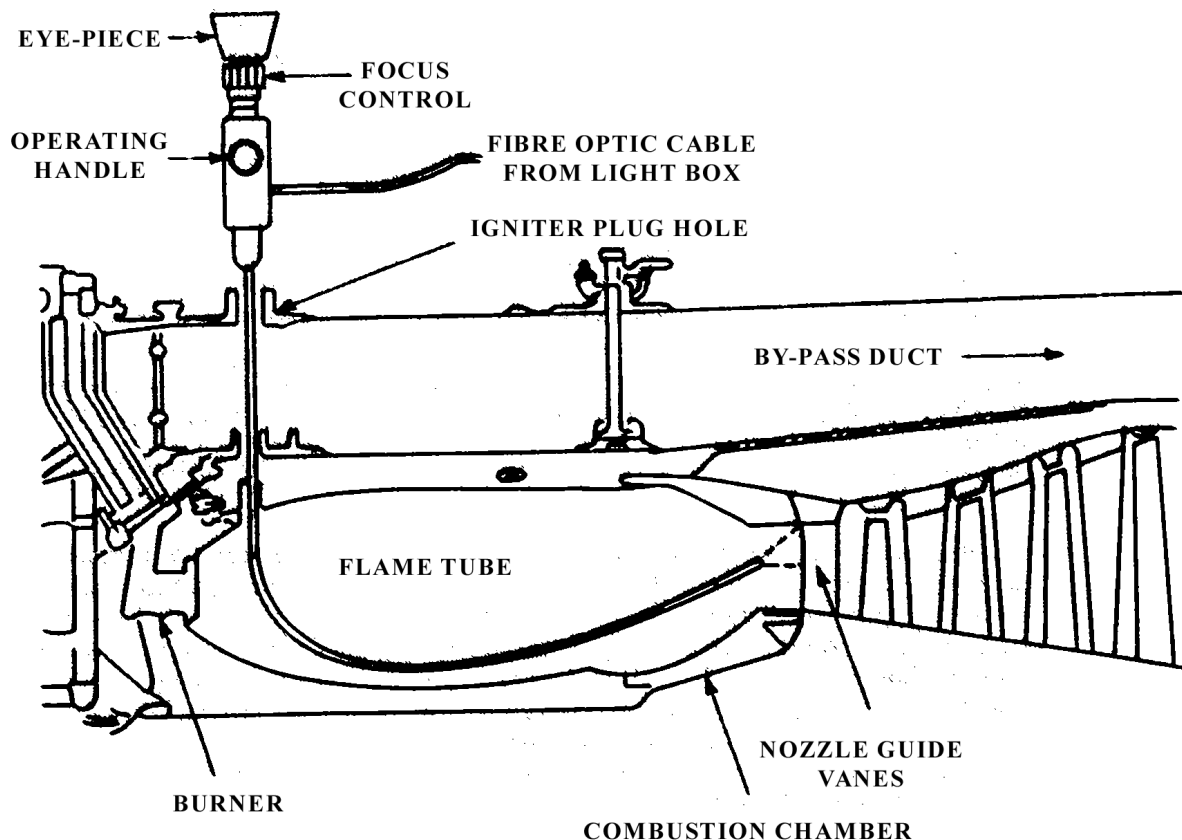
Fig. 22.1, Flexible Endoscope Inspection Equipment

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.

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UNIT - XVII
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.
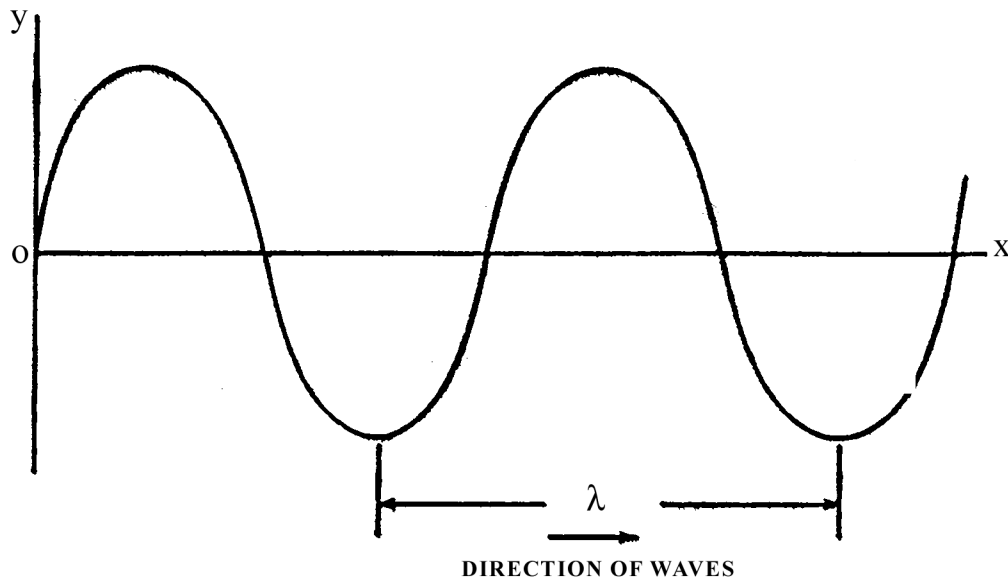
Fig. 23.1, Form of Sound Waves

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.
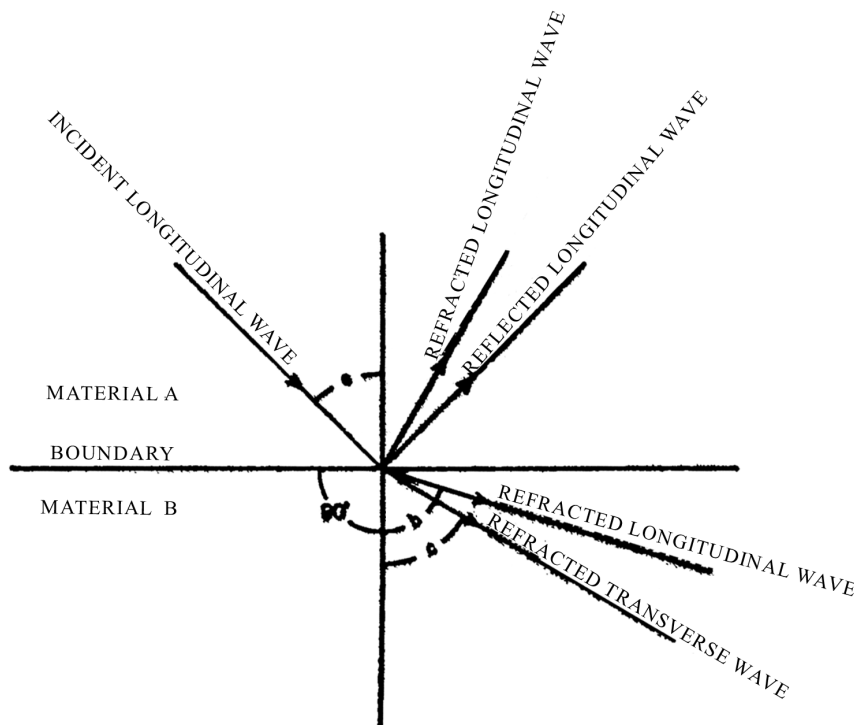
Fig. 23.2, Mode Conversion

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.
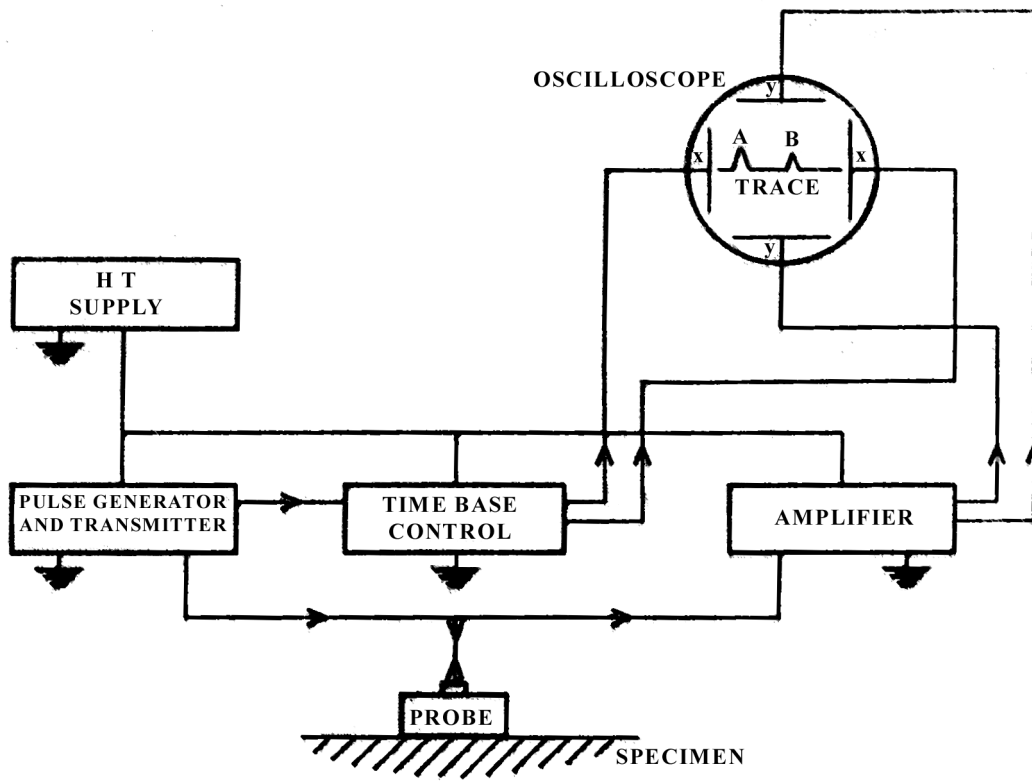

Fig. 23.3, Simple Block Diagram of Ultrasonic Set

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.

