Materials & Hardware

[According to the Syllabus Prescribed by EASA for Module 6 (Material and Hardware) and DGCA for AME knowledge examination]

FIRST EDITION

MATERIALS AND HARDWARE

Prepared by
Laxmi Narain Verma Memorial Society

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Dedicated To

Shri. Laxmi Narain Verma

[Who Lived An Honest Life]

Preface

This book is prepared by LNVM Society Group of Institute. The book is designed to aid the students in their day to day study. The chapters in this book discussed are on Material and Hardware.

New materials have been added in this book. This volume contains information about Aircraft Materials and Hardware, Springs, Rivets, Bearings, Gears, Fluid Lines & Fittings and part of Electrical System etc. Since the study of General Engineering is very vast, all the materials connected with EASA Module 6, Material and Hardware has been covered in this book.

This material will also be of great help to the students appearing for DGCA, AME knowledge Examination.

Grateful acknowledgment is extended to the Director (Mr. C.C. Ashoka) for his active involment to make material available for inclusion to make this book take its shape.

I would very much appreciate criticism, suggestion and detection of errors from the readers which will be gratefully acknowledged.

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Senior Instructor
L.N.V.M. Society Group of Institutes Dated : Dec. 2010

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CHAPTER-1
TERMS AND DEFINITIONS

VARIOUS PHYSICAL TERMS USED IN WORKSHOP TECHNOLOGY

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

Hardness

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

Brittleness

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

Malleability

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

Ductility

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

Elasticity

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

Density

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

Fusibility

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

Conductivity

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

Contraction and Expansion

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

HEAT-TREATMENT TERMS

Critical Range

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

Annealing

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

Normalizing

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

Heat Treatment

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

Hardening

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

Quenching

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

Tempering

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

Carburizing

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

Case-hardening

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

PHYSICAL-TEST TERMS

Strain

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

Stress

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

Tensile Strength

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

Elastic Limit

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

Proportional Limit

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

Proof Stress

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

Yield Strength

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

Yield Point

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

Elongation (Percentage)

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

Reduction of Area (Percentage)

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

Modulus of Elasticity

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

Thus

$$E = \text{unit stress} / \text{unit strain}.$$

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CHAPTER-2
AIRCRAFT MATERIAL : FERROUS

STEEL PRODUCTION METHODS

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

1. **Cementation process**

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

2. **Crucible process**

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

3. **Open hearth process**

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

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

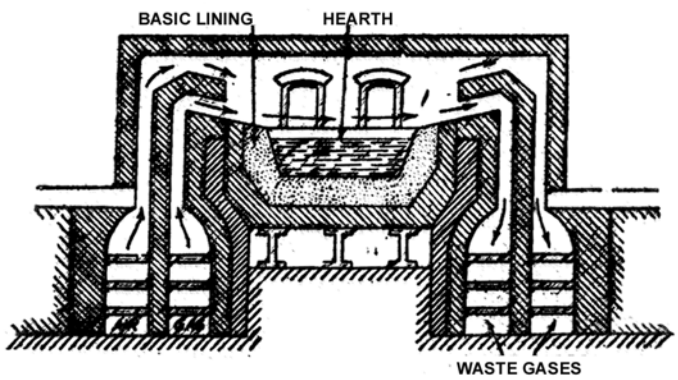

Fig.2.1 An open hearth furnace.

Although its size varies with the desired melting capacity, 10 to 25 meters length and 4 to 6 meters width are very common. Attached to the furnace are regenerative chambers for preheating the combustion air in case of a coke fired furnace and the air-gas mixture in case of a gas fired furnace. A sectional view of an open hearth furnace is shown in Fig.2.1The 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.

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-2.2) 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.

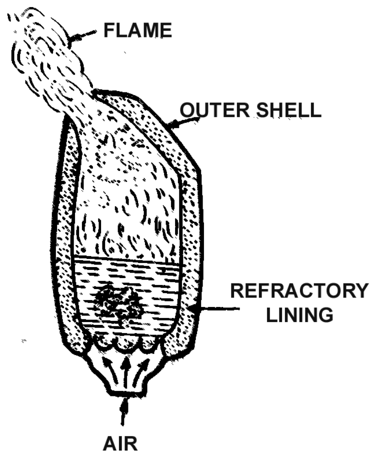

Fig.2.2 A Bessemer Converter

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

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

5. The Linz-Donawitz Process

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

6. The Electric Process

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

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

Direct arc furnace

It consists of a steel shell having a spherical bottom, as shown in Fig.2.3. 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.

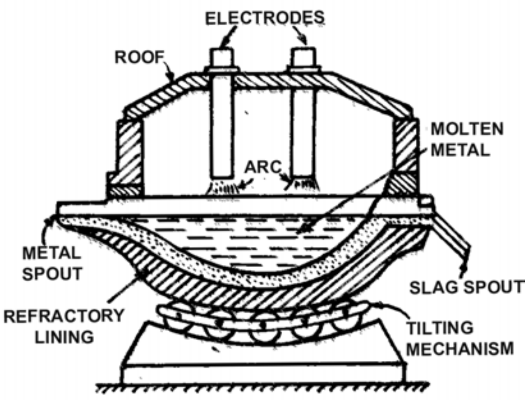

Fig. 2.3. A direct arc furnace

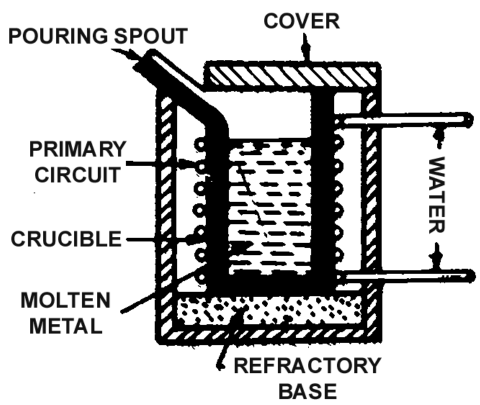

Fig.2.4. A direct arc furnace.

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

High frequency electric furnace

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

The duplex processes

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

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

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 2.1.

TABLE 2.1. APPLICATIONS OF PLAIN CARBON STEELS

Types of steel	*Applications*
Dead mild steel.	Welded and solid drawn tubes, thin sheets and wire rods.
Mild steel.	Forgings, stampings, structural sections such as angles and channels, plates for boilers and ships, bars and rods, wire, tubes and castings.
Medium carbon steel.	Drop forgings, boiler drums, marine shafts and axles, rotors and discs, agricultural tools and implements, aero engine cylinders, high tensile tubes and wires, bright drawn bars, castings for automobile engine components, laminatedsprings 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, mandrelsand drawing dies.
1.4 -1.5 % carbon	Lathe tools for machining harder metals, gauges, engraving tools.

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 2.2.

Table 2.2. 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 accompained 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^{0}C.

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^{0}C. 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 quenced, provides a martensitic structure to the alloy. Hence, the name. Due to formation of chromium carbides the corrosion resistance of this alloys is decreased. Different amounts of carbon are used to vary the strengths of these alloys. They are costlier than ferritic stainless steels and can be hardened by heat treatment. Their main applications are in the manufacture of items like springs, bolts, nuts, screws, valves, cutlery, etc.

c. Austenitic stainless steels

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

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

2. Magnetic steels

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

3. Heat resistance steels

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

Some typical compositions of such ferrous alloys are given below :

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

4. Maraging steels

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

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

5. High Speed Steels (HSS)

These steels are meant for the manufacture of cutting tools, specially those used in metal machining, and other similar applications where the amount of heat developed during the operation is very high and the tools used are required to retain their hardness at elevated temperatures. The factors responsible for high heat generation are the application of higher cutting speeds, heavy cuts, hardness of material being machined, high friction at tool and job interface, etc. All such factors contribute to heat generation and raising the temperatures to such an extent that the cutting edge of the tool may become red hot. If the tool material is unable to retain its hardness at that time it will fail to perform the cutting operation. A high carbon steel tool fails to meet this requirement and that necessitated the development of these alloys (*H.S.S*). It is reckoned that tools made of these alloys can safely operate at 2-3 times higher speed than those possible with high-carbon steel tools and retain their hardness upto a temperature of 620^{0}C.

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.

HEAT TREATMENT OF STEEL

It has long been known that a great variation in the properties of steel could be obtained by heating the metal to a high temperature and quenching quickly in a liquid, such a brine, water, or oil. Unfortunately, each alloy required a different treatment, and since the actual effects were not understood, the whole science of heat treatment was a hit or miss affair. Recently a new science known as "metallography" has been developed; it deals with the internal structural of metals and the principles underlying changes in structure. By means of etching and microscopic examination the internal structure of steel in all its various states has been studied. Due to these studies and the work of numerous investigators heat treatments is today an exact science.

Heat treatment of steel is based upon the fact that the metal has a crystalline structure which assumes different forms at various temperatures. The change in structure as the temperature decreases is normally slow, and it has been found that by rapid cooling, such as dropping the hot metal in a cold liquid, the normal structure at high temperatures can be retained at atmospheric temperatures. This new structure has totally different physical properties from the normal atmospheric-temperature structure. Numerous variations are possible, depending upon the temperature from which the metal is quenched and the speed of quenching. The practical terms which describe the heat treatments normally used are: annealing, normalization, hardening, drawing. In addition to these we have special treatments called carburizing, cyaniding, and nitriding. To develop the desired properties all aircraft steels are subjected to one or more of these operations. This chapter will be devoted to the theory and practical applications of heat treating.

CRITICAL RANGE

Materials are said to be allotropic when they possess the property that permits them to exist in various forms without a change in chemical composition. Carbon, which exists as diamond, graphite, and charcoal, is a common allotropic substance. Pure iron is also allotropic, existing in three states: namely, *alpha, beta* and *gamma* iron. In this case each of these states is stable only between very definite temperature limits alpha iron up to 1400^0F., beta iron from 1400^0F. to 1652^0F., and gamma iron above the latter temperature.

When molten iron solidifies and is permitted to cool at a uniform rate, it is found that at 1652^0F. the cooling stops momentarily. At this point a change in the structure of the iron has taken place, in which gamma iron has been transformed into beta iron. This rearrangement of the structure has resulted in the evolution of heat, which accounts for the retardation of the cooling. This point is designed by the symbol Ar_3 and is called the *upper critical point.* As the cooling continues, it is found that a second retardation occurs at 1400^0F. Obviously this is caused by the transformation of beta into alpha iron with the resultant evolution of heat. This point is indicated by Ar_2, the *second critical point.*

In the heating of pure iron similar points occur in which heat is absorbed without a rise in the metal temperature. These points are designated Ac_2 and Ac_3.. These heat-absorption points are some 20^0F. higher than the respective Ar_2 and Ar_3 point. The critical range is the range of temperature between the lower and upper critical points.

Carbon steels have definite critical points and a critical range. The exact temperature at which these points occur and the number of point depend upon the carbon content of the steel . Low-carbon steels have three critical points. In addition to the preceding two points described for iron, when a small amount of carbon is added to the iron another point designated as Ar_1 occurs at 1274^0F. There is, of course, a similar point on a rising heat designated Ac_1. The point Ar_1 is called the *lower critical point* or the *recalescent point because the intense evolution of heat causes the metal to glow.*

The *"r"* in the symbol *Ar* is derived from the French word *refroidissement,* which means cooling. Similarly, the "c" in the symbol Ac is the first letter of *chauffage*-heating.

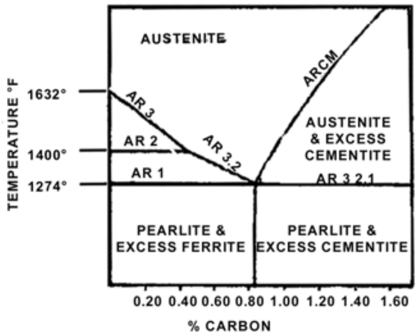

Fig.2.5. Critical Points of Steel

Referring to Figure 2.5 it can be seen that the number of critical points and the scope of the critical range depend upon the carbon content. There are three critical point up to a little over 0.4% carbon. In this region the two upper critical points merge, forming a single point, Ar_{3-2}. At 0.85% carbon all the critical points unite, and we have one point, *Ar3-2-1. Above* 0.85% carbon a new point designated Ar_{cm} extends above the Ar_{3-2-1} point.

Alloy steels possess similar critical points, but they occur at different temperatures for each steel. Nickel and manganese have the property of materially lowering the critical range. In fact, the 13% manganese steel has a critical range below atmospheric temperatures.

INTERNAL STRUCTURE OF STEEL

The internal structure of steel is almost wholly dependent upon the exact relationship of the iron and carbon. The carbon is in chemical combination with the iron as iron carbide (Fe_3C), called *cementite.* In steels containing 0.85% carbon, the cementite forms a perfect mixture with the pure iron (called ferrite) present. This mixture is called *pearlite* because of its resemblance in appearance to mother-of pearl. Pearlite is a mechanical mixture of six parts of ferrite to one part of cementite. Steels with less than 0.85% carbon are composed of pearlite and excess ferrite. Practically all aircraft steels are of this type. On the other hand, tool steels which contain more than 0.85% carbon are composed of pearlite and excess cementite.

In metallurgy the name *eutectic alloy* is given to that alloy of two substances which has the lowest fusing point. In every alloy there is one percentage combination of the two elements that will fuse at the lowest temperature. Variation of the percentage composition of either element, up or down, will increase the temperature of fusion. A similar condition exists in steel in the critical range, although here we are dealing with a solid solution. You will note in Figure 9.1 that the lowest temperature for the upper critical point occurs at 0.85% carbon content. This alloy has been named the *eutectoid.* Steel with less than 0.85% carbon is called *hypo-eutectoid* and with more than 0.85% *hyper-eutectoid.* Steels with excess ferrite are hypo-eutectoid, and steels with excess cementite are hyper-eutectoid.

Pearlite is normally a laminated structure consisting of alternate layers of ferrite and cementite. In some cases pearlite has a granulated appearance and is called granular pearlite. If steel is cooled very slowly through the critical range, laminated pearlite, which is the most stable form, will result. Pearlite is relatively strong, hard, and ductile. It has a tensile strength of over 100,000 p.s.i., an elongation of approximately 10%, and maximum hardening power. This latter point is extremely significant. It means that the greatest hardness from heat treatment is obtained by steel containing -.85% carbon. It is also true that starting with low-carbon steel, greater hardness is obtainable as the carbon content increases and approaches 0.85%. This point is important when selecting a steel to give great strength and hardness after heat treatment.

Ferrite is pure alpha iron in carbon steels. In alloy steels containing nickel, molybdenum, or vanadium these alloying elements are in solid solution in the ferrite. Ferrite is very ductile and has a tensile strength of about 40,000 p.s.i.. It should be noted that it imparts these properties to low-carbon steels of which it is the major constituent. Ferrite does not have any hardening properties.

Cementite is iron carbide (Fe_3C). It is very hard and brittle and produces a hardening quality on steels of which it is a part.

Austenite, the name given to steel when it is heated above the critical range, consists of a solid solution of cementite in gamma iron. It is stable only when maintained at a temperature above the critical range. It will, however, attain perfect homogeneity if sufficient time is allowed. The grain size of steel, it has been found, is smallest just above the critical range, and it is a known fact that the smallest grain size will give the strongest and best metal. For this reason, when steel is heated for subsequent hardening or working, its temperature is kept just above the upper critical point for the time necessary to insure thorough heating of the material.

Annealing

Annealing of steel is effected by heating the metal to just above Ac_3, soaking at that temperature for a definite time, and cooling very slowly in the furnace itself. This treatment corresponds to number 2 just above. The time of soaking is about one hour per inch thickness of material to make certain that all of the material is brought up to temperature. Slow cooling is usually obtained by shutting off the heat and allowing the furnace and metal to cool together down to 900^0F. or lower, at which time the steel may be removed from the furnace and cooled in still air. An alternate method to restrict the rate of cooling is to bury the heated steel in ashes or lime.

Annealed steel is fine grained, soft, ductile, and without internal stresses or strains. It is readily machinable and workable. In the annealed state steel has its lowest strength. For that reason it is often given a subsequent heat treatment so as to increase the strength after all machining and mechanical work are complete. The ductility of annealed steel is utilized in tube and wire drawing and in rolling sheet. After the steel has passed through the dies or rolls several times, re-annealing is necessary to relieve the stresses induced by the cold work and to prevent cracking.

There are several modifications of the full annealing treatment used when all of the effects are not essential, and speed and economy are important.

Process annealing Consists in heating below Ac_1 in the region between 1020^0 and 1200^0F. This treatment is commonly used in the sheet and wire industries to restore ductility.

Spheroidizing is a form of annealing applied particularly to high-carbon steels to improve their machinability. As indicated by the name, a globular cementite structure is obtained. In this form the cementite can be pushed aside by the cutting tool instead of offering great resistance as when present in this laminated form. The operation of spheroidizing consists in prolonged heating just slightly below the critical range, followed by slow cooling.

Shop annealing is the term used to describe the practice of heating steel with a welding torch to 900^0 to 1000^0F. and dropping it into a pail of ashes or lime to restrict the cooling rate. This treatment will relieve internal strains. It is never used in aircraft work unless it is to be followed by a regular heat treatment.

In all annealing processes, due to prolonged heating at high temperatures and slow cooling from these temperatures, the surface of metal is prone to scale. The scale on steel is iron oxide. Whenever possible, annealing should be done in closed receptacles to exclude air from the metal. The receptacle should not be opened until it has cooled almost to room temperature. In the case of high-carbon steels the prevention of scale formation is particularly important. Oxidation of the carbon at the surface will occur if not guarded against. This decarburisation is injurious to the metal and must be avoided. When steel parts have not been annealed in a receptacle, the scale must be removed by a cleaning or pickling treatment.

Normalising

Normalizing is a form of annealing which consists in heating the steel above Ac_3 and then cooling in still air. Due to the more rapid quenching obtained by air-cooling as compared to furnace-cooling, the steel is harder and stronger but less ductile than annealed material. Normalising is required whenever it is desired to obtain material of uniform physical characteristics. Forgings are generally normalised to relieve all internal stresses. Normalizsing, too, will relieve stresses. Refine the grain, and make steel more uniform just as annealing will, but, at the same time, improved physical properties are obtained. Because of the better physical properties, aircraft steels are often used in the normalised condition but seldom if ever in the annealed state. If annealed steel is used in fabrication for ease of working, it is subsequently normalized or heat treated to a higher strength.

Welded parts are frequently used in airplane construction. Welding causes strains to be set up in the adjacent material. In addition, the weld itself is a cast structure as opposed to the wrought structure of the rest of the material. These two types of structure have different grain sizes, and to relieve the internal stresses and refine the grain, all welded parts should be normalised after fabrication. Such treatment will reduce the possibility of cracks and fatigue failures in service. Normalising of welded parts is considered so important by one government department that it even requires this treatment for engine mounts. In many cases where large furnaces are not available, or the basic design of mount /will not permit normalising without too much warping, it is necessary to design an assembled mount made up of small sections. The sections can be normalised individually and bolted or riveted together.

Low-carbon steels are often normalised to improve the machining qualities and to reduce distortion in subsequent heat-treating operations. In actual practice the aircraft manufacturer buys tubing, sheet, and bar in the normalised condition, performs the necessary machining or welding operations, and then normalises or heat treats the finished article. In connection with the purchase of normalised material it is often necessary to specify the maximum tensile strength that is acceptable. This is particularly true of thin sheet which, when quenched in still air, will cool far more rapidly than heavier material. As a result, thin sheet will be composed of sorbite as well as pearlite- the usual constituent of normalised steel. The sorbite makes the steel stronger but also more brittle. Chrome-molybdenum sheet steel, as purchased in the normalised state, will often run from 110,000 to 125,000 p.s.i. ultimate tensile strength. Where severe bending is to be done, the purchase order should specify a maximum of 95,000 p.s.i. which is the accepted strength for normalized chrome-molybdenum steel.

Medium-and high-carbon steels should be normalised and then annealed before machining or fabrication. This sequence of operations is sometimes called double annealing. The resultant structure is similar to that obtained by spheroidizing, as described previously. In aircraft work the amount of machining done is usually small and the annealing is often omitted.

Some alloy steels cannot be satisfactorily hardened without first being normalised. This is especially true of alloys containing chromium. The accepted explanationof this phenomenon is the necessity for the complete solution of the chromium and iron carbides in the gamma iron. Solution is effected by normalizing prior to hardening.

Hardening

Hardening is the first of two operations required for the development of high-strength steels by heat treatment. Hardening consists of heating above. Ac_3 soaking at that temperature until the mass is uniformly heated and then quenching in brine, water , or oil. This treatment produces a fine grain, maximum hardness and tensile strength, minimum ductility and internal strains. In this condition the material is too hard and brittle for practical use. A light blow, as from a hammer, would shatter the material.

Heating is conducted as little above Ac_3 as is practical, in order to reduce warping and the possibility of cracking when the material is quenched. On the other hand, large objects are heated to the upper limit of the hardening range in order to assure thorough heating. For the materials and sections used in aircraft work, quenching in oil is invariably the method employed. The heat absorption of oil is slower than that of water or brine, and consequently the cooling operation is more gentle. Less warping and cracking occurs and sufficient hardness is obtained.

Quench cracking is a result of nonuniform or too rapid cooling of the steel. The transition from austenite to martensite results in an increase of volume. When a piece is quenched, the external surface will cool rapidly and becomes a hard, brittle martensite shell. As the internal austenite cools and becomes martensite it increases in volume and internal stresses are set up which may crack the earlier-formed outer shell.

As explained previously under Theory of Heat Treatment, the rapid quenching from a temperature above the critical range arrests the transitions from austenite to pearlite, and results in the formation of martensite and some troostite Martensite is the hardest form of steel and is responsible for the extreme hardness and brittleness of hardened steel.

Drawing (Tempering)

Drawing (or as it is sometimes called, tempering) is the second operation required to develop high-strength, heat-treated steel. It consists of heating hardened steel to a temperature well below Ac_1, soaking at that temperature, and then quenching in oil or air. This treatment relieves the strains in hardened steel, decreases the brittleness, and restores ductility. In addition, the strength and hardness are some what reduced. The strength, hardness, and ductility obtained depend upon the temperature to which the steel was reheated. The higher the temperature, the lower the strength and hardness but the greater the ductility. By decreasing the brittleness of hardened steel, tempered steel is made tough and still retains adequate strength.Tempered steels, as used in aircraft work, have from 125,000 to 200,000 p.s.i. ultimate tensile strength.

When hardened steel is reheated as in tempering, the transition from austenite to pearlite is continued further, and the martensite is converted to troostite and then sorbite. Tempered steel is composed largely of sorbite, which gives it toughness. Hardened steel, reheated to a low temperature and quenched, is composed of troostite and sorbite, and is still very hard and strong but more ductile than hardened steel, hardened steel reheated to a higher temperature and quenched is composed of sorbite and some pearlite, and is tougher and more ductile but still retains considerable strength and hardness.

The temperature at which tempering should be carried out, depends upon the purpose for which the article or tool is to be used, and the table below gives the temperature for high carbon steel.

When the articles have been brought to the tempering temperature, it may be quenched or allowed to be cooled naturally. The temperature for this operation is often judged by the colour of the oxide film which appears on a freshly polished surface of the article, and those colours are given in the table below :-

TEMPERATURE AND APPROXIMATE COLOUR GUIDE

The colour and corresponding temperature are given in the table below :-

COLOUR OF STEEL	APPR. TEMP. DEG. C	APPLICATION
Dazzling white	1400 - 1500	
Brilliant white	1300 - 1400	
White	1200 - 1300	High speed tungsten steel
Pale yellow	1100 - 1200	
Yellow	1000 - 1100	Austenite Nickel -Chrome stainless steel.
Orange	900 - 1000	High Chromium stainless steel
Light Cherry red	800 - 900	Low carbon and nickel chrome steel.
Cherry red	700 - 80	High carbon steel
Dull red	600 - 700	
firs Visible red	500 - 600	
Oxide Colours		
Blue	300	Tempering range tools, such as springs, axes,
Purple	295	screw drivers, chisels hacksaw blades etc.
Purple Brown	285	
Brown	270	
Golden yellow	250	
Straw	240	
Pale Straw	200	

"ONE HEAT" METHOD OF HARDENING AND TEMPERING

This method is used for tools which require a hard point or cutting edge with the remainder left tough to withstand shock, e.g. cold chisels, lathe tools etc.

The complete procedure for making, hardening and tempering a chisel is as follows :-

a. First get the appropriate metal of approximate shape and size. Then heat it to bright red, and forge to shape as required.
b. Normalise, when cold grind roughly to shape
c. Heat the cutting end half of the tool to cherry red, plunge vertically into water to about a quarter of the length and keep it moving a little up and down to prevent a sharp line between the quenched and unquenched parts, which would cause "Water line" cracks.
d When the point is black withdraw from the water polish the point with emery or sand stone and observe the tempering colours formed as the heat flows down from the unquenched parts.
e. When the desired colour appears, instantly quench the tip, wait if necessary, till all visible red heat dies away before dipping the remainder to cool it.
f. Grind the cutting edge, taking care not to over heat the tool.

PRACTICAL HEAT TREATMENT

The first important consideration in the heat treatment of a piece of steel is to know its chemical composition which, in turn, determines its critical range. When the critical temperature is known the next consideration is the rate of heating and cooling to be employed to insure completion of transition or retardation of transition as the case may be. The carrying out of these operations is beset with practical problems. These involve the use of furnaces for uniform heating, pyrometers for controlling temperatures, handling of hot metal, and quenching in suitable mediums. Some notes on the more vital considerations in heating, soaking, and quenching are given below.

Heating

The aim in heating is to transform pearlite to austenite as the critical range is passed through. This transition takes time; so a relatively slow rate of heating is employed. It is customary to insert the cold steel in the furnace when it is from 300^0 to 500^0F. below the hardening temperature. In this way too rapid heating of the cold steel through the critical range is prevented. It is cheaper to keep a furnace up to the hardening temperature and remove heated steel and insert new cold steel periodically without permitting the temperature to drop several hundred degree before inserting the new cold work. This is sometimes done where the work is not extremely important, but it does the possibility of cracking, depending on the shape of the material, due to rapid heating and expansion.

In reheating for tempering, the furnace should not be above 800^0 to 1000^0F. when the work is inserted and ,in any case, not above the tempering temperature of the steel which is being treated. If the tempering temperature is too high, the transition from martensite to sorbite will be accelerated beyond control of the heat treater.

Several types of furnace are employed in heating. The common type is a "dry heat" furnace and is fired by oil, gas, or electricity. A uniform temperature must be maintained throughout the furnace, and the work must be properly placed to insure uniform heating. The work must not be placed too close to the wall of the furnace; otherwise radiated heat from the wall will heat one face of the work beyond the rest, with resultant uneven heating. In a dry furnace it is desirable to maintain a neutral atmosphere, so that the heated steel will neither oxidise nor decarburise. Practically, however, this condition is difficult to realise, and considerable scaling of the work results. In this respect the electric furnace is the most satisfactory because only a slight amount of scaling takes place. An atmosphere free of oxygen is maintained in one type of electric furnace. There is practically no scaling of the work in this type of furnace. Special paint coatings, such as "Galvo Anti-scale," are sometimes used to minimize scaling during the heating operation when atmospheric control is not available.

A "liquid heat" furnace is frequently used for parts which have been finished-machined before heat treatment. In this type of furnace, parts are heated in a molten salt bath. Here there are several advantages, the most important being the complete elimination of scaling. In addition, better temperature regulation and more uniform heating are attainable. For production work where speed is essential, faster heating is possible with the liquid bath than with dry heat. Numerous other advantages are claimed for the liquid bath, but those just given are the most important.

Soaking

During the soaking period the temperature of the furnace must be held constant. It is in this period the rearrangement of the internal structure is completed. The time of soaking depends upon the nature of the steel and the size of the part. Heavier parts require longer soaking to insure equal heating throughout. In specifying hardening temperatures, it is customary to give a range of from 50^0 to 75^0 F. within which the material must be soaked. Light parts are soaked in the lower part of this range and heavy parts in the upper part of the range. For the steels and sizes normally used in aircraft construction a soaking period of from 30 to 45 minutes is sufficient. During the tempering operation the steel is soaked from 30 minutes to one hours, depending on the thickness of the material.

Quenching

The rate of cooling through the critical range determines the form that the steel will retain. In annealing, the heated steel must be furnace cooled to 900^0F., which is below the critical range, provides sufficient time for complete transition from austenite to pearlite, which is the normal, stable condition of steel at atmospheric temperatures. In normalising, the heated steel is removed from the furnace and allowed to cool in still air. The cooling is more rapid than in annealing, and complete transition to pearlite is not attained. Some sorbite remains in normalisedsteel, which accounts for the improvement in physical properties over annealed material. Air cooling is a very mild form of quench.

In order to harden steels, it is necessary to use a more rapid quenching medium. There are three mediums commonly used-brine, water, and oil. Brine is the most severe quenching medium, water is next, and oil the least severe. In other words, oil does not cool the heated steel through the critical range as rapidly as water or brine. However, oil does cool rapidly enough to develop sufficient hardness for all practical purposes. In aircraft work high-carbon and alloy steels are oil quenched. Medium-carbon steel is water quenched and mild-carbon steel (S.A.E. 1025) is quenched in either brine or water. A severe quench is required for steels with relatively low carbon contents in order to develop the required hardness. This observation agrees with the comments previously made in the paragraph under Internal Structure of Steel relative to the importance of the carbon content on the hardening properties of steel.

Oil quenching is preferred to water or brine when sufficient hardness is obtainable because of the reduced strain, warpage, and cracking of the steel when cooled more slowly. When the structure changes from austenite to martensite, the volume is increased; and if the change is too sudden, cracking will occur. Cracking occurs particularly in the lower temperature ranges when the steel is no longer plastic enough to readjust itself to expansion and contraction. The shape of a part is extremely important if excessive warping and cracks are to be avoided. Thin flanges on heavy sections are especially bad. When tubular parts are quenched, they should be immersed with the long axis vertical to reduce warpage.

Small parts when quenched cool more rapidly than large parts, and harden more uniformly throughout. In large parts the inside core is usually softer and weaker than the rest of the material. This fact must be given consideration in design in calculating the cross-sectional strength. Values obtained from heat-treated parts of small sectional cannot be applied directly to larger sections. Strength values normally quoted are based on heat-treated sections 1 to 1½ inches in diameter. As explained in the chapter on Steel and Its Alloys, many possess the property known as penetration hardness. These alloys harden quite uniformally throughout when heat treated and quenched, and no allowance need be made for a soft core unless the section is excessively large. Such sections are seldom used in aircraft work.

The quenching oil is normally maintained between 80^0 and 150^0F., but if water is used as the quenching medium it is held at a temperature below 65^0F. This control involves a large reservoir of liquid and some method of providing circulation and cooling. The rate of cooling through the critical range is governed by the temperature maintained in the quenching medium. In as much as variations in this temperature have an appreciable effect on the rate of cooling, it is obvious that the quenching-medium temperature must be held within limits if consistent results are to be obtained.

After steel is reheated and soaked for tempering, it is quenched in either air or oil. Chrome-nickel steels, however, must be quenched in oil-not air-after tempering in order to avoid "temper brittleness" to which this particular group of steels is subject if air quenched.

HEAT TREATMENTS FOR AIRCRAFT STEELS

As previously explained, each type of steel has different hardening qualities which are governed by its composition. For this reason the practical heat treatments of various steels differ somewhat as to heating temperatures, soaking periods, and quenching methods. In the following pages an effort has been made to describe the heat-treatment operations commonly used on aircraft steels. Since these data are presented purely for the general information of the reader, and not as a reference for the practical heat treatment, there has been no hesitancy to discuss an interesting point right in the body of the description. For more specific information on the steels listed, or on others not listed, the steel manufacturer should be consulted and he will gladly furnish the required data.

The heat treatments listed in the following pages do not conform wholly to the Army or Navy specifications or S.A.E. recommendations but are an average of the three. Due to slight variations-in the chemical composition of steel made by different manufacturers, in heat-treating equipment, in the size of average parts, and in the technique of heat -treater- a definite, narrow range for hardening and tempering temperatures cannot be laid down. The figures given will satisfy average conditions, but the individual heat treater may have to vary them a little to obtain satisfactory results.

The range of hardness numbers for a given tensile strength is also an average figure. Each factory should establish its own correlation between tensile strength and hardness numbers by heat-treating tensile test specimens, recording their hardness, and then testing to determine their ultimate tensile strength. For important work tensile specimens should be heat treated along with the work and tested. Absolute faith should not be placed in hardness readings alone.

It will be noted under Item 4 of S.A.E. 2330 steel that there is a discussion of the relationship between the tempering temperature to be used and the actual hardness of the steel after the hardness operation. Use of the suggested proportion on material above or below average may save time and labor, particularly where too soft tempered material would otherwise be obtained, thus requiring both re-hardening and re-tempering.

The lower part of the heating ranges should be used for material less than ¼ inch thick.A majority of airplane parts fall in this category. Prolonged heating of this material should also be avoided to prevent grain growth.

Cycle Annealing

This is a process in which austenite is transformed isothermally to pearlite at high temperatures, and this latter structure is retained when the work is cooled to room temperature. In actual practice the steel is austenitised (heated to a temperature above the critical temperature and soaked until a stable austenitic structure is formed through out the part) at a temperature above but within 100^0F. of the critical temperature. It is then quenched in a molten salt bath maintained at a temperature below the critical temperature but above the "knee" temperature unless the shape of the S curve is such that too long a period of time would be required to complete the transformation, in which case a somewhat lower temperature is used. After complete transformation is effected the work is cooled to room temperature by air or water without further changing the microstructure.

Sometimes the transformation is allowed to proceed only a certain amount before the work is removed from the quenching bath and allowed to air cool. By this means a variation in properties is obtainable. Cycle annealing permits better structure in a fraction of the time required for the full annealing and spheroidizing operation. Cycle annealing requires from 4 to 7 hours as compared with 18 to 30 hours for standard annealing.

Austempering

This is a process in which austenite is transformed isothermally to bainite at moderate temperatures The material is austenitised and then quenched in a molten salt bath maintained at a temperature above the *Ms* but below the "knee" temperature. The work is held in the bath until the transformation to bainite is complete and then it is removed and cooled to room temperature by air or water. In some cases, to insure adequate cooling to below the "knee" , it is necessary to quench in a bath maintained at a lower temperature than that required for the final hardness desired. In this case the bainite product is transferred for tempering to a second bath maintained at a higher temperatures. This procedure permits the austempering of slightly larger sizes of material than would be possible by using only the second bath for quenching. The double operation is sometimes referred to as isothermal quenching.

Austempering is most useful when the steel is to be used in the hardness range of Rockwell C-48 to C-58.As compared to standard quench and temper steels of the same hardness, austempered steel has about 30% additional elongation, 100% greater reduction of areas and impact strength, but slightly less yield strength. Spring products and other items requiring increased elasticity as well as hardness are obtainable by austempering. Then finish of the part after austempering is the same as the initial material before heat treatment. The relative gentleness of the quench results in minimum distortion and cracking of the work.

As explained previously, a rapid-quenching or deep-hardening steel is required to get by the "knee" of the S curve. This requirement limits the austempering process to carbon steels above 0.55% carbon and to alloy steels . The maximum cross-sectional area of S.A.E. 1095 steel that can be austempered is the equivalent of a rod 0.148 inch in diameter; S.A.E. 4140 is limited to a 0.50- inch diameter; and a material like SAE 4365 is limited to a 1.0- inch diameter.

Martempering

This is a process in which austenite is uniformly transformed to martensite at low temperatures by continuous cooling. In this process the work is austenitised and then quenched in a molten salt bath maintained at a temperature just above the *Ms* temperature of the steel being treated. The work is held at this temperature only a short period of time-long enough to permit all of the material to reach the same temperature, but not long enough for the transformation to bainite to begin. The work is then removed from the bath and allowed to air cool. The transformation from austenite to martensite occurs during this air cooling, at which time the difference in temperature between the outer skin and the centre of the work is negligible. When room temperature is reached and the transformation to martensite is complete the work is subjected to a normal tempering operation to obtain the desired physical properties.

It should be noted by quenching a part in the salt bath at a temperature above *Ms*, temperature uniformity throughout the part is obtained before any transformation or change in microstructure takes place. When the part is slowly cooled in air from this temperature the transformation occurs uniformly throughout. By this means nonuniform volume changes are reduced, high internal stresses are avoided, and warpage, cracking, and distortion are minimized. These are the particular advantages of martempering. Martempering is limited largely to high-alloy steels and small cross-sectional areas for the same reason that applies to austempering, namely, the necessity for getting by the "knee" of the S curve in quenching if the full advantage of the process is to be realised. S.A.E. 8630 steel can be martempered up to a cross-sectional area equivalent to a round of 1- inch diameter; S.A.E. 8740 can be processed up to 1½-inch diameter.