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UNIT - XVIII
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.
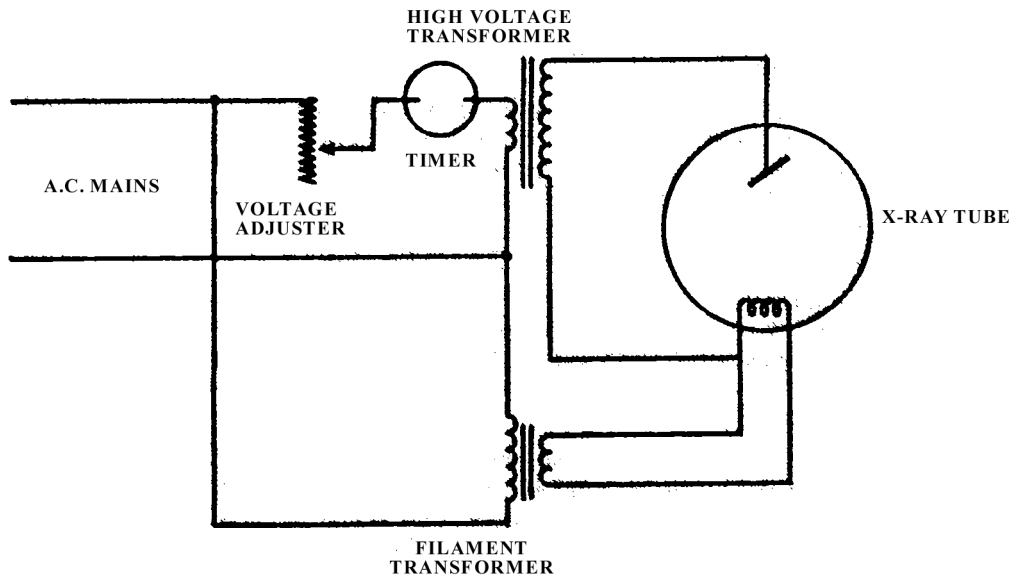
Fig. 24.1, Typical Circuit of An X-ray set

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.

■■■

UNIT - XIX
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.

SOUND MATERIAL   **FAULTY MATERIAL**
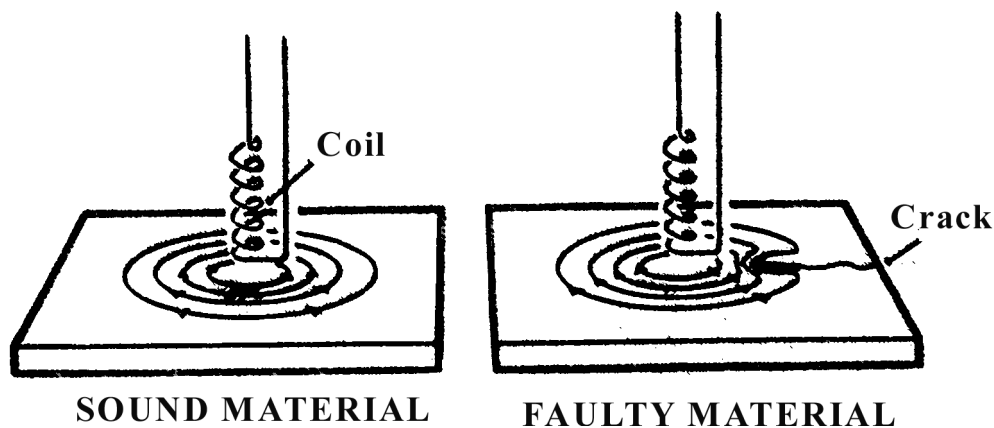
Fig. 25.1, Eddy Current Flow

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 ($58 \, \text{m} \backslash \Omega \, \text{mm}^2 = 100 \% \, \text{IACS}$).

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.
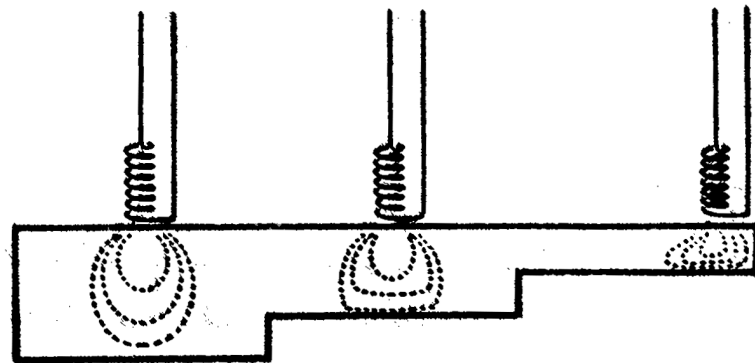
Fig. 25.2, Geometric Effects on primary magnetic field

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, $P \approx \dfrac{500}{\sqrt{f \sigma \mu}}$ where P is in mm, and σ is in $\text{m} \backslash \Omega \, \text{mm}^2$.

Effects of Frequency

Any particular material possesses what is known as a characteristic frequency $\left(f_g \right)$, 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 f / F_g 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.
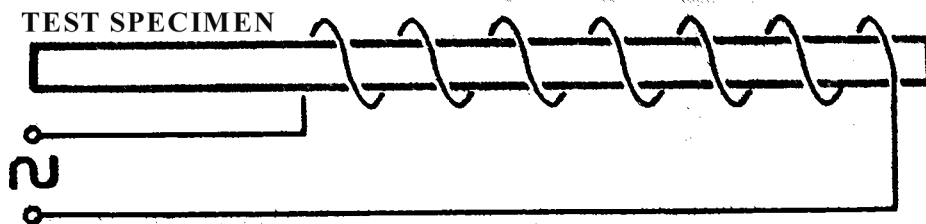
Fig. 25.3, Single primary coil system

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.
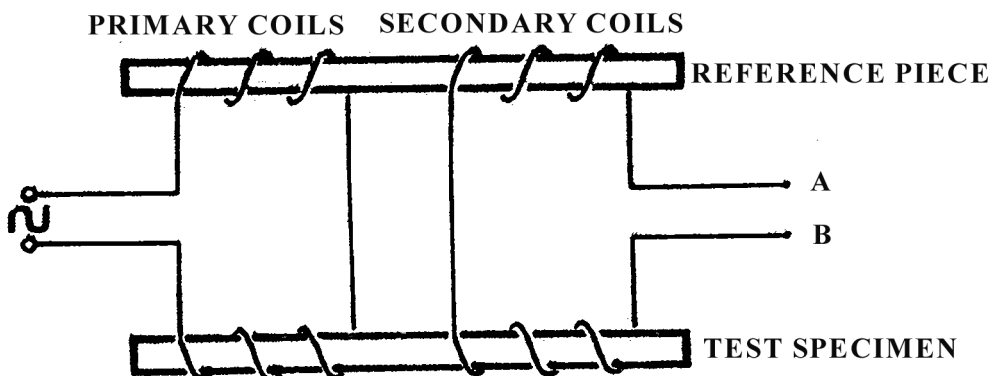
Fig. 25.4, Comparative Coil System

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.

A   B

TEST SPECIMEN
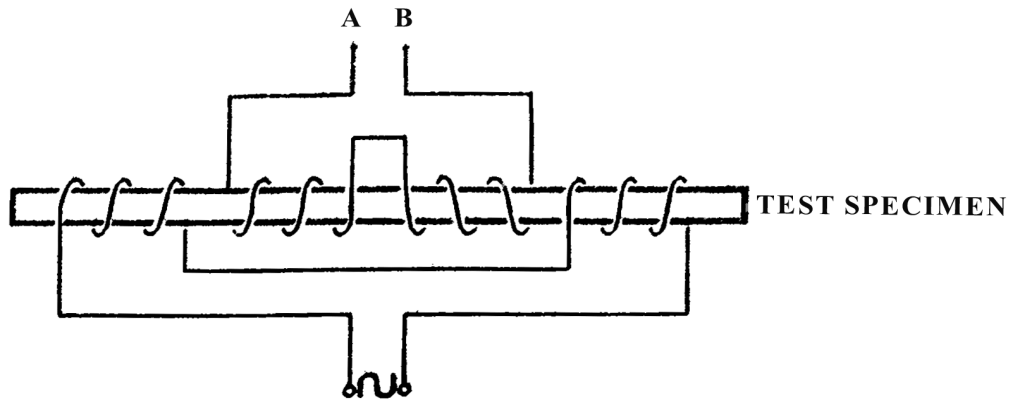
Fig. 25.5, Differential Coil System

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.

FERRITE CORE
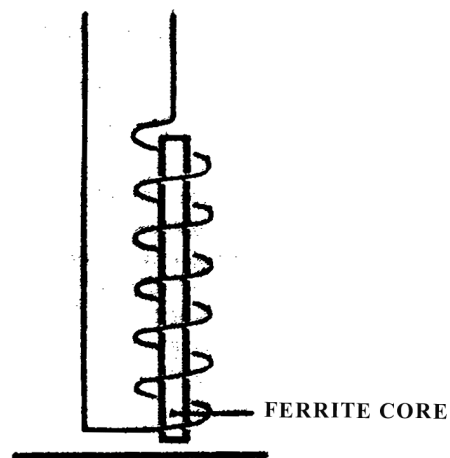
Fig. 25.6, Surface Coil

UNIT - XX
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.
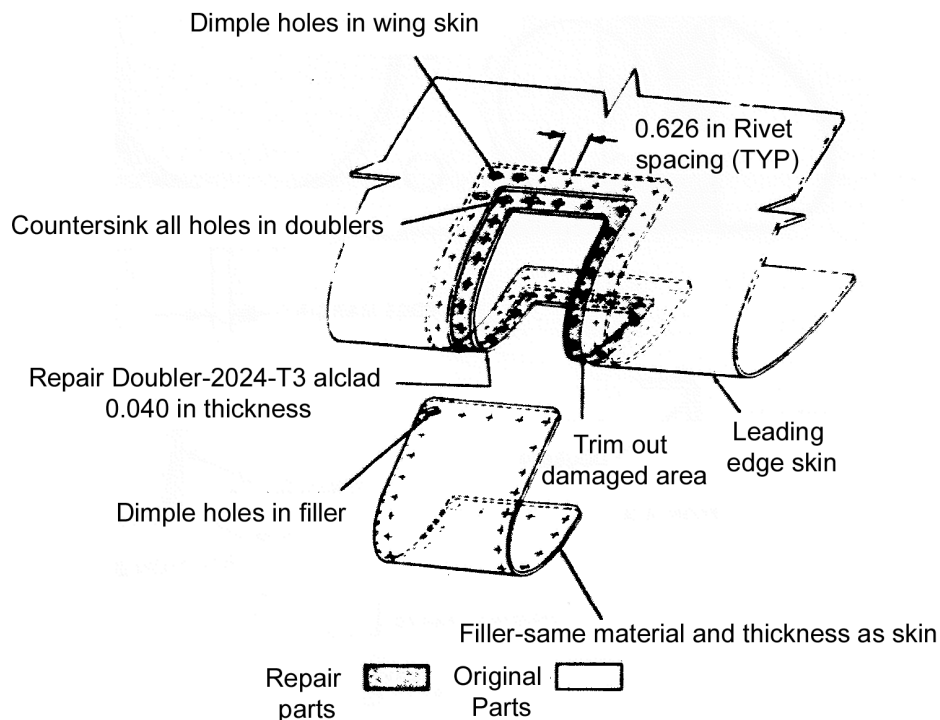
Fig. 36.1, Leading edge repair

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.

0.75 in Rivet
spacing (TYP)
Flange and Web

A

A

B — C

B — C

Cut Line

0.25 Edge
Margin

Spar Collar

Doubler
Shim

Formed Angle

Section A.A

Section
B.B

Section
C.C

Original Parts

Repair Parts
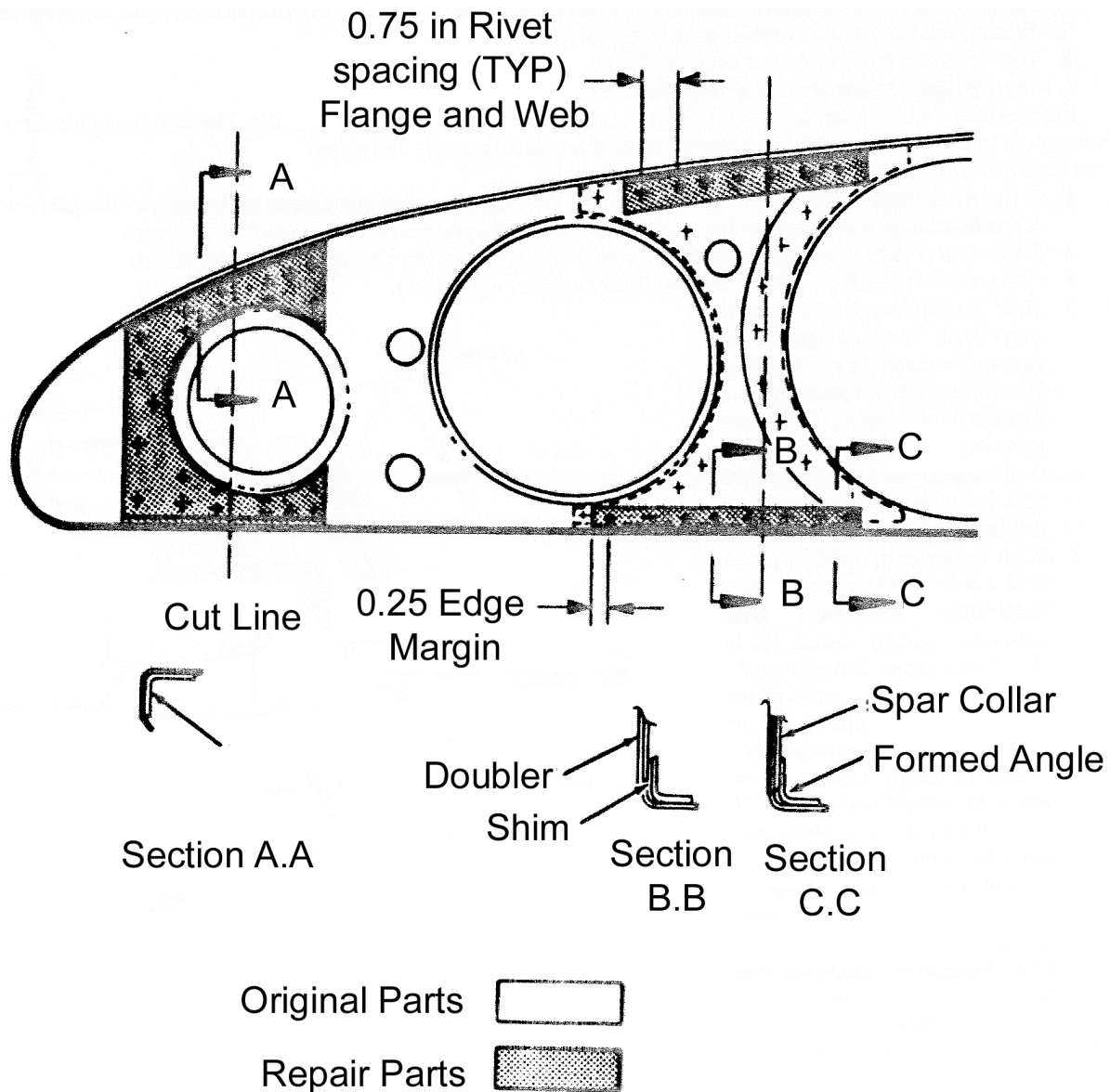
Fig. 36.2, Wing rib repair

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.
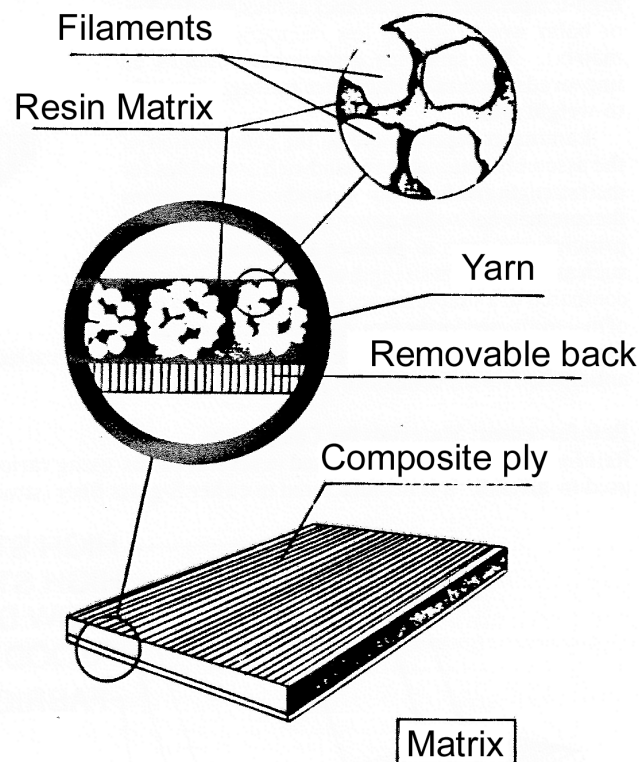
Fig. 36.3, Fibrous material encapsulate in a matrix

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.
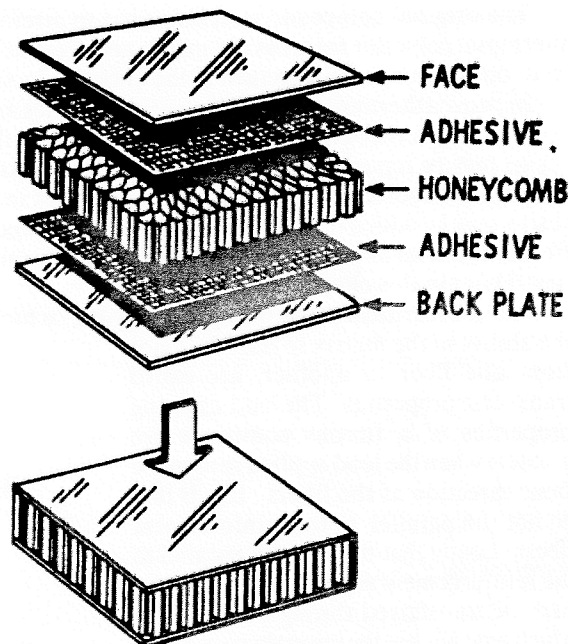
Fig. 36.4, Honey comb sandwhich construction.