HARDENABILITY

In recent years hardenability has come to the forefront as the primary basis for the selection of a particular type of steel. This criterion is logical since the physical properties normally required for a given application are directly related to the hardness of the material. Steels with equivalent hardening characteristics can be used interchangeably irrespective of their chemical compositions. In the future it is anticipated that most steel will be purchased under "H" steel specifications, which prescribe hardenability limits as well as over- all chemical compositions. When steel is purchased under this type of specification the aircraft manufacturer's heat-treating problems will be simplified, as all material will come up to the required hardness when properly heat treated. In the past, when material was purchased solely by chemical composition, there were many occasions when a sour lot of material would not respond to heat treatment for some unexplainable reason.

"H" steel specifications have been prepared for most of the commonly used steels. Steel in accordance with this type of specification is designated by adding an H to its numerical designation. Thus we have 4130 H, 8740H, etc., to identify steels manufactured to hardenability-band limits. Tables and charts have been prepared for each type of steel to define its hardenability limits.

A jominy or end-quenched hardenability test has been adopted as the standard method for determining hardenability limits in order to permit comparisons between different steels. This test is based on the concept that the hardening of steel by quenching is a function of heat extraction--rapid extraction resulting in high hardness and slow extraction resulting in low hardness.

The standard Jominy specimen is a round 1 inch in diameter by 4 inches long which has been machined after normalising to remove all scale or decarburized surfaces. To insure uniformity the specimen is normalised at the temperature listed below for one hour, machined to finished dimensions, and the is held for 30 minutes at the austenitising temperature listed below. The furnace should be at the austenitising temperature when the specimen is inserted. A protective atmosphere furnace or other means is essential to protect the bottom end of the specimen from scale or decarburization.

Quenching of the specimen must start within 5 seconds after its removal from the furnace. The specimen is quenched by suspending it vertically with its bottom end ½ inch above a water orifice with a ½-inch opening which discharges water at a rate of approximately 1 gallon per minute. The water must be at a temperature between 40^0 and 85^0F and must impinge against only the bottom or quenched end of the specimen. Quenching in this manner is continued for 10 minutes.

A cooling rate of 600°F per second is attained at the quenched end. The rate of cooling is slower as the distance from the quenched end increases and is only 4 ° per second at the opposite end. Since the cooling rate varies along the entire length some point will duplicate every quenching condition met with in practice from water to air quenching, and from the surface to the centre of various sizes of material .for instance, the cooling of the specimen at 3/8, 3/4, 1 1/16. and 1½ inches from the quenched end will result in hardness equivalent to that obtained at the centre of 1-, 2-, 3-, and 4-inch rounds respectively when quenched in still oil. This type of results can be consistently correlated and therefore can be used to predict the attainable hardness for any shape from data supplied by the end-quenched specimen.

Steel series	**Maximum carbon content (%) temperature (^{0}F).**	**Normalising temperature (^{0}F.)**	**Austenitising**
1000			
3100			
4000	Up to 0.25 incl	1700	1700
4100	0.26 to 0.36 incl	1650	1600
4600	0.37 and over	1600	1550
8600			
8700			
	Up to 0.25 incl	1750	1750
6100	0./26 to 0.36 incl	1700	1650
	0.37 and over	1650	1600
2300			
2500	Up to 0.25 incl	1700	1550
3300	0.26 to 0.36 incl	1650	1500
4800	0.37 and over	1600	1475
9200			
9200	0.50 and over	1650	1600

To obtain the hardness readings of the end-quench specimen, two flats 180^0 apart are carefully ground along the entire length of the specimen. Wet grinding is preferable, to avoid changing the quenched condition, and the flats should be at least 0.015 inch deep. Rockwell C hardness readings are then taken every 1/16-inch from the quenched end for 1 inch and at greater intervals for the remainder of the length. The Rockwell readings are then plotted on a standard chart in which the ordinates represent hardness and the abscissas represent distance from the quenched end. The chart applying to each steel is necessarily a band bounded by a maximum and a minimum curve. This spread is due to the variations permitted in the chemical compositions of a given steel.

In ordering "H" steel it is customary to specify two specific points of the desired hardenability band. In the preferred method , the distance from the quenched end where a specified Rockwell C hardness is desired is called for. Usually a minimum and maximum distance is given within which the desired hardness number must fall. In the alternate method, a minimum hardness number (or a range of hardness numbers which will be acceptable) at a specified distance from the quenched end is called for. In addition, in either of these methods, the minimum and maximum hardness 1/16-inch from the quenched end may be specified. The steel producer will list on the shipping papers the heat hardenability at the specified points or at 1/16, 1/8, 1/4,1/2 inches, etc., from the quenched end.

CASE HARDENING

As commonly practiced, casehardening consists of carburising a piece of steel, quenching either mildly or rapidly, reheating to refine the core, quenching rapidly, reheating again to refine and harden the case, quenching rapidly, tempering at a low temperatures, and cooling slowly. For un-important parts and with some steels one or more of these operations can be eliminated. A detailed discussion of the theory and practical application of each of these operations follows.

Carburizing

Carburising steels may be either carbon or alloy steels but must be within the low-carbon range. The carburising process consists in heating these steels in contact with a carbonaceous material. This material may be either solid, liquid, or gaseous. Above the critical range the iron carbide in steel passes into solution in the gamma iron, as explained under Heat-Treatment. Low-carbon steels are weak solutions and will absorb free carbon. The carbon-rich carbonaceous materials when heated give off a gas containing carbon which diffuses into the steel surface. The depth of penetration depends upon the carbonaceous material, the temperature, and the time allowed.

The absorption of carbon at the surface will greatly increase the carbon content in this region. This carbon content will range from 0.80 to 1.25% at the surface and will taper off toward the centre with the core remaining at the original content. Subsequent heat treatment will harden the case and toughen the core. This behaviour is to be expected from the explanation made under Heat Treatment, where it was shown greater hardness could be obtained from high-carbon steels.

Solid Carburising

The oldest and most commonly used method of carburising is with a solid carbonaceous material. This material is usually bone, charred leather, wood charcoal, or coke. These materials are used singly or mixed together and usually contain an energiser to increase the formation of carburising gases when treated.

The parts to be carburised are packed in a metal box (usually nichrome) with at least 2-inch legs, so that the furnace gases may circulate freely around the entire box. All surfaces of the parts must be covered with at least ½ inch of the carburising material. The box must have a lid which can be sealed tight. A common seal is most fire clay to which a little salt has been added to prevent cracking. When the box is properly packed and sealed it is ready for insertion in the furnace.

The furnace should be brought up to 1600-1700^{0}F. as quickly as possible. The range of some carburising steels is 1600-1650^{0}F., other 1625-1675^{0}F., and still others 1650-1700^{0}F. All fall under 1700^{0}F. More rapid penetration can be obtained at higher temperatures, but grain growth will increase rapidly and affect the quality of the steel. The temperature should be kept as close to the critical range as possible to avoid grain growth. It should be borne in mind, however, that due to the size of the box and the packing, the enclosed parts will lag about 100^{0}F. behind the furnace when being heated. The furnace must be kept at the carburizing temperature some what longer to allow for this lag.

The carburising temperature is held until the desired depth of case is obtained. The time required varies for the different carburising steels. For S.A.E. 1020 carbon steels, which is often used for case-hardened parts, the variation of depth of case with time at temperature is as follows :

Depth of case	Time at 1,650^{0}F.
$1/64$ inch	one hour
$1/32$ inch	Two hour
$3/64$ inch	Four hours
$1/16$ inch	Six hours
$1/8$ inch	Sixteen hours

In aircraft work a case depth of 1/64 or 1/32-inch is commonly used, since the abrasion is seldom great and shock resistance is important. Thick cases are liable to crack under shock loads.

After carburising the box is removed from the furnace and allowed to cool in air, or the parts removed and quenched in oil from the carburising temperature. The slower method of cooling is employed when warpage must be avoided. This cooling completes the carburising process, and the parts are then ready for grain refinement, hardening, and tempering.

Liquid Carburising

Carburising in a liquid salt bath has recently been successfully developed. This method is applicable to small parts where a depth of case not greater than 0.040 inch is satisfactory. Liquid carburising has the advantage of forming a case uniform in depth and carbon content. In the use of solid carburising it is often impossible to obtain uniform results on small parts packed in a box since temperatures near the sides differ from those in the centre. Furthermore, liquid carburizing is faster than solid carburising because laborious packing is eliminated.

A salt that melts several hundred degrees below the carburising temperature is used as the liquid heat. An amorphous carbon is added to the bath to furnish the required carbon. Periodically, additional carbon is added to keep the bath saturated. A layer of carbon covers the top of the bath to reduce volatilisation loss.

As with the solid material the depth of case obtained is dependent on the time and temperature. The following are typical figures for S.A.E. 1020 steel :

Depth of case, inches		**Time, hours**
1,600^{0}F	***1,675^{0}F***	
0.006	0.006	1/3
0.010	0.012	2/3
0.016	0.018	1
0.020	0.024	2
0.026	0.030	3
0.035	0.040	4

After carburizing, the parts may be quenched in water or oil. They are then ready for refinement hardening, and tempering.

CYANIDING

Cyaniding is a surface hardening of steel obtained by heating it in contact with a cyanide salt, followed by quenching. Only a superficial case-hardening is obtained by this method, and consequently it is seldom used in aircraft work. It has the advantage of speed and cheapness, however, and may be used to advantage on relatively unimportant parts.

The cyanide bath, which is usually sodium or potassium cyanide, is maintained at 1550-1600^{0}F. The work to be hardened is preheated to 750^{0}F. and then immersed in the bath for from 10 to 20 minutes. It is then withdrawn and quenched in water until cold. A superficial case of 1/64 -inch maximum depth is obtained. The case is hard but not homogeneous. Great care must be taken to remove all scale before cyaniding and to insure uniform cooling, or soft spots will be present in the case. Immersing the work for 20 minutes does not increase the case materially but results in high-carbon spots and brittleness.

In cyaniding it is also important to use a closed pot since the fumes are extremely poisonous.

The hard case obtained from cyaniding is not due wholly to a high carbon content; as a matter of fact, the carbon content is relatively low. Chemical analysis shows the presence of nitrogen in the form of iron nitride in the case. It is this constituent which imparts the hardness as well a brittleness to the case. It should be noted that the core is also hard and brittle after cyaniding, which is, of course, undesirable.

NITRIDING

Nitriding is the surface hardening of special alloy steels by heating the metal in contact with ammonia gas or other nitrogenous material. The process of nitriding has great possibilities, however, and should eventually supersede casehardening by carburizing on all important work. A harder case is obtainable by nitriding than by carburizing. In addition, there is no distortion or cracking associated with nitriding and the case obtained appears to be corrosion resistant in most mediums, including salt water.

Nitriding is applicable only to special steels, the most common of which are called nitralloys. A process has recently been developed for nitriding stainless steels to obtain an ultrahard corrosion-resistant material. In aircraft work, steel in accordance with Army-Navy Aeronautical specification AN-S-19 is normally used. This specification describes two types of nitralloy-composition A, which is a high-core strength steel, and composition B, which is a free-machining steel. The chemical and physical properties of these steels are as follows :

CHEMICAL COMPOSITION

	A(%)	*B(%)*
Carbon	0.38-0.45	0.30-0.40
Manganese	0.40-0.70	0.50-1.10
Phosphorus	0.040 max.	0.040 max.
Sulphur	0.050 max.	0.060 max.
Silicon	0.20-0.40	0.20-0.40
Chromium	1.40-1.80	1.00-1.50
Aluminum	0.85-1.20	0.85-1.20
Molybdenum	0.30-0.45	0.15-0.25
Selenium	------	0.15-0.35

INDUCTION HARDENING

Induction hardening is one application of induction heating which is finding numerous applications in aircraft and automotive work. Induction heating is the process of heating metallic substances by means of a powerful, rapidly alternating electromagnetic field. The current that produces this field is usually carried in a copper coil that encircles that work to be heated. Induction heating is a differential heating, that is, the surface of the work heat up first very rapidly and then the core of the material. When steel is used and the work is quenched immediately after the surface is heated to a high temperature, a casehardened surface is obtained without having effected the properties of the core material. The depth of the case and or heat penetration varies with the frequency and intensity of the electromagnetic field and the length of time the current is on. Induction heating is used for surface hardening, and thorough-heating for heat treating, annealing, normalizing, brazing, soldering, forging, forming, or melting of metals. The required frequency, power, and heating time must be determined for each application.

Dielectric heating is similar to induction heating but is applicable only to nonconducting materials (dielectric materials) such as might be used for electric insulation. Plastics and compressed wood are typical applications. Dielectric heating is done by means of an electrodynamic field, the work being placed between two or more plates. Dielectric heating uniformly heats the material from the surface to the center as opposed to the differential heating of the induction-heating process.

There are four types of induction-heating equipment in common use. They are different in principal and in the current frequencies they can provide. The four types are as follows :

1 The first type uses the power-line frequency of 60 cycles per second and voltages up to 880. Transformers are used if required to attain the desired voltage. Current requirements range up to 1,500 amperes. This type of equipment is used for the preheatment of joints to be welded, the stress-relieving of welds, and the heating of ingots for rolling or forging.

2. The motor-generator type of equipment converts 60- cycles power to frequencies from 1,000 to 12,000 cycles at capacities up to 1,000 kilowatts rated power. This type of induction-heating equipment is the most widely used. It is used for surface hardening of crankshafts, gears, and similar parts, for brazing tool tips, for melting metals in large quantities, and for heating forging stock. This method of heating forging stock has the advantage of eliminating scale, uniformly heating the stock to the working temperature, and saving considerable time and space normally required by furnace heating.

3. Spark-gap generator equipment produces a rapid reversal of the electromagnetic field at frequencies up to 4000,000 cycles and 25 kilowatt output. It is used for the heat treatment of gears and precision gages and for the annealing of continuous strip for stamping and forging.

4. Vacuum-tube oscillator equipment producing frequencies from 1000,000 to 10,00,000 cycles at capacities up to 400 kilowatts. The electronic induction-heating equipment consists of a transformer which raises the line voltage to that required for the oscillator-tube operation, a set of rectifier tubes which converts the alternating-current line power into direct current to supply the oscillator circuit, oscillator tubes of the high-frequency type, capacitors, and inductance coils which produce the high-frequency current to be delivered to the heater coil.

The heater coil is a separate unit which is designed to suit the size, shape, and material of the work to be heated. It may be a long cylinder of many turns or just a few turns, a flat pancake of only 1 or 2 turns, or a special shape to adapt it to the contour of the work. Copper tubing equipped with provisions for running cooling water through the inside is frequently used in the construction of heater coils. With this type of coil, high frequencies and current densities can be used to raise the surface temperature of a steel piece above its critical temperature in a fraction of a second.

The surface hardening of steel parts, usually referred to as induction hardening, is the primary application of induction heating in aircraft and automotive work. In this process the heat is applied so rapidly that the high temperatures are confined to the surface layers with the inner core remaining relatively cool and unaffected. When the current is shut off the rapid conduction of the surface heat to the cooler interior results in self-quenching of the hardened surface. For full hardness, however, a water quench is usually necessary.

When the current is applied the surface heat is transmitted by conduction almost instantaneously to the inner core of the material. To permit dissipation of this heat without raising the core temperature to a point where its structure is affected it is necessary to have adequate core material. A piece of tubing, for instance, must have a wall thickness at least twice the depth of the surface hardening. In induction hardening there is no sharp line of demarcation between the hard surface case and the inner core. There is a gradual transition from a hard case to the original properties of the core.

A normalised structure is desirable to obtain the best results from induction hardening. The short time during which the surface of the work is above its critical temperature requires a very rapid solution of the carbides as required to attain a hardened surface. This solution is assisted by starting with a sorbite or fine pearlite structure.

To permit uniform heating of the surface it is desirable that its cross section be symmetrical. Variations in cross-sectional areas along the length of the work are all right. Symmetrical coils may be used for heating unsymmetrical objects, since the natural tendency of high-frequency currents is to follow the contour.

There is no distortion of the work due to induction hardening.

The selection of induction-heating equipment should be predicated on the thickness of the work to be heated or hardened. Frequencies above 100,000 cycles are required for 1/8-inch or thinner material; 9600 cycles or higher are required for ¼ - inch material; and 1920 to 9600 for ½ - inch material. The thinner the material, the higher the frequency required.

Induction-heating equipment is frequently used for soldering and brazing. In this operation the brazing material or solder is set in place at the joint and the work placed in or near a heating oil. A closely controlled heat is developed at the joint in both the brazing material or soldering material and the adjacent portion of the work. Both the leading and trailing edge of hollow steel propeller blades are inside brazed. Beads of brazing material are laid along the inside edge and the propeller is moved edgewise through the coil. The brazing material melts and fuses with the steel to form an even, firm joint. The numerous wires leading into an electrical connector can be soldered simultaneously with a simple setup.

In dielectric heating, an alternating electric field of between 1,000,000 and 200,000,000 cycles per second is set up by means of a high-frequency vacuum-tube oscillator. This high frequency results in a uniform heating of the entire cross section of the work. It is particularly adaptable for heating thick sections of nonconducting material which otherwise would take several hours of surface heating because of limited thermal conductivity. Material is heated between two or more plates from which the electrostatic current emanated. This type of heating is employed in curing impregnated materials, gluing, bonding, and preheating plastics prior to molding. A typical application is in the manufacture of compressed and impregnated wood-propellers which consist of wooden sheets, plastic impregnated, which are bonded together under high heat and pressure. Dielectric heating cures the assembly uniformly in a fraction of the time required by any other method.

SHOT PEENING

Shot peening is sometimes referred to as shot blasting. It should not, however, be confused with sand blasting or other surface-cleaning processes. Shot peening is a recent development that improves the fatigue and abrasion resistance of metal parts. It is applicable to ferrous and nonferrous parts, but it is mostly used on steel surfaces. This process has been reported to increase the life of parts subject to repeated stresses (such as springs) from 3 to 13 times. The fatigue loads of shot-peened parts can be increased if an increase in the life of the part is not a consideration.

The shot-peening process consists of throwing hardened steel balls at the surface of the work to be peened. The steel balls, or shot, are thrown against the surface either by compressed air or by centrifugal force as the shot is fired from a rotating wheel. The intensity of the process can be varied by regulating the size of the shot, the hardness of the shot, the speed at which it is fired, and the length of time the work is exposed to the shot. If the shot peening is too intense the work may be fractured internally, thereby undoing all the good expected from the peening. Saturation of the surface with the little indentations made by the shot is a quick visual method of inspecting the intensity of the shot-peening operation. It is desirable to run a sample piece to set up the conditions to be used in the production process.

Shot peening prestresses the surface of the work and adds to the fatigue and abrasion resistance. It leaves the surface with a countless number of shallow indentations where the hardened shot has struck. The surface of each of these indentations has been cold-worked by being stretched in every direction, and becomes harder, stronger, and less ductile than before. The net results is an increase in compressive stress in the skin, and an increase in tensile stress just below the surface. The compressive stress in the skin will counteract any tensile stress that normally might start a crack or fracture.

Fractures usually start at a point of localized stress concentration. Sharp shoulders, tool marks, scratches, and notches should be avoided for this reason. The indentations made by the hardened steel balls are well rounded, and they are so numerous they dissipate any stress concentration over a wide area. Care must be taken to chamfer all sharp external corners before shot peening, however, or they will be worked out into sharp, fin-like extensions which will induce early failures. Shot peening of relatively rough surfaces can be done considerably cheaper than polishing, and the fatigue of the peened surface equals or exceeds that of the polished surface.

Shot peening can be applied to irregular or complicated surfaces such as gear teeth, helical springs, universal joints, axles, rocker arms, bearings, propeller shanks and hubs. It has been applied to fillets and grooves to offset stress concentrations. When applied to gear teeth it produces a surface with increased resistance to wear and to pitting corrosion. Shot peening appears destined for more and more applications.

■■■

CHAPTER-3
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 conductivity.* Used for heavy conductors 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 copper,* 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 vessels 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.

Note : Details of Magnesium Alloy is discussed in Chapter no. 5.

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 importance due to some exceptional properties they possess, like lightness, ease in fabrication, good machinability, high resistance to corrosion, attractive appearance and good castability etc. Some commonly used nonferrous alloys are described in the following articles.

BRASSES

All brasses are basically alloys of copper and zinc. There are two main varieties of brasses :

1. Alpha brass (upto 37% Zn) - for cold working.
2. Alpha Beta brass (33% to 46% Zn) - for hot working.

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

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

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

Common types of brasses in engineering use are the following :

Cartridge brass

It has 70% Cu and 30% Zn. It is very strong and ductile. It is used for a wide range of drawn components like cartridge cases, head lamp reflectors, radiator shells and drawn tubes.

Muntz metal

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

Naval brass

It contains 60% Cu, 39% Zn 1% tin. It is more or less similar in composition to Muntz metal except that 1% Zn is replaced by 1% tin. As a result of this change the resistance to sea water corrosion is vastly improved. This alloy is, therefore, widely used for cast and forged fittings for ships.

Admiralty brass

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

Gilding brass

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

Delta brass

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

Free cutting brass

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

Beta brass

It contains 50% Cu and 50% Zn. Higher percentage of zinc renders it hard and brittle, but it softens quickly when heated and melts at 870^{0}C. 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 HCI 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.

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^{0}C and can be hardened by reheating to 500^{0}C. 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.

Note : Details of Nickel alloys is discussed in detail in chapter no. 4.

BEARING METALS

A *Bearing metal* should possess the following important characteristics :

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

Babbit metal

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

Lead alloy

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

Phosphor bronze

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

Cadmium alloy

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

Cintered metal

Bearings suitable for light and medium loads are made by sintering metallic powders. A popular composition consist of 90% Cu, 10% tin and a small addition of graphite. Cintering is done at 700^0C. Oil retaining bearings can be made through this process.

OTHER ALLOYS

Dow metal

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

Beryllium copper

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

Hastelloy

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

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

Vitallium

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

Aluminium brass

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

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.*

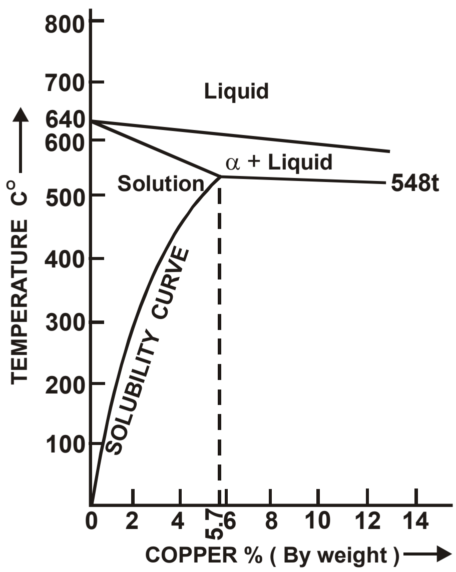

Fig. 3.1, Phase diagram of an aluminium-copper alloy.

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. 3.1. 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^{0}C is 5.7%. Now, if the alloy is cooled slowly from this stage the second phase (θ)precipitates out of the α solid solution because the solubility of copper in aluminum reduces from 5.7% to about 0.2% at room temperature, 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 unstable condition needing diffusion. To achieve that, it is reheated to between 150^{0}C to 200^{0}C and held there to allow precipitation of copper, resulting in a single phase structure consisting of α -solid solution and the precipitate. This is known as *ageing* and if this is carried out under carefully controlled conditions the resulting structure (hence, the material) will be extremely hard and strong.

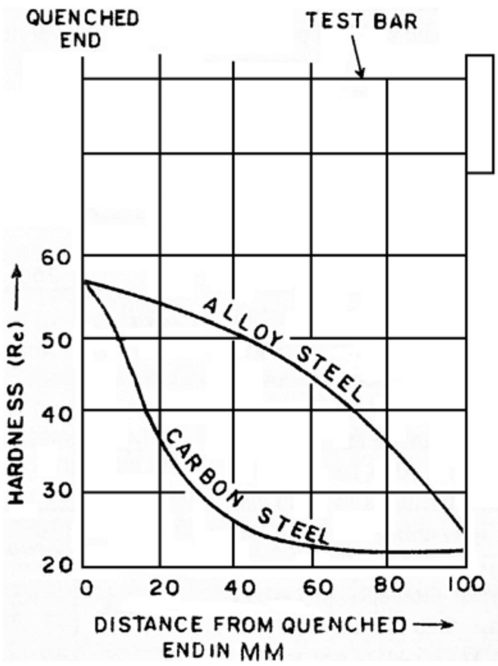

Fig. 3.2, Graph of hardness values of two Jominy test bars in Jominy hardenability tests conducted on test bars made of carbon steel and alloy steel.

The phase diagram shown in Fig 3.1 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 3.1).

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 3.1 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.,^{0}F**	**Quench**	**Temper desig**	**Temp ^{0}F.,**	**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	1-2 hr	T5
				or		
				345-355	8 hr	T6
6061	960-980	Water	T4	315-325	18 hr	T6
				or		
				345-355	8 hr	T6
7075	870	Water		250	24 hr	T6

Fig. 3.3, 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^{0}F., the beginning of the aging process is delayed for several hours, while dry ice(-50^{0}F. to - 100^{0}F.) 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^{0}F. to 375^{0}F. They should be controlled within a very narrow range (plus or minus 5^0) to obtain best results. (See figure 3.3.).

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.

HEAT TREATMENT OF ALUMINUM ALLOYS

The annealing procedure for aluminum alloys consists of heating to an elevated temperature, holding or soaking them at this temperature for a length of time depending upon the mass of the metal , and then cooling in still air. Annealing leaves the metal in the best condition for cold-working. However, when prolonged forming operations are involved, the metal will take on a condition known as "mechanical hardness" and will resist further working. It may be necessary to anneal a part several times during the forming process to avoid cracking. Aluminum alloys should not be used in the annealed state for parts or fittings.

Clad parts should be heated as quickly and carefully as possible, since long exposure to heat tends to cause some of the constituents of the core to diffuse into the cladding. This reduces the corrosion resistance of the cladding.

Heat Treatment Of Aluminum Alloy Rivets

Aluminum alloys rivets are furnished in the following compositions : alloys 1100, 5056, 2117, 2017, and 2024.

Alloy 1100 rivets are used in the "as fabricated" condition for riveting aluminum alloys sheets where a low-strength rivet is suitable. Alloy 5056 rivets are used in the "as fabricated " condition for riveting magnesium alloys steels.

Alloy 2117 rivets have moderately high strength and are suitable for riveting aluminum alloy sheets. These rivets receive only one heat treatment, which is performed by the manufacturer, and are anodized after being heat treated. They require no further heat treatment before they are used .Alloy 2117 rivets retain their characteristics indefinitely after heat treatment and can be driven anytime. Rivets made of this alloy are the most widely used in aircraft construction.

Alloy 2017 and 2024 rivets are high-strength rivets suitable for use with aluminum alloy structures. They are purchased from the manufacturer in the heat-treated condition. Since the aging characteristics of these alloys at room temperatures are such that the rivets are unfit for driving, they must be reheat treated just before they are to be used. Alloy 2017 rivets become too hard for driving in approximately 1 hours after quenching. Alloy2024 rivets become hardened in 10 minutes after quenching. Both of these alloys may be re-heat treated as often as required; however, they must be anodized before the first re-heat treatment to prevent intergranular oxidation of the material. If these rivets are stored in a refrigerator at a temperature lower than 32^{0}F. 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^{0}F. to 950^{0}F 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^{0}F to 930^{0}F 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^{0}F to 780^{0}F, 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^{0}F. to 500^{0}F. 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^{0}F. 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^{0}F. 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.

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 (isknown 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.

SELECTION OF MATERIALS

The weight, strength, and reliability of materials used in aircraft construction are extremely important. All materials used must have a good strength/weight ratio in the form used, and must be thoroughly reliable to eliminate any possibility of dangerous, unexpected failures. In addition to these general properties the material selected for a definite application must have specific properties that make it suitable for the purpose. No one material is adaptable for all purposes. A particular part, member, or assembly must be studied from many viewpoints before the best material that can be used in its construction is determinable. In order to make the best choice the designer must have a thorough knowledge of the materials available. In the foregoing pages the author has attempted to describe all the materials and processes used in aircraft work in sufficient detail to enable the reader to choose the proper material for any application. In this chapter the author will enumerate the points to be considered in selecting a material. The materials used in the construction of each part of an airplane at the present time will also be given.

CONSIDERATIONS

The author has arbitrarily divided the points to be considered in selecting a material into economic considerations and engineering considerations. The engineer is apt to neglect the economic considerations, with the result that construction will be very costly because of the cost of the material itself and perhaps also because of delays incident to obtaining the required material and the reworking of jigs and tools.

ECONOMIC

The economic points that should be considered before selecting a material may be itemized as follows :

1. **Availability**
   It is extremely important that any material selected for use in the construction of aircraft should be available in sufficient quantities to satisfy normal and emergency requirements. The material should also be purchasable from a reputable manufacturer who can guarantee a reasonable delivery date. This latter point is particularly important in the construction of an experimental plane when material requirements cannot be anticipated.

2. **Cost**
   The cost per pound should be compared with the cost of other available materials. In making this comparison the savings resulting from a higher strength/weight ratio or better working properties must be considered.

3. **Shop Equipment Required**
   The initial and maintenance cost of shop equipment required for the working of the material selected must be considered. In an established factory the possibility of using jigs and dies on hand is a factor in the choice of a material.

4. **Standardisation of Materials**
   It is advantageous to stock as few materials as possible. In selecting a material for a particular application the possibility of using one already on hand for other purposes should be considered.

5. **Reliability**
   It is essential that the material selected be of consistent high quality. The author has known many instances where a batch of material was received that cracked when bent, or would not take the required heat treatment. The selection of a standard material manufactured by a reputable manufacturer will minimize the likelihood of obtaining a sour lot of material.

6. **Supplementary Operations Required**
   In selecting a material the cost and time necessary for such operations a heat treatment, cleaning, plating, and so on, should be considered. A material that can be used in its natural state has a great advantage from a manufacturing standpoint over one that requires one or more supplementary operations.

ENGINEERING

The engineering considerations that determine the choice of a particular material may be itemized as follows :

1. **Strength**
   The material must be capable of developing the required strength within the limitations imposed by dimensions and weight. Dimensional limitations are particularly important for external members and for wing beams in shallow wings.

2. **Weight**

Weight is usually considered in conjunction with strength. The strength/weight ratio of a material is a fairly reliable indication of its adaptability for structural purposes. In some applications, such as the skin of monocoque structures, bulk is more important than strength. In this instance the material with the lightest weight for a given thickness of sheet is best. Thickness or bulk is necessary to prevent local backling or damage because of careless handling.

3. **Corrosion**

Due to the thin sections and small safety factors used in the design of aircraft, it would be dangerous to select a material that is subject to severe corrosion under the conditions in which it is to be used. For specialized applications, such as seaplane hull construction, the most corrosion-resistant material available should be used. For other general uses an efficient protective coating should be specified if materials subject to corrosion are used.

4. **Working Properties**

The ability to form, bend, or machine the material selected to the required shape is important. After the type of material is determined, the proper temper must be chosen to facilitate the mechanical operations that are necessary for the fabrication of the fittings or part.

5. **Joining Properties**

The ability to make a structural joint by means of welding or soldering, as well as by mechanical means such as riveting or bolting, is a big help in design and fabrication. When other properties are qual, the material that can be welded has a definite advantage.

6. **Shock and Fatigue Strength**

Aircraft are subject to both shock loads and vibrational stresses. It is essential that materials used for critical parts should be resistant to these loads.

SPECIFIC MATERIAL APPLICATIONS

In the following pages the author will enumerate the various parts of an airplane and list the materials that are used at the present time in their construction. Insofar as possible, the major reasons for the choice of a particular material will also be presented. In many instances two or more materials are used for identical parts. This difference of opinion between designers may be due to local operating conditions, the price range of the airplane, or the previous experience of the designer. Many designers are progressive and adopt new materials rapidly, while others are content to lag behind and let the first type break new ground for them. It must be remembered that new developments in the near future may result in many changes in the present type of construction.

In the listing of aircraft parts, the author has taken a standard single-engine tractor airplane and named the parts beginning with the propeller and working aft to the tail. It is hoped by this means to make to reader's task easier in spotting a particular part despite any differences in terminology between him and the author,. General parts such as bolts, bushings, and so forth, are enumerated at the end.

■ ■ ■

CHAPTER-4
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 gaaood 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 4.1.

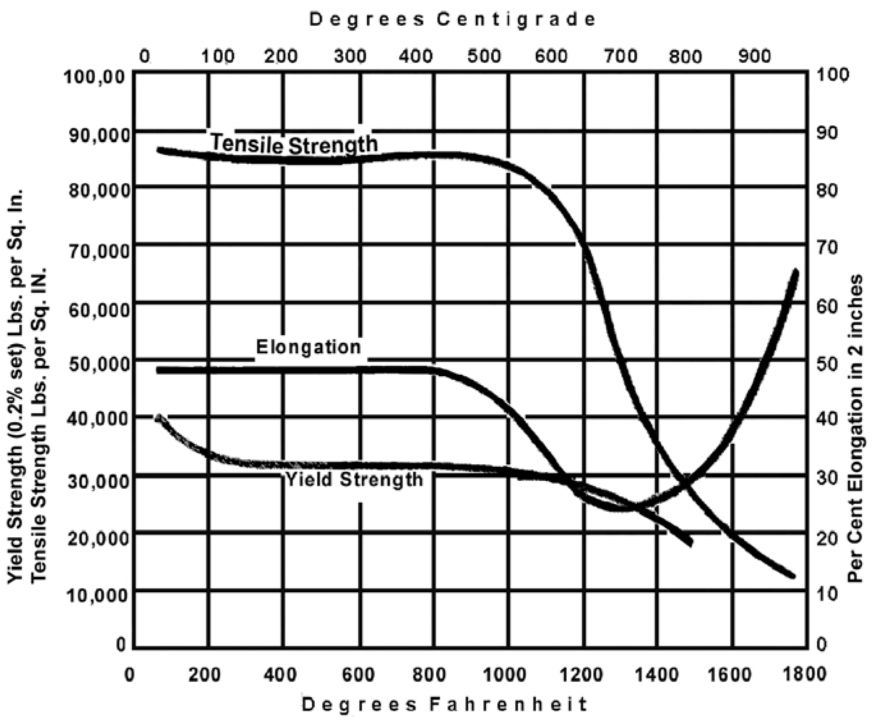

Fig.4.1.High-temperature Properties of Inconel

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

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

Annealing and Stress Relieving

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

Internal stresses set up during cold rolling or during fabrication may be relieved without appreciable softening by heating the metal for 1 hour at $800\text{-}900^0$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 1800^0F 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 700^0F 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 2300^0F and 1850^0F. 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.

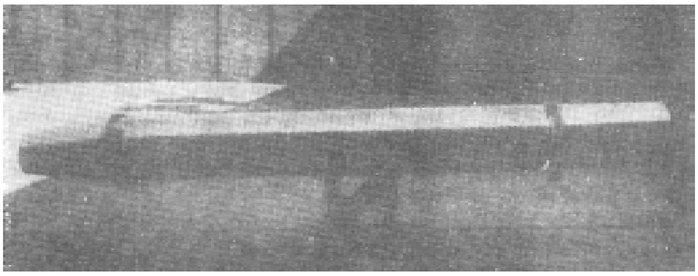

Fig.4.2. Jet Tail Pipe: Inconel.

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^{0}F), 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^{0}F. 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.

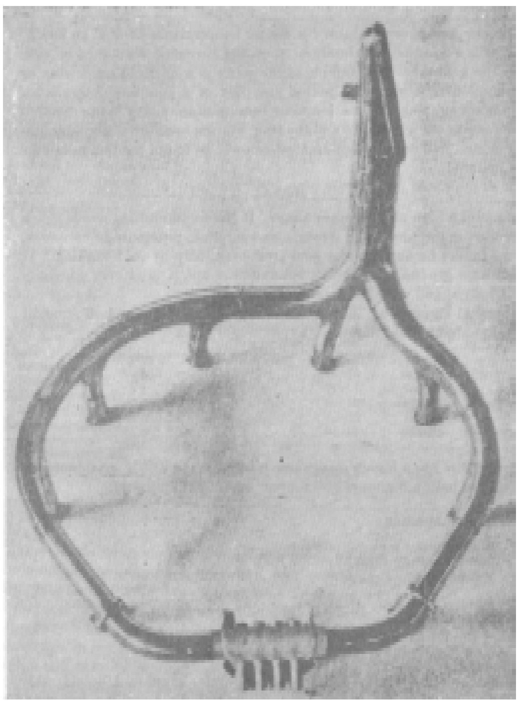

Fig.4.3.Exhaust Collector and Hot Spot ; Inconel

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 ($^1/_8$ to $^1/_4$ 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^{0}F.
	(1315-1350^{0}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 :

1600^0F.	5 to 10 min.
1800^0F.	1 to 4 min.