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).
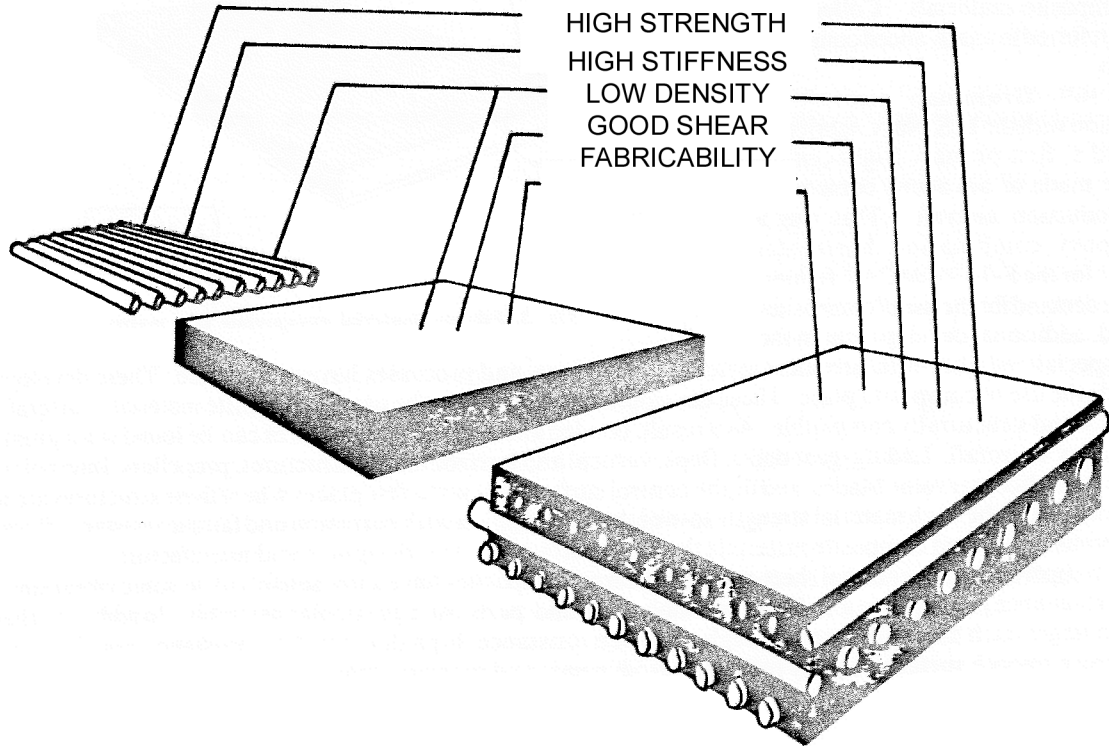
HIGH STRENGTH
HIGH STIFFNESS
LOW DENSITY
GOOD SHEAR
FABRICABILITY

Fig. 36.5, Solid laminate using reinforced fibers.

FIBER WRAP   SURFACE COVERING

METAL D-TUBE   FOAM MATERIAL
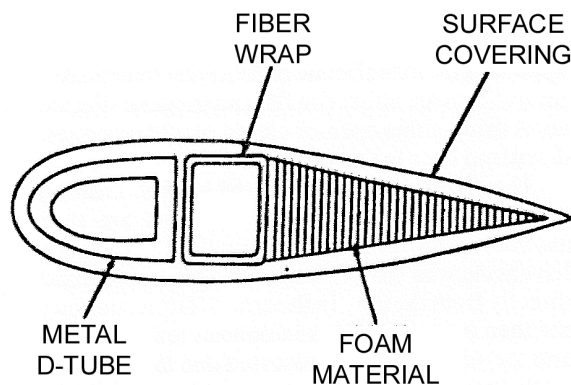
Fig. 36.6, An assembly using composite components

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.

CONTINUOUS MILLED FIBERS

CHOPPED STRANDS   **CHOPPED STRAND MAT**   **CONTINUOUS STRAND MAT**

WOVEN ROVING   **WOVEN FABRIC**
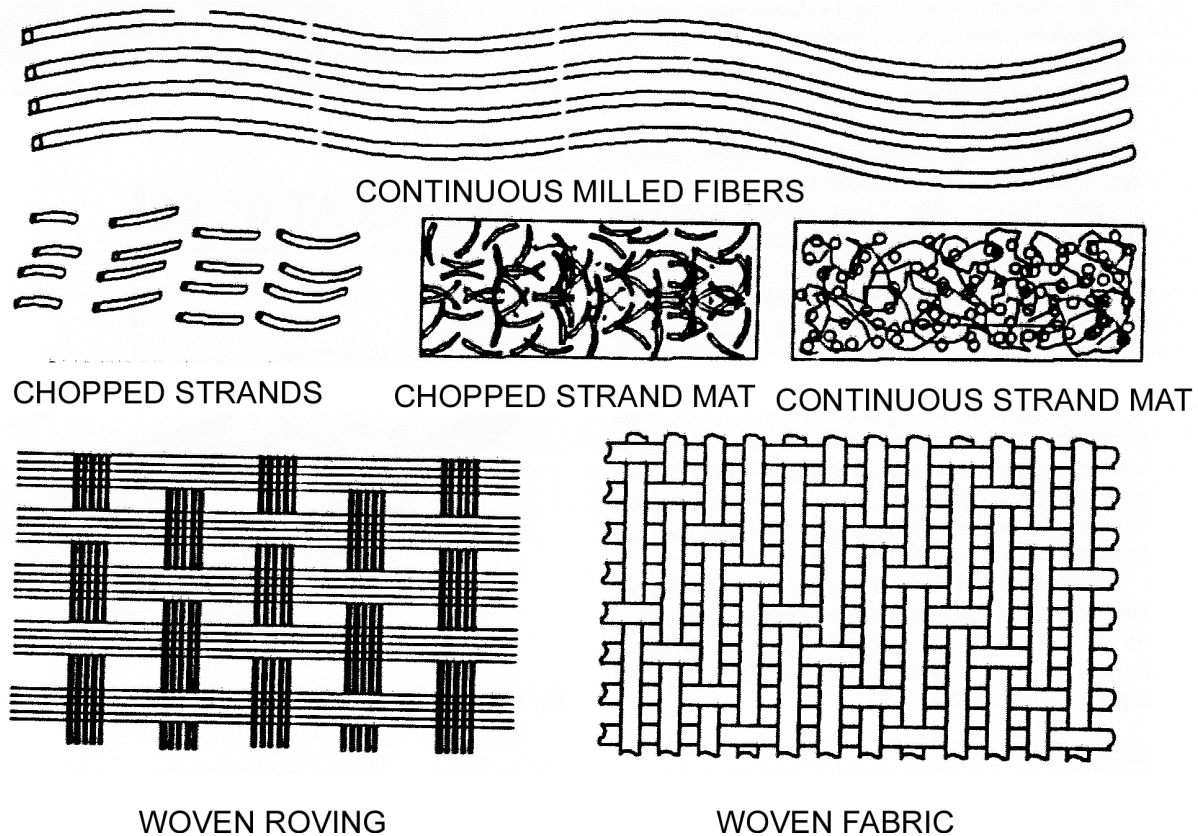
Fig.36.7, Chopped strands, woven roving, woven fabrics, continuous-strand mats, chopped strand mat and milled fibers

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.

HOLLOW   SOLID CIRCULAR   NON-CIRCULAR
FIBER   CROSS SECTION   CROSS SECTION
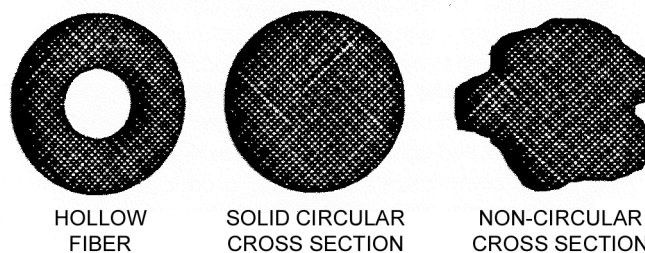
Fig.36.8,   Hollow fibers, of non-circular cross section, and solid, circular cross-sectional fibers.

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°
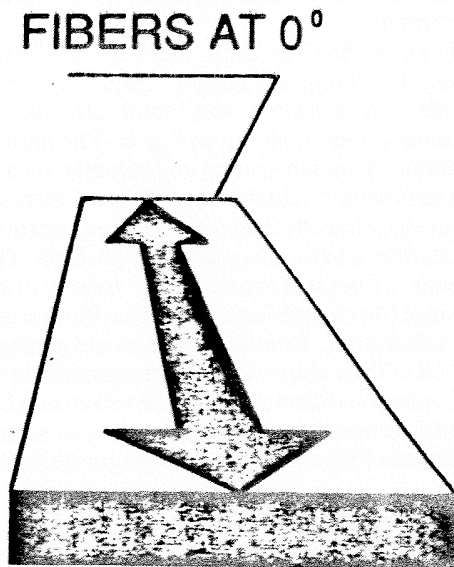
Fig. 36.9, Unidirectional weave
(woven at right angles to each other)
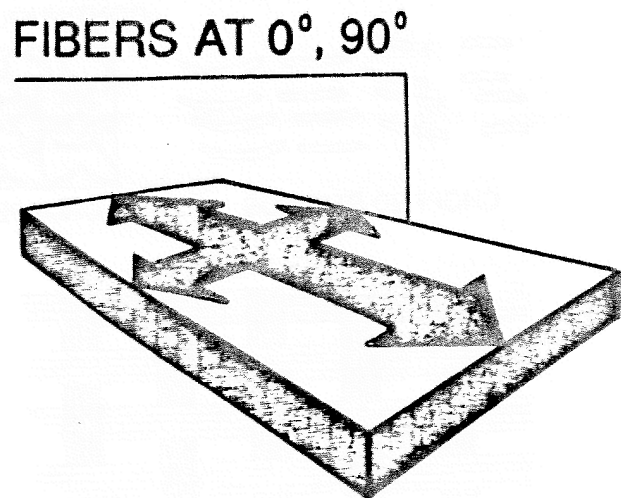
Fig. 36.10, Bidirectional weave
(woven in a continuous straight line)

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.
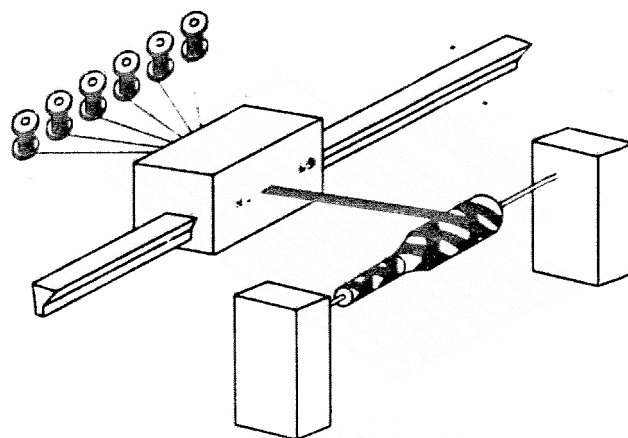
Fig.36.11, Filament winding consists of resin impregnated continuous fibers, wrapped on a mandrel the shape of the part.

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.
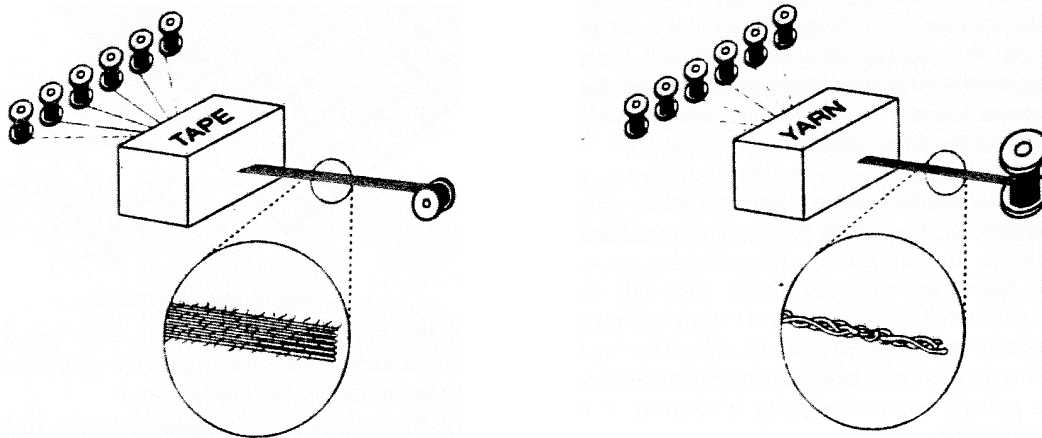
Fig. 36.12, Tows to yarn and tape.

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.
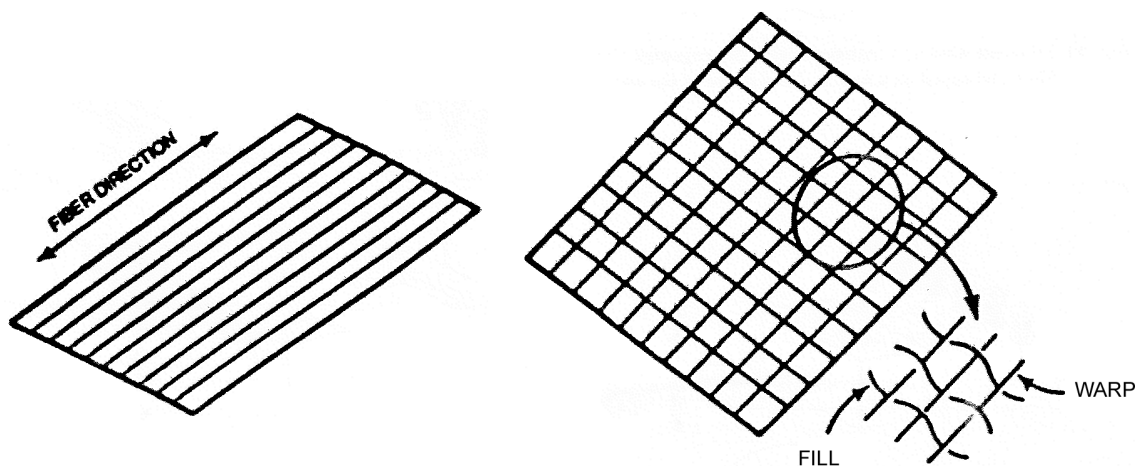
Fig. 36.13, Weave Definition.

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.
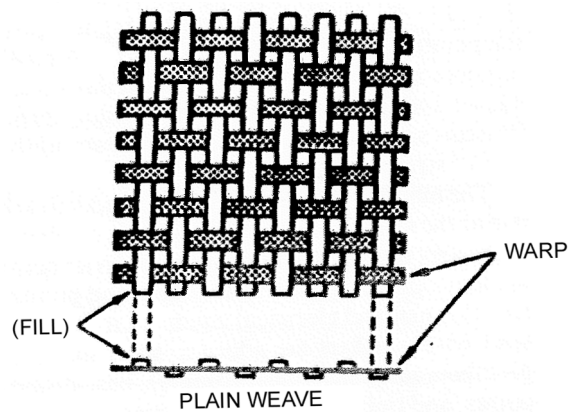
Fig. 36.14, Plain weave

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°C) or a factory-mixed and frozen system that requires an accurately controlled elevated temperature cure cycle up of 700 °F (371°C). Epoxy matrix is normally cured at either 250°F (121°C) or 350⁰F (177°C) range but require temperatures as high as 600°F (316°C). Bismaleimide adhesives cure in the 350 °F (177° C) range but require higher postcure temperatures of up to 700 ° F (371°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
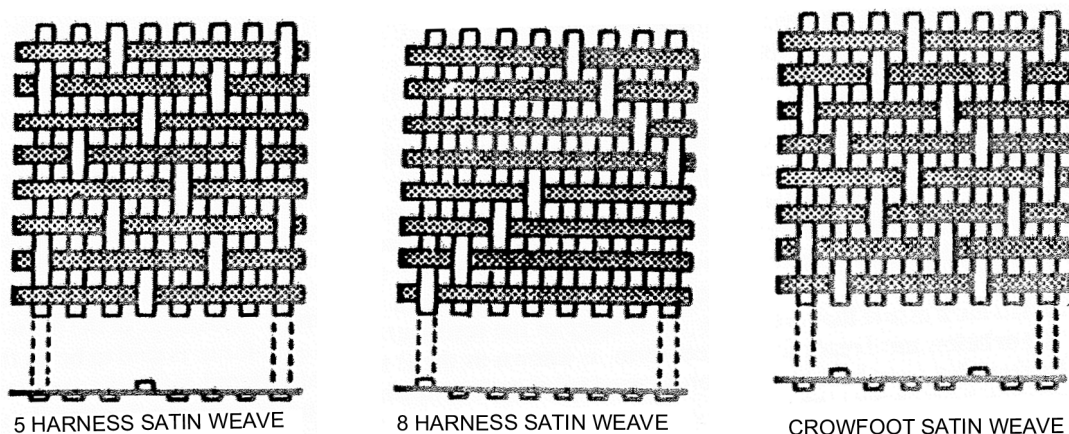
Fig. 36.15, Satin weave

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 $0°F(-18°C)$ 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.

CORE MATERIALS
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.
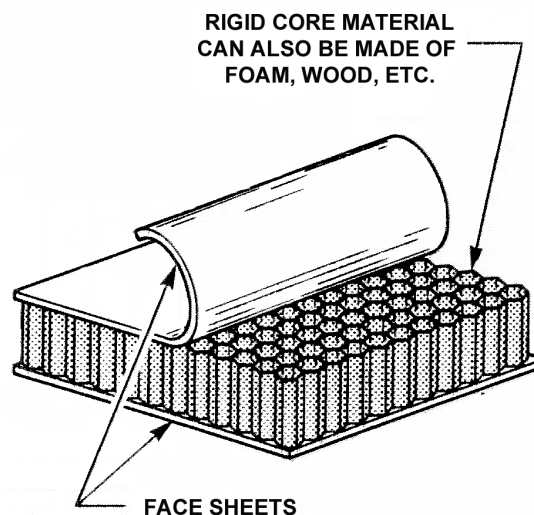

RIGID CORE MATERIAL CAN ALSO BE MADE OF FOAM, WOOD, ETC.

FACE SHEETS

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
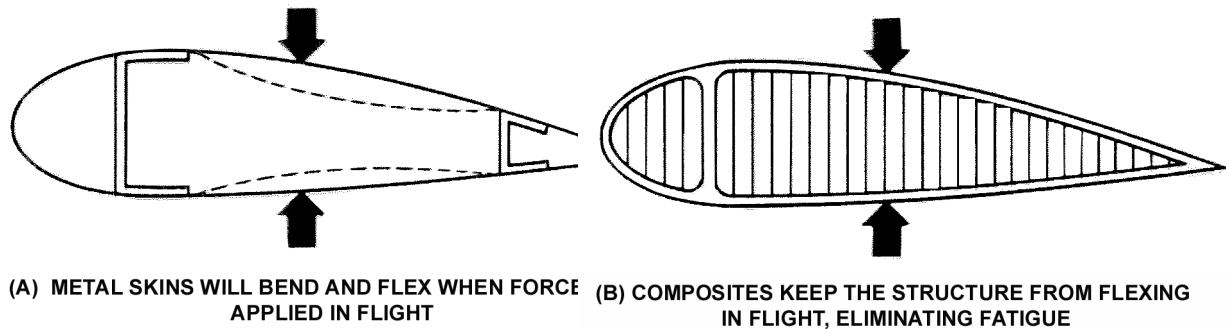
Fig. 36.17, (A) Metal skins will bend and flex when forces are applied in flight. (B) Composites keep the structure from flexing in flight, eliminating fatigue.