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

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

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

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

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

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

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

Working Properties

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

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

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

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

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

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

Welding

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

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

Brazing

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

Corrosion

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

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

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

Available Shapes

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

Uses

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

SPECIFICATIONS

Inconel :	
AN-N-4	Wire and welding rod
AN-QQ-N-268	Bars, forgings and rods.
AN-QQ-N-271	Sheet and strip
AN-WW-T-831	Tubing, seamless, round
An-WW-T-833	Tubing, welded, round
Monel :	
Federal QQ-N-281	Forgings, rods, sheet, wire
Navy 46 M7	Forgings, rods, sheet, wire
Navy 44 T38	Tubing
K Monel :	
Federal QQ-N-286	Forgings, rods, strip, wire
Navy 46N5	Forgings, rods, strip, wire

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CHAPTER-5
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 5.1 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).

Table 5.1, Magnesium Alloys- Specifications and Uses

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

AN Aero specifications must be used in Army and Navy airplanes.
S.A.E. is abbrevation for society of Automotive Engineers.
A.M.S. are S.A.E. Aeronautical Material Specifications.
A.S.T.M. is abbrevation for American Society for Testing Materials.

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

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

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

Physical Properties. Pure magnesium has the following properties :

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

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-5.1. Stratosphere Gondola; Magnesium-alloy Sheet

The fabrication of wrought magnesium-alloy parts will require new shop tools and tecnique. The reason is that many forming operations can only be done at elevated temperatures from 450^0 to 700^0 F. The close-packed hexagonal crystal structure of these alloys permits only a small amount of deformation at room temperatures. Zinc has a similar crystal structure. Copper and aluminum have what is known as face-centered cubic crystal structure and as a result are very ductile and easily worked at room temperature. As the temperatures of magnesium alloys is raised above 450°F. 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 5.2 . 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 5.2, MAGNESIUM ALLOYS- CHEMICAL COMPOSITION

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

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

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

MAGNESIUM - ALLOY CASTINGS

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

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

These alloys are available in various chemical compositions and physical conditions. The choice of alloy depends upon the properties required for the intended application. The available casting alloys and their mechanical properties are listed in Table 5.4.

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. How ever, 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 5.3. Type II and III-aalloys require a pretreatment of not less than two hours' duration during which time the temperature of the furnace should be increased slowly from 640^{0}F to the heat-treatment temperature. Heating slowly through this range avoids fusion of the lower melting eutectics in the alloy before they are absorbed into solid solution in the heat-treatment operation. The presence of small amounts of calcium in an alloy reduces the danger of partial fusion and pretreatment is unnecessary. Type III-b in Table 5.3 is such an alloy.

TABLE 5.3, 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^{0}F.	10 at 325^{0}F	
	AM265	H	II	(as cast--- stabilized A.C.S.)		18 at 350^{09}F 4 at 500^{0}F.
A	AM265	H	II	10 at 730^{0}F.	14 at 420^{0}F; 18 at 350^{0}F.	4 at 500^0
C-sand cast	AM260	C	III-a	18 at 770^{0}F.	18 at 350^{0}F	4 at 500^{0}F
C-sand cast	AM 260		III-b	(as cast---stabilized A.C.S.)		8 at 325^{0}F
C-sand cast	AM260		III-b	14 at 780^{0}F.	12 at 150^{0}F.; 20 at 350^{0}F.	8 at 325^{0}F.
C-permanent mold	AM260	C	III-c	(as cast---stabilized A.C.S.)		10 at 325^{0}F. 4 at 500^{0}F
C-permanent mold	AM 260	C	III-c	18 at 770^{0}F	10 at 235^{0}F. - 350^{0}F	4 at 500^{0}F

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

Fig. 5.4, Magnesium-alloy Castings-Mechanicasl Properties

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

Yield strength is defined as the stress at which the stress-strain curve deviates 0.2% from the modulus line.
Alloy C is used for both permanent-mold and sand castings.

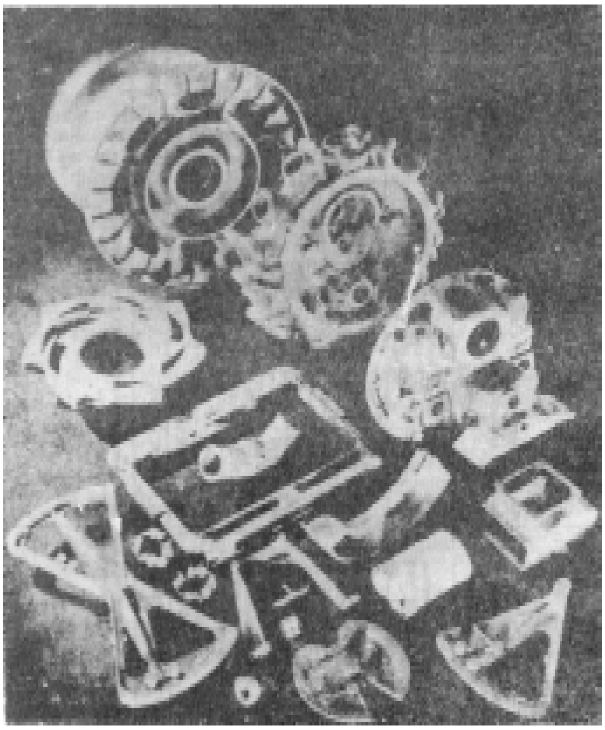


Fig.5.2. Sand-cast Magnesium Parts

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 200^0F. in the solution heat-treated condition. A temperature of 350^0F. is the maximum recommended when the alloys are stabilized or aged.

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

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

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

Army-Navy Aeronautical Specification AN-QQ-M-56 describes three types of magnesium-alloy sand castings, identified as compositions A, B, and C. The mechanical properties of these casting alloys and the heat-treated conditions in which they may be purchased are listed in Table 5.4.

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

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

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

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

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

Permanent-mold castings

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

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

Wall thickness of $\frac{1}{8}$ inch for small areas nd $\frac{5}{32}$ inch for large areas may be obtained in permanent-mold castings.

Dimensional tolerances as low as 0.01 inch can be held, but $\pm \frac{1}{64}$ 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 5.4.

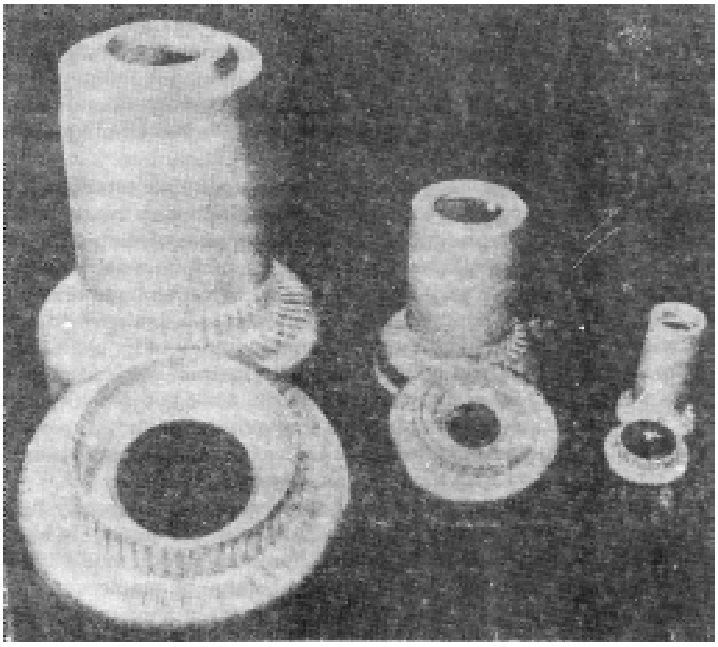


Fig.5.3. Permanent-mold Cast Magnesium Aircraft Wheels

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 5.4.

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^{0}F. 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 $\pm$ 10% with a minimum tolerance of 0.010 inch. The straightness of Extrusions can be held to 1 in 1000, which is equivalent to $1/16$ inch in 5 feet.

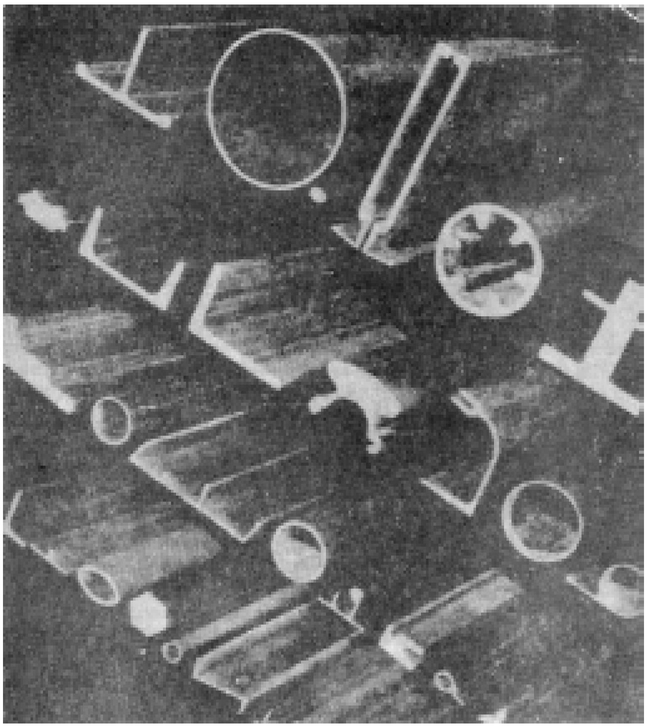


Fig.5.4. Miscellaneous Magnesium Extruded Shapes

The mechanical properties of magnesium-alloy extrusions are given in Table 5.5. 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^{0}F. 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.

Table 5.5, Magnesium-alloy Extrusions-Mechanical Properties

Form	Specification			Tension			Compression yield (p.s.i.)	Brinell hardness (500 kg./10 mm.)	Shear (p.s.i.)	Fatigue 500×10^6 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		

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

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

In the design of forgings, shape corners, notches, tool marks, and rapid changes of section be avoided to minimize stressconcentrations. Generous fillets and radii of at least $1/8$ 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.

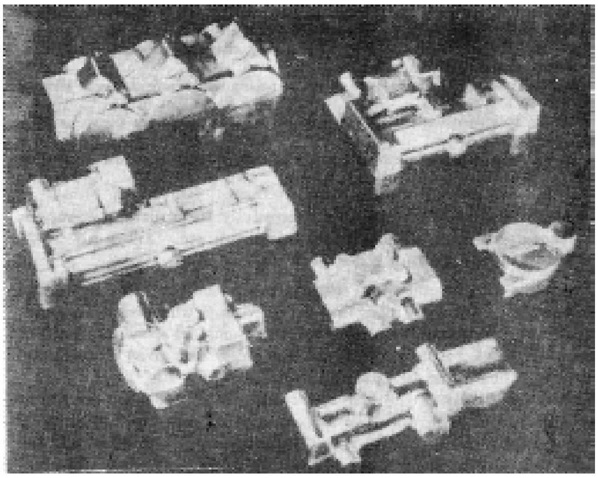


Fig.5.5. Press-forged Magnesium Hydraulic Parts

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.

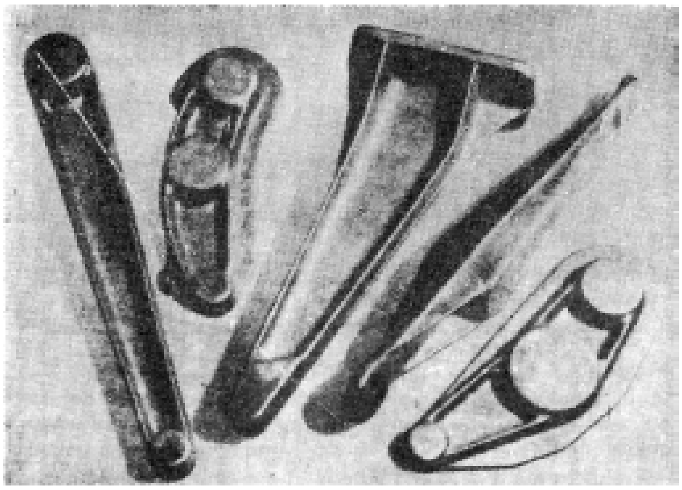
The mechanical properties of the forging are given in Table 5.6. Other properties are as follow :

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.

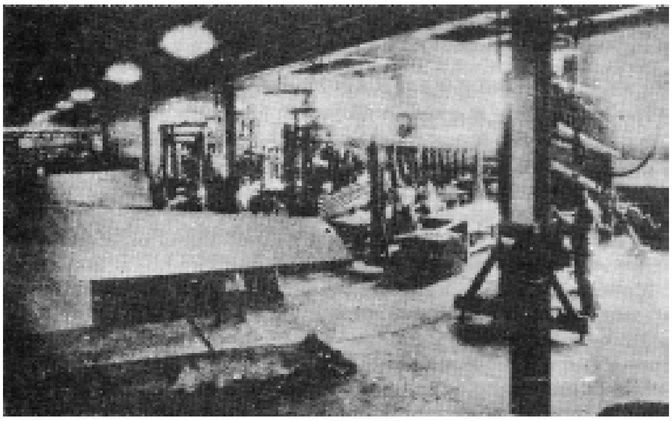


Magnesium-alloy forgings have been used for aircraft-engine bearing caps, housings, rocker-arm supports, cargo-door and aileron hinges, hydraulic cylinders and valve bodies, levers, brackets, fittings, and crank cases.

Sheet, Plate, Strip

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

Sheet is available in thicknesses from 0.016 inch up. It can be obtained in lengths up to 144 inches and widths up to 48 inches. Strip is available in thicknesses from 0.016 to 0.051 inch in coils up to 125 feet long.



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

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

The mechanical properties of magnesium-alloy sheet, plate, and strip are given in table 5.7. Other properties are as follow AN-M-28 Annealed sheet has medium strength, limited formability, and excellent arc-welding characteristics. Hard rolled sheet has high strength, good hot formability, and excellent arc-welding characteristics.

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

Table 5.6, Magnesium-alloy Forgings- Mechanical Properties

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

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

Table 5.7, Magnesium-alloy Sheet, Plate, Strip-Mechanical Properties

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

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

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

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

SHOP FABRICATION PROCESSES

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

Machining

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

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

1 Cutting edges must be kept sharp and tool faces polished to insure free cutting action and reduce the adherence of magnesium particles to the tool tip. Tools must be designed to allow for ample chip room, and tool clearances should be 10° to 15°. Large feeds are advantageous in reducing the frictional heat.

2. If the precautions of paragraph 1 are not taken the magnesium part being machined may distort, owing to excessive heat. This distortion is most likely to happen on thin sections, in which the heat will cause a large rise in temperature. Parts which tend to distort during machining can be stress-relieved by heating at 500^0F. for 2 hours. If the part is stored for 2 or 3 days prior to finish machining the same result is attained.

3. Magnesium cuts closer to size then aluminum or steel. Reamers should be specified several ten-thousandths oversize compared to those used on other metals; taps should be specified from several ten-thousandths to two thousandths over size depending on the diameter.

4. Because of its lower modulus of elasticity, magnesium will spring more easily than aluminum or steel. Consequently it must be firmly chucked but the clamping pressure must not be great enough to cause distortion. Particular attention must be paid to light parts, which can easily be distorted by chucking or by heavy cuts.

5. A cutting fluid* is used in reaming and in screw-machine work or when cutting speeds exceed 500 feet per minutes. The cutting fluid is primarily a coolant. In all other operations magnesium can be machined dry with good results.

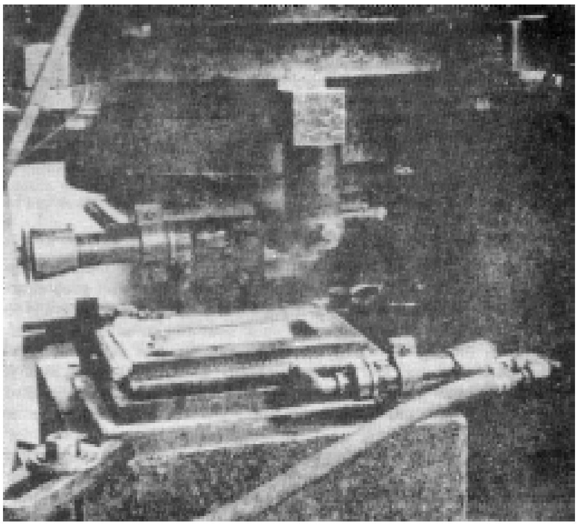
6. In grinding, a liquid coolant* should be used or the grinding dust should be exhausted and precipitated in water.

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

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

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

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



Shearing

In shearing magnesium sheet a rough, flaky fracture is obtained if the proper equipment is not used. The clearance between shearing blades should be on the order of 0.003 inch, and the upper shear blade should have a rake angle of around 45^0. The sheared edge may be improved by a double shearing operation known as "shaving". This consists of removing an additional $\frac{1}{32}$ to $\frac{1}{16}$ inch by a second shearing. The maximum thickness recommended for cold shearing are 0.064 for hard rolled sheet and $\frac{1}{8}$ inch for annealed sheet. These thicknesses can be increased if shearing is done at an elevated temperatures, but in any case sawing should be resorted to for cutting plate.

Blanking and Punching

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

Routing

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

Forming Magnesium Alloys

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

The recommended forming or working-temperature ranges are given in Table 5.8. In addition, the minimum bend radii are given for room temperature and for the recommended working-temperature range.

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

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

TABLE 5.8, MAGNESIUM ALLOY- FORMING TEMPERATURES AND BEND RADII

Alloy	Condition	Working temperature range (°F)	Bend radii for 90^0 bends (material) up to 0.125 in thick (t = thickness)	
			Working temperature	70^0F.
AN-M-28	Annealed	550-650	2-3*t*	7*t*
AN-M-28	Hard rolld	400 max.	5-7*t*	14*t*
AN-M-29	Annealed	400-500	1-2*t*	5*t*
AN-M-29	Hard rolled	275 or 300 (less than 15 min.)	5-6*t*	8*t*
AN-M-30	Annealed	550-650	1-2*t*	6*t*
AN-M-30	Hard rolled	400 max.	6-7*t*	9*t*

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

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

Hand Forming

In hand forming the material should be clamped in a soft-jawed vise or to a form block. A heat-resisting wood such as birch or a metal should be used for the form block. Metal form blocks made of magnesium alloy have the advantages of having the same thermal expansion as the work. The form block may be preheated in an oven or elecrtrically heated. The work can be heated by conduction from the hot form block, it can be preheated, or it can be heated with a torch. If it is torch heated, a contact pyrometer should be used to avoid overheating. A leather maul should be used for hammering. Hand forming should be used if the quantities are too small to justify the manufacture of dies, or if the part is very intricate.

Bending

Machine bending is frequently used for the manufacture of stringers, clips, and stiffeners made from sheet or strip. A press-type brake is used almost exclusively because of the ease with which it can be equipped with strip electric heaters on either side of the dies. Bends of the smallest possible radii are obtainable if a very slow press speed is used to finish the bend. When possible, both the dies and the work should be heated. If the dies alone are heated the work will absorb heat by contact and can be bent satisfactorily. If the work alone is heated, the bending operation must be rapid, before the dies dissipate the heat at the bend. Bends parallel to the grain direction are easier to make because of the greater elongation of magnesium alloys in the transverse direction.

Extrusion Bending

Extrution may be bent by hand, using a torch for heat and a contact pyrometer to avoid overheating. Production bending can be done with standard angle rolls, with mating dies, or on a stretch-forming machine. The work should be preheated if the working is severe, and the dies also if the operation is slow or the extruded section is large. Forming temperatures of 600^0F. permit very severe working of all the extrusion alloy. Only alloy AN-M-25 is limited as to working temperature. If it is not to be aged after forming it can be worked at 600^0F., the same as the other alloys. If this material is worked between 350^0 and 500^0F. it will be partially aged, with a resultant increase in strength and reduction in ductility. Material in the aged or heat treated and aged condition can be formed up to a temperature of 380°F, without change of properties. At this working temperature the alloy in these conditions can be bent about the same as the unaged alloy at room temperature.

Tube Bending

Standard pipe-bending machines using an internal mandrel can be used for bending magnesium-alloy tubing. Small-radius bends may require heating, as with other materials. If hot tubing is to be bent about a wood form it is advisable to metal-face the form. AN-T-71 and AN-T-72 alloys can normally be bent at room temperatures, while AN-T-72 alloys can more likely to require heating.

Shallow Drawing and Pressing

In shallow drawing the parts are more pressed than drawn, since there is very little metal flow. Wing ribs, door reinforcing panels, and fairings are typical examples of parts fabricated by this method. The Guerin patented process of using a rubber pad as the female die is most frequently used, although male and female metal dies would be justified for large quantities. In the Guerin process a rubber pad 6 to 10 inches thick is contained in a metal box and acts as the female die. A heated male die and work blank are placed on the platen of the press and the female rubber die brought in contact with them. A pressure of 1000 p.s.i. is exerted through the rubber and the blank assumes the shape of the male die. Synthetic rubbers or specially compounded natural rubbers are required for working temperatures up to 450^0F. Ordinary rubber is satisfactory for temperatures up to 350^0F. To prevent the rubber from sticking to the formed part, cornstarch or flaked mica is spread on the blank prior to pressing. Since in the Guerin process only a male die is needed it can be produced cheaply and revised when necessary without great difficulty. The male die is best made of magnesium to avoid differences in thermal expansion between the blank and the die. If aluminum is used it should be made approximately 1.002 oversize, if steel or iron approximately 1.004 oversize, to compensate for the differences in thermal expansion between these materials and the magnesium-alloy blank.

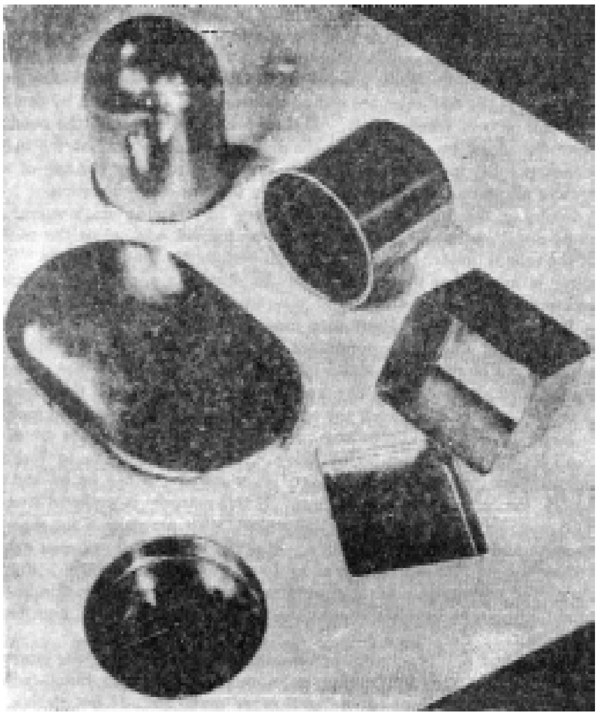


Fig.5.9. Drawn Magnesium Parts

Deep Drawing

Oil-tank ends, nose spinners, wheel dust covers, and hub caps have been deep drawn successfully. Cylindrical cups can be deep drawn to a depth 1½ times their diameter in a single draw-which is a reduction of 60% to 65%. Square junction boxes can be drawn to a depth equal to the side dimensions. Either a hydraulic or a mechanical press can be used for deep drawing. For maximum depth draws the clearance between the die and the punch should be from 0.25 to 0.35 of the stock thickness plus the stock. As explained above, dimensional allowances must be made for the differences in thermal expansion if the die material is other than magnesium alloy. The male die or punch can be magnesium alloy, aluminum alloy, cast steel, or cast iron. Dies of mild steel which has been stress relieved have been used quite generally. Heat-resisting Meehanite cast iron gives promise of working out very well as die stock. Draw rings and pressure pads are made of mild steel which is highly polished and well lubricated. The pressure pad should impart sufficient pressure to the blank to prevent wrinkling but not too much to prevent it form being drawn through the clamping surfaces. Preheating the work blanks and heating the dies to working temperature are essential to insure proper drawing temperature and a uniform product. The blank should be lubricated on both sides as well as the die surfaces to prevent scoring or galling. Colloidal graphite suspended in a volatile carrier such as alcohol or naphtha may be sprayed on both sides of the blank; other commercial products can also be used. If colloidal graphite is to be used, sheet should be ordered with an oiled finish instead of the customary chrome-pickled finish. This specification is necessary because of the extreme difficulty of removing graphite from a chrome-pickled surface. For lubricating the dies, a mixture of 20% graphite in tallow applied by buffing with an asbestos cloth is satisfactory.

Sizing

Sizing is a cold operation employed to bring hot-drawn work closer to tolerance. When extremely accurate tolerances are required the part is normally drawn slightly oversize and then sized cold to finish dimensions. A cold-sizing die consists of a punch and a draw ring, both slightly undersize to allow for springback. The punch forces the part through the draw ring and the operation is completed.

Spinning

Spinning is used to fabricate circular articles such as propeller spinners and wheel caps. In this operation the blank is clamped against a maple or metal chuck which is shaped to the desired form. The chuck is then supported in the spinning lathe and rotated at the proper speed so that the part of the blank being worked on will move past the tool at from 1700 to 1900 feet per minute. The operator uses a wedge or a hardwood stick to force the blank against the chuck, whose shape it then assumes. Laundry soap or a mixture of 2 parts tallow and 1 part paraffin are satisfactory lubricants. Moderate spinning may be done at room temperatures. Normally, however, the blank should be heated to between 500^0 and 600^0F. by a gas torch, a properly disposed ring of gas burners, or by conduction through a heated metal chuck. The area of the original blank should be about the surface area of the finished part. The fact that the material is thinned somewhat in spinning allows sufficient additional area for trimming.

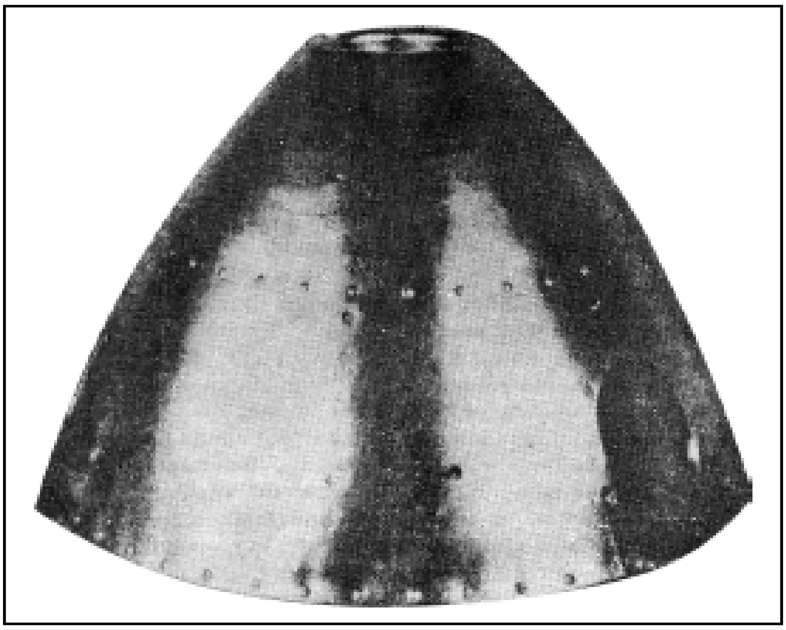


Fig.5.10 Magnesium Propeller Spinner

Roll Forming and Die Drawing

This method of fabrication is used for the production of shapes with thin walls that can not be extruded. It consists of drawing strip through a series of dies or rolls, each set of which changes the shape somewhat nearer to the finished shape desired. Heated strip, adequate bend radii, lubrication, and gradual changes in shape are all necessary for this type of fabrication.

Stretch Forming

In stretch forming, the work is held in the jaws of two machines and pressure is applied between the blank and the die Stretch forming is used primarily to obtain double curvature of a surface. It is essential that the die be heated and the blank should be preheated or heated by conduction from the die. Temperatures of from 450^0 to 550^0F. are normally used. If the magnesium-alloy sheet is held in the jaws of the stretching machine they should be lined with energy cloth rather than with serrations which would rupture the metal. Another method is to sandwich the magnesium blank between the die and a preformed mild carbon sheet which is held in the jaws of the machine. In this case the magnesium is not inserted in the jaws. Dies in this operation should be designed for some overforming to allow for springback and creepback during cooling.

Drop hammering

Drop hammering is not practical due to the difficulty in keeping the work heated long enough to complete the operation. Some drop-hammered parts have been made, but they required several reheatings of the material.

JOINING METHODS

Most of the standard methods of joining metals are adaptable for use with magnesium. Riverting, gas welding, arc welding, and spot welding are commonly used. The adaptations of these processes to magnesium alloy are described in the following pages.

Riveting

Riveting is the most commonly used method of assembling magnesium-alloy structures. Special consideration must be given to rivet selection, design of joints, driving technique, and corrosion protection of the assembly.

Magnesium-alloy rivets are not practical because they work harden too rapidly when driven cold. Aluminum-alloy rivets of 2S, 3S, A17ST, 17ST, 24ST, 53S-T61, 56SO, and 56S- ¼ H have all been used in assembling magnesium alloys. For aircraft work the use of 56S- ¼ H is recommended for all purposes except flush riveting in which case 56S-O rivets are used. A17ST rivets can be used for field repairs but requires assembly with wet zinc chromate primer and good paint protection to minimize corrosion. 56S rivets contain 5% magnesium and no copper and are less subject to galvanic corrosion than any of the other rivets listed above. 56S - ¼ H rivets can be used as received, no heat treating or quenching being required. They can be driven cold up to $\frac{5}{16}$ inch diameter. If it is necessary to drive rivets over this diameter they should be heated to 650^0F. 56S -¼ H rivets have a minimum ultimate shear strength of 24,000 p.s.i.; A25ST rivets have a strength of 25,000 p.s.i.

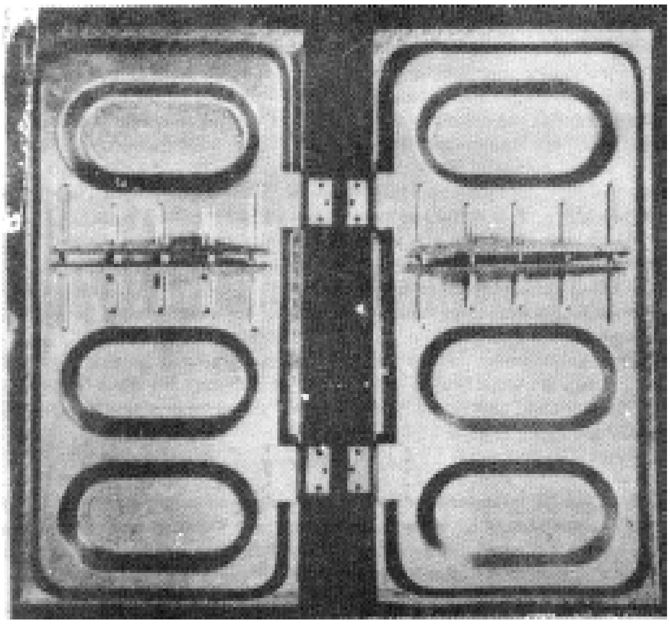


Fig.5.11. Magnesium-alloy Aircraft Doors Assembled by Riveting and Spot Welding

For well-balanced joints, rivets diameters should not exceed 3 times the thickness of the sheet, and should not be less than the thickness of the heaviest sheet being joined. For proper heading the rivets shank should protrude from 1 to 1.25 rivet diameters; this protrusion will give a flat aircraft-type bucktail with a minimum height of 0.4 rivet diameter, and a minimum diameter of 1.33 rivet diameter. An edge distance of 2 ½ times the rivet diameter is recommended to prevent cracking or bulging of the edge of the sheet. A rivet spacing of 4 times the rivet diameter is the minimum recommended.

Structural rivet holes should be drilled and not punched. Punching gives a hole with a flaky edge which is likely to crack under load. Non- structural sheets up to 0.040 inch thick can be punched if desired. In drilling, the use of a drill with a 10^0 helix angle will give smooth, accurate holes. When parts are clamped or assembled prior to drilling they should be disassembled after drilling and the chips removed. If this is not practical an air hose should ne used to clean the chips away.

Pneumatic hammers or squeeze riveters may be used, but excessive pressures and indentation of the magnesium should be avoided. The standard types of rivet heads may be used in assembling magnesium alloys. Up until recently it was necessary to use countersunk rivet heads with 120^0 included head angle, but now it is possible to satisfactorily dimple sheet for the standard 100^0 rivet heads. As stated above, 56- SO countersunk rivets must be used to minimize the cracking of the sheet under the riveting pressure.

Machine countersinking is limited to minimum sheet thickness for each diameter of rivet if efficient riveted joints are to be obtained. The recommended minimums are as follows :

Rivet diameter (inch)	Minimum sheet thickness for countersinking (inch)
$^{3}/_{32}$	0.040
$^{1}/_{8}$	0.051
$^{5}/_{32}$	0.064
$^{3}/_{16}$	0.081

When flush riverting is required for thinner sheets than those listed, it is necessary to pressure countersink the sheet.

In pressure countersinking magnesium-alloy sheet, it is necessary to heat the sheet in the vicinity of the dimple. This heating is best done by using dies electrically heated to between 450^0 and 550^0F. The work is heated locally by contact with the dies. By this method 15 to 30 dimples per minutes can be made in production. A 5000- pounds dimpling machine will make 3/16-inch dimples satisfactorily in 0.072- inch sheet. Prior to dimpling, holes should be punched or drilled at least 15% smaller than the rivet diameter. After dimpling, the holes should be drilled or reamed to the correct size and burred. A sharp edge should not be left on the bottom of the dimpled sheet against which rivet head is to be formed, if cracking is to be avoided. This edge should be removed and a flat provided of about 1.33 times the rivet diameter.

56S rivets do not require any particular corrosion-preventive methods when used for assembling magnesium alloys. Any other type of rivet should be set in wet zinc chromate primer. If it is necessary to use steel or brass rivets, bolts, or nuts, they should be cadmium or zinc plated and set in wet zinc chromate primer. All faying surfaces should be painted with the coats of zinc chromate primer before assembly.

Gas Welding

Magnesium alloys can be gas welded, using oxyacetylene, oxyhydrogen and methane. When using any of these gases a neutral or slightly reducing flame should be used. Oxyacetylene can only be used with difficulty on sheet thinner than 0.064 inch.

Standard welding equipment and torches are used for welding magnesium. A variety of tips from 0.035 to 0.081 inch should be available for use. An extruded filler rod of the same composition as the material being welded should be used. If two different alloys are being welded together the filler rod should match the alloy with the lower melting point. Filler rods melt between 1100^0 and 1200^0F, Filler rods are available in diameter from 1/16 to ¼ inch. A 1/16-inch rod is satisfactory for welding 0.020-inch sheet, a 3/32-inch rod for intermediate thickness, and a 1/8-inch rod for 0.128-inch material. A flux must be used to coat the rod and either side of the edges to be welded, in order to prevent oxidation of the metal. Fluxes are usually purchased in the form of powder, which must be stored in tightly closed glass bottles because of its hygroscopic nature. The flux paste for use in welding is prepared by mixing parts of powder with one part of water, by volume.

Only but joints may be made in gas welding magnesium alloys. In any other type of joint the hygroscopic, corrosion flux may be trapped in the joint with disastrous results. For the same reason, it is necessary to make welds with a single pass. This limits the material that can be welded to ¼ -inch thickness. To allow for warpage and shrinkage a 1/16-inch larger gap should be allowed between the mating edges to be welded. For thin material up to 0.040 inch thick this allowance is not essential, but the adges should be flanged up 1/16 to 1/8- inch. A gap up to 3/8- inch wide can be filled in when using thicker material. This fill is sometimes useful in making repairs. When material over 1/8-inch thick is to be welded, the top corners of the seam should be beveled before welding.