HONEY COMB CONSTRUCTION   VS "I" BEAM CONSTRUCTION
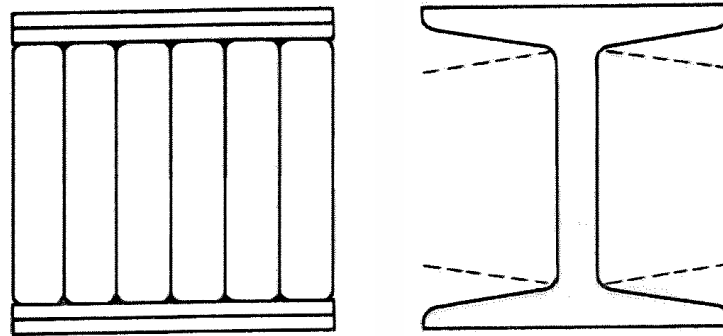
Fig.36.18, this concept can also be shown using a spar I-beam example. The flanges of the I-beam will bend and flex; however, with a solid core material, the tendency to bend is eliminated.

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.
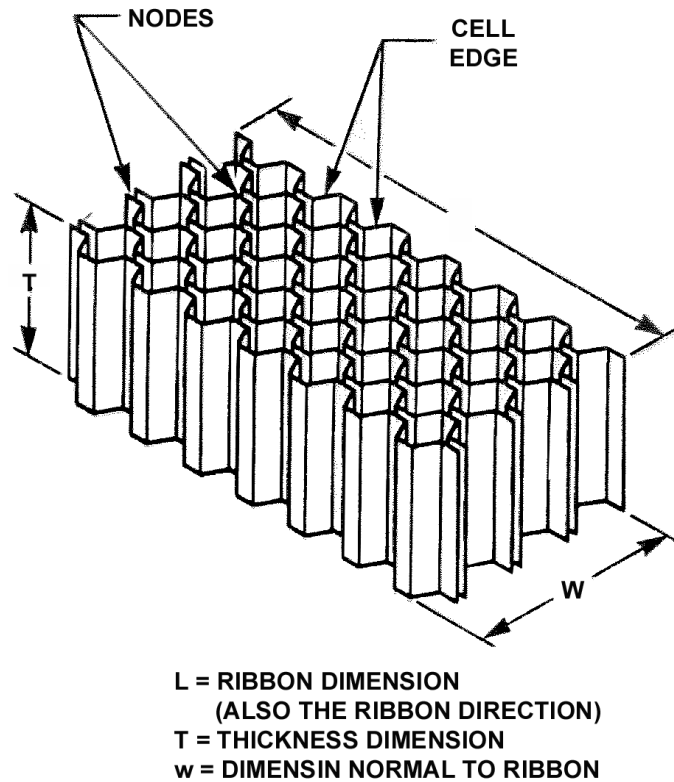
L = RIBBON DIMENSION
(ALSO THE RIBBON DIRECTION)
T = THICKNESS DIMENSION
w = DIMENSIN NORMAL TO RIBBON

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.
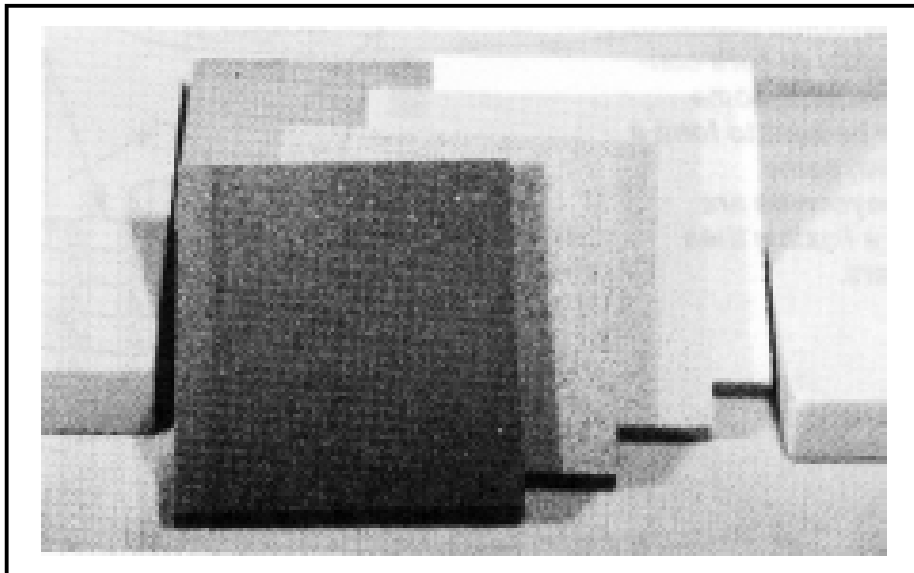
Fig.36.20. Foam cores for sandwich construction can be styrofoam, urethane, poly vinyl chloride, or strux (cellulose acetate). While easily shaped, foam construction can provide much greater strength and stiffness over plain laminates.

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.
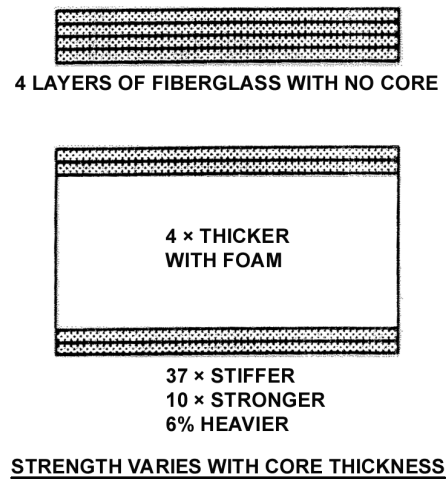
4 LAYERS OF FIBERGLASS WITH NO CORE

**4 × THICKER
WITH FOAM**

**37 × STIFFER
10 × STRONGER
6% HEAVIER**

STRENGTH VARIES WITH CORE THICKNESS

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.
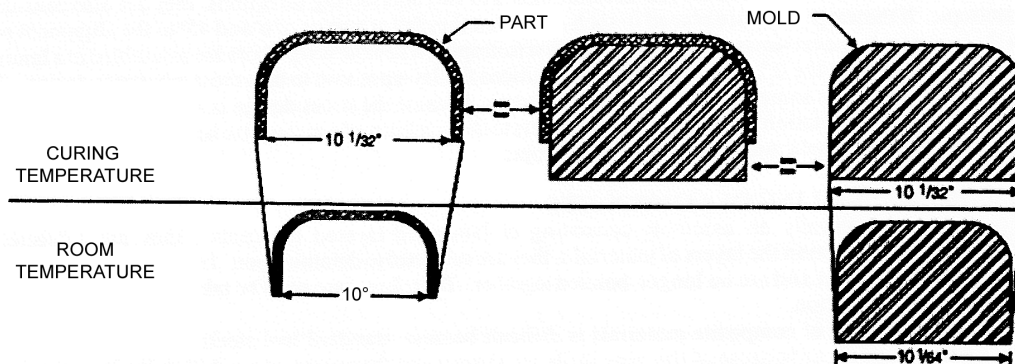

Fig. 36.22, Compensating for the different coefficients of thermal expansion of molds and parts material.

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 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.
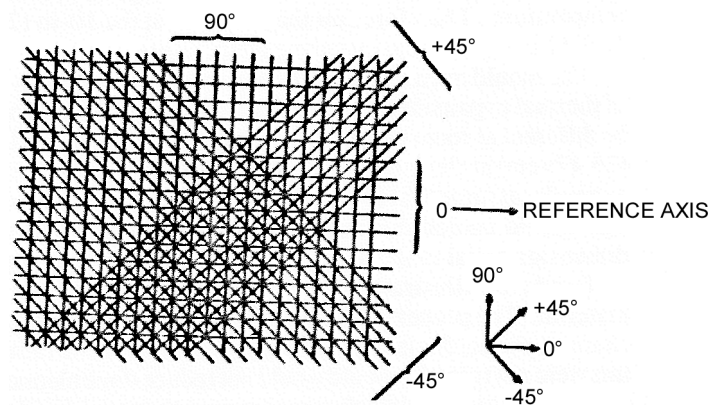

Fig. 36.23, Warp orientation.

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.
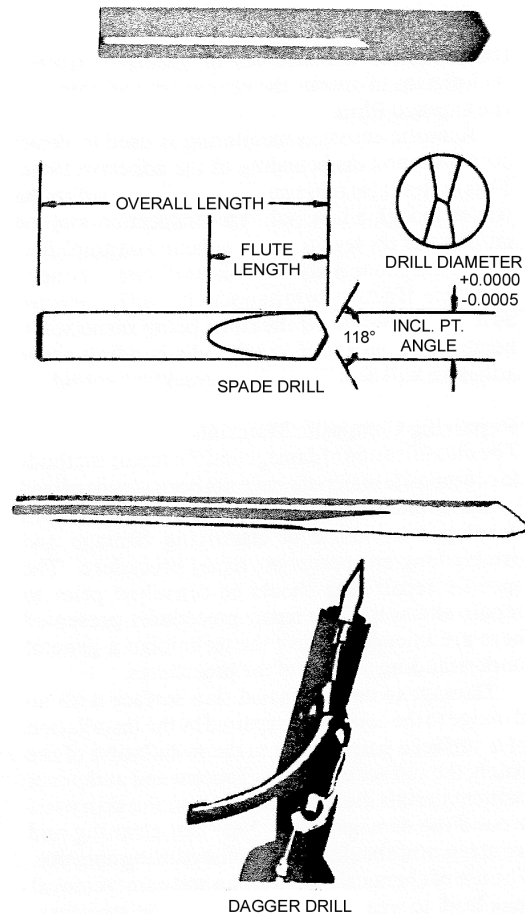

Fig. 36.24, Spade and dagger drills. (Federal mogul, Metal Remover Division.)