Before welding, all oils, grease, and dirt should be removed by means of gasoline or carbon-tetrachloride. Any oxide or chemical coating should be removed from the edges to be welded by using steel wool, a wire brush, or a file. Welding on a chrome-pickled surface will results in weld porosity and impair the free flow of the material.

Fig.5.12. Torch Welding a Magnesium Aircraft Oil Tank

The work should be placed in a jig to hold it in alignment while being tack welded. In tack welding the torch is held almost perpendicular to the surface. Tack welds are made from 1½ to 6 inches apart, depending on the thickness of the sheet and the nature of the part. Usually the work is then removed from the jig and finish welded. In running the seam weld, the torch should be held at 45^0 to the work. The rod should be held in the outer flame until the base metal melts and forms a puddle, and then the rod should be dipped in the puddle intermittently. At the end of the seam the torch should be lifted slowly to prevent too-rapid cooling and the formation of a crate. Leather or wooden hammers may be used for straightening buckled or warped seam welds. This hammering improves the strength of the weld. If large deformations must be straightened, the work should be reheated to 600^0 to 750^0F.

Immediately after welding the following operations should be performed :

1. Wash in hot running water, and scrub with a stiff bristle until all traces of the flux are removed and the surface is clean.
2. Chrome-pickle the work by immersing it for one minute in the following solution : 1.5 pounds of sodium dichromate, 1.5 pints of concentrated nitric acid, enough water to make 1 gallon.
3. Wash in cold running water.
4. Boil for 1 to 2 hours in the following solution : 0.5 pound of sodium dichromate, enough water to make 1 gallon.
5. Rinse in cold water, followed by a dip in boiling water.

Magnesium-alloy welds may be inspected visually, by radiography, or by the fluorescent oil penetrant method.

Only the 1.5% manganese alloy gas welds readily. This alloy is available as sand castings (AN-QQ-M-56B), sheet (AN-M-30), extrusions (AN-M-26), tubing (AN-T-73), and forgings (AN-M-22). The other two alloys which are available in sheet form, AN-M-28 and AN-M-29, are limited to free welds only without any restriction. When sheet material is welded to castings or to forgings of heavier sections, the mating edge must be tapered or beveled to the sheet thickness. The heavy part should also be preheated to 600-700^0F.

Arc Welding

In arc welding magnesium alloys there is no restriction on the type of joint used. An inert-gas shield is used to prevent oxidation in place of the corrosive flux that limits gas welding to butt joints. This inert-gas sheild makes multipass welds possible and removes the limitation on the thickness of material that can be welded. There is less warpage with arc welding than with gas welding because the higher heat available is more localized and fuses the joint quickly with less diffusion of heat to adjacent areas. All wrought magnesium-alloy materials have good arc weldability except AN-M-29 sheet, which is limited to unrestrained welds if cracking is to be avoided. This is the same limitation this material has when gas welded and its strength with either type of weld is the same Arc welds in AN-M-28 and AN-M-29 material are stronger than the equivalent gas welds.

For arc welding magnesium alloys a direct-current or rectified-alternating-current machine of 100- to 200- ampere capacity is required. A machine with a stable arc equipped with a continuous amperage regulator to provide adequate current control is necessary. In arc welding magnesium, reversed polarity (electrode positive, work negative) is used. A tungsten electrode has been found to do the best job. The arc between the electrode and the work is enveloped in an inert-gas sheild which excludes oxygen from the weld area and prevents oxidation. Either helium or argon may be used, The inert gas is fed from a cup about ½ inch in inside diameter which surrounds the electrode except for ¼ to 3/8 inch at the tip. A tungsten electrode 3/32-inch in diameter is used for welding 0.030 - inch sheet; electrode diameter increases to 3/16-inch for 0.125 -inch sheet.

In arc welding, a good rigid jig must be used to hold the work in position. The complete welding operation is done in the jig, and usually tack welding is not necessary if the jig is properly constructed. A good jig will reduce warpage and hold the joints tight. No gap between joints is permissible.

Good cleaning of the joints to be welded is a must , as previously described under Gas Welding. In the welding operation the torch should be held perpendicular to the work to provide the best shielding by the inert gas. The filler rod should be fed to the arc are not dipped in the molten puddle. The filler rod should preferably be of the same composition as the material being welded. A filler rod of 1/16-inch diameter should be used for 0.030-inch sheet, increasing to 1/8-inch diameter for 0.125-inch sheet.

After welding it is essential that the assembly be stress relieved by heat treatment to release residual stresses that will otherwise cause stress corrosion cracking. These internal stresses may run as high as 15,000 p.s.i. The heat treatment must be done with the work held in a jig to prevent warpage. For annealed material the relief treatment consists of heating the work at 500^0F. for 15 minutes; for hard rolled material it must be heated for one-hour at 265^0F. for AN-M-29 sheet, and at 400^0F. for AN-M-28 or AN-M-30 sheet. After heating the work should be cooled in still air.

Since no flux is used, the welds need only be wire brushed. Inspection of the welds should be made for undercutting, cracks, porosity, craters, overlapping, or inclusions. Visual examination, radiography, or the fluorescent oil penetrant method may be used.

Spot Welding

Spot welding of magnesium alloys have been limited to low-stress applications and to parts not subject to excessive vibration. Service experience on these secondary applications has been satisfactory thus far but additional experience will be required before spot welding can be generally adopted for primary aircraft structural use. All sheet and extrusion alloys can be spot welded either to alloys of like compositions or to the other alloys. The ease with which alloys of different composition can be spot welded to each other is determined by the similarity of the alloying elements present in each. The spot welding of AN-M-28 composition material to AN-M-30 is very difficult because of the great difference in their chemical composition. Two parts of unequal thickness can be spot welded together if an electrode with a larger contact area is used against the thicker material.

Alternating-current or direct-current stored-energy spot welding machines as used for aluminum alloys are satisfactory for use with magnesium alloys. Water-cooled electrodes with 2- to 8- inch dome tips are preferable.

Areas to be welded must be free of pickle coatings or oxidized surfaces. Material to be spot welded should be purchased oiled instead of chromepickled to simplify the cleaning operation. Chemical cleaners are still in the experimental stage (immersion in a 20% chrome acid solution at 150^0F for 2 minutes appears to have promise), so wire brushing must be resorted to in order to clean the areas to be welded. Both sides of the sheet must be cleaned. A power-driven wire brush rotating at over 2500 feet per minute peripheral speed is used. The side of the sheet which the electrode will touch must then be finished with No.3 steel wool or No.160 to 240 aluminum oxide cloth. Small areas can be hand cleaned by using stainless-steel wool or aluminum oxide abrasive cloth. Stainless-steel wool is preferred for its nonmagnetic qualities.

The diameters of proper spot welds vary from 0.20 inch for 0.020-inch sheet to 0.375 inch for 0.10- inch sheet. Weld penetration should be from 30% to 80% into each of the parts being welded together. Weld penetration and diameter can be determined by cutting a cross section through the weld, smoothing the surface with emery cloth, and etching for 10 seconds with a 10% to 50% solution of acetic or tartaric acid. The weld zone will darken and becomes quite visible.

Copper pick- up in the spots from the electrodes will cause corrosion and must be avoided. The presence of copper will show up as a black discoloration after chrome pickling or etching with a 10% acetic acid solution. If copper is found, the welds should be cleaned up with steel wool or aluminum oxide cloth.

Spot welds can be made through faying surfaces freshly coated with zinc chromate primer. The primer must be well thinned so that it will squeeze out from under the spot when the pressure is applied and permit good metal-to-metal contact. Protective coatings for faying surfaces are adversely affected by the dichromate treatment finally given most magnesium-alloy assemblies. It is generally considered desirable to omit the faying-surface protection in favor of the dichromate treatment.

Inspection of the spots for cracks and porosity may be accomplished by microscopic examination or by radiography.

CORROSION RESISTANCE

Magnesium, in common with other metals, is subject to corrosion. In recent years its resistance to corrosion has been greatly improved and is now equal to or better than that of many commonly used metals. This advance in corrosion resistance is largely due to the introduction of the controlled-purity type of alloy. In these alloys impurities such a iron, nickel, and copper are limited to very small percentages. The use of chemcial treatments that provide a passive surface layer and makes good paint base is also essential for aircraft use.

Army-navy Aeronautical Specification AN-M-12 describes the following four protective treatments for use on magnesium alloys :

Type-I Chrome-pickle treatment. Used to protect parts in shipment, storage, or during machining.

Type-II Sealed chrome-pickle treatment. A modified chrome-pickle treatment adaptable to all magnesium alloys. It is an alternative finish to Types III and IV when a dimensional change is permissible.

Type III Dichromate treatment. Provides maximum protection and paint adhesion and has no effect on dimensions of parts. Applicable to all alloys except the 1.5% manganese as covered by AN-M-30 for sheet material.

Type IV Galvanic anodizing treatments. This treatment is recommended for use on the 1.5% manganese type alloy. It is also applicable to the other alloys No dimensional change.

The corrosion of magnesium alloys can be caused by any one of the following circumstances :

1. **Environment**

   Salt atmosphere are much worse than inland exposures. In ordinary atmospheres bare magnesium alloy will for a protective coating of magnesium hydroxide, which is porous but subsequently is covered to hydrated carbonates and sulphates that are nonporous. This surface film cannot be relied on for general usage, however, and one of the protective treatments listed above plus paint protection is required to resist atmospheric corrosion.

2. **Galvanic Corrosion**

   Metal-to-metal contact will create a galvanic cell when moisture is present. This condition is developed even when two magnesium alloys of different compositions are in contact, particularly AN-M-30 material and one of the other magnesium alloys. A protective treatment and two coats of zinc chromate primer in the faying surfaces are required for protection. When two dissimilar metals are used, this protection plus the insertion of an insulating material between the faying surfaces is desirable. Magnesium is the least noble of all the structural metals and consequently is the one to suffer when galvanic corrosion is set up. Fortunately, 56S aluminum-alloy rivets and the magnesium alloys do not react on each other. These rivets exclusively should be used in assembling magnesium alloys structures.

3. **Surface Contamination**

   Metallic impurities in the surface resulting from wire brushing or similar operations should be removed by acid pickling or by chrome pickling. Welding flux resulting from gas welding should be removed by chrome pickling and boiling in a dichromate solution, as described under Gas Welding earlier in this chapter.

4. **Stress Corrosion**

   This type of corrosion occurs when a part with internal residual stresses is subject to corrosion influences. It is evidenced by cracking or fracture without any prior evidence of surface corrosion. Stresses above 25% of the yield strength will cause this type of failure. Sheet material in accordance with AN-M-28 and AN-M-29 that has been arc welded is particularly subject to this type of corrosion. The relief of stresses by heat treatment is essential. This operation has been described earlier in this chapter under Arc Welding.

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CHAPTER-6
MECHANICAL TESTING OF METALS

INTRODUCTION

A wide range of materials find use in engineering applications. This includes both, metals as well as non-metals. However, in manufacturing practice metals and their alloys still have a wider application, although it is not at all possible to altogether ignore the non-metallic group of materials. With the development of newer non-metallic materials, which have overcome their inherent drawbacks to a considerable extent, there is a tough competition many a times between these two groups while selecting the material for a component. If both are found to be equal in performanece requirements it is the cost factor that decides as to which of the two should be selected.

The basic concern of an engineer while selecting the material for a particular component is to match the service requirements of the component with the proporties of the material under consideration. As such, in order that an engineer is capable of selecting a proper material for a specific application he shoulad be fully conversant with the different properties found in different materials, methods of determining these properties, procedures for testing them, their limitations, etc. Also, it is well known that a larger part of manufacturing and fabrication activities involve the use of soild materials, especially metals and their alloys. Our discussions in this chapter will, therefore, be in the context of metals and metal alloys.

Further , as stated above, different materials possess different properties in varying degrees and, therefore, behave in different ways under given conditions. These properties include*mechanical properties,electrical properties, thermal properties, chemical properties, magnetic properties* and *physical properties*.A design or manufacturing engineer is basically intrested in knowing as to how a particular material will behave under applied loads, i.e., in knowing the *mechanical properties* of the material under consideration. Our discussions in this chapter will, therefore, mainly confine to the review of main mechanical properties of metals and their alloys, although a brief review of main mechanical properties of metals and their alloys, although a brief review of other properties will also follow at the end of this chapter.

STRESS AND STRAIN

When a load is applied to a structure or a component its material may either deform or break. The ultimate result will depend upon the amount of load applied, cross sectional area of the section under and the nature of the material. Natural tendency of the material is to resist deformation. This resistance against the action of the applied load is offered by the internal forces, called*stresses,*which are developed in the material when the external load is applied. Mathematically, the *stress* is expressed as the force or load per unit area of cross-section of the component, i.e.,

$$S=\frac{P}{A}$$

where, S = stress, P = Load applied, and A = Area of cross section.

Strain represents the deformation caused per unit length of a body, i.e., the change in length per unit length of the body.From this it follows that it is a ratio of change in length of a body to its original length. Since it is a ratio it has no unit. however, it can by expressed in millimeter per metre or as a percentage. Mathematically, it is expressed thus:

$$e = \frac{\Delta L}{L} = \text{longitudinal strain (or unit strain)}$$

where, e = Strain

Δ L = Change in length

and, L = Original length of the body.

The strain caused in a body can be *lateral strain* or *shear strain* according to the manner in which the load is applied on to the body.

The stresses caused in a body and the corresponding strains developed are also named according to the nature of loading a body. For example, if a body is subjected to pulls from either end it is under tension, i.e., the tendency of the applied load is to elongate the body. The resulting stress in the body is, therefore, known as *tensile stress* and the corresponding strain as tensile strain. Similarly, when a body is so loaded that the tendency of the load is to squeeze it, i.e., to shorten it, the stress caused is termed as compressive stress and the coresponding strain as compresive strain.

In the same way, if a body is acted upon by two equal and opposite loads, acting upon its opposite surfaces, the tendency of the load will be to make a portion of the body slide over the other, i.e.. to shear the body along a common plane. Such a loading will cause a shear stress and the corresponding strain will be known as shear strain.

Let it also be clear that the deformation in the material due to applied load is not necessarily along the length alone. It can be in length, volume or both, which ultimately leads to a change in shape of the body. In order to generalise the above definition of strain we can better say that engineering strain is the deformation per unit dimension. If this deformation is along the length then it is called longitudinal strain, if in the volume then volumetric strain and when in transverse direction the shear strain or transverse strain.

Hooke's Law

Named after its developer Robert Hooke, this law states that within the elastic limit, the stress is direcly propertional to the strain, i.e., the ratio of stress to strain is a constant. This constant is known as Young's modulus of Elasticity or Coefficient of Elasticity and is represented by the letter 'E'. Mathematically expressing :

$$E = \frac{S}{e} = \text{constant}$$

this constant of proportionality is different for different materials and also different types of stresses. In case of tensile and compressive stresses it is known as Young's modulus of elasticity (E), in case of shear stresses and strains it is known as Modulus of rigidity (G) and when volumetric stresses and strains are in play this consatnt is known as the Bulk modulus (K). In general, this constant is known as the Modulus of material.

Poisson's ratio

If a force is applied on a uniform body, say a bar or a test specimen, along its axis, the body is strained both in the direction of application of force as well as in a direction normal to it.The strain in the direction of application of force is called longitudinal strain and that in the direction normal to it the laterial strain. The ratio between the lateral strain and longitudinal strain is called Poisson's ratio.Its value is constant for a particular material but varies for different materials. For each material it is an important elastic constant. For most of the materials commonly used in engineering practice its value ranges between 0.3 to 0.6. Mathematically expressing :

$$\text{Poisson's ratio} = \frac{\text{lateral strain}}{\text{lengitudinal strain}} = \text{constant.}$$

STRESS-STRAIN RELATIONSHIP

The relationship between stress and strain can be best under stood with the help of a *stress-strain curve. This* curve can be easily drawn by plotting a graph between the different values of stresses and corresponding strains, obtained during the tensile test of a material specimen, stress values being taken along the ordinate and the corresponding strain values along the abscissa.

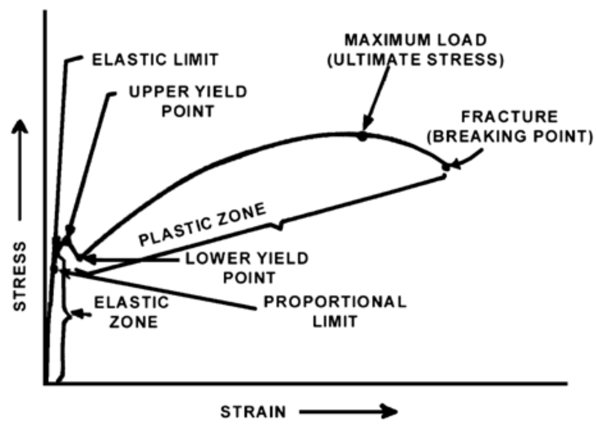


Fig. 6.1, An engineering stress-strain curve for a ductile material.

In order to make it quite clear let us take the example of tensile test performed on a specimen made from a ductile material, say low carbon steel (mild steel). Fig.6.1. represents the curve plotted from the data obtained during such a test. When engineering stresses of different magnitudes are applied to the test specimen they cause corresponding changes in the length of the specimen. Both these readings, i.e., the magnitudes of the applied stresses and the corresponding changes in length, recorded on strain measuring devices, are noted down. By dividing the latter data by the original length of the specimen different values of *engineering strains,* corresponding to different values of applied *engineering* *stresses,* are calculated and recorded. A graph is then plotted between the different values of applied loads (stresses) and the corresponding values of resulting strains. By joining these points a curve of the type shown in Fig.6.1 is obtained

A close study of the curve reveals that the material elongates elastically in the beginning of the test, i.e., the strain increases in direct proportion to the applied stress. Obviously, if the load is removed during this range the specimen will automatically return to its original length, i.e., the material will perfectly obey the Hooke's law. This state will continue till the stress-strain values reach a specific common point called the *Limit of proportionality* or simply *proportional limit.* If the material is loaded beyond this stage it will not obey the Hooke's law perfectly.

Beyond this point you will notice another point on the curve, called the elastic limit. This point corresponds to the maximum stress value upto falling between the 'zero' stress value and the elastic limit is known as *elastic region.* In some materials the proportional limit and elastic limit are almost identical, but in most of the materials the elastic limit is slightly higher than the proportional limit.

If the material is loaded beyond the elastic limit the applied stresses cause plastic deformation, i.e. the material fails to return to its original shape and size or we can say that it retains its elongation permanently even after the loads are removed. Also, beyond the elastic limit the increase in strain does not bear the same direct proportionally with the corresponding stress. In fact, beyond the elastic limit, the strain is found to increase more rapidly than the corresponding stress. This process continues till a point is reached where it is noticed that the strain increases even without any further increase in the stress. At this point the material is found to stretch suddenly. This point is known as *yield point.* In case of the material under consideration there are two distinct yield point, called the *upperyield point* and the *lower yield point*. The *upper yield point* corresponds to the maximum stress preceding the extensive strain, the *lower yield point* following this strain.

With further straining of material into the plastic range its *load-bearing ability* increases. In other words its *nominal stress,* which is the ratio of applied load to original cross- sectional area of the specimen, increases. The reason for this increase is **work hardening.** The load bearing ability of the material is said to be equal to the product of its strength and cross-sectional area. Because the cross-sectional area of the specimen decreases during its tensile stretching its strength increases, and so its load-bearing ability. During tensile testing a stage is arrived where the decrease in cross sectional area with increased strain acquires a predominant position compared to the corresponding increase in strength. At this stage the load bearing capacity of the material is at its peak and so is the value of the *tensile stress.* This represents the value of the stress at maximum load. It can be found out by dividing the load at that point by the original cross-sectional area of the specimen and is known as *ultimate tensile stress* or simply *ultimate stress,* which corresponds to the *ultimate tensile strength* of the material.

At this point a typical phenomenon works in that the strain continues to increase slowly without any increase in the load, i.e., stress. This phenomenon of slow increase in strain with time without any further increase in stress is called *creep.* The cross sectional area of the specimen is the weaker point of the test bar at this stage, which continues to become weaker and weaker as the slow extension continues, and further deformation becomes localized around this weakest point and a *neck* is formed there. The entire further deformation takes place within the neck. Further straining of the material is surprisingly accompanied by a reduction in applied stress and that is why the stress-strain curve falls beyond the point of ultimate stress. If straining is continued further the test specimen finally fractures (breaks) at a point where its cross sectional area is minimum. The strength at this point is known as the *fracture strength* or *breaking strength.* In ductile materials the fracture strength is less than the ultimate tensile strength and final fracture is always preceeded by necking. In brittle materials, however, the stress-strain curve is terminated before necking can start and, therefore, fracture takes place without necking.

ENGINEERING AND TRUE STRESS AND STRAIN

We have seen in the previous article that when a tensile test specimen loaded it elongates and its cross-sectional area reduces. This reduction, however, is not uniform through the length of the specimen but is confined to a relatively smaller portion somewhere near the middle of the length. It is also seen that the change in cross-sectional area is negligible within the elastic zone, but appreciable beyond the elastic limit. Another notable feature of the test is that one portion of the specimen starts deformation more rapidly than the rest as the test progresses.

The obvious question, therefore, is as to which area should be considered for computing the stress for a known load, i.e., weather it should be the original area of the specimen to the actual area at the instant when the stress is being calculated. Both these options are used. When the original area is considered for this purpose the stress obtained is known as *engineering stress* or *nominal stress* and when the actual area is considered the computed stress is called the *true stress*. Mathematically expressing :

$$\text{Engineering stress} = \frac{\text{Load}}{\text{Original area}} = \frac{P}{A}$$

$$\text{True stress} = \frac{\text{Instantaneous load}}{\text{Instantaneous area}} = \frac{P}{A_i}$$

$$\text{Similarly, Engineering strain} = \frac{\text{Change in length}}{\text{Origional length}} = \frac{\Delta L}{L}$$

But, as stated above, after the start of necking one portion of the specimen deforms more rapidly than the rest, i.e., the elongation in this portion will be more than the rest of the specimen. It, therefore, follows that the strain will not be homogeneous and, as such, it is not logical to consider the entire length of the specimen for findings out the*true strain*. The strain can be calculated from the following relationship :

$$\text{True stain} = \int_{L_o}^{L_i} \frac{\Delta L}{L}$$

Or, in terms of area,

$$\text{True strain} = \frac{\text{Orginal area}}{\text{Instantaneous area}}$$

PRINCIPAL MECHANICAL PROPERTIES

Those characteristics of the materials which describe their behaviour under external loads are known as*mechanical properties* of materials. Since all the engineering components, articles, tools and machinery, structures, etc., manufactured and fabricated through various processes are likely to be subjected to external loading in some way or the other at some stage, specially during use, it is essential that the design and manufacturing engineers possess a sound knowledge of the mechanical properties of materials in order to design and manufacture sound articles, components and structures to avoid failures during use. It is only with the sound knowledge of these properties that the selection of a proper material for a particular part will be possible.

These properties largely depend upon the structure of the material and the various factors contributing to this structure, such as grain size, type of bonding, presence and nature of imperfections , grain boundaries, etc,. as explained in the last chapter. A brief review of these properties will follow in this chapter.

STRENGTH

It can be described as the measure of ability of a material to withstand external forces. In other words, we can say that it is resistance offered by a material when subjected to external loading. Higher the strength the higher is the resistance offered by the material to deformation and, therefore, higher is the amount of the external load it can withstand without failure.

Depending upon the type of load applied the strength can be *tensile, compressive, shear or torsional.* The various strengths shown by a material during a tensile test are shown on the curve in Fig.6.1 and describe earlier. The stress in the material at the elastic limit is known *yield strength* and the maximum stress before the fracture is called *ultimate strength*. When in tension, the ultimate strength of the material represents it *tenacity.* Analogues strengths for a material in compression, shear and torsion can also be determined through respective tests.

ELASTICITY

It is a type of tensile property of a material due to which it resists permanent deformation under applied loads, i.e., the property which enables the material to spring back to its original size and shape as soon as the external loads are removed. It has already been discussed in sufficient detail under stress and strain. Also, several related terms like yield point, proportional limit, elastic zone, etc. have been fully explained.

STIFFNESS

It is also known as *rigidity*. It is that property of a material due to which it is capable of resisting *deflection* or *elastic deformation* under applied loads. This is very important for those parts or components which are required to remain perfectly aligned under externally applied loads. The degree of stiffness of a material is indicated by the*young's modulus* if it obeys the Hooke's law, by *Modulus of elasticity, in case of tensile and compressive stresses, modulus of rigidity in case of shear stresses and Bulk modulus* in case of volumetric deformation.

PLASTICITY

It is the property of a material due to which it can undergo permanent deformation without failure or rupture. This property is widely used in several mechanical processes like forming, shaping, extruding, rolling, etc. Due to this property various metals can be transformed into different products of required shapes and sizes. This conversion into desired shapes and sizes is effected either by the application of pressure, heat or both. In general, it is found that plasticity increases with increase in temperature.

MALLEABILITY AND DUCTILITY

Both *malleability* and *ductility* in a material are due to plasticity. It should be clearly understood that while plasticity is the controlling property *malleability* and *ductility* indicate the ability of the material to undergo specific mechanical working processes without rupture. Some other terms used in the same sense, i.e., to indicate the response of the material to specific mechanical processes are *formability and workability*.

Coming specifically to the above two main terms, *malleability* can be defined as the ability of a material for being flattened into sheets without cracking through cold or hot working. *Ductility* of a material relates to its ability to be drawn into wires without rupture and without losing much strength. Some common ductile metals are lead, tin, silver, aluminum, copper, iron, steel, etc.

All the metals are not necessary both ductile and malleable . For example, lead can be easily shaped into sheets by rolling or hammering but cannot be drawn into wires, i.e., while it is *malleable* it is not *ductile*. It is generally reckoned that while ductility is a tensile characteristics malleability is a compressive characteristics. *Ductility* of a material is usually indicated by *the percentage elongation prior to necking or the percentage reduction in area in the necked region* during the tensile test of the material.

BRITTLENESS

A material is said to be brittle if it fails with little or no ductility. Thus, it can be considered as the opposite of ductility. But, a brittle material should not be considered as lacking in strength. It only shows the lack of plasticity. To elaborate it further let us consider the example of cast iron, which is a brittle but sufficiently strong material. It is found to break suddenly as soon as its stress strain curve begins deviating from a straight line.

TOUGHNESS

It is the property on account of which a material is able to withstand bending or torsion without fracture and is equal to the work per unit volume needed to fracture the material. In other words we can say that it indicates the amount of energy adsorbed by the material before its actual failure or fracture occurs. One method of determining toughness of a material is to conduct tensile test on its specimen and construct a stress-strain diagram from the data obtained through the test. The total area under the stress-strain curve will represent the energy (work) required per unit volume to fracture the material. However, in order to get correct values the variation in temperature and rate of application of load during testing should be taken into account because they can appreciably change the nature of the stress-strain curve and, therefore, the toughness value of the material. The work or energy absorbed by the material is usually expressed as *modulud of toughness*.

To understand it more clearly let us compare two different materials, one brittle (say glass) and the other tough (say wrought iron). If sudden load is applied to two pieces, one each of the above materials, the glass piece breaks suddenly while the wrought iron piece will absorb a substantial amount of energy before failing. Accordingly, therefore, wrought iron is supposed to be much tougher than glass. Since this property enables a metal to withstand both elastic and plastic deformations it is of very great significance for design and manufacturing engineers who have to design and manufacture a large number of parts and structures which are supposed to bear shock loads and vibrations during use. It's, therefore, amply clear that it is commonly associated with shock or impact loading and, hence, to *impact strength*.

RESILIENCE

It is the measure of the capacity of a material to absorb energy within the elastic limit. When a material is externally loaded within elastic limit it absorbs *strain energy*. It is a potential energy and it is released when the applied load is removed. The amount of energy that a unit volume of material can absorb within the elastic range (Fig.6.1.) is known as *resilience*. The maximum amount of energy that can be stored in a material (body) upto the elastic limit is called *proof resilience*. The amount of proof resilience per unit volume of the material is known as *modulus of resilience*. This property indicates the capacity of a material to withstand shock loads and vibrations.

HARDNESS

This property is quite closely related to the strength of a material. Although it is a basic and very important property of materials no precise definition of this property has yet been established. However, a common way to defining this property is in terms of the capacity or ability of a material to resist permanent indentation, such on scratching, wear, penetration, abrasion, cutting, etc. Several types of tests are used to determine the hardness of materials. Of these, the most commonly used tests are *brinell, rockwell* and *Vickers* hardness tests. These tests will be described in detail later on in this chapter.. These tests give numbers which are indicative of the relative hardnesses of the material under test.

A particular term which often used in the descripition of this property, specially in the context of steel, is*hardenability*. It is indicative of the degree of hardness that the metal can acquire through the hardening process, i.e., heating and quenching. Not only the degree but even distribution of the induced hardness in the metal is determined. The more uniformly the induced hardness is distributed throughout the structure of the metal the higher will be the hardenability of the metal concerned.

IMPACT STRENGTH

This property encompasses both toughness and strength of a material. In short, it can be defined as the resistance of the material to fracture under *impact loading, i.e.*, under quickly applied dynamic loads. Two standard tests are normally used to determine this property (1) The *Izod* impact test and (2) The *Chirpy* test. Details of these tests will be described later in this chapter.

FATIGUE

This property of a material decides its behaviour under a particular type of loading, in which a much smaller load than the one required for material failure in a single application is repeatedly applied innumerous times. Thus, the material is subjected to repetitive cycles, in very large number, of fluctuating stress. Under such conditions the material fails at a much lower stress than the one required for its failure fracture under a single application of steady loads. This phenomena of material failure, under the conditions described above, is known as *fatigue*. The stress at which the material fails due to fatigue is known as *fatigue strength.* The fatigue always shows a brittle fracture with no appreciable deformation of the material at the fracture. It is also reckoned that in almost all metals there is a well defined value of stress below which the material will not fail due to fatigue even if there is a repeated application of load in the above manner. This value of stress , which is much below the normal yield stress, is known as the *fatigue limit* or *endurance limit* of the material.

The phenomenon of fatigue failure is very important from the point of view of design and manufacture of various components which are supposed to be subjected to repeated or cycle loading continuously. Some examples of such components are rotating machine parts, motor shafts, gears, components of high speed turbines and aero engines, aircraft wings, etc. The factors which generally govern the fatigue strength of a material are its chemical compositions, extent of cold working and grain size.

CREEP

The property of material due to which it is progressively deformed at a slow rate with time at a constant stress is called *creep.* A large number of components in different engineering applications such as pressure vessels in high temperature chemical processes, aircraft, steam and gas turbines, power plants, furnaces, etc. , are subjected to constant stresses for long periods. Under such conditions the material undergoes slow deformation over a long period of time, rendering it unserviciable. If this deformation is allowed to continue even after that it may result in total failure of the structure. It is due to *creep*.

Most metals show creep at elevated temperatures. Creep in materials occurs in three stages, known as *primary, secondary and tertiary. Creep strength* is the term used to denote the stress for a definite rate of strain at a constant temperature.

MACHINABILITY, FORMABILITY AND WELDABILITY

These three terms, instead of being truely the properties of materials, are actually indicative of the response of materials to specific methods of metal processing. For example, the ease with which a material can be cut to provide it the desired shape and size indicates its degree of machinability, which is expressed as a percentage. This percentage, called *machinability index* is determined by comparing the metal under consideration with *free cutting steel* of which the machinability rating is assumed to be 100 percent. However, this is not the only aspect that effects the suitability of a material. Several other properties of the material are to be considered to decide upon its suitability because the type of machining operation, required degree of surface finish, desired tool life, etc., call for specific properties in the material to be machined.

Similarly, *formability* indicates the response and suitability of the material for plastic deformation processes. Materials, however, behave indifferent manner at different temperature and also respond differently to different deforming processes. Some materials may exhibit very good formability at high temperaturte but show a very poor response if deformed at room temperature. Some materials may readily flow when deformed at slow speed but they will break, as if they are brittle materials, if higher deformation speeds are employed. So, while deciding the overall *formability* of a material all these aspects should be taken into consideration.

The term *weldability* of a material indicates its ability to respond to the welding process under given fabrication conditions in order to enable successful fabrication of a well designed structure which, in turn, should successfully render the intended service when put to use.

TESTING OF METALS

Many types of mechanical tests are conducted on metal specimens in order to ascertain their different mechanical properties and, thus, their suitabilities for specific uses. The data obtained from theses tests is of direct use for the design engineers in order to decide as to whether a particular material conforms to the required specifications or not. This helps in the selection of a suitable material for a specific use and also its soundness. All the test procedures have been standardised. The prominent Indian institutions involved in standardising the test procedures, developing standard specifications for materials and standard definitions of the related terms are the *Bureau of Indian Standards (*formerly *I.S.I.), National Physical Laboratory (NPL)* and the *National Test House (NTH).* All the mechanical tests can be grouped into two main categories :

1. **Destructive tests.**
   Which include tensile test, compression test, hardness tests, impact test, fatigue test, creep test, etc.

2. **Non-destructive tests.**
   Which include visual examination, radiographic test, ultrasonic test, penetrating-liquid test, magnetic particle or magnetic dust test, etc.

These test procedures will now be described in detail in the following articles.

THE TENSILE TEST

It is a very commonly used test, performed to determine different tensile properties, viz., ultimate tensile strength, yield strength., elastic limit, proportional limit, breaking strength, % elongation, % reduction in area, modulus of elasticity, etc. This test can be performed either on an exclusive *tensile testing machine* or on a *Universal testing machine.* The latter type of machine is more commonly preferred because, bending test, etc., can also be performed on this machine whereas the former type is a single purpose machine. These days *Electronic Universal Testing Machines* with *microprocessors* are also available in the country. These machines carry high loading efficiency of the order of ± 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 counductanceof different tests on the same machine.

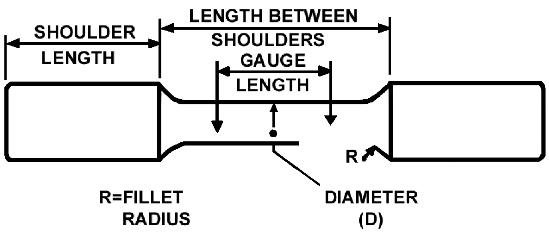
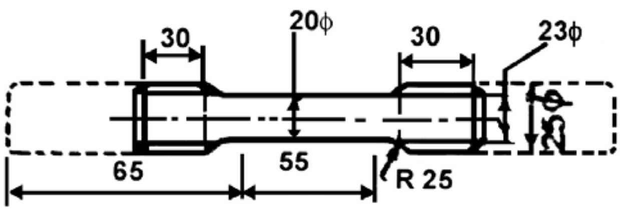


Fig.6.2 Main parameters of tensile test specimen with plain ends

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.6.2 with all the essential feature indicated on it.



Machining tolerance in dia = ± 0.5
All dimensions are in mm

Fig.6.3. 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.6.3. and such test pieces are highly recommended for use in our country.

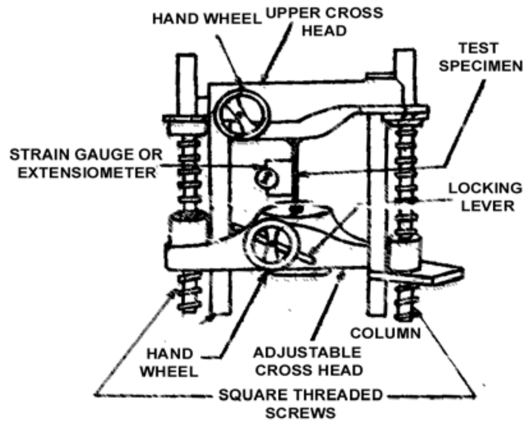


Fig.6.4. Schematic setup of a U.T.M., showing the test specimen gripped between the two cross heads.

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.6.4. 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.

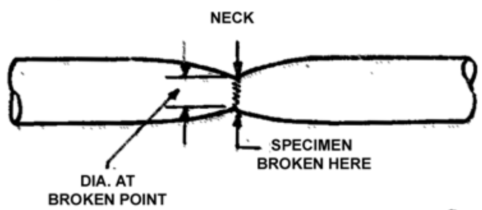


Fig 6.5. Broken pieces of specimen joined together for final measurements.

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.6.5. 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.