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 γ-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.
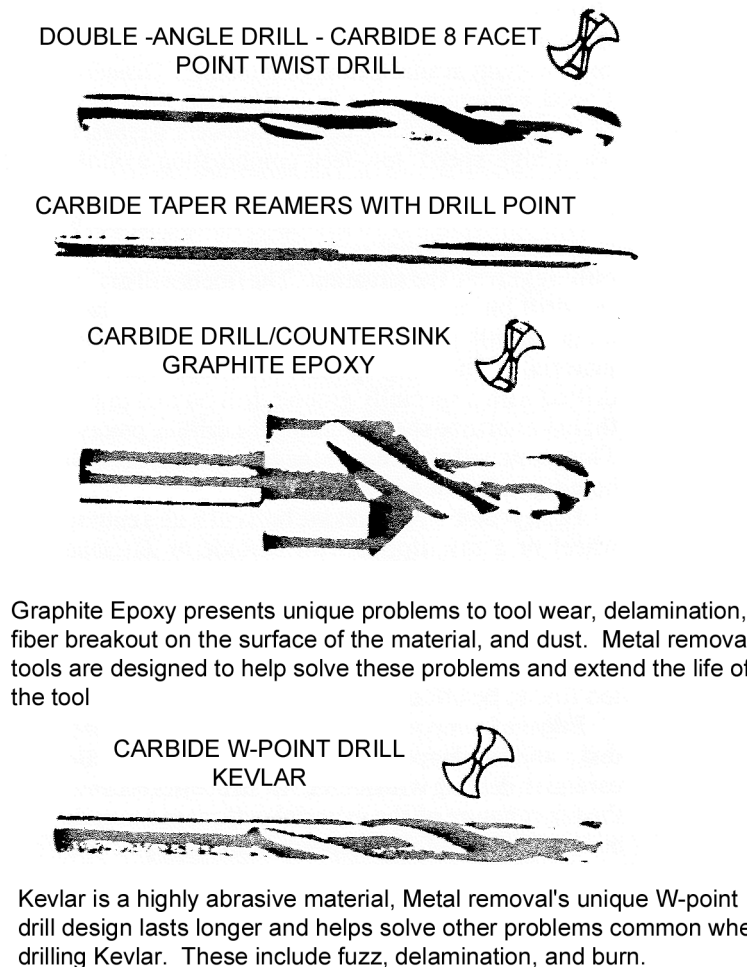
DOUBLE -ANGLE DRILL - CARBIDE 8 FACET
POINT TWIST DRILL

CARBIDE TAPER REAMERS WITH DRILL POINT

CARBIDE DRILL/COUNTERSINK
GRAPHITE EPOXY

Graphite Epoxy presents unique problems to tool wear, delamination, fiber breakout on the surface of the material, and dust. Metal removal tools are designed to help solve these problems and extend the life of the tool

CARBIDE W-POINT DRILL
KEVLAR

Kevlar is a highly abrasive material, Metal removal's unique W-point drill design lasts longer and helps solve other problems common when drilling Kevlar. These include fuzz, delamination, and burn.

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.
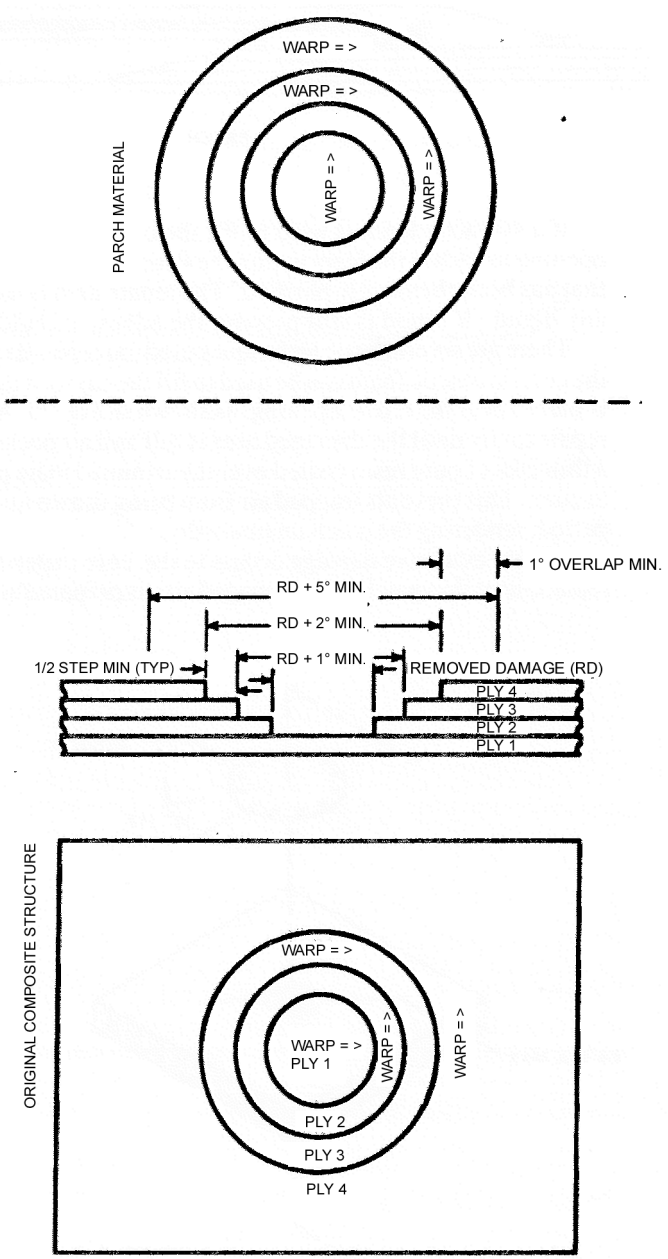

Fig. 36.26, Layout of a three-layer cut-back composite repair.

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.
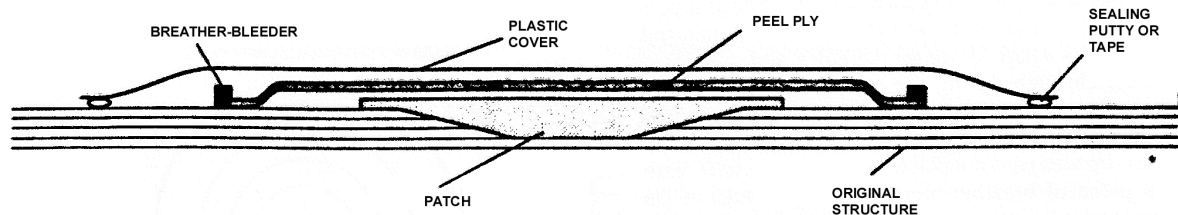

Fig. 36.27, Vacuum bag repair arrangement

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.

SECTION A-A
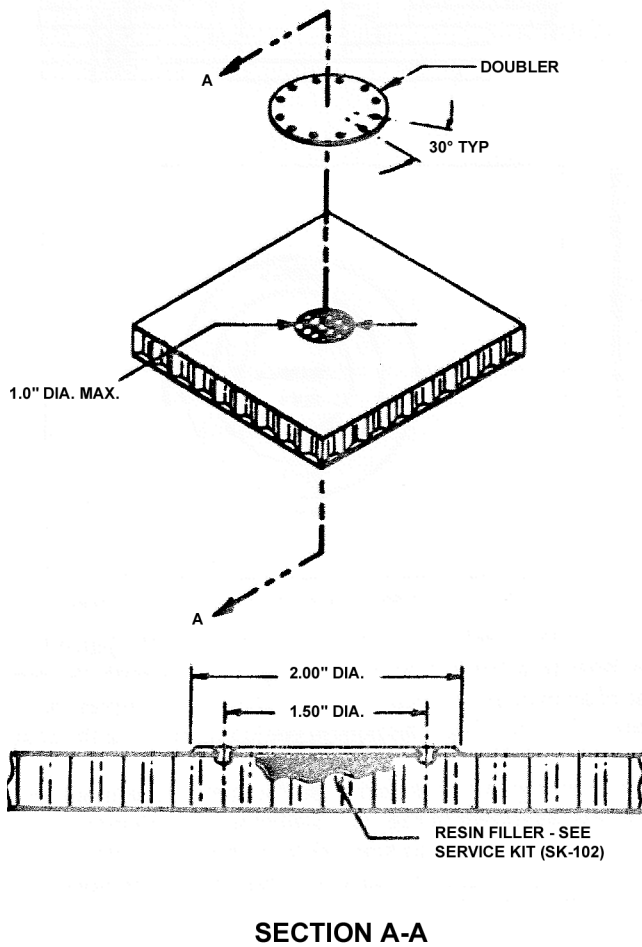
Fig. 36.28, A riveted surface patch repair,
(Grumman American Aviation)
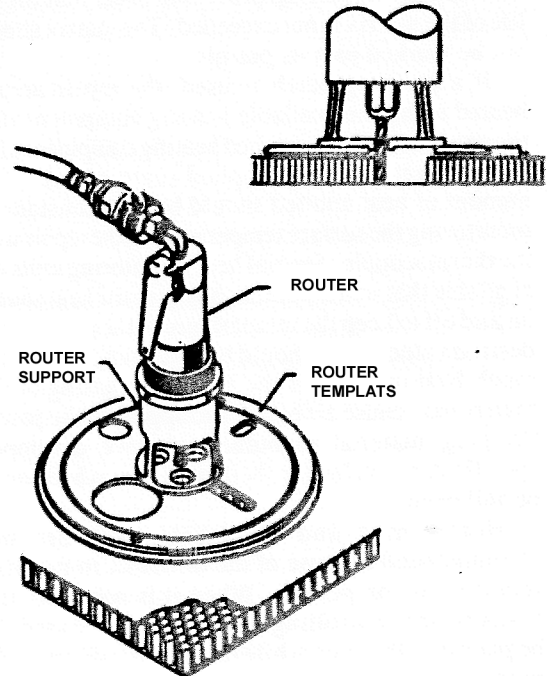
Fig. 36.29, Router, support assembly, and template.
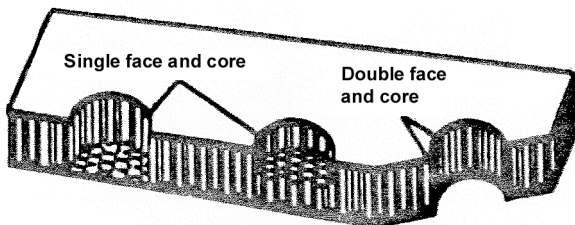
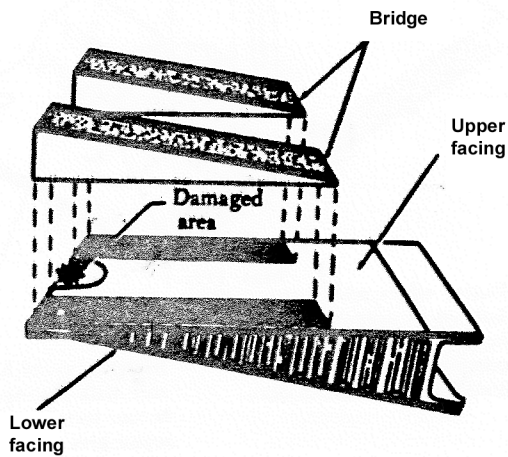*Fig. 36.30, Areas routed out prior to repair*

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.
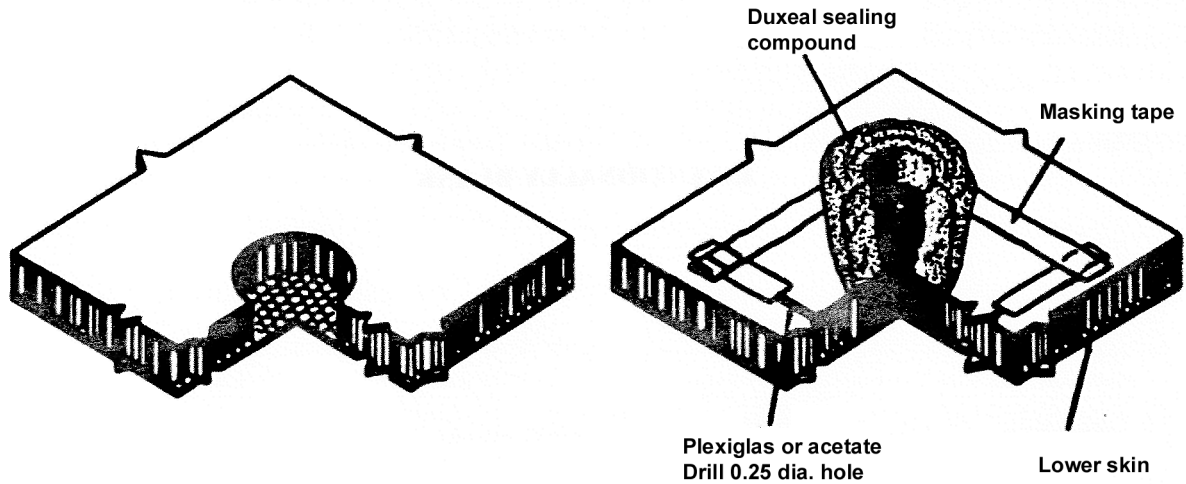

Fig. 36.32, A potted repair to the core and skin

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.
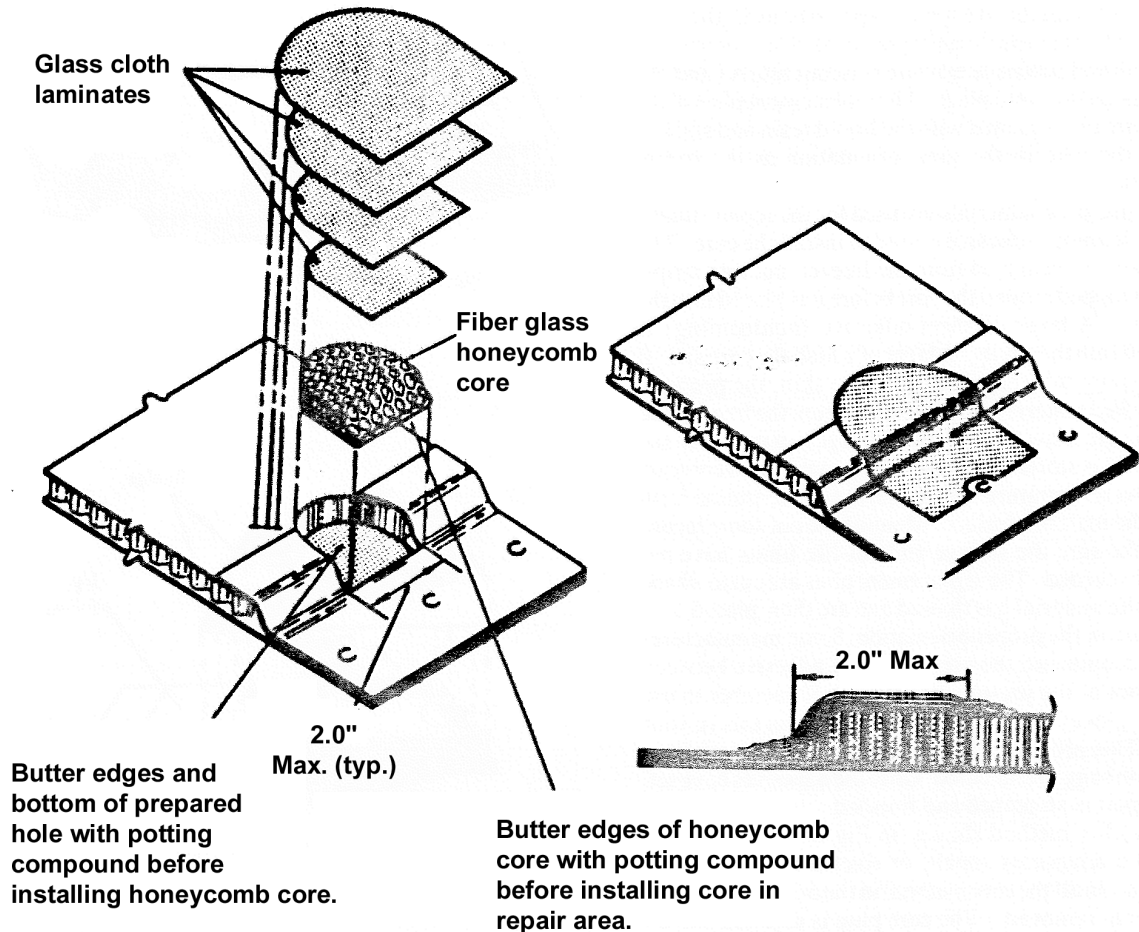

Fig. 36.33, A plug repair on an edge.

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.
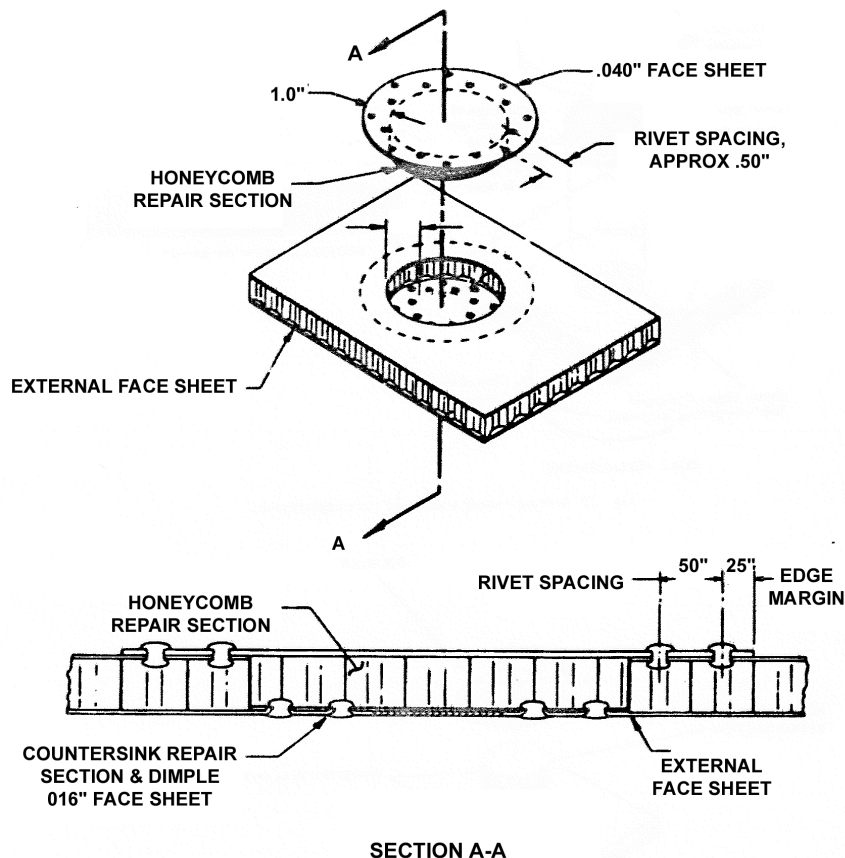
Fig. 36.34, A riveted plug repair.

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