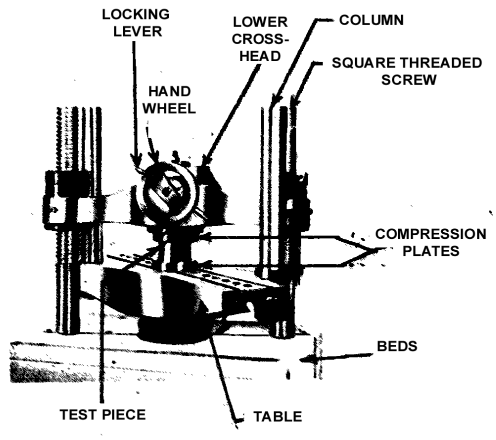


Fig.6.6. Setup for a compression test on a universal testing machine.

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 6.7.) :

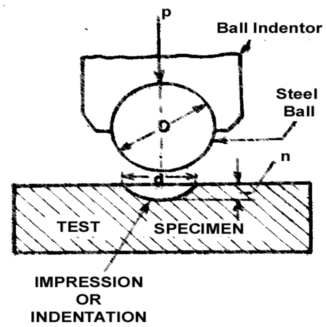


Fig 6.7. Important parameters of a Brinell hardness test.

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

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 employes 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.6.8. 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* : $R = 100 - 500\,t$

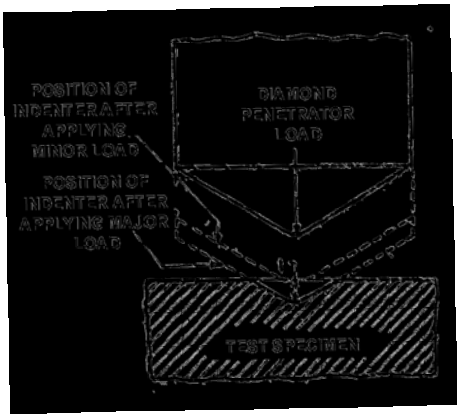


Fig.6.8. Principle of Rockwell testing

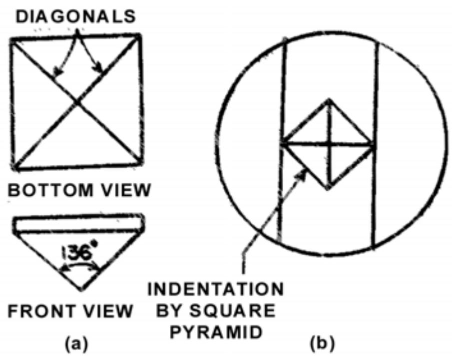


Fig 6.9. Details of square pyramid and indentation produced during Vickers hardness test.

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 6.1 below :

TABLE 6.1, USE OF ROCKWELL SCALES

Scale	Majorload	Indenter	Suited for Rockwell testing of :
A	60	Brale	Hard surfaces like those of case hardened steel,cemented carbides, etc.
B	100	Ball	Aluminum, copper, brass, malleable cast iron and grey cast iron
C	150	Brale	Hardened steel, white cast iron, etc.

Other scales from *D* onwards are meant for relatively softer and annealed material. Also, with the help of conversion tables it is possible to convert Rockwell hardness number into Brinell hardness number.

VICKERS HARDNESS TEST

This test is similar to Brinell hardness test in the sense that here also an indentation is made in the surface of the test specimen by pressing an indenter point at static load into it. The method of determining the hardness number also is same i.e., through the relationship between the load applied and the surface area of the penetration made. But, there is a marked difference between the indenters used and the smaller loads applied. In case of *Vickers hardness test a square-based diamond pyramid,* containing 136° angle between opposite faces [see Fig 6.9.(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 6.9. (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 :

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

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

$$\text{or} \quad = \boxed{1.8544\frac{P}{d^2}}$$

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 6.10) 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.6.10. The ratio of their lengths is approximately 1 : 7.

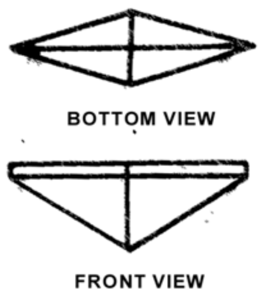


Fig.6.10.Diamond Knoop indenter used in Knoop hardness test

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 6.11. 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.

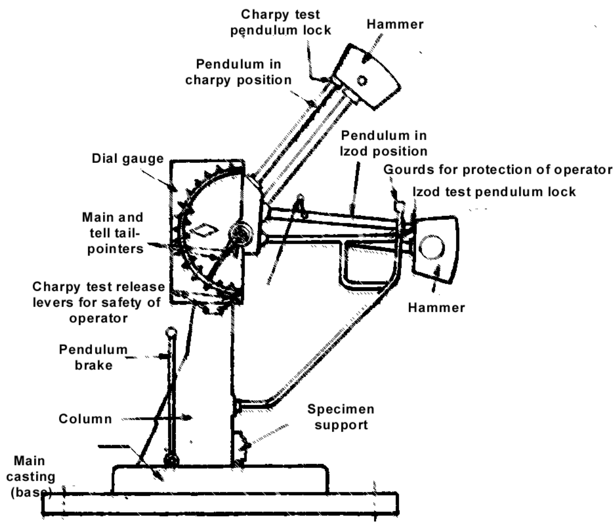


Fig 6.11.A pendulum type Impact testing machine.

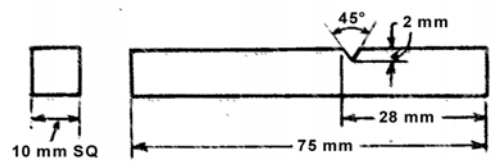


Fig.6.12. Standard dimensions of an Izod impact

The test specimen used for **Izod impact test** is held in the support in a cantilever position, as shown in Fig .6.11. dimensions of the specimen are shown in Fig.6.12. 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 6.14 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 6.15). 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 6.16 and the method of calculation of the energy consumed in the fracture of the test specimen in either test is as follows :

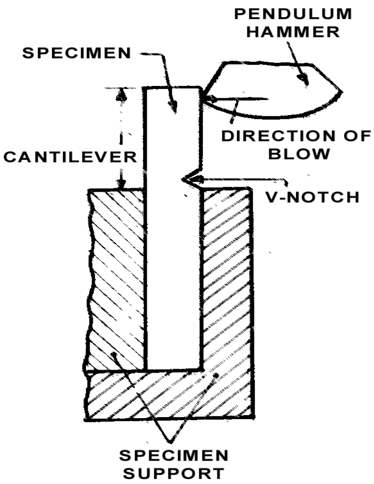


Fig 6.13 The test specimen held in contilever position for Izod impact test.

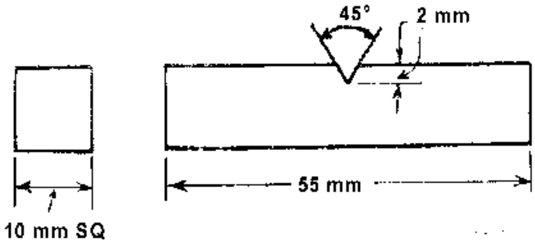


Fig 6.14. Principal dimensions of a charpy Impact test specimen

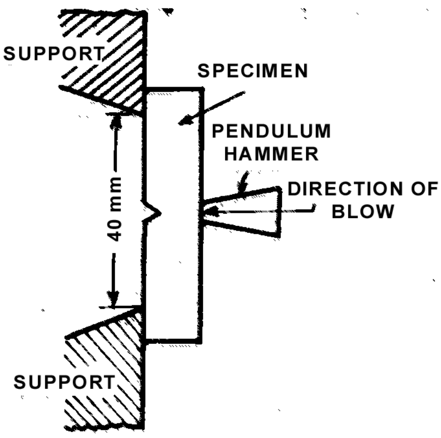


Fig.6.15.Charpy test specimen held in supports in proper position for test.

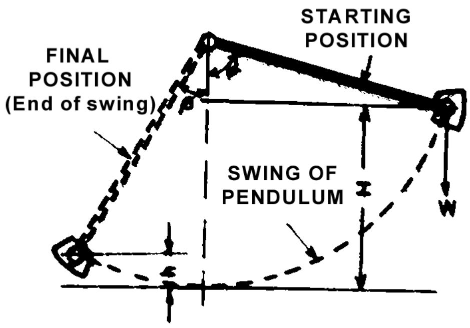


Fig.6.16. Schematic diagram showing the principle of Izod and charpy impact tests.

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
∴ 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.

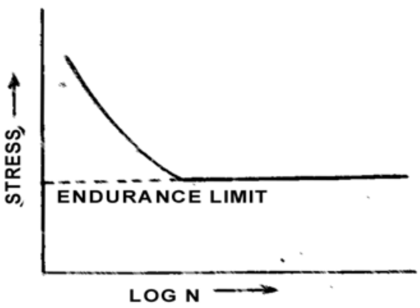


Fig 6.17. Fatigue (S-N) curve for mild steel

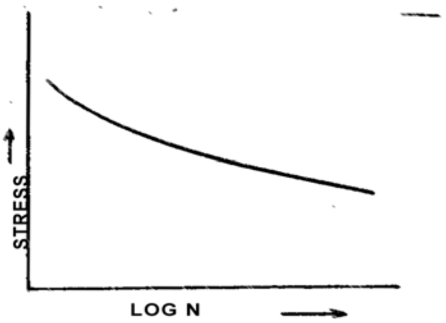


Fig.6.18. S-N curve for Aluminium

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. 6.17 and 6.18 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. 6.19, which clearly indicates the different stages of creep.

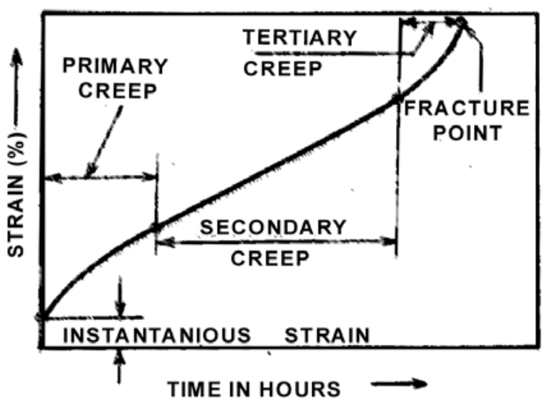


Fig.6.19. A typical creep curve showing different stages of creep

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.

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CHAPTER-7
PLASTICS

Plastics are a large group of synthetic and natural organic materials which can be molded under heat and pressure, cast, extruded, or fabricated into a variety of shapes. There are some eight hundred trade names describing plastic products, many of which are identical materials. Plastics may be classified in a number of ways as described below.

Plastics have been used in many aircraft applications and recent developments indicate a broadening of such applications. As in automotive practice they have been used for knobs, handles, paneling, and similar items. In addition they have been used in the manufacture of ammunition chutes and boxes, fairings, emergency hatch covers, control-surface tabs, wing tips, droppable fuel tanks, wheel fairings, air ducts, and similar parts. Plywood impregnated with plastic resin has frequently been used in the manufacture of entire airplanes. Experimentation is currently underway in the manufacture of fuselages and wings of a glass fiber impregnated with plastic. This material has a tensile and compressive strength of around 50,000 p.s.i.

The first plastic ever developed was made by treating cotton cellulose with nitric acid. The resulting nitrocellulose plastic was named celluloid. Later a second plastic was developed when sour milk was mixed with formaldehyde. The casein plastic that resulted is used commercially in the manufacture of buttons and buckles. The real development of plastics began with the discovery of bakelite, which is obtained by mixing phenol (carbolic acid) and formaldehyde. Micarta and formica are similar materials. Plastics of this type are referred to as phenolics.

Plastics are formed by polymerization, which is a chemical process resulting in the formation of a new compound whose molecular weight is a multiple of that of the original substance. This new compound has entirely different physical properties. The resins which are components of plastic materials are high polymers, the chemistry of which is not yet fully understood. The chemical composition and the molecular size and structure of these resins, however, are largely responsible for the physical properties of the plastic materials they form.

CLASSIFICATION
An infinite number of plastics can be developed but as the present time only about twenty are in commercial use. These can be classified into four different types, namely, synthetic resin plastics, natural resins, cellulose and protein. Plastics may also be subdivided into two major classifications which are depndent ontheir reaction to heat, namely the thermoplastic and the thermosetting types.

Synthetic Resin Plastics
This group of plastics is the largest and is manufactured by the use of raw materials such as phenol, urea, formaldehyde, glycerol, phthalic anhdride, acetylene, and petroleum. Phenol formaldehyde, urea formaldehyde, and melamine formaldehyde are the thermosetting plasties of this group that are most commonly used; the acrylic, vinyl, and styrene plastics are the most commonly used thermoplastics.

Natural Resins
These resins are used in the production of thermoplastic type molding compunds. Hot-molding compositions are prepared by adding suitable fillers to shellac, rosin, or asphalt. Shellac compositon are used for electrical insulators, telephne parts, and phnograph records.

Cellulose
Plastics derived from cellulose are widely used and well known. Cellulose, the basic raw material, is obtainable as ordinary cotton or pulped wood. Cellulose plastics are used inthe manufacture of pen and pencil barrels, tool handles, drafting instruments,photographic film, artificial leather, transparent window material, airplane dopes, and lacquers. Cellulose nitrate (celluloid), cellulose acetate, and regenerated cellulose (cellophane) are cellulose plastics.

Protein Plastics
These plastics are manufactured from the casein of skimmed milk and from soybean meal. These proteins are kneaded into a colloidal mass, and then formed into sheets, rods, or tubes by means of suitbale presses or extrusion machines. the formed pieces are then hardened by treatment with formaldehyde. Buttons, knobw, etc. cab be machied from the hardened raw material or the colloidal protein mass can be shaped to the desired form and then hardened with formaldehyde. This type of plastic is very hygroscopic and will warp and crack if exposed to vrying moisture conditions.

TABLE 7.1. THERMOPLASTIC MATERIALS

Type	Composition	Form	Specific	Tensile gravity	Heat strength	Trade names resistance	Typical uses
	Cellulose nitrate	Sheet, rod, tubing, ribbon, film	1.35	6,000	140°F.	Celluloid, Nitron, Nixonoid, Pyralin, Kodaloid, Herculoid	Spectacle frames, novelties
Cellulose	Cellulose acetate	Sheet, rod, tubing, foil, film, molding compounds	1.28	5,600	150°F	Fibestos, Kodapak, Lumarith, Vuepak, Tenite I, Plastecele, Nixonite, Macite, Chemaco, Bakelite C.A. Class I	Hardware, movie film cabin windows
	Cellulose acetate butyrate	Molding compounds	1.20	4,000	130°F.	Tenite II, Hervose C, Bakelite C.A. Class II	Hardware, flashlight cases, pencils
	Vinylidene chloride	Tubing, tubing fittings, molding compounds, extrusions	1.65	6,000	170°F	Saran, Velon	Tubing for water, chemicals, and airwoven screening, water-resistant fabrics
	Polyvinyl butyral	Sheet, resin, molding compounds	1.07	2,000	160°F.	Vinylite X, Saflex, Butacite, Butvar	Safety-glass interlayer, water-proof coatings
Vinyl	Polyvinyl alcohol	Sheet, rod, tubing, molding compounds				PVA, Resistoflex	Tank linings, tubing, safety-glass Interlayer
	Polyvinyl chloride	Molding compounds	1.30	2,000	175°F.	Geon, Vinylite Q, Chemaco	Electric cable jacketing
	Polyvinyl acetate	Sheet, film, molding compounds	1.35	9,400	130°F.	Vinylite A, Gelva	Plotting and navigating instruments, insulation, raincoats, map and chart protection
Acrylic	Methyl methacrylate	Sheet, rod, tubing, molding powder	1.18	8,100	190°F.	Plexiglas, Lucite	Aircraft enclosures, windows, windshields, lenses
Polyethylene	Polyethylene	Sheet, rod, tubing, molding powder	0.92	1,800	190°F	Polythene, Polyethylene	Electrical insulation
Polystyrene	Polystyrene extrusions	Molding compound,	1.06	4,700	170°F. Styramic,	Bakelite Polystyrene, Loalin, Styron, Polyflex.	Insulators, coaxial cable insulation, battery boxes, bottle covers
Polyamide	Polyamide derivative	Molding compounds, filaments	1.15	5,000	165°F.	Nylon, Norelco	Rope, bristles, window screening, electric insulation
Casein	Casein derivative	sheet, tubing, rod,	1.34	10,000	300°F.	Ameroid	Buttons, buckles

Thermoplastics

Thermoplastic mateils will repatedly soften when heated and harden when cooled. These materials can be heated until soft, molded into the desired shape, and when cooled will retain this shape. The same material can be reheated any number of times and reshaped. Data on thermoplastic materials are given in Table 7.1. The values listed should be used only comparateively and the manufacturer should be consulted if exact values of design purposes are required.

Thermosettng Plastics

Thermosetting plastics are chemically changed by the first application of heat and are thereafter infusible. They will not soften on further application of heat and cannot be reshaped after once being fully cured by the application of heat Recently, thermosetting-plastic laminates have been made available commercially in a condition not fully cured and these can be given a final heating which softens them momentarily, thus permitting reshaping. This operation is known as post-forming.

Data on thermosetting plastics are given in Table 7.2. Due tot he infinite variety of products obtainable by using different fillers, reinforcements, and processes, only generla values are listed. the manufacturer should be consulted for specific design values.

MANFUFACTURING PROCESSES

A number of manufacturing processes are employed to create usable forms of plastics for industrial applications. Some of these processes are applicable only to thermosetting materials or thermoplastic mateials while others are used for either type of plastic. these processes are described briefly below.

Molding

Both thermoplastic and thermosetting materials can be molded satisfactorily. The moding compund usually consists of the plastic resin and a filler, and sometimes a plasticiser which improves the moding properties. Fillers such as alpha cellulsoe and wood flur increase the strength somewhat and reduce the cost since they are cheaper than the resin; mica and asbestos are sued to obtain good electrical properties and heat resistance ; macerated fabric or cotton cord give the best mechanical properties.

Compression Molding

This process is equivalent to the press forging of metals. It consists of placing molding compound in a heated mold cavity, and then applying pressure to the other half of the mold. The moding compund softens, flows throughout the mold cavity, and then sets in final form to a rigid, heat-reisting solid. When this process is used with thermoplastic materials the mold must be aftercooled to harden the plastic part before it is ejected. Molding pressures of from 1000 to 20,000 p.s.i. and temperatures around 300°F. are used in this process.

Compression molding is applicable to relatively simple parts with thick sections and weighing up to 50 pounds. Metal inserts can be molded in place. The removal of the flash or fin is sually the only finishing operation required on compression-molded parts.

Transfer Molding

This process is a modification of compression molding in which just the required amount of material is heated in a container above the mold and is then forced into the mold under high pressure. Pressures as high as 100,000 p.s.i. are used. Complicated parts can be made with this process.

Injection Molding

This Process is equivalent to die-casting of metals. It is applicable to thermoplastic parts of relatively simple design not weighing over 2 pounds. Metal inserts may be molded in place. Parts manufactured by this process have good dimensional accuracy. In this process the molding compund is heated in a chamber from which it is forced by a ram into a relatively cool mold. The part hardens in a few seconds in the cool mold and is then ejected. High-speed procuction is obtainable in this process with fully automatic machinery.

Jet Molding

This process is a modification of injection molding which is applicable to thermosetting materials. In jet molding the nozzle leading into the mold is continuously cooled by water except when the ram pressure is appplied, at which time extreme heat is generated at the nozzle. The mateial passing through the nozzle is thoroughly heated and plasticised as it enters the mold cavity. After this brief application of heat the nozzle is again cooled with water, thus keeping the mateial in it uncured and plasticised and ready for the next stroke of the ram. The material in the heated mold cavity sets fairly quickly and is then removed.

Complicated parts weightin up to about 1 pound can be jet molded. These parts require very little finishing. A high production rate is obtainable with this process.

TABLE 7.2. THERMOPLASTIC MATERIALS

Type	Composition	Form	Specific	Tensile gravity	Trade names	Typical uses
Phenolic	Phenol-formaldehyde	Cast	1.25 - 1.70	2,000 - 10,500	Bakelite Cast Resinoid, Catalin, Prystal, Durez, Opalon, Textolite, Corolite	Knobs, buttons, handles, small machined parts
	Phenol-formaldehyde, Furfural-aldehyde phenol	Molded - wood flour, paper, fabric, asbestos, etc., fillers	1.25 - 2.00	3,500 - 9,500	Bakelite, Durez, Durite, Haveg, Indur, Makalot, Michrock, Resinox, Textolite, Corolite, Heresite, Insurock, Neillite	Pulleys, knobs, handles, instrument cases, terminal blocks, electrical plugs
	Phenol - formaldehyde	Laminated - paper, fabric, asbestos, or glass - cloth base	1.34 - 1.80	10,000 - 38,000	Aqualite, Catabond, Celeron, Coffite, Dilecto, Duraloy, Formica, Insurok, Lamicoid, Lamitex, Micarta, Ohmoid, Panclyte, Phenolite, Spauldite, Synthane, Taylor, Textolite, Veinite, Vulclid	Gears, electrical applications, paneling, structural parts
Amino	Melamine - formaldehyde	Molded - cellulose fabric, asbestos fillers	1.40 - 2.00	5,500 7,000	Melmac, Resimene Plaskon Melamine, Catalon Melamine	Electrical applications
	Urea - formaldehyde	Molded - cellulose filler	1.45 - 1.55	6,000 - 13,000	Bakelite Urea, Beetle, Plaskon, Phonite, Uformite, Sylplast	Containers, kitchenware thermos caps
	Urea - formaldehyde	Laminated - cotton base	1.22	5,000- 7,000		Molded shapes
Allyl	Allyl	Cast	1.31	5,000 - 6,000	Allite 39	Aircraft enclosures, lenses
	Allyl	Laminated - glass - fabric base	1.72 - 1.83	34, 200 - 56,100		Structural applications

Casting

This process is usually limited to thermosetting materials which are poured into molds and hardened by slow baking. since a long time is required for cuing, sheet, rod, and tubing are normally cast and the required parts are machined form them.

Extruding

This process is applicable to thermoplastic materials. It is used to produce rods, tubes, strips, and other sections as well as to insulate wire and cable. In this process the molding compound is softened by heating, and is then forced through a die with an aperture of the desired shape. Continuous extruding is obtained by suing a self-feeding screw-type ram or stuffer.

Extrusion molding is a variation of injection molding in which the extruder nozzle is used to feed the mold. Pressures are lower than in injection molding but larger parts can be manufactured.

Laminating

This process is applicable to thermosetting plastic materials. It is used in the manufacture of sheet, tubing, rod, and simple shapes. These laminates consist essentially of a reinforcing material such as paper, fabric, or glass fiber, impregnated with a synthetic-resin binder, layers of which are fused together under heat and pressure. The commonly used binding resins are phenol-formaldehyde, melamine-formaldehyde, and urea-formaldehyde.

The reinforcing material is thoroughly impregnated with the resin binder, is dried, and is then cut into sheets of the desired size. To manufacture laminated sheet a number of the impregnated sheets are piled on top of each other and placed in a hydraulic press. They are then subjected to a temperature around 300°F and a pressure of from 1000 to 2500 p.s.i. During this curing operation the resin is transformed into an infusible solid, after which the laminate is removed from the press. Polished plates are used in the press and a polished surface is obtained on the sheet laminate.

Laminated tubing is made either by rolling or molding. Rolled tubing is formed by rolling impregnated reinforcing material on a mandrel under high tension and pressure, after which it is cured by baking without further pressure. Molded tubing is made by rolling the impregnated material on a mandrel and then curing it in a mold under heat and pressure. The mandrel is then removed. Rod is made in the same manner as molded tubing without the use of a mandrel.

The manufacture of the laminates as just described is frequently referred to as high-pressure molding or laminating. A similar process known as low-pressure laminating is often used in the manufacture of curved or odd-shaped parts. In this process layers of wood veneer or other material are coated with a bonding resin and are supported in or over a form of the desired shape. The entire assembly is placed in a rubber bag which is then evacuated, following which the bag and its contents are placed in a closed vessel containing from 75 to 250 pounds per square inch of steam pressure. The bonding time varies from several minutes to 2 hours, after which the work is removed.

A number of low-pressure laminating plastics have recently been developed. The use of these new resins in bonding and impregnating permits the fabrication of laminated structures in large and complex shapes at low temperatures and pressures. In some cases only sufficient pressure is required to insure good contact between the laminations. Cotton fabric, glass fabric, glass fiber, and paper are used as reinforcements in low-pressure laminates.

PHYSICAL PROPERTIES

The strength of cast and molded plastics is not sufficiently high to justify their use as structural components of aircraft. Some cast phenolic resins do have good compressive properties however, and are used to make forms and dies. Properties of molded parts vary with the resin, the filler, the method of molding, and the thickness of the sections. Data obtained on test specimens are seldom representative of production parts. It is obvious that this type of material can only be used in secondary parts in aircraft construction.

Laminated plastics show much better promise of being used in aircraft structural applications. The average physical properties of a number of laminates are given in Table 7.3.

Until recently, laminated plastic materials were developed and used primarily for their electrical properties. The classification of these materials was made by the National Electrical Manufacturers Association (NEMA) according to the type of reinforcing material employed. Thus the four grades listed in Table 7.3 consist of the following.

Grade C : Cotton fabric weighting over 4 ounces per square yard.
Grade XX : Paper base
Grade L : Fine-weave cotton fabric weighing 4 ounces or less per square yard
Grade AA : Asbestos fabric base.

Later developments have been for structural or commercial purposes and have not been classified.

TABLE 7.3. PHYSICAL PROPERTIES - LAMINATED PLASTICS (AVERAGE)

Material	Specific gravity	Grain direc-tion	TENSION Ultimate strength (p.s.i.)	TENSION modulus of elasticity ($\times10^{-6}$)	TENSION %Elong. before fracture	COMPRESSION Ultimate strength (p.s.i.)	COMPRESSION Modulus of elasticity ($\times10^{-6}$)	BENDING Modulus ((p.s.i.)	BENDING Modulus of of rupture ($\times10^{-6}$)	SHEAR Flat - elasticity	SHEAR Edge - wise	Bear- wise	Use ing strength
Grade C phenolic	1.34	With Cross	14,700 9,600	1.23 1.0	2 2	27,800 27,500	1.60 1.20	21,400 16,300	1.35 1.05			16,750 18,350	Gears. Good impact strength
Grade XX phenolic	1.34	With Cross	16,700 14,600	1.64 1.31	2 2	23,800 23,400	2.15 1.62	18,400 16,100	1.55 1.28	12,850 13,950	14,080 14,300	20,000 19,650	electrical applications; good machinability
Grade L phenolic	1.34	With Cross	18,900 12,500	1.60 1.11	2 3	25,800 24,700	1.72 1.32	21,400 18,200	1.36 1.06	10,250 12,650	13,850 14,250		Small gears and fine machining applications
Grade AA phenolic	1.58	With Cross						17,250 15,400	1.34 1.24	11,900 14,900	9,600 12,210		Moisture and heat resistant
High-strength paper-base phenolic	1.39	With Cross 45°	24,600 24,200 26,100	2.20 2.18 2.24	1½ 1½ 2	22,700	2.33	28,400 29,700	2.26 2.15	13,600 13,500	14,500 15,100	33,000 33,000	Structural material
Glass-cotton-base phenolic (high-pressure)	1.64	With Cross 45°	38,000 37,700	2.16 2.13	2 2	26,800 22,900 18,200	2.36 2.31	34,800 33,800 24,900	2.15 1.81 1.26	17,200 17,900	13,500 15,700	28,500 31,600	Structural material
Glass-fabric base urea-phenolic (low-pressure)	1.74	With Cross 45°	27,400 19,700 10,400	1.76 1.14 .86	3½ 2½ 4	6,600		18,400	1.54				Molded shapes, radomes
Cotton-base ureas (low - pressure)	1.22	With Cross	5,100 6,900	.56 .33	22 8	7,000 8,700		6,400 9,600	.43 .42				Molded shapes
Fiberglas base CR-149 resin (low-pressure)	1.76	With Cross 45°	54,700 45,700 19,500	2.49 2.13		54,100 56,800 27,900		84,600 62,600 40,900	2.98 2.34 1.36				Primary structure

Glass-reinforced laminates give promise of becoming an important aircraft structural material. Glass materials for laminating are in the form of square-weave fabrics and also in the form of unidirectional fibers with sufficient cotton fill to hold them in position. Individual fibers have a strength of 350,000 p.s.i. The fibers in square-weave fabrics go over and under and tend to cut each other when stressed. Alternate layers of unidirectional fabric cross-banded to give equal strength in two directions are more satisfactory. Glass fabric is used in both high-pressure and low-pressure laminates.

A fuselage section and wing section have been made experimentally of a sandwich-type material consisting of a cellular cellulose acetate core that is very light, wrapped in a glass-fabric laminate. The whole assembly is bonded together and gives a light bulky structure with a smooth strong surface. When tested, the fuselage section was reputed to have a smooth contour until ultimate failure. This type of structure lends itself well to maximum weight saving sine it can be laminated in tapering sections.

WORKING PROPERTIES

Joining

Plastic materials are usually joined by means of rivets, bolts, screws, or inserts. When using rivets or bolts it is advisable to use washers under the heads to distribute the compressive load of the riveting or nut tightening. Washers also resist the tendency to pull the head of the rivet through the sheet when a joint is eccentrically loaded. When screws are used, coarse threads should be specified.

Thermosetting materials can also be joined by cementing. Cements of the Cycleweld type will develop shear strengths of 3000 p.s.i. and failure under test will occur in the plastic and not the joint. This type of cement is cured at a temperature around 300°F. in 15 minutes, with sufficient pressure being applied to insure contact between the two surfaces being bonded. A Vinylseal cement is also used for bonding thermosetting plastics but this cement is a thermoplastic and will soften when heated. It is not satisfactory for bonding joints under continued stress.

In joining laminated-plastic materials it is important that the fastenings apply the loads across the laminations. The interlaminar strength is low (except in compression) and cleavage of the bonding plane will result if loads are in a direction that tend to delaminate the material.

Machining

Plastics can be machined without difficulty but the reinforced thermosetting plastics are very hard on cutting tools, causing them to dull rapidly. In general, tools with cemented tungsten carbide or stellite tips are used. In turning, high speed and light cuts are best. Overheating caused by excessively high speed or a dull tool will result in a poor finish and inaccurate dimensions. In milling, large-diameter cutters with many teeth operating at high speed should be used. Drilling should be done with high-speed steel drills which are kept sharp. Reaming and tapping can be done with the same tools used for metal. Fine threads are best cut on a lathe, but self-opening dies or milling cutters should be used for normal production threading. Band and circular saws can be used for sawing, but should operate at approximately 5000 and 10,000 feet per minute respectively. In punching, the clearance between die and punch must be much less than used for metal and both punch and die must be sharp.

Forming

Thermosetting plastics have very little ductility at room temperatures and cannot be formed like metals. Single-curvature parts with a large radius can be formed but must be held in this shape by adequate fastening. Reinforced thermosetting plastics such as laminates can be originally cured to a desired shape but the die cost is high and only justifiable when large quantities are involved. It is difficult to mold the high-pressure laminates in any but flat or simple curved shapes; but low-pressure laminates can be molded to practically any desired shape.

In the last few years an undercured laminated phenolic sheet has become available commercially that can be formed by the aircraft manufacturer. Grade C material which is reinforced with a coarse-weave fabric appears to be the best for this purpose. The forming of a thermosetting material after it has once been heat-set is referred to as post-forming.

Post-forming is the reshaping of a partially cured laminated sheet which still retains some thermoplastic qualities that permit forming. In this process the work must be brought up to temperature and formed quickly, since final polymerisation and setting will occur with heat and time. Heating is usually done in hot-air ovens, in an oil bath, or in contact with hot plates. It takes from 20 to 60 seconds to bring the material up to a temperature just under 350°F. the material beings to soften at 250°F. and blisters at 350°F. When the work is at temperature it must be quickly placed in the dies and pressure applied and held for a short time. The formed part should be allowed to cool before removing it from the form, but this process can be accelerated by air cooling; cooling normally requires one to two minutes.

A 3-inch-diameter cup of 1/16-inch material has been drawn 1½-inches deep by this process. Close dimensions are hard to hold, however, and square outside corners are not obtainable. The thickness of the formed part is fairly constant. Bend radii of 3*t* (where *t* is the thickness of the material) can be obtained on material up to 1/8 inch thick, and 4*t* on material up to 3/16 inch thick.

The formed part has the physical characteristics of the Grade C material from which it was made. It is suitable for applications exposed to temperatures from -70°F. to +200°F. In general, these parts are used for such nonstructural purposes as fairings, wheel pockets, and similar pressed parts. Material 1/16-inch thick 36 by 96 inches in size is most generally used for aircraft applications.

USES

Throughout this chapter, applications of the various plastic materials have been described. At the present time in aircraft construction plastics have established themselves for many nonstructural applications which are similar to their use in automobiles and home appliances. Their use as fairings, radomes, doors, and ducts is also well established. They have not yet received general acceptance as primary structural material, but current developments with glass-fabric reinforced laminates give promise of meeting aircraft structural requirements.

The use of thermoplastic sheeting materials for cabin enclosures is of course universal. This application is described more fully in Chapter 08.

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CHAPTER-8
TRANSPARENT MATERIALS

Transparent materials are used in aircraft for windshields and for general cabin glazing. Two types of material are used; glass and a variety of transparent plastics. A shatterproof glass is used in the interest of safety. A high-grade laminated plate glass is used for windshields and bombers' windows where perfect vision is essential. In military aircraft a laminated bullet-resistant glass is used for the part of the windshield directly in front of the pilot or other crew members. For the relatively unimportant side windows and skylights a cheaper grade of laminated sheet glass or one of the transparent plastics is used. In some planes, where weight and/or expense are important considerations, transparent plastics are used throughout. In general, transparent plastics will scratch, discolour, and distort much more than glass and must be frequently replaced.

GLASS

Shatterproof or nonscatterable glass consists of two or more pieces of glass held together by a single-ply filler of a transparent plastic. A vinyl plastic is most often used for this purpose. An adhesive is used on both sides of the filler to bind the two pieces of glass together. The filler is cut back a short distance from the edge to allow space for a sealing compound. This sealing compound is waterproof and protects the adhesive. It extends from 1/16 to 5/32 inch in from the edge of the glass.

There are two types of nonscatterable glass available.

1. Laminated plate glass

This glass is made of two pieces of class A polished plate glass. It is obtainable in thicknesses from 3/16 inch up. Generally 3/16 and 1/4-inch glass are used for aircraft windshields. The dimensions of the windshield determine the thickness necessary. It is easier to obtain ¼-inch glass because of the difficulty in procuring clear plate glass thin enough so that two layers will be only 3/16 inch thick.

Laminated plate glass for aircraft windshield is procurable either flat or curved. To relieve mounting strains which will crack the glass and to provide a mechanical mounting means this type of glass is procurable with an extended plastic edge. This plastic edge is a thickened-up extension of the plastic filler between the layers of plate glass. This plastic edge frequently incorporates metal reinforcing strips. The extended edge can be drilled and mounted with screws to the windshield frame. This arrangement provides a positive mounting without inducing strains in the glass. It is particularly desirable when using curved glass since the curve of the glass and windshield frame are seldom exactly alike.

Bullet-resistant laminated plate glass as commonly used for windshields of military aircraft is composed of a number of varying thicknesses of plate glass. The front layer of glass is usually specified to be 1/8-inch thick and the rear layer not greater than 5/32-inch thick. The intermediate layers, of which there must be at least two, may be of any thickness. A ¾-inch-thick glass overall has been generally used for military windshields. Bullet-resistant glass of this thickness will prevent complete penetration of a .30 caliber bullet hitting the glass at an angle 45° and a velocity of 2700 feet per second. Bullet-resistant glass can be procured with either of two degrees of light transmission, Sthe glass having the greatest light transmission being the most expensive but being desirable for night-flying airplanes.

In some military installations the illuminated gunsight reflects directly on the bullet-resistant glass and to avoid a double image it is mandatory that the front and rear faces of the glass in this area be parallel to each other. It is usually necessary to specially grind the glass in this area to obtain parallelism since the number of glass laminations and plastic fillers precludes obtaining the required parallelism by manufacturing controls.

2. Laminated sheet glass

This glass is made from class B, clear window glass of the best quality. It is obtainable in thicknesses from 1/8 - inchup. For side windows, skylights, and similar secondary applications 1/8-inch glass is generally used. This type of glass has considerably more distortion than plate glass and should not be used for windshields.

Physical Properties

In the design of planes to fly in the substratosphere it will be necessary to consider the strength of glass. A pressure differential of 10 to 12 pounds per square inch may exist between the inside of the cabin and the outside atmosphere. Glass manufacturers recommend that a factor of 10 be applied to these loads to insure against glass breakage. The mechanical properties of glass are as follows:

Tensile strength (p.s.i.)	6,500
Compressive strength (p.s.i.)	36,000
Modulus of elasticity	10,000,000
Weight (¼-in. glass) (lb./sq.ft.)	3.29

The plate -glass expansion coefficient (-70°F. to + 100°F.) is .00000451 per °F. This expansion is two-thirds that of steel and one-third that of aluminum.

Testing Nonscatterable Glass

An impact test is made on this type of glass to determine its effectiveness in preventing flying of glass in a crash. The impact test consists of dropping a ½-pound spherical steel weight from a height of 16 feet on the center of a 1-square-foot surface of the glass. The glass is supported along all edges by a wooden frame extending 3/8-inch in from each edge. The glass must be at a temperature between 70°F. and 80°F. to pass this test the glass must not separate from the adhesive and there must be no puncture of the filler. Small chips of glass may leave the underside of the sheet due to fracture within the bottom plate.

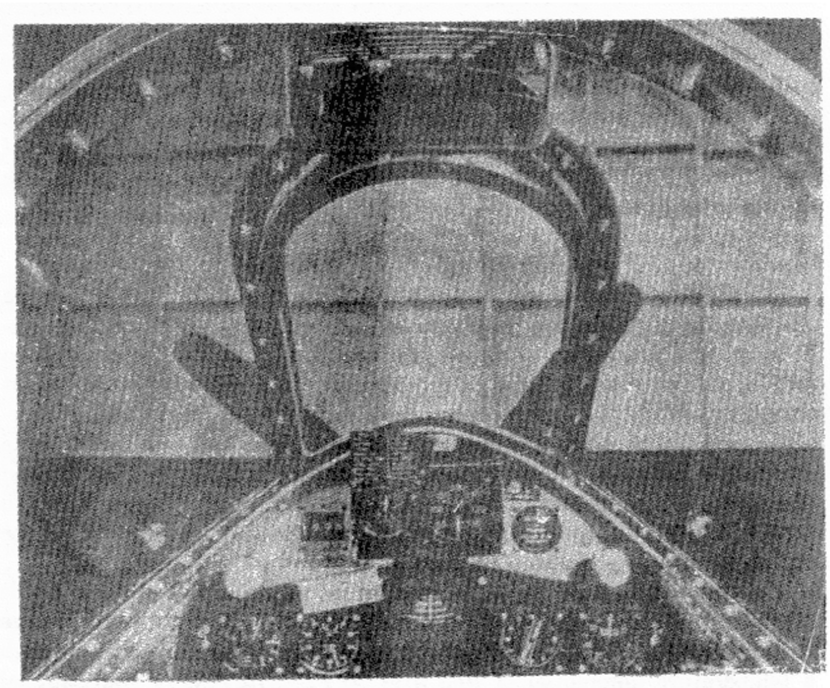

Figure 8.1, Windshield - Bullet-proof Glass Pane

The glass must also stand a heat-resistance test without signs of cracking. In this test the glass is maintained at 32°F. for 30 minutes and then raised uniformly within 2 minutes to 104°F. It is maintained at this temperature for 40 minutes and then cooled down to 32°F. again within 5 minutes. This test simulates an airplane climbing to altitude, where the temperature is colder, and then descending to a warmer temperature somewhat more quickly.

Bubbles, scratches, and other defects are checked by the unaided eye under good illumination.

A test for definition and distortion is made by means of a 6-power telescope focused on a distant target. When the glass is interposed in the line of vision the target must still appear clearly defined and undistorted. The glass specimen should be shifted in order to check different portions.

TEMPERED GLASS

This is an exceptionally strong glass that is used for large windshields. It is produced by heating glass uniformly over the entire surface to 1250°F. and then suddenly quenching it to room temperature. By this process the outermost surface of the glass is placed under high compression and the inside under tension. The strength of tempered glass is due to the surface compression which must first be overcome before the ordinary strength of the glass comes into play. Tempered glass has a compressive and tensile strength of approximately 36,000 p.s.i. Its coefficient of expansion is only .000003 per °F. It can be manufactured only in ¼-inch thickness or greater.

TRANSPARENT PLASTICS

The ideal transparent plastic for aircraft use should be strong, scratch resistant, noninflammable, colourless, transparent, and unaffected by sunlight or by temperature changes. In addition, it should be possible to mold it to the desired shape in the aircraft manufacturer's plant and it should be obtainable in reasonably large sizes. In common with all aircraft materials it should also be homogeneous, light, and readily available at a reasonable price. Unfortunately, no transparent material yet devised can meet all these specifications. At the present time it is customary to replace windshields and cabin enclosures at frequent intervals when the old material becomes distorted, discolored, or excessively scratched.

The chief problem in the use of plastics for windshields and cabin hoods is to allow for the expansion and contraction of these materials with change in temperature. In almost any flight to altitude an airplane goes through a temperature differential of well over 50°F. Army-Navy Aeronautical Specification AN-P-45, which describes the proper installation of transparent sheet plastic material, requires provision for contraction and expansion from -67°F. to +158°F. is the manufacturing temperature, the amount of contraction that will occur in the temperature ranges specified is about twice as much as the amount of expansion. When installing transparent plastics in a framework, it is necessary to allow for a 1/8-inch movement in 12 inches to permit free expansion and contraction of cellulose acetate plastic sheeting; acrylate and allyl-base plastics require only about 0.09-inch movement in 12 inches. This allowance is usually provided by drilling oversize holes in the plastic material and using shoulder rivets or screws inserted through tubular spacers in the frame to avoid clamping down on the plastic material. If tight riveting is employed, the plastic material will contract sufficiently to cause it to crack under the slightest outside pressure. If touched lightly with the finger under these conditions it will shatter. At the temperatures reached around 25,000 feet it will crack of its own accord due to the magnitude of internal contraction strains. Installation in channels is the ideal method for eliminating contraction strains. A 1/16-inch-thick packing should be pasted to the plastic sheet before insertion in the channel. A flush channel installation is made by routing the plastic sheet to a depth equal to the thickness of the supporting channel leg plus packing. since this leaves the plastic a little thin in this region a reinforcing strip of plastic is cemented on the inside. By properly shaping the inside channel leg it can be hooked around the ledge formed by the reinforcing strip, thus obtaining a positive and secure mounting. The expansion that occurs when it is exposed to a hot sun and warm weather will permanently distort the material unless clearances are provided to permit the take-up.

Several transparent plastic materials commonly used for aircraft wind-shields and cabin enclosures, as well as for inspection hole covers, are described below.

Pyralin

This material is a pyroxylin nitrocellulose plastic. It is a solid solution of nitrocellulose in camphor. The nitrocellulose used is nonexplosive and less inflammable than guncotton nitrocellulose. The nitrocellulose used is known as pyroxylin. The pyroxylin is mixed with camphor and alcohol, heated, and pressed into solid blocks. The desired thickness of sheet is sliced from these blocks.

Sheets of this material may be purchased for aircraft work from 0.030 to 0.150 inch thick. A full sheet is usually limited in size to 21 by 50 inches. The weight of a sheet of this size in the thicknesses available are listed below :

Thickness (in.)	*Weight (pounds)*
.030	$1\frac{2}{3}$
.040	$2\frac{1}{4}$
.050	$2\frac{2}{3}$
.060	$3\frac{1}{3}$
.070	$3\frac{3}{4}$
.080	$4\frac{1}{4}$
.090	$4\frac{3}{4}$
.100	$5\frac{1}{4}$
.125	$6\frac{1}{2}$
.150	8 - 0

Pyralin is a thermoplastic material that can be softened by heating and molded under pressure into forms with double curvature such as are used on the tops of sliding cabin hoods. It can be readily sawed and drilled. Pyralin is inflammable. In the past it has been very commonly used on commercial airplanes.

Plastecele

This material is a cellulose acetate plastic. It is manufactured in the same manner as nitrocellulose plastics. The sizes obtainable and their weights are the same as listed above for pyralin.

This material is flame-resisting and is frequently used on military airplanes. It will burn only slowly when a lighted match is held to it. The test for transparency requires that standard typewritten copy on blueprint paper, which is white on a blue background, shall be wholly legible to the normal eye when held 6 inches behind the material and viewed through it in daylight.

This material is thermoplastic and can be readily shaped by means of heat and pressure. Hot water at 150°F. can be used to soften the material, and air applied at 50 p.s.i. pressure will press the softened material into the mold. This air also cools and sets the material.

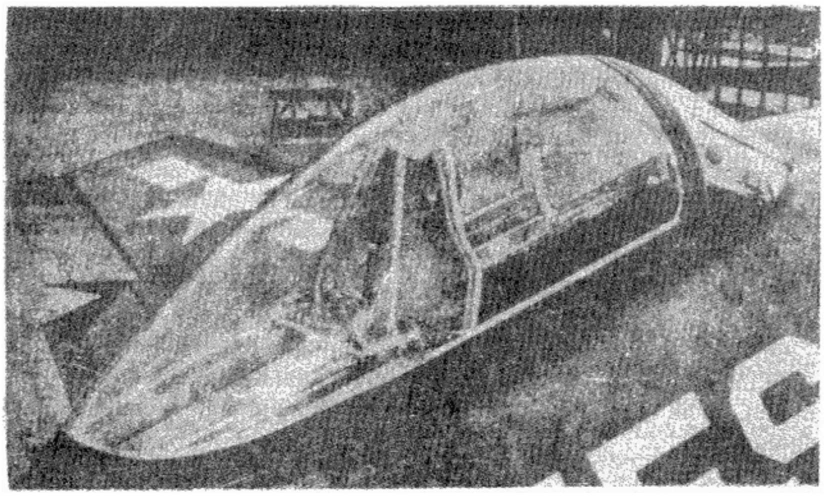

Figure 8.2, Cabin Enclosure - Plexiglas

Like other transparent plastics this material suffers from too great contraction and expansion. It is fairly satisfactory in other respects. Proper mounting to permit give and take with temperature changes will greatly increase its service life.

Vinylite

This material is a copolymer resin of vinyl chloride and vinyl acetate. It is non inflammable and has the general properties required for aircraft cabin enclosures. It is available in the usual range of commercial sizes.

Plexiglas and Lucite

These are acrylic thermoplastics. They are colorless and transparent and do not discolor with age. They are inflammable only to the extent that they will burn slowly when warmed and ignited by a flame. Acrylic plastics will not scratch quite as easily as cellulose plastics. They have a coefficient of expansion about two-thirds that of the cellulose plastics but also require installation in channels or other methods permitting free movement.

The acrylic plastics are formed at temperatures between 200° and 250°F. They are available in thicknesses up to ½ inch and in standard sizes up to 35 by 48 inches. Special sheets up to 50 to 60 inches are available in thicknesses form 0.10 to 0.25 inch inclusive.

Acrylic plastic sheet is covered by Army-Navy Aeronautical Specification AN-P-44. It is currently used in about 80% of aircraft enclosures. Its specific gravity is 1.18.

Allite 39

This is an allyl-base thermosetting plastic. It is covered by Army Air Forces Specification 12040. This material is more resistant to scratching than the acrylic plastics and is immune to crazing. It cracks easily around bolt holes and cannot be mounted by this method. It can be formed only in single-curvature sections having a large radius of flat . It can be cast by the manufacturer into compound-curved panels.

Allite 39 can be formed to simple curvatures when heated to 200-220°F. It is available in sheets 45 to 57 inches and in thicknesses from 1/16 to 5/16 inch. Its specific gravity is 1.31.

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CHAPTER-9
NATURAL AND SYNTHETIC RUBBERS

The shortage of natural rubber during the war years resulted in large scale developments for the manufacture of synthetic rubber. Five basic types of synthetic rubber have been developed commercially and are currently in general use in industry. These basic types are commonly known as buna S, buna N, neoprene, butyl, and thiokol. These materials have been used in many aircraft applications during the war and will continue to be used in the future.

Hundreds of different compounds of each of the five basic types are obtainable by variations in compounding and processing. Emphasis on any desired characteristic is possible but usually is accompanied by a loss in other desirable properties. Each compound must be developed to meet specific engineering requirements. Unless the designer has had experience with a specific compound in a similar application it is best to consult with technicians of the rubber-products manufacturer. The manufacturer should be informed fully and accurately of the service conditions under which the part will be used. For example : in the case of a bellows type seal to be used on the firewall of an airplane around a throttle rod, it should be expalined that the seal will be subjected to hot, oily conditons, and will be flexed repeatedly. With this type of information the best compound for this application can be prescribed.

Table 9.1 has been prepared to give a general idea of the properties of the five common types of synthetic rubber as compared to natural rubber. In general, natural rubber has better physical properties but the synthetic rubbers have greater resistance to deterioration, heat, and abrasion. It should be noted that the synthetic rubbers that have the greatest resistance to deterioration are least like rubber in processing and application.

Both the natural and synthetic rubbers are polymers or copolymers and are chemically similar to the plastics. A polymer is a complex material formed by a polymerisation reaction. In this reaction a relatively simple chemical is converted to an extremely complex material with entirely different properties due to reaction with itself. Catalysts are usually required to aid this chemical reaction. In copolymerisation two simple chemical react to form a single complex product with new properties.

Synthetic rubbers are commercially available as latex, sheet, tubes, extrusions, moldings, rubberized fabrics, sponge materials, cements, and adhesives. In the following pages the various types of rubber are described in more detail, together with the applications they have found in industry.

NATURAL RUBBER

Natural rubber is a polymer of isoprene. It is prepared from the sap of a number of plants and is easier to process than the synthetic rubbers. Natural rubber can be readily vulcanized, or cured, to almost any desired degree of hardness. It has better tensile strength and resilience than the synthetic rubbers but deteriorates much more rapidly when subjected to air, ozone, light, heat, petroleum products, or aromatic oils.

Natural rubber has been used for tires and tubes, electrical insulation, and numerous other everyday products.

SYNTHETIC RUBBER

Buna S

Buna S is a copolymer of butadiene and styrene. The name buna S is derived as follows : Bu is the first syllable of butadiene. Na (for natrium) is the chemical symbol for sodium, which in the early days was used as a catalyst in the polymerization of butadiene. S stands for styrene. This material is also referred to as GR-S which is the abbreviation of Government Rubber - Styrene. This name is a result of the large United States government developments of synthetic - rubber plants during the war.

Buna S synthetic rubber is the most nearly like natural rubber. It can be vulcanized with sulphur and cured to a hardness equal to hard rubber. Buna S must be compounded with a black pigment such as carbon black to bring out its best physical properties. As a consequence commercial buna S is usually black. Buna S is the synthetic rubber normally used for tires and tubes as a substitute for natural rubber. It can be used to replace rubber in most applications.

Buna N

Buna N is a copolymer of butadiene and acrylonitrile. The N is the first letter of nitrile. These compounds are sometimes referred to as nitrile rubber. This material is also known as GR - A, which is the abbreviation of Government Rubber - Acrylonitrile. Some commercial names of buna N are Perbunan, Hycar, Chemigum, Thiokol RD, and Butaprene. None of these compounds are identical but merely belong to the same family.

Table 9.1, Comparative Properties of Natural and Synthetic Rubber*

Properties	Natural rubber	Buna S	Buna N	Neoprene	Butyl	Thiokol
Available forms	Latex, solid	Latex, solid	Latex, solid	Latex, solid	Solid	Dispersion, powder, solid
Adhesion and cohesion	Excellent	Fair	Fair	Good	Good	Good
Vulcanizability	Excellent	Good	Good	Good	Fair	Fair
Extensibility	Excellent	Good	Good	Excellent	Excellent	Good
Resilience	Excellent	Good	Fair	Very good	Low	Good
Tensile strength	Excellent	Fair	Good	Very good	Good	Fair
Impermeability to gases	Good	Good	Good	Very good	Excellent	Low
Resistance to cold flow	Very good	Good	Good	Good	Fair	Fair
Resistance to abrasion	Very good	Very good	Very good	Very good	Fair	Low
Resistance to tear	Very good	Fair	Fair	Good	Good	Fair
Resistance to heat	Good	Very good	Very good	Very good	Fair	Low
Resistance to cold	Very good	Very good	Good	Very good	Good	Good
Resistance to air	Fair	Good	Good	Excellent	Excellent	Excellent
Resistance to light	Fair	Fair	Low	Excellent	Excellent	Excellent
Resistance to petroleum	Low	Low	Excellent	Good	Low	Excellent
Resistance to aromatic oils	Inadequate	Inadequate	Fair	Low	Inadequate	Excellent

* This table should be used only to obtain a general idea of the inherent properties of the synthetic rubber types listed.

Buna N is similar to rubber in that it can be vulcanized with sulphur and can be cured to hard rubber. It has excellent resistance to oil and will resist heat up to 250° F. in normal applications . It stiffens at -45°F. It has good abrasion resistance and has good "breakaway" properties when used in contact with metal. For example, when it is used as a seal on hydraulic piston it will not stick to the cylinder wall. This material is adversely affected by ozone and sunlight. Its properties are improved by the addition of carbon black.

Buna N can be bonded by vulcanization or cement to metal surfaces. It is not necessary to brass plate the metal as is one to obtain good adherence with natural rubber. A sandblasted surface is desirable. Uncured stock can be made to adhere to the metal by applying heat and pressure, thus curing the stock at the same time. Cured stock can be made to adhere by using the proper cement and applying heat only. Phenolformaldehyde resin cements are satisfactory for this purpose. Cold-setting cements have also been used but not very satisfactorily.

Buna N is used for oil and gasoline hose, tank linings, hydraulic accumulator bags, gaskets, and seals.

Neoprene

Neoprene is a polymer of chloroprene. Neoprene is available in many different types, some of which are copolymers. Its designation GR-M refers to Government Rubber - Monovinyl Acetylene type. Neoprene was the first commercially successful synthetic rubber.

Neoprene is a good general-purpose rubber that has good resistance to oil and excellent resistance to heat, air, light, and flame. It has better light resistance than any other rubber. It can be vulcanized without sulphur but cannot be cured to as hard a condition as hard rubber.

Neoprene is used for oil -resistant hose, carburetor diaphragms, gaskets, shoe soles, barrage balloons, truck tires, cements, tape, and caulking.

Butyl

Butyl is a copolymer of isobutylene and small amounts of unsaturated hydrocarbons such as butadiene or isoprene. It is produced cheaply from petroleum by-products, one of which is isobutylene. It is also referred to as GR-I which is the abbreviation of Government Rubber - Isobutylene. It is also known as Flexon.

Butyl can be vulcanized with sulphur but-cannot be hardened to the condition of hard rubber. Butyl has excellent gas impermeability and for this reason may become the first-choice material for tire tubes. It is also used for gas masks, plywood molding bags, life jackets, and chemical storage.

Thiokol

Thiokol is a polysulfide polymer. It is sometimes referred to as polysulfide synthetic rubber. Its designation GR-P is the abbreviation for Government Rubber - Polysulfide.

Thiokol has the highest resistance to deterioration but the lowest physical properties. It is particularly noted for its resistance to aromatic hydrocarbons and aromatic blended gasolines. Thiokol can be vulcanized with zinc oxide but not to a hardness comparable with hard rubber.

Thiokol is used for oil hose, tank linings for aromatic aviation gasolines, paint spray hose, gaskets, and seals.

MANUFACTURING PROCESSES

Synthetic-rubber materials are availabel in fabricated solid forms. Tubes, window strips, and miscellaneous shapes are extruded in the same manner as plastics or metal. After extrusion the finished shape is vulcanized or cured to the desired hardness by placing the material in an open steam trough.

Molded rubber parts are superior to extrusions. They are denser, have better physical properties, and can be held to closer tolerances. In compression molding the raw stock is prepared by extruding to the approximate shape, or by die punching pieces to shape. This prepared raw stock is similar to the finished article in density and has the consistency of a semihard tough puttylike substance. This material is worked into a shape closely approximating the finished article and is placed into a mold cavity. a temperature of 250-350°F and a pressure of 1000-4000 p.s.i. are applied to cure the part in the mold.

Injection molding as syntheitc-rubber parts is now under development. In this process the raw stock is forced into the mold under high pressure and both the mold and the stock are preheated. Very close tolerances are obtainable in this tye of molding.

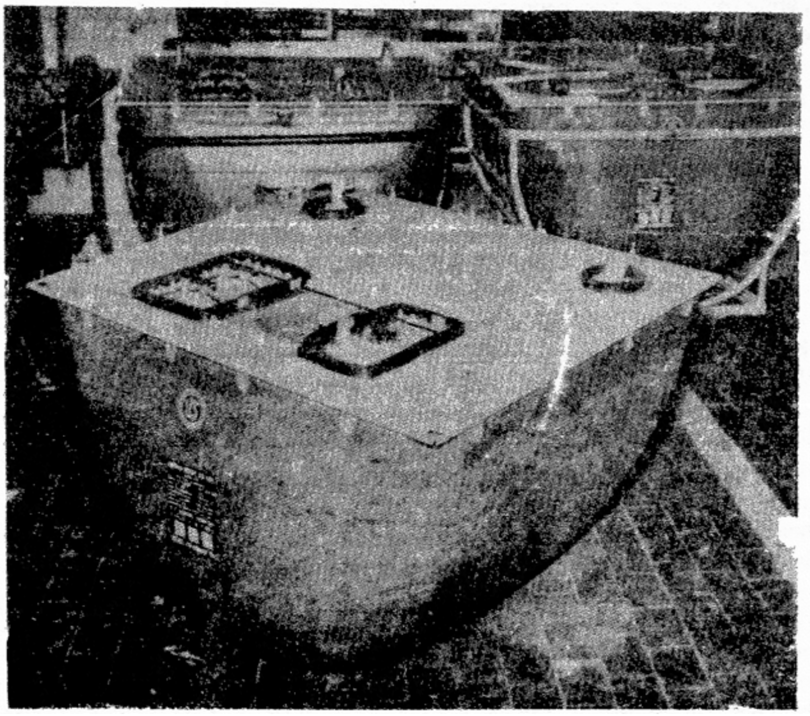

Figure 9.1, Bullet - proof Fuel Tank - Synthetic Rubber

VULCANIZING

Vulcanizing is the name applied to a number of processes which increase the elasticity and strength and reduce the tackiness of rubberlike materials. Curing has the same meaning as vulcanizing when used in connection with rubber processing.

The process of vulcanizing was first introduced by Charles Goodyear in 1839. In this process, sulphur was intimately mixed with rubber and heated. A certain amount of the sulphur disappears, apparently dissolving in the rubber and giving the material new properties. In later years other agents, such as peroxides and polynitro compounds, were found to produce the same results as the original sulphur.

Unvulcanized or uncured rubber is thermoplastic and softens when heated. The plasticity of uncured rubber is greatly reduced after vulcanization. Vulcanized rubber will not soften when heated but will scorch or burn if the temperature is high enough. It is customary to form or mold uncured rubber materials to the desired shape and then to vulcanized them to the required degree of stiffness and mechanical stability.

■■■

CHAPTER-10
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.

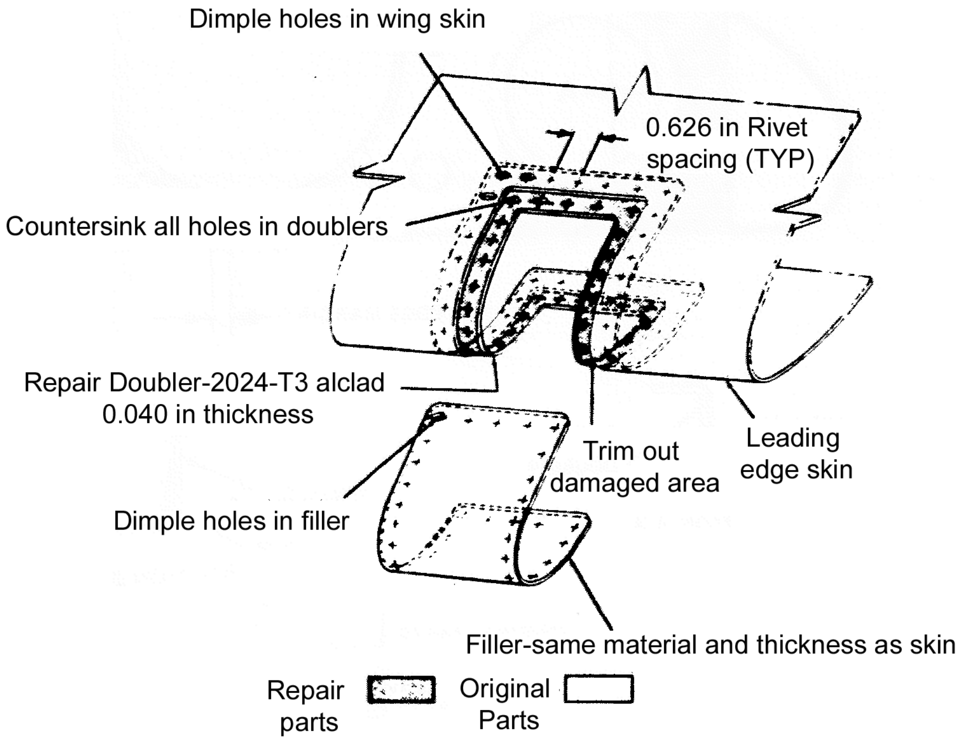

Fig. 10.1, Leading edge repair

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. 10.1. 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. 10.2. 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. 10.2.

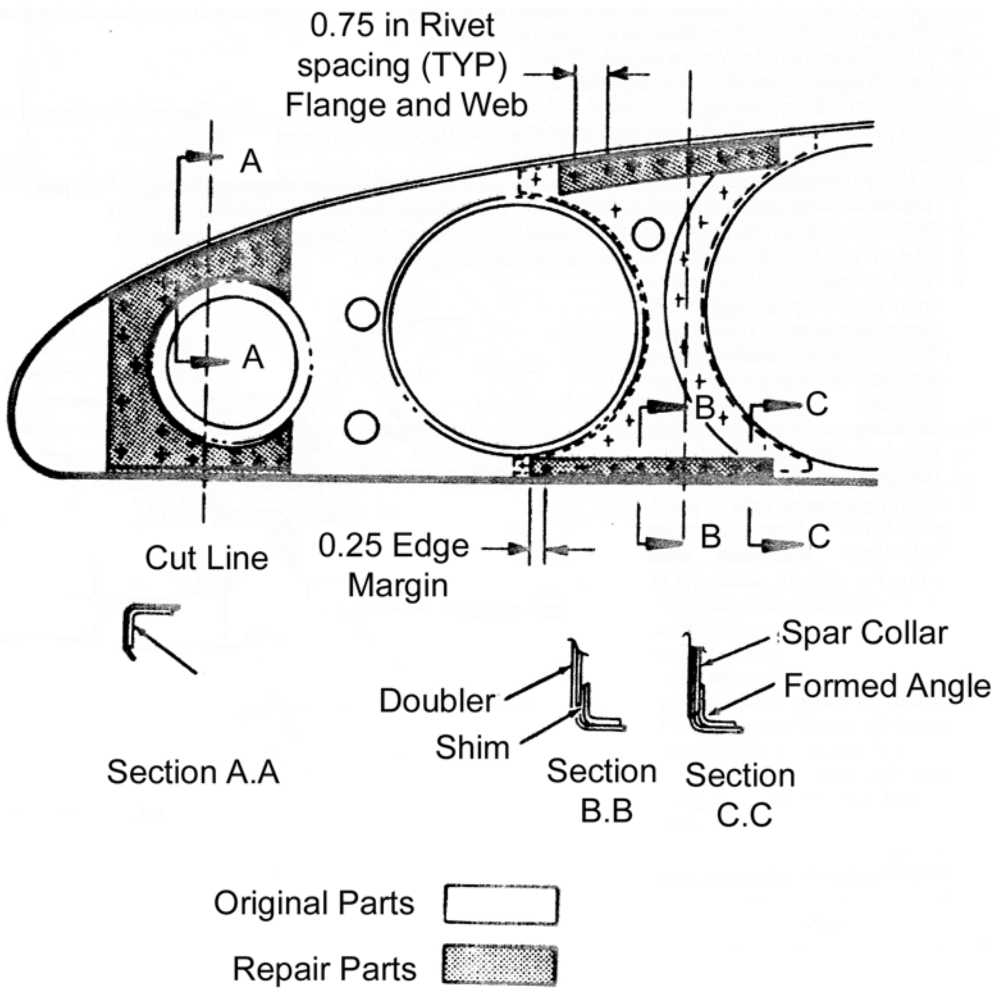

Fig. 10.2, Wing rib repair

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. 10.2 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. 10.3.

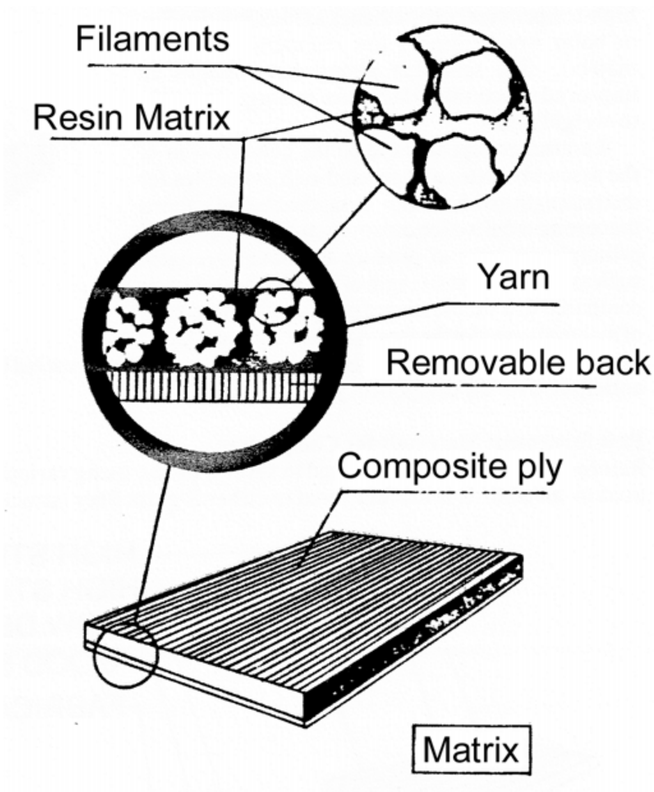

Fig. 10.3, Fibrous material encapsulate in a matrix

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.

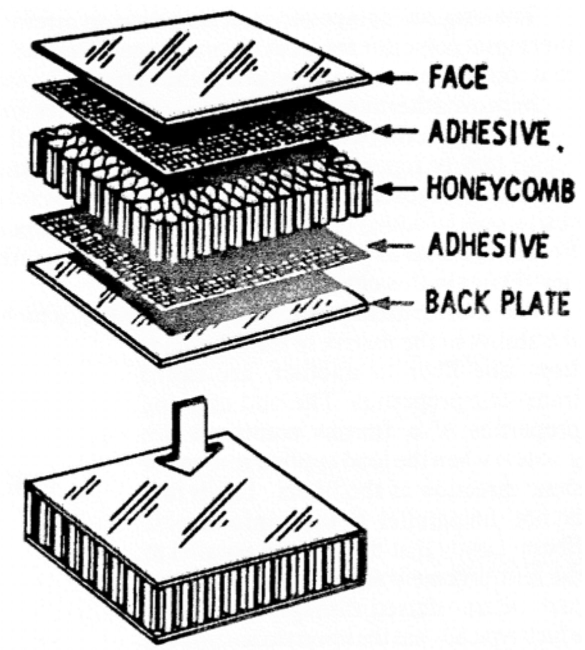

Fig. 10.4, Honey comb sandwhich construction.

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. 10.5).

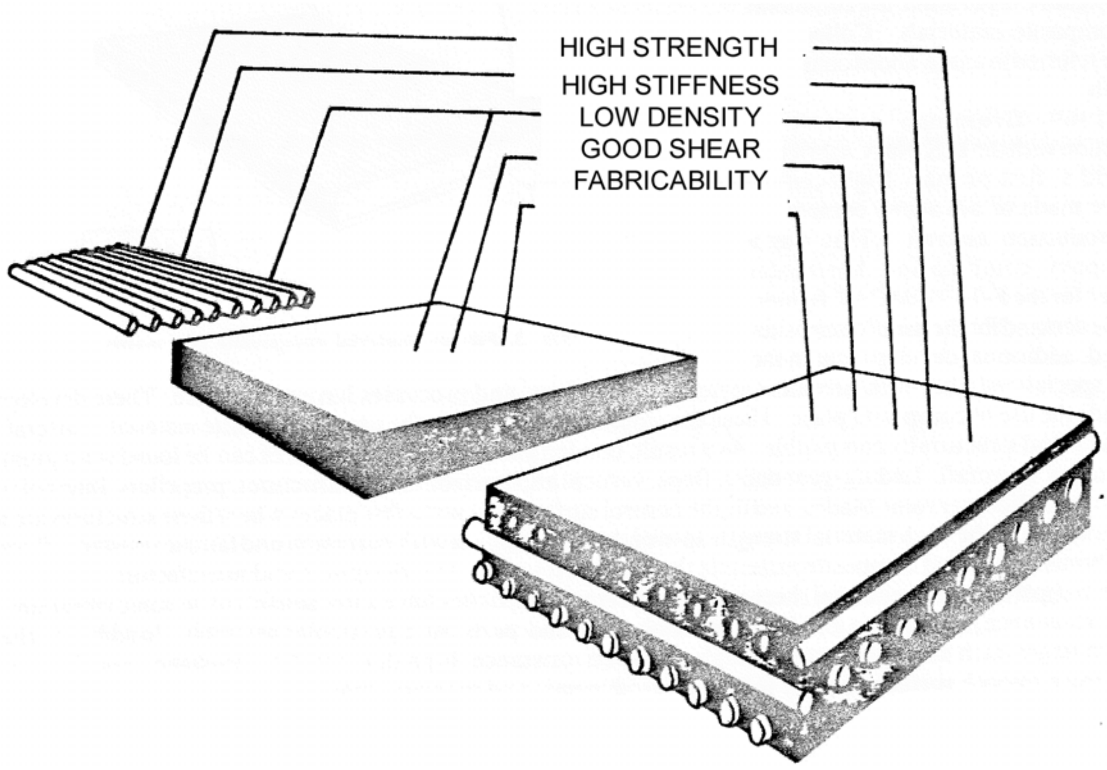

Fig. 10.5, Solid laminate using reinforced fibers.

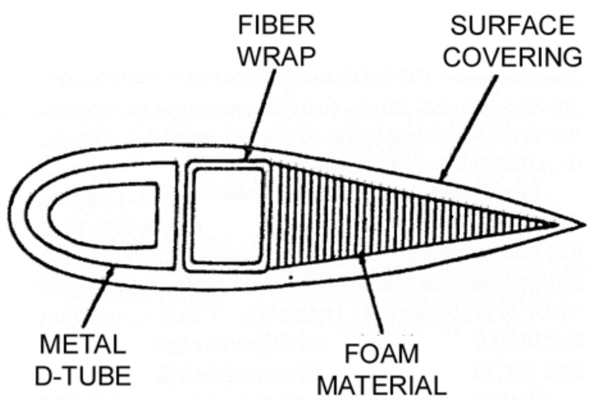

Fig. 10.6, An assembly using composite components

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. 10.4), which may be fabricated from reinforced paper, Nomex, fiberglass, aluminium, or carbon; a rigid foam (for example, high-temperature polyurethane), as illustrated in Fig. 10.6 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. 10.7 shows some of the configurations of glass.

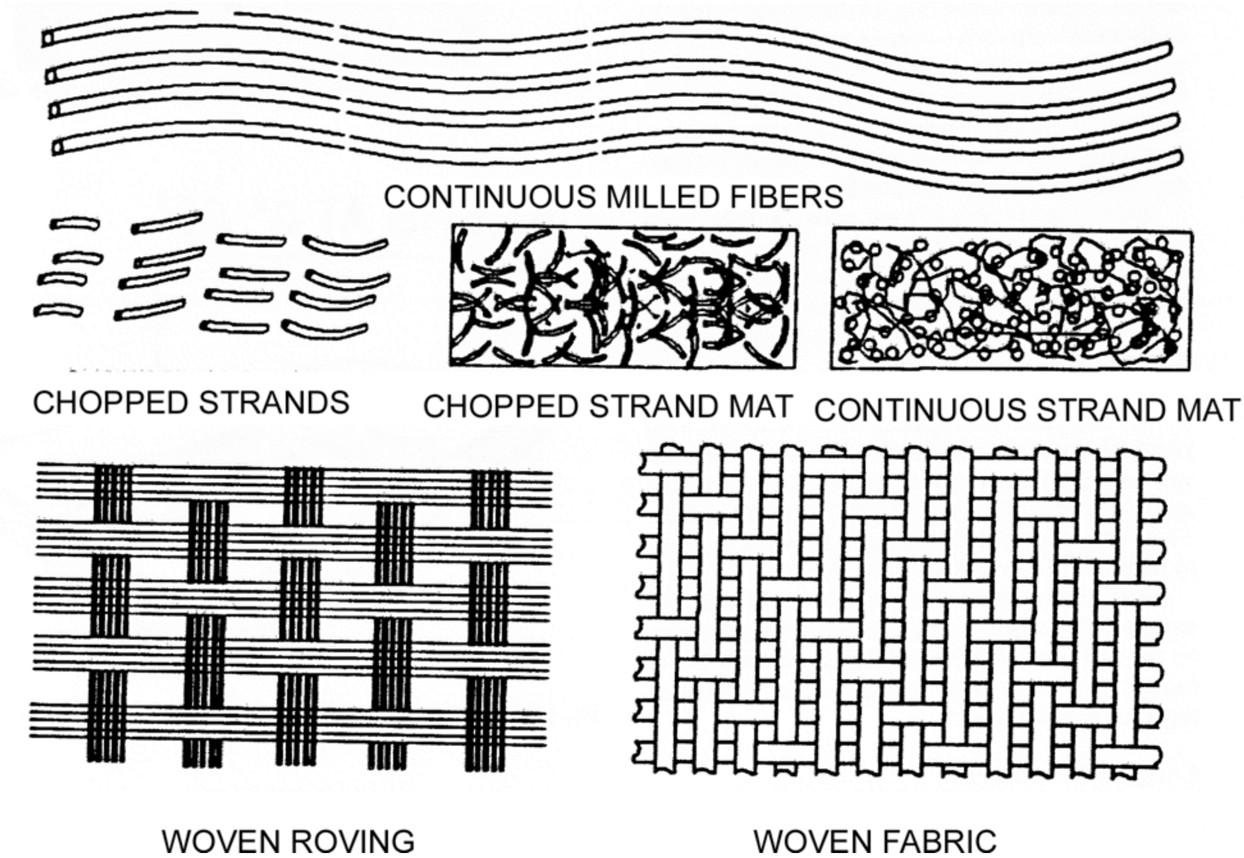

Fig.10.7, Chopped strands, woven roving, woven fabrics, continuous-strand mats, chopped strand mat and milled fibers

As stated, carbon, Kevlar, boron, tungsten, quartz, and ceramics and collectively known as high-strength advanced composites. They are produced in the form of particles, flakes, fillers, and fibers of various lengths. A detailed analysis of all composite forms is beyond the scope of this text. However, due to the common use of fiber-form composites in the aviation industry, further discussion of fiber forms is appropriate.

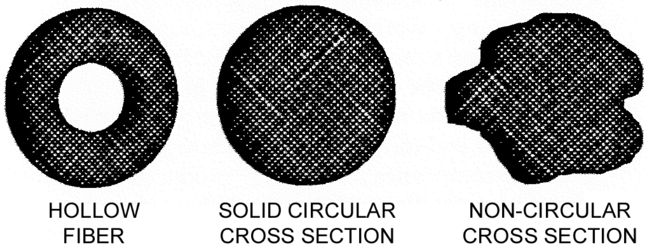

Fig.10.8, Hollow fibers, of non-circular cross section, and solid, circular cross-sectional fibers.

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. 10.8. The most common of these are solid-circular cross-sectional fibers, which are commonly found in general and commercial aviation applications.

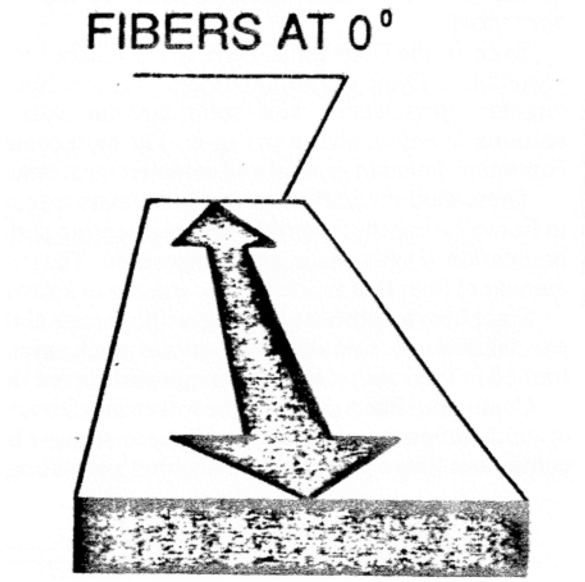

Fig. 10.9, Bidirectional weave (woven at right angles to each other)

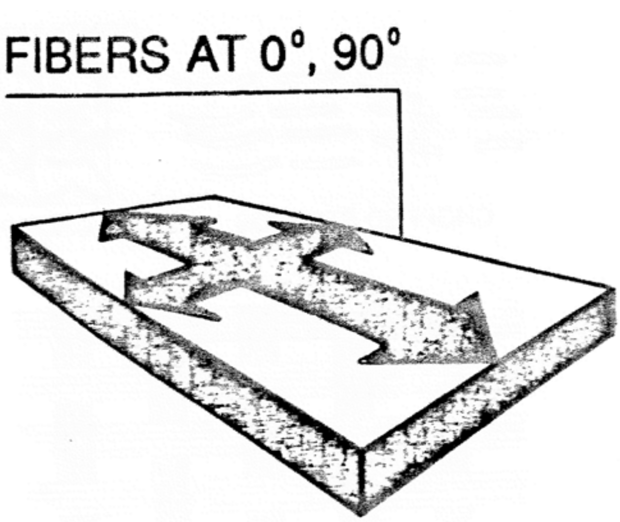

Fig. 10.10, Unidrectional weave (woven in a continuous straight line)

These solid-circular cross-sectional fibers are combined with strong, stiff, heat-resistant, synthetic resin matrices to form a composite material. The engineering performance of a fiber-matrix combination depends upon the fibers' orientation, length, shape, and composition. The mechanical properties of a composite are directly proportional to the amount of fiber that is oriented by volume in a particular direction.

Since fiber length has a bearing on the process-ability of the composite, this consideration is of major concern during part fabrication. Continuous fibers are much easier to handle than short ones, but the former are sometimes more limited in their ability to make compound curved shapes, particularly boron.

Continuous fibers can either be woven into fabrics that are bidirectional, woven at right angles to each other (Fig. 10.10), or unidirectional, woven in a continuous straight line (Fig. 10.9). Filament winding consists of resin-impregnated continuous fibers wrapped on a mandrel simulating the shape of the part (Fig. 10.11), 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.

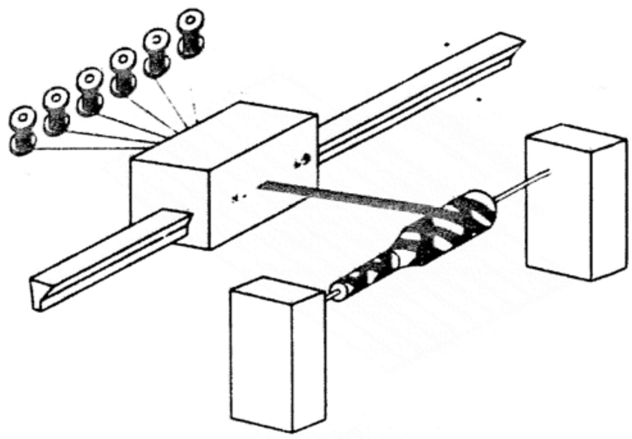

Fig.10.11, Filament winding consists of resin impregnated continuous fibers, wrapped on a mandrel the shape of the part.

The fibers are manufactured by first creating individual filaments. These filaments are then assembled into tows, as shown in Fig. 10.12 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.

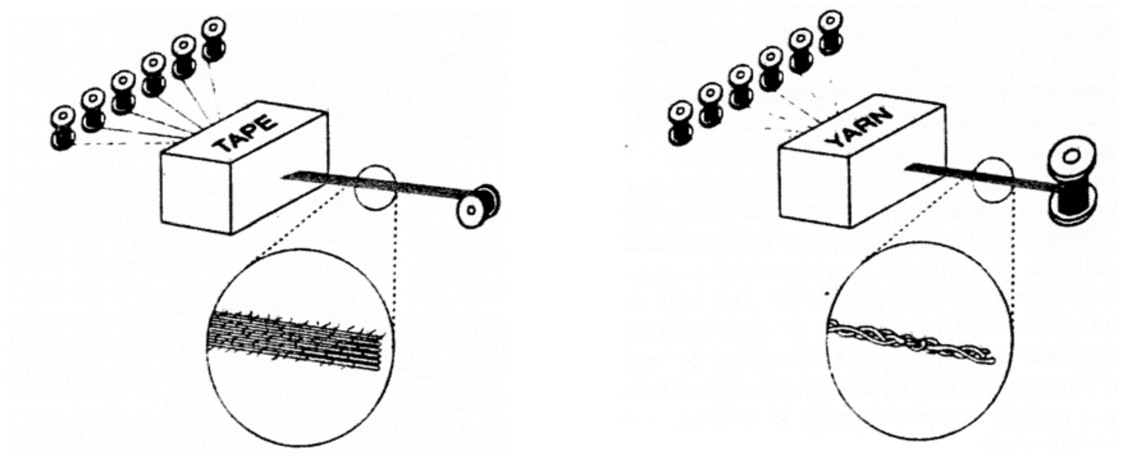

Fig. 10.12, Tows to yarn and tape.

A weave (see Fig. 10.13) 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.

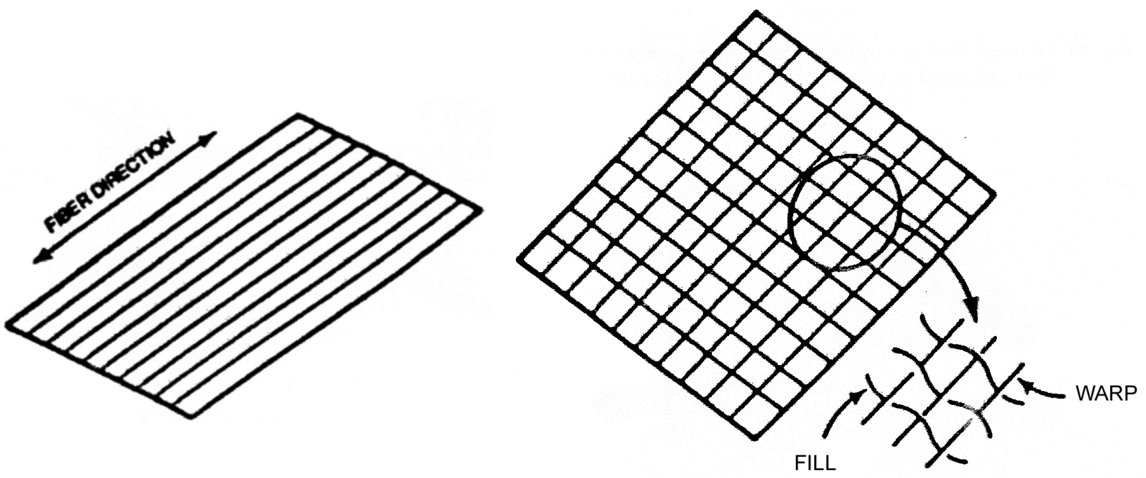

Fig. 10.13, Weave Definition.

Bidirectional fabrics are available with various weave patterns, yarns per inch, and ounce per yard weight. A plain-weave (Fig.10.14) 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.10.15) 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.

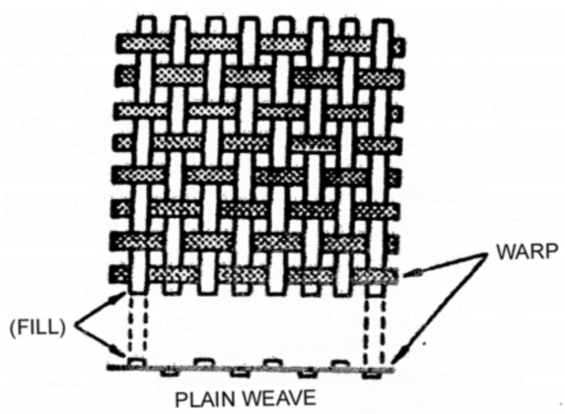

Fig. 10.14, Plain weave

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 350°F (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.

Fig. 10.15, 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 $0\,^{o}$F ($-18\,^{o}$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.

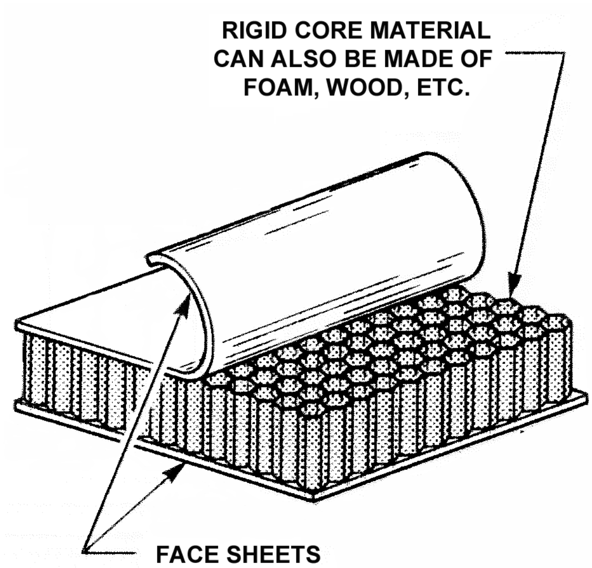

Fig. 10.16, The use of a core material can dramatically increase the strength of a structure without adding significant weight.

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.

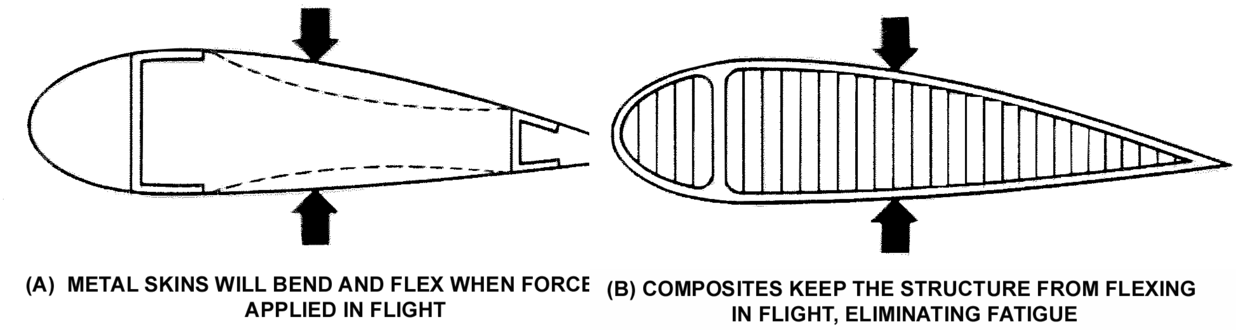

Fig. 10.17, (A) Metal skins will bend and flex when forces are applied in flight. (B) Composites keep the structure from flexing in flight, eliminating fatigue.

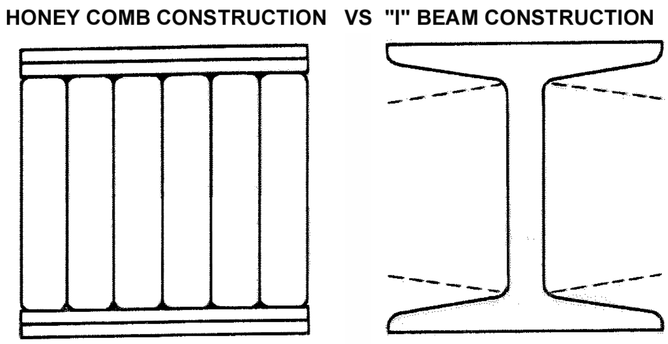

Fig.10.18, this concept can also be shown using a spar I-beam example. The flanges of the I-beam will bend and flex; however, with a solid core material, the tendency to bend is eliminated.

Two popular core structures are foram and honeycomb. Core materials may also come in wood. Honeycomb has the greatest strength-to-weight ratio, but foam is usually more forgiving. If a foam core is damaged, It has a memory and will return to about 80% of its original strength. Most honeycomb cores have little resiliency.

HONEYCOMB

this type of core structure has the shape of natural honeycomb and has a very high strength-to-weight ratio. Honeycomb cores may be constructed of aluminum, Kevlar®, carbon, fiberglass, paper, Nomex, or steel. Nomex is a trade name of DuPont and is widely used as an advanced composite core material. Nomex is a paper impregnated material.

It is common to find these honeycomb cores laminated with a variety of composite or metal skins.

Honeycomb cores are made by crimping the core material into place. The pattern has what is known as a ribbon direction. The ribbon direction can be found by tearing along one side of the honeycomb. The direction of the tear is parallel to the direction of the ribbon. The honeycomb will not tear except in the ribbon direction. It is important when doing a repair to line up the ribbon direction of the replacement honeycomb core with the ribbon direction of the original part.

Honeycomb can be joined together with a foam adhesive. The foam adhesive used to join honeycomb together comes in the form of a tape. The foam adhesive is laid between the parts to be joined and heated to cure. During the curing process, the foam expands into the crevices of the honeycomb.

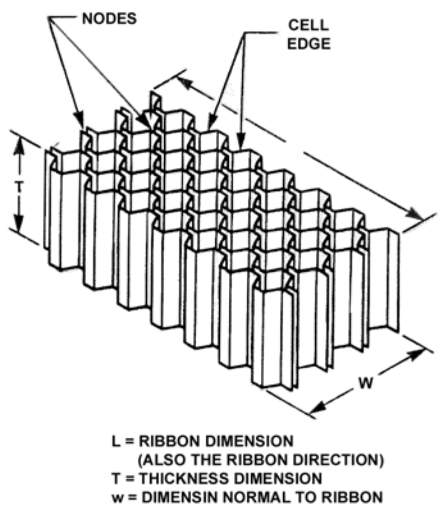

Fig. 10.19, Honeycomb comes in a variety of core configurations, some may be bent to form a curve, some honeycombs are more flexible than others.

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.

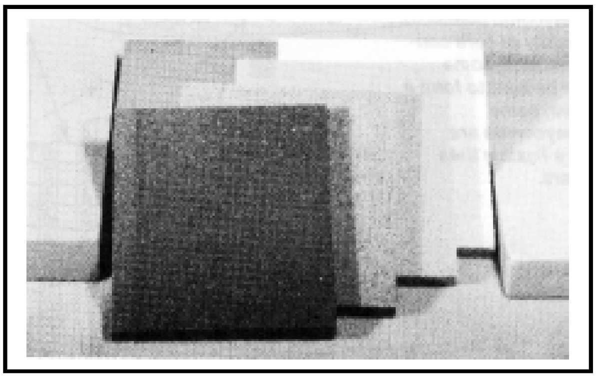

Fig. 10.20. Foam cores for sandwich construction can be styrofoam, urethane, poly vinyl chloride, or strux (cellulose acetate). While easily shaped, foam construction can provide much greater strength and stiffness over plain laminates.

In figure 10.21 , the advantages of a sandwich structure can be shown by comparing four layers of solid fiberglass laminate to a foam core sandwich structure that is four times as thick. This part has two layers of fiberglass on top and two layers of fiberglass on the bottom of the foam. The part becomes 37 times stiffer than the laminate and ten times stronger, with only a six percent increase in weight. This is not an excessive amount of weight to be added in exchange for the amount of strength and stiffness which are gained by using the foam core.

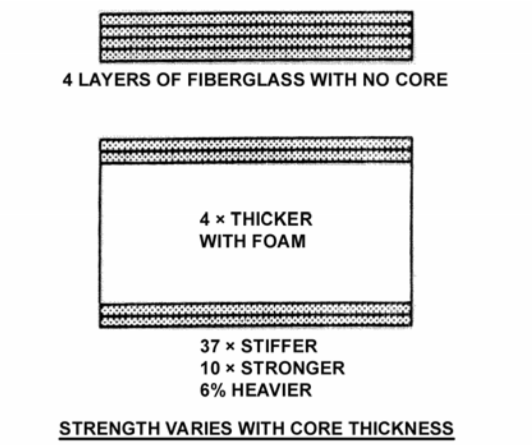

Fig. 10.21, Strength to weight advantages of sandwich construction.

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.

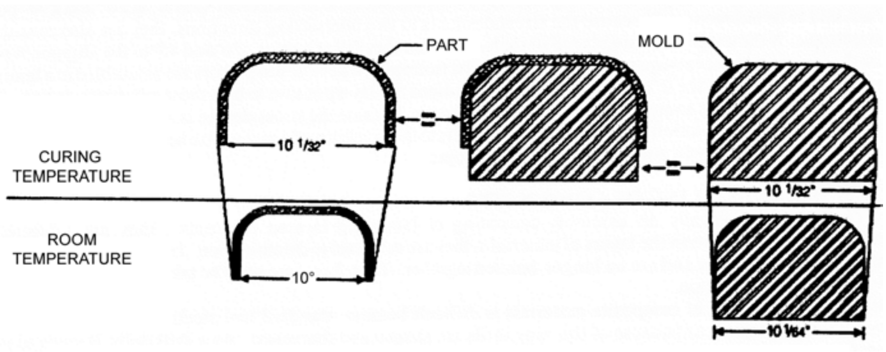

Fig. 10.22, Compensating for the different coefficients of thermal expansion of molds and parts material.

Figure 10.22. 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 andthe mould form is the inside the channel, the coefficient of thermal expansion for the mould material must be greater than that of the part material. If this were not true, the mould would not reduce dimensionally enough to allow the part to contract to the proper finished dimension , causing interference between the mould and the part. However, if the mould is the outside the U channel, the coefficient of thermal expansion for the mould material must be less than that of the part material or interference will again develop as the part and mould are cooled to room temperature.

The removal of the composite materials from the moulds can result in damage to the part if the moulds are not properly prepared with a damage to the part if the moulds are not properly prepared with a release agent, or release film, which is used to prevent the bonding of the matrix to the mould itself. The type of releasing media used is determined by the type of matrix form used, the heat of the curing process, and the material from which the mould is fabricated.

In low-volume production process and repairs, a vacuum bag. Which is a plastic bag surrounding the part material from which air has been evacuated, and a separate heat source may be used. Common heat sources include controlled ovens, portable "hot bonds", and heat blankets. The resin-matrix cures and the fiber-reinforcement materials are bonded in close proximity to each other. The strength of the lay-up depends on the volume of the fibers and their orientation.

High volume and critical composite structures are often heated using an autoclave, which is an oven that heats the material while it is under pressure.

WARP-ORIENTATION TECHNIQUES

As previously mentioned The strength or load-carrying properties of a fibrous composite are greatest when the load applied runs in the same direction as the fibers. Loads that do not run parallel to the reinforcement fibers must at least in part be transferred through the matrix, which typically has the lowest load-carrying capability.

When designing a composite part, the engineer considers the relation of the design load to an arbitrarily selected orientation line on the part. The reinforcing fibers in a composite material will usually be designed to run parallel to the load. It is, therefore, important that the fibers to the design of the part. To do this the engineer will specify a 0° plane as an alignment indicator. The orientation of the warp fibers as a fabric is rolled off the bolt is defined as the 0° position for the fabric.

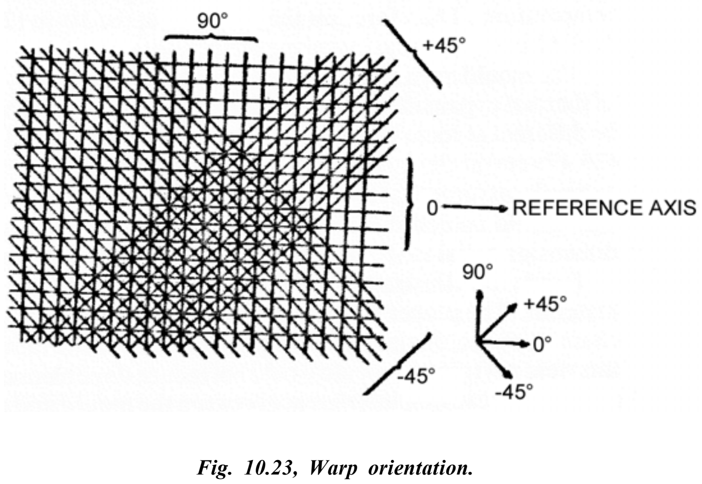

Fig. 10.23, Warp orientation.

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^o plane. This is frequently done in the form of a warp clock (see Fig.10.23), 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.

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 ^{o} and a 90 ^{0} 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^o and 45^o to the alignment point (0 ^{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 0^0, 45^o, 90^o, and -45^0 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.

TRIMMINGANDDRILLINGOFCOMPOSITES

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.10.24) or a long tapered form sometimes referred to as a dagger drill (Fig. 10.24). Fig. 10.25. 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.

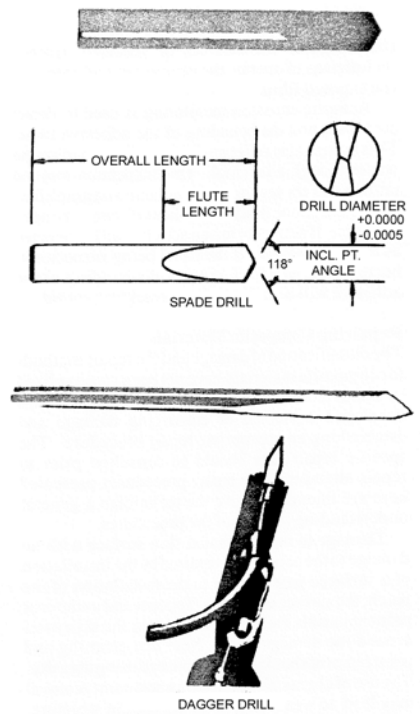

Fig. 10.24, Spade and dagger drills. (Federal mogul, Metal Remover Division.)

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.

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.

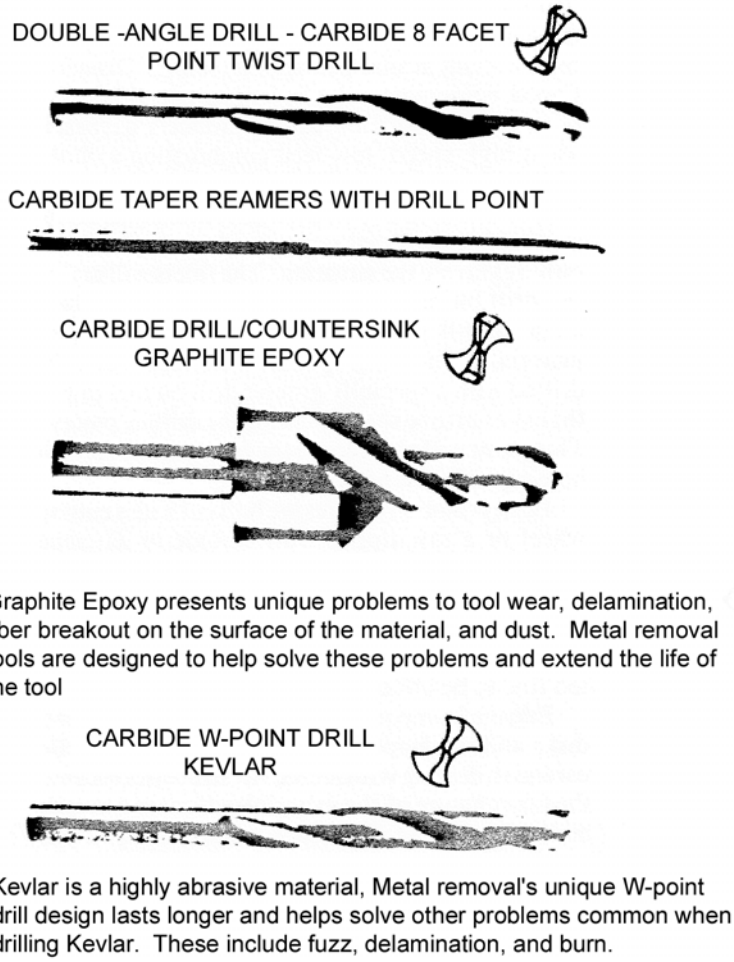

Fig. 10.25, Various types of composite tooling. (Federal Mogul, Metal Remover division)

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CHAPTER-11
METHODS OF CURING OF COMPOSITES.

Composite matrix systems cure by chemical reaction. There are room temperature cure systems which will cure at room temperature, but can be accelerated by the use of applying external heat. There are some matrix systems which require heat to cure the composite to achieve the maximum strength.

Failure to follow the proper curing requirements, or improper usage of curing equipment, can cause defects which are cause to reject the repair. Proper curing or handling during the cure has a direct effect on the strength of the repair. During the curing process, humidity may cause a problem unless the repair is vacuum bagged.

ROOM TEMPERATURE CURE

Some repairs may be cured at room temperature (65- 80 ^{0}F) over a time span of 8-24 hours, depending on the type of resin system used. The curing process can be accelerated by the application of low heat to some room temperature resin systems. Low heat is considered to be about 140 to 160^{0}F. Check the applicable cure time for the specific material used.

Full cure strength is usually not achieved until after five to seven days. If the repair calls for a resin system that can be cured at room temperature, it would be for parts which are used in areas where there is no exposure to high operating temperatures (usually above 160 ^{0}F).

Such room temperature cures are usually used with composite parts that are used in lightly loaded, or non-structural parts.

HEAT CURING

The most widely accepted method of curing structural composites employs the use of resins which cure at higher temperatures. These adhesives and resins require elevated temperatures during their cure in order to develop full strength and reduce the brittleness of the cured resin. Heat will also reduce the curing time.

When a part is manufactured at a high temperature, the repair patches which are used in its repair may have to be cured at the manufacturing temperature in order to restore the original strength. These resins usually cure at a temperature of 250 to 750 ^{0}F. The amount of heat applied should be held constant by monitoring the surface temperature of the repair. Although curing by applying heat in some instances produces a stronger repair, over-heating can cause extensive damage to the component. If too much heat is applied, the vaporisation, or “gassing” of the matrix may cause bubbles to form on the surface. A dry area is also an indication of excessive heat.

Although the fibers will withstand higher temperatures than the matrix, the recommended curing temperature should not be exceeded in order to avoid material disintegration or further delamination of the existing structure around the repair.

When a part is to be cured with heat, it is not enough to simply apply heat at the final cure temperature. It is important that the resins be allowed enough time to flow properly before they go through their process. If this is not allowed, a resin rich area may result.

It is also important to allow a repair to cool at the proper rate. Composites gain much of their cure strength in the cooling down process. A slow rate of temperature rise and a gradually cooling process is desirable, but not usually possible, unless a monitor or controller is available. A monitor, or controller, is a device that is used to regulate the temperature in a specific way.

The “*step cure*” and “*ramp and soak”* are probably the most commonly used with composite repair. They will ensure a slow rate of temperature rise and decline.

STEP CURING

Step curing is used when a manually operated controller is used. It requires that the technician make the adjustments manually at specific time intervals. Step curing is the process of bringing up the temperature slowly by raising the temperature to one point and holding it there, then bringing it up again and holding it there, until the cure temperature is reached. This allows the slow heating process which is critical in the curing of the composite.

After the cure time has elapsed, the temperature can be stepped down by reducing the temperature slightly and holding it there, then bringing it down slowly again and holding it there until room temperature is reached. This slow cooling down will give a stronger final cure to the component.

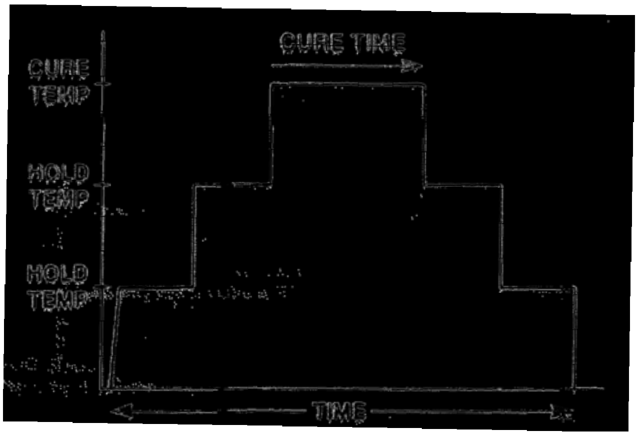

Fig. 39.1, Step curing is normally used where a manually operated controller is hand adjusted by the technician. Time and temperature must be watched closely.

RAMP AND SOAK CURING

A more sophisticated and accurate curing may be done with a programmable controller. A controller may be programmed in a "ramp and soak" mode, which is used to heat or cool a repair at a specific rate. For example (fig 11-2) a structural repair manual may specify that a repair be heated to a temperature of 400 ^{0}F and that the temperature be reached at a slow, constant rate of change from room temperature at eight degrees per minute. If room temperature was 70 degrees, it will take approximately 41 minutes to reach the 400 degree mark ($400^0 - 70^0 = 330^0$, $330^0 + 8^0$ each minutes = 41.25 minutes). This heating process is called the "ramp".

Once the repair has been heated to 400 ^{0}F, the structural repair manual may require that this temperature be held for a specific amount of time; in this example, for two hours. The mode which the controller operates during these two hours is referred to as the "soak".

Following the soak, the structural repair manual may specify that the temperature be ramped down to room temperature at a specific rate. In our example, a five degree per minute cool down rate will take an hour and six minutes

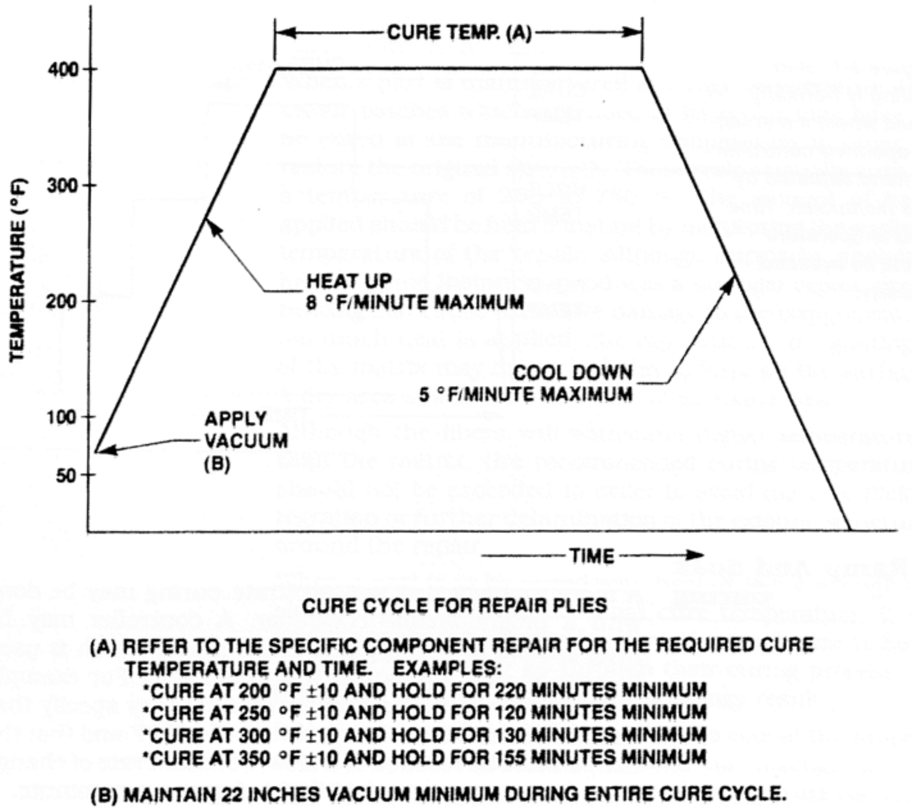

Fig. 11.2, Profile for a ramp and soak cure.

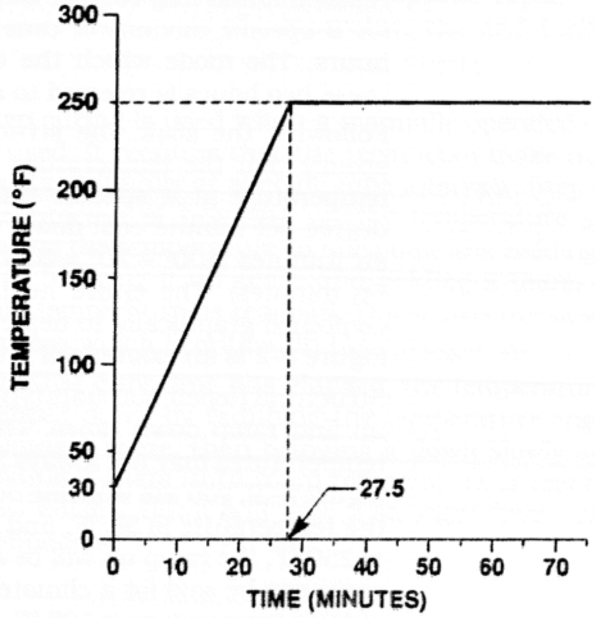

Fig. 11.3, Cold Climate. If the cure is to be done in a cold climate where the temperature outdoors is 30°F, the cure ramp up time is to be at eight degrees per minute. 250° - 30° = 220° ÷ 8° = 27.5 minutes to climb to the cure temperature of 250 degrees at a rate of eight degrees per minute.

($400^0 - 70^0 = 330^0$, 330^0+5^0 each minute = 66 minutes). The entire heating and cooling cycle are combined graphically to depict a ramp and soak profile. Figure 11.2 is an example of a ramp and soak profile.

Structural Repair Manuals typically will not give the ramp up and down times. This is because the starting temperatures may not always be the same. If, for example (Figure 11.3), you are working outside in a cold climate and the temperature is 30 ^{0}F, and the final cure temperature is 250 ^{0}F, the ramp up will be a longer period of time. The same can be said for a climate which is very warm. If the outside temperatures is 105 ^{0}F, and the final cure temperature is 250 ^{0}F, the time it takes to ramp up will be substantially shorter to achieve the same final cure temperature (fig 11.4).

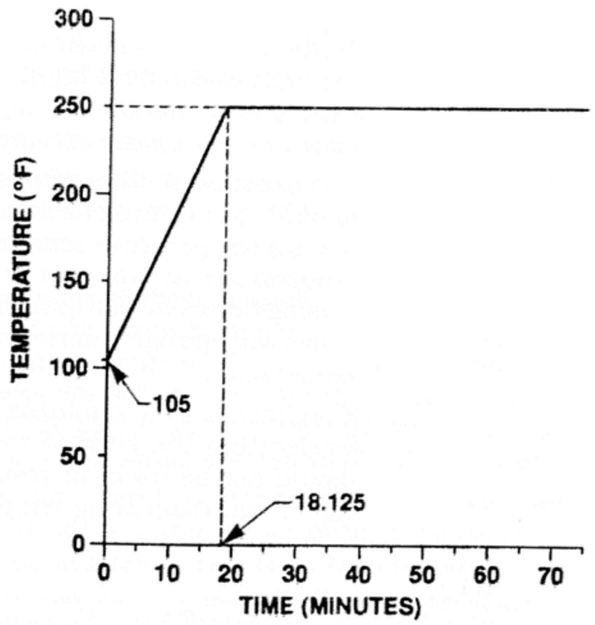

Fig. 11.4, Warm Climate. If the cure is to be done in a warm climate where the temperature outdoors is 105° F, the cure ramp up time is to be at eight degrees per minute. 250° - 105° = 145° + 8° = 18.125 minutes to climb to the cure temperature of 250 degrees at a rate of eight degrees per minute.

HEATINGEQUIPMENT

Heat Lamps

The use of heat lamps to cure composite parts is *not* recommended. The temparature cannot be accurately controlled, and the heat may localise in one spot. Scorching or blistering of the part may occur if the heat lamp is too close, or is left on too long. Heat lamps generate high surface temperatures, which have a tendency to cure a repair too rapidly.

Fig. 11.5, Heat lamps are NOT recommended. They tend to overheat and heat only localized spots.

Drafts in the work area can also affect the amount of heat. The light of the heat lamp must hit all areas of the part. If there is a shadow on any area, it will not cure at the same rate as a part with the light shining on it.

A *templestik* or other temperature monitoring device can be used, but it must be monitored constantly. A templestick is a temperature sensitive crayon that will melt at the temperature at which it is rated,. Another temperature sensing device is a strip with temperature sensitive ink on it that will change colors when the heat reaches a certain temperature.

If nothing else is available, heat lamps may be used for accelerating the cure of room temperature resins. They should not be used on resins that need to be cured at a higher manufacturing temperature.

Heat Guns

When a heat gun is used to cure a composite part, it must be controlled with a monitor. A typical heat gun can generate temperatures of 500 to 750°F when it is left on constantly. If the cure temperature is 350°F and a heat gun is used to cure the component, the heat gun should be monitored with a controller to maintain a constant temperature.

To control a heat gun, a thermocouple is used with the controlling unit to keep the temperature constant. The controller will allow the heat gun to get up to the desired temperature, then the thermocouple senses that it is at the set temperature and will shut off the heat gun. The heat gun cycles on and off around this temperature to hold the temperature fairly constant.

Problems may occur if the heat gun is focused in one place on the repair. If a heat gun should shift position during the curing cycle, excessive evaporation of the resins in one spot amy leave dry areas which will be cause to reject the repair.

A heat gun is often used to cure repairs when the contour of the part will not allow the use of a heat blanket. On composite components with very contoured shapes, heat blankets sometimes lack enough flexibility to conform to the shape of some parts.

In this case, a tent around the part can be fabricated to hold the hot air within a confined area. The tent can be made of vacuum bagging film and attached to the part with sealant tape. To prevent excessive curing, be sure the heat gun is not pointed at the part. If the cure temperature of the part is 250°F, the bagging film used for the tent should be able to withstand a high heat range.

Another alternative to using bagging film as a tent is to use a cardboard box, or anything which will hold the heat in. Heat guns may present a fire hazard and should never be left unattended during the cure process.

If a tent-like structure is used with a heat gun, a shaded area is not a problem as it was with the heat lamps. The heat will reach all areas of the part.

Over Curing

Ovens offer controlled, uniform temperature over all surfaces. Some ovens have vacuum ports installed to provide vacuum pressure while curing. Oven curing is frequently used by manufacturers. When using an oven for repair work, the part must be removed from the aircraft, and the part must be small enough to fit into the oven.

When an aircraft part has metal hardware attached, it should not be cured in an oven, because the metal will heat up at a faster rate than the composite. This uneven heating or high temperature may deteriorate the adhesives under the metal, causing failure of the bond.

Ovens may also present a problem by heating up the whole part, not just the repair area. The areas which are not being repaired are subjected to very high temperatures and may deteriorate the existing bond. Ovens which are used to cure composites must be certified for that purposed.

Autoclaves.

Autoclaves are usually used in the manufacture of composites and are not usually used in the repair procedures unless the part must be remanufactured. Autoclaves ay be used to remanufacture a part if the damage in very large and it is necessary to put the part into the original mold, and cure it with high heat and high pressure. In this case, the part is vacuum bagged and is heated to the curing temperature at a controlled rate, while additional pressure is applied within the autoclave. Normally, parts that are vacuum bagged are subject to one atmosphere of pressure, but an autoclave can apply substantially more pressure to a part. Two or three atmospheres of additional pressure may be added while the part is being manufactured, or cured, in an autoclave.

If the damage is large and extensive enough, it may be sent to a remanufacturing facility. Large manufacturing facilities have the molds and capabilities to repair large damaged surfaces. If an extensively damaged component is not cured with the molds and high heat and pressure, the part may not regain its original strength.

Caution should be taken when operating any autoclave. They can be very dangerous if not operated properly.

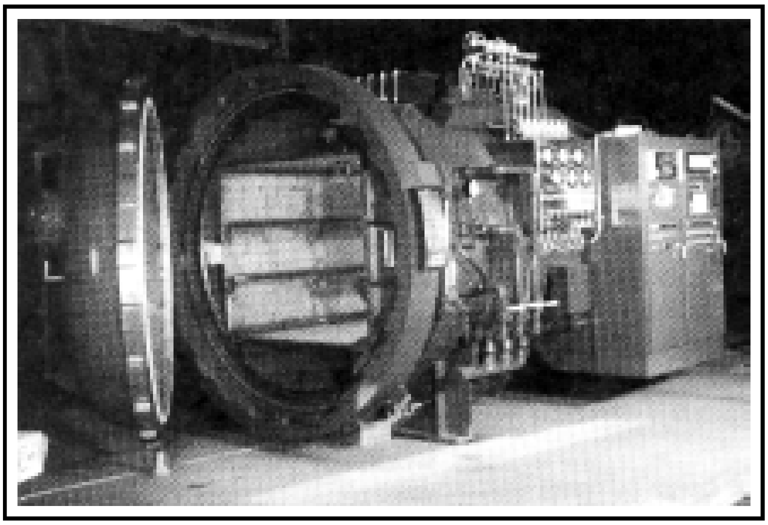

Fig. 11.6, An autoclave provides both heat and pressure under extremely controlled conditions. They are normally used for manufacturing.

Heating Blankets

Heating blankets are probably the most widely accepted form of applying heat to a composite component for repair work. They will uniformly heat the repair area without heating a larger area than necessary. They are usually used with a controller, or hot patch bonding machine, which means the accuracy of the cure is higher. They can be used with vacuum bagging to hold the heat directly into the surface.

Heat blankets are made of a flexible silicon and come in a variety of forms and sizes. Heating coils within the blanket are powered by a controller regulating unit. A thermocouple is used with the blanket it monitor the heat and to control the temperature.

Most manufacturers recommend the use of a heating blanket for curing repairs because of its ability to evenly heat the part. The ramp and soak method of heating is easily accomplished with the heat blanket method, and results in a stronger cure. The heat blanket must cover the repair completely, and usually is an inch or two larger than the largest size patch. However, if the heat blanket is too large, the heat may damage surrounding areas of the part.

The heat blanket is vacuum bagged into the repair area so that no matter where the repair is being done, the heat blanket will be next to the patches to be cured. For example, if the underside of a wing is to be repaired, the vacuum bagging film with vacuum applied will hold the heat blanket tightly to the patches as they are being cured.

Some heat blanket are very flexible, to bend around curved surfaces, yet others are made for flat use only. A flat heat blanket should not be used on a curved surface, as this may break the wires in the heat blanket. Flexible heat blankets are available to go around a curve, such as a leading edge.

If the part is sharply contoured, customized heat blankets made to the shape of a specific part can be used. This would most commonly be used if the same type and size of part is repaired repeatedly.

A typical bagging operation with the use of a heat blanket is shown in figure 11.7.

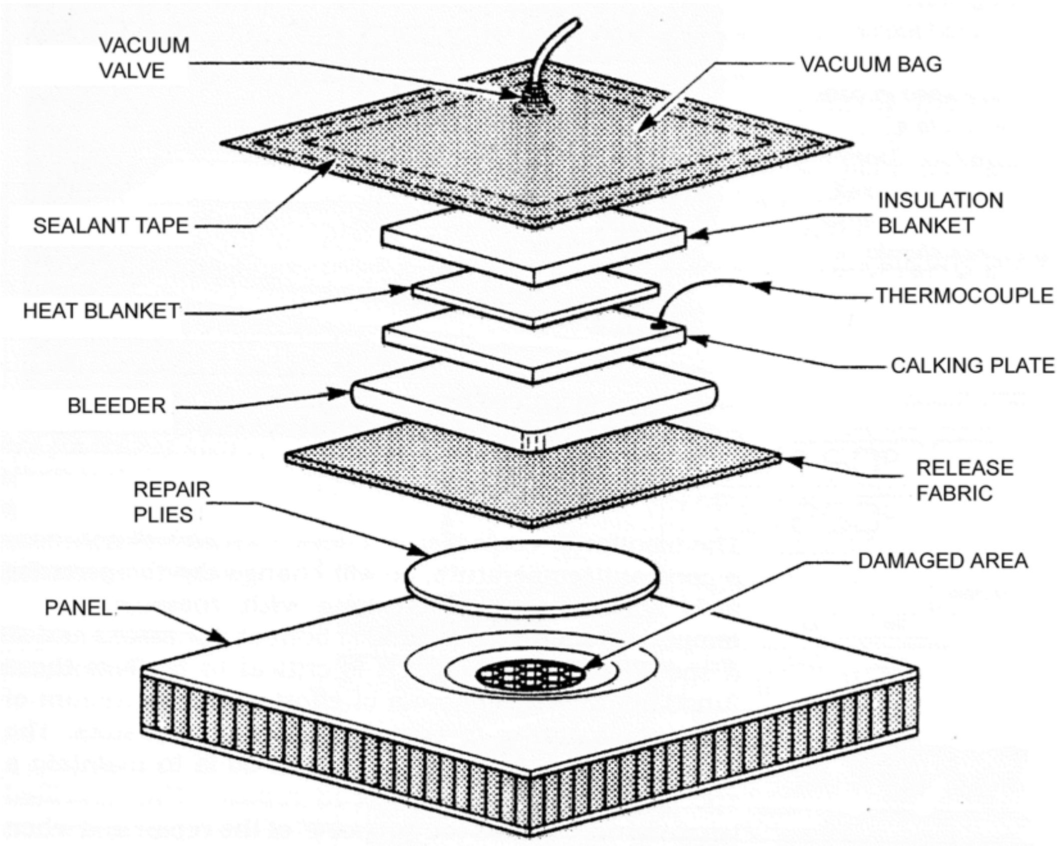

Fig. 11.7, A typical bagging operation with the use of a heat blanket.

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CHAPTER-12
TYPE OF DAMAGES OF COMPOSITE AND THE METHODS OF INSPECTION

COSMETICDEFECTS
A cosmetic defect is a defect on the outer surface skin that does not involve damage of the structural reinforcing fibers. It may be caused by chipping or scratching during handling, does not usually affect the strength of the part, and is usually repaired for esthetic reasons. On some structural components made of either aramid or carbon/graphite, their top layer may be of fiberglass. If damage is to the fiberglass, it many times would e considered negligible or cosmetic damage.

IMPACTDAMAGE
Impact damage may occur if struck by a foreign object. The degree of damage may range from slightly to quite severe. Probably the most common cause of impact damage results from careless handling during transportation, storage, or by standing parts on their edge without adequate protection.

Because of the thin face sheets on a sandwich panel, they are susceptible to impact damage. An area which has been subjected to impact damage should also be inspected for delamination around the impacted area.

Nicking, chipping, cracking or breaking away pieces of the edge or corner can also be caused from improper handling.

DELAMINATION
Delamination is the separation of layers of material in a laminate. Another type of delamination to a sandwich construction would be a separation of the skin to the core structure. Delamination can occur with no visible indications. To compound the problem, delamination often accompanies other types of damage, particularly impact damage. As figure 12.1 shows, delamination occurs when the discrete layers of reinforcing fibers separate from each other in a laminate, or from the core material in a sandwich structure. This can occur as the result of several causes among which are impact, moisture in the fabric or lightening strikes.

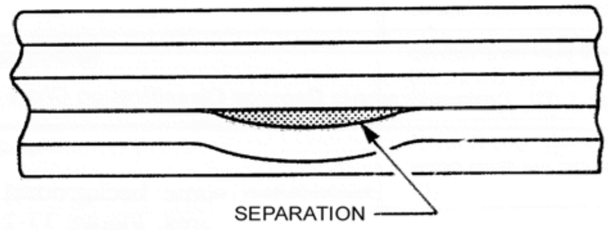

Fig. 12.1, Delamination of fabric layers

In those instances where visible damage has occurred, it is best to assume that the damage has radiated around the visual damage into areas which exhibit no visual damage. An air pocket between layers of fabric may also be the result of improper bonding of the composite. This may occur during manufacturing, or more often during a repair operation. If this is the case, it may have been caused by any of the following :

1. Improper resin/catalyst
2. Improper mixing or weighing of the two matrix components
3. Inadequate amount of pressure or heat during the cure cycle.
4. Improper cleaning of dirt, grease or foreign materials on the surface which is to be bonded.

CRACKS
Cracks can occur in advanced composite structures, just as in metallic ones. Sometimes they can be detected visually, other times they may require more advanced methods of NDI. A crack may be just in the top paint or matrix layer, and not penetrate into the fiber material at all. A crack may also extend into the fiber material and into the core, but appear to be just in the top surface. A thorough inspection should be made to determine the extent of each crack.

HOLEDAMAGE
Hole damage may occur from impact damage, over-torquing fasteners or as a result of fastener pull-through. Holes drilled in the wrong location, wrong size, or wrong number of holes can also be classified as hole damage.

Damage due to lighting strike may burn off resins, leaving bare cloth.

INSPECTION METHODOLOGY

Areas on the aircraft which are subject to damage, such as leading edges made of thin face sheets over a honeycomb panel, should be inspected more often than areas which are more protected by design, such as the vertical stabilizer. Visual inspection to these areas should be accomplished periodically, more in depth inspection should be done at regular overhaul intervals.

Many times the inspection method requires that the component be removed from the aircraft in order to be inspected correctly. This type of inspection is usually accomplished at the time of the aircraft's overhaul. Between overhaul inspections, visual inspection is usually adequate.

VISUAL INSPECTION

Visual inspection is used to detect cracks, surface irregularities (from an internal flaw), and surface defects such as delamination and blistering. A visual inspection will usually detect surface flaws. A light and magnifying glass are useful in detecting cracked or broken fibers. A small microscope is helpful in determining whether the fibers in a cracked surface are broken, or if the crack affects only the resin.

Delaminations may sometimes be found by visual inspection, if the are is examined at an angle with a bright light shown on the surface. The delaminated area may appear to be a bubble, or an indentation in the surface. A coin tap test should be used if you suspect an area of delamination.

COIN TAP TEST

To detect internal flws, or areas suspected of delaminations, a coin tap test is used. Coin tap lightly along a bond line or area suspected of having delaminations. Listen for variations in the tapping sound. A sharp solid sound indicates a good bond. A dull thud indicates bond separation. However, changes in the thickness of the part, reinforcements, fasteners, and previous repairs may give flase readings. Whenever damage is found visually, coin tap around the area to find damage such as a delamiantion that cannot be seen visually. Much of the time if there is a hole, crack, or other damage, there is also delamination around the area.

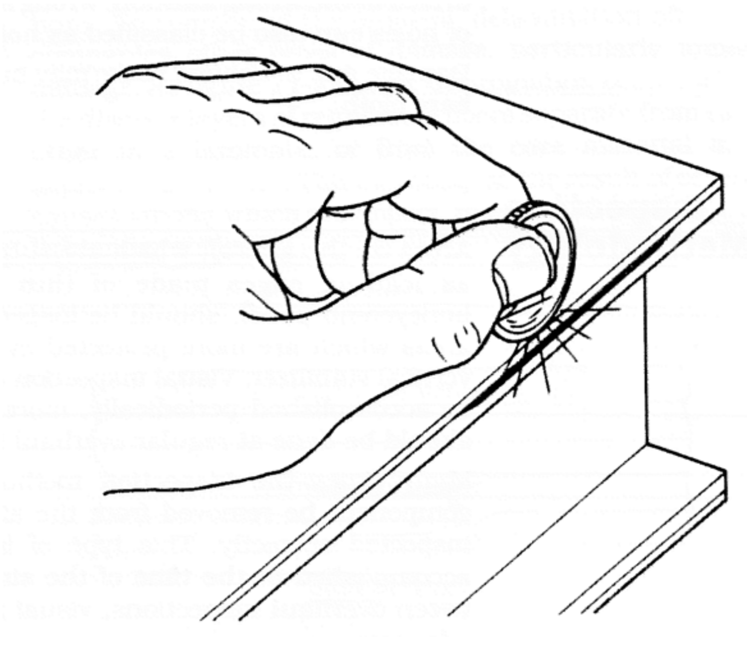

Fig. 12.2, Coin tap test.

ULTRASONIC INSPECTION

For internal damage inspection an ultrasonic tester may be used. Ultrasonic testing uses a high frequency sound wave as a means of detecting flaws in a part. This is done by beaming a high frequency wave through the part and viewing the echo pattern on an oscilloscope. By examining the variations of a given response, delaminations, flaws or other conditions are detected. A newer type of ultrasonic machine has been recently developed to detect flaws in honeycomb cores. Ultrasonic equipment may be ineffective for detecting some types of damage on some composite structures.

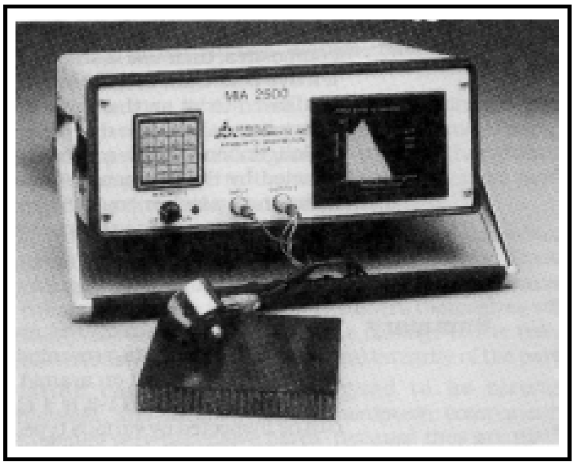

Fig. 12.3, Ultrasonic tester for composite use. (Stavely Instruments).

THERMOGRAPHY

Thermography locates flaws by temperature variations at the surface of a damaged part. Heat is applied to the part, then the temperature gradients are measured using an infrared camera or film. Thermography requires a knowledge of the thermal conductivity of the test specimen and a reference standard for comparison purposes.

LASER HOLOGRAPHY

This process calls for the suspect part to be heated and then photographed using a laser light source and a special camera system. It is used to detect disbonds or water in honeycomb and impact damage.

RADIOGRAPHY

Radiography can be used to detect cracks in the surface as well as internal cracks that cannot be visually detected. Radiography will also detect water inside the honeycomb core cells. It is useful in detecting the extent of the damage that cannot be visually detected.

HARDNESS TESTING

After a repair has cured, a hardness tester, such as the Barcol, could be used to determine whether the resins have reached their proper strength. A special chart is used to interpret the results for different types of resins and pre-pregs. Hardness testing does not test the strength of the composite, but only the matrix strength.

DYE PENETRANT

Dye penetrant has been used successfully for detecting cracks in metallic surfaces, however, with the advanced composites, their use is still questioned. The reason is that if a dye penetrant is used on the composite structure and is allowed to sit on the surface, the wicking action of the fibers may take in the dye penetrant and then they would no longer bond to new material. The entire area which was affected by the dye penetrant would have to be removed before new patches could be applied. This in effect could extend the damage to the size which would make the part non-repairable.

SUMMARY

Carbon/graphite structures are easier to inspect with some of the methods presented. Ultra sound and x-ray may not be as useful on aramid or honeycomb composite components. Figure 12.4 is a chart showing defects that can be inspected by various types of inspection equipment.

INSPECTION	SERVICE-INCURRED DEFECTS						
	IMPACT	DELAMINATIONS/ (DISBONDS)	CRACKS	HOLE DAMAGE	WATER	LIGHTNING STRIKE	BURNS/ OVERHEATING
VISUAL	X		X	X		X	X
X-RAY	X		X	X	X	X	
ULTRASONIC		X	X				

Fig. 12.4, Defects that can be located by various types of inspection equipment.

REPAIRINGCOMPOSITEMATERIALS

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. 12.5. 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.

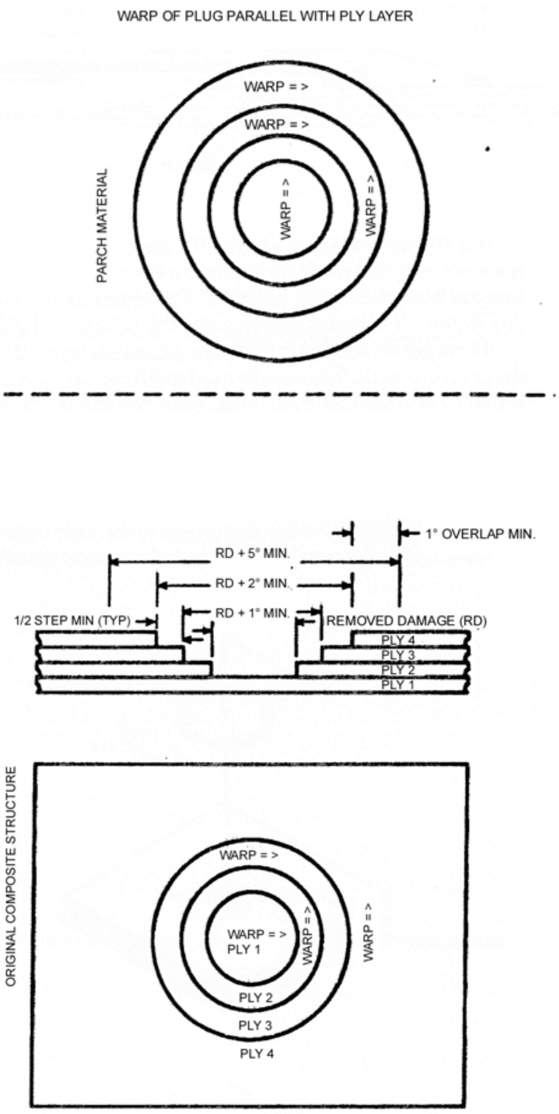

Fig. 12.5, Layout of a three-layer cut-back composite repair.

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 praocess. 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. 12.6.

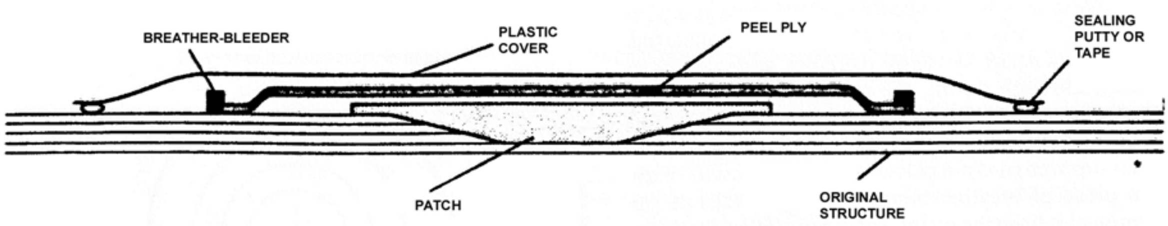

Fig. 12.6, Vacuum bag repair arrangement

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. 12.7. 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. 12.8 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. 12.9. 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.12.10.

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.

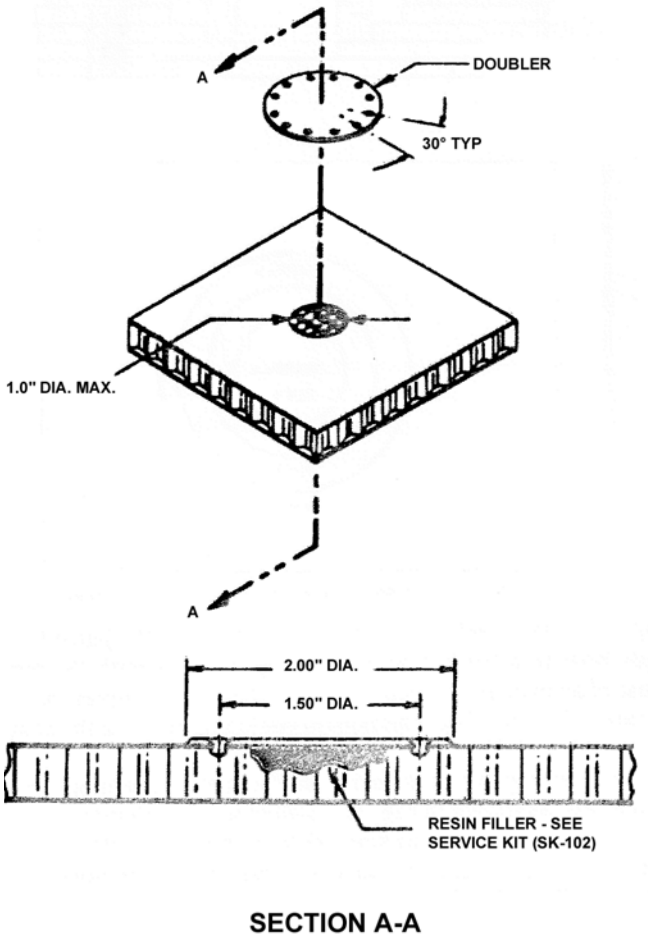

Fig. 12.7, A riveted surface patch repair, (Grumman American Aviation)

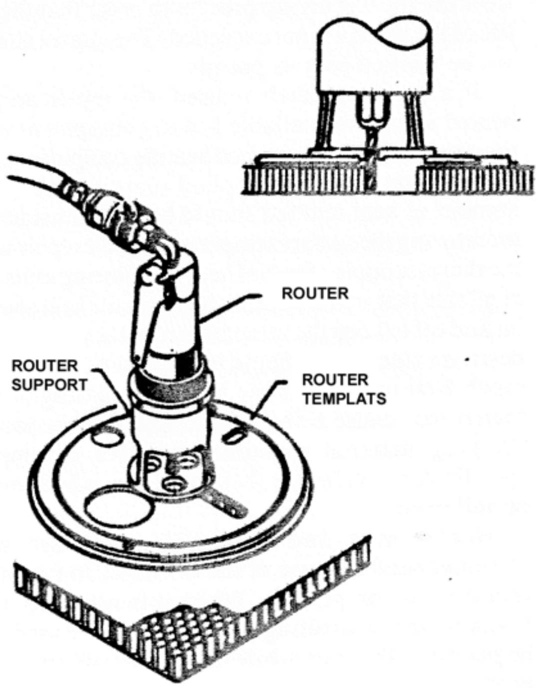

Fig. 12.8, Router, support assembly, and template.

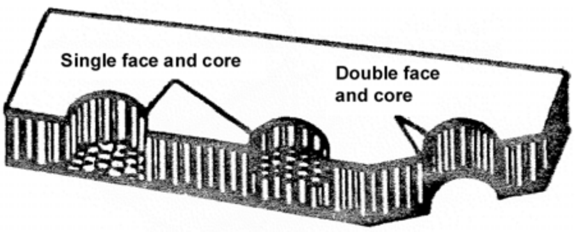

Fig. 12.9, Areas routed out prior to repair

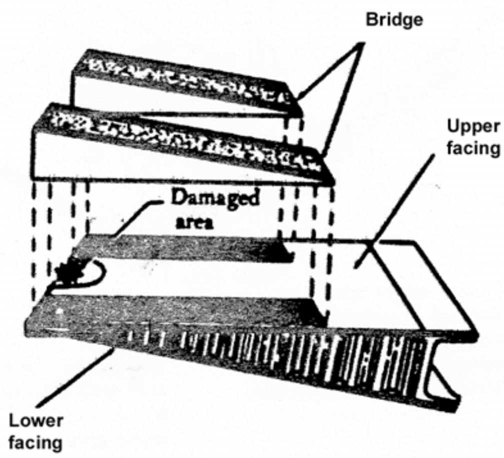

Fig. 12.10, Bridges used for router support.

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. 12.11. 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.

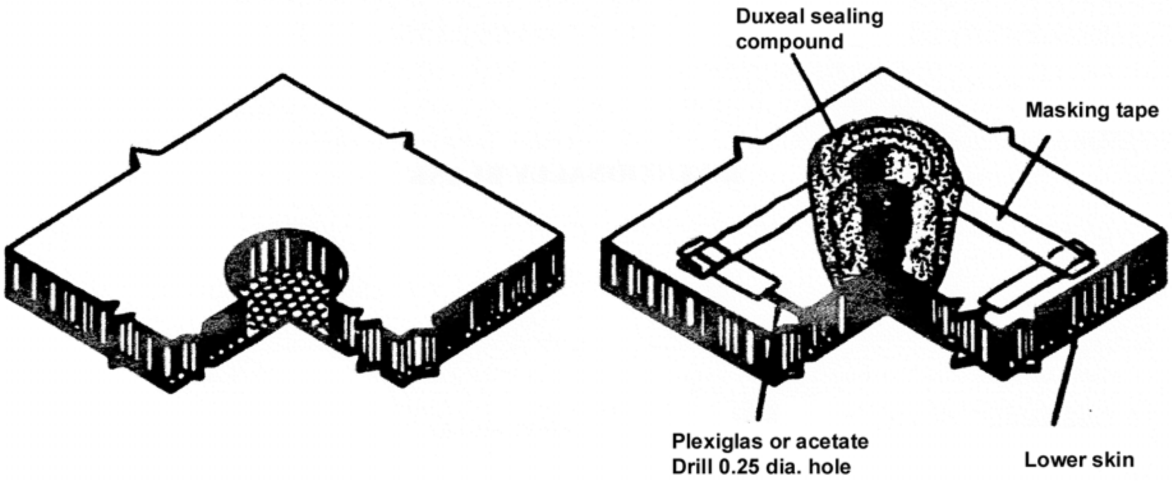

Fig. 12.11, A potted repair to the core and skin

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.

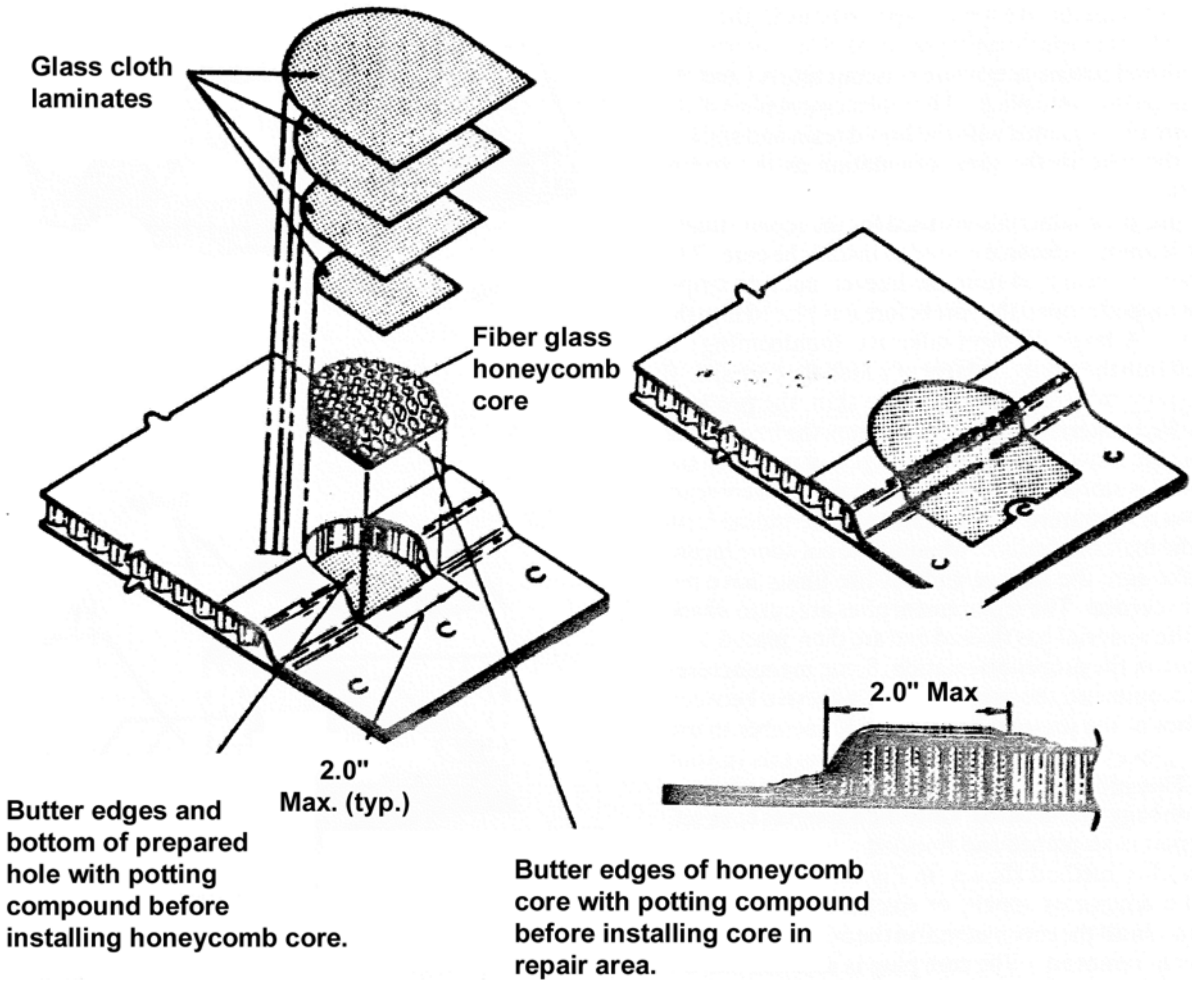

Fig. 12.12, A plug repair on an edge.

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. 12.12. The repair is vacuum bagged and cured. Once the adhesives have set, the repair is smoothed and finished.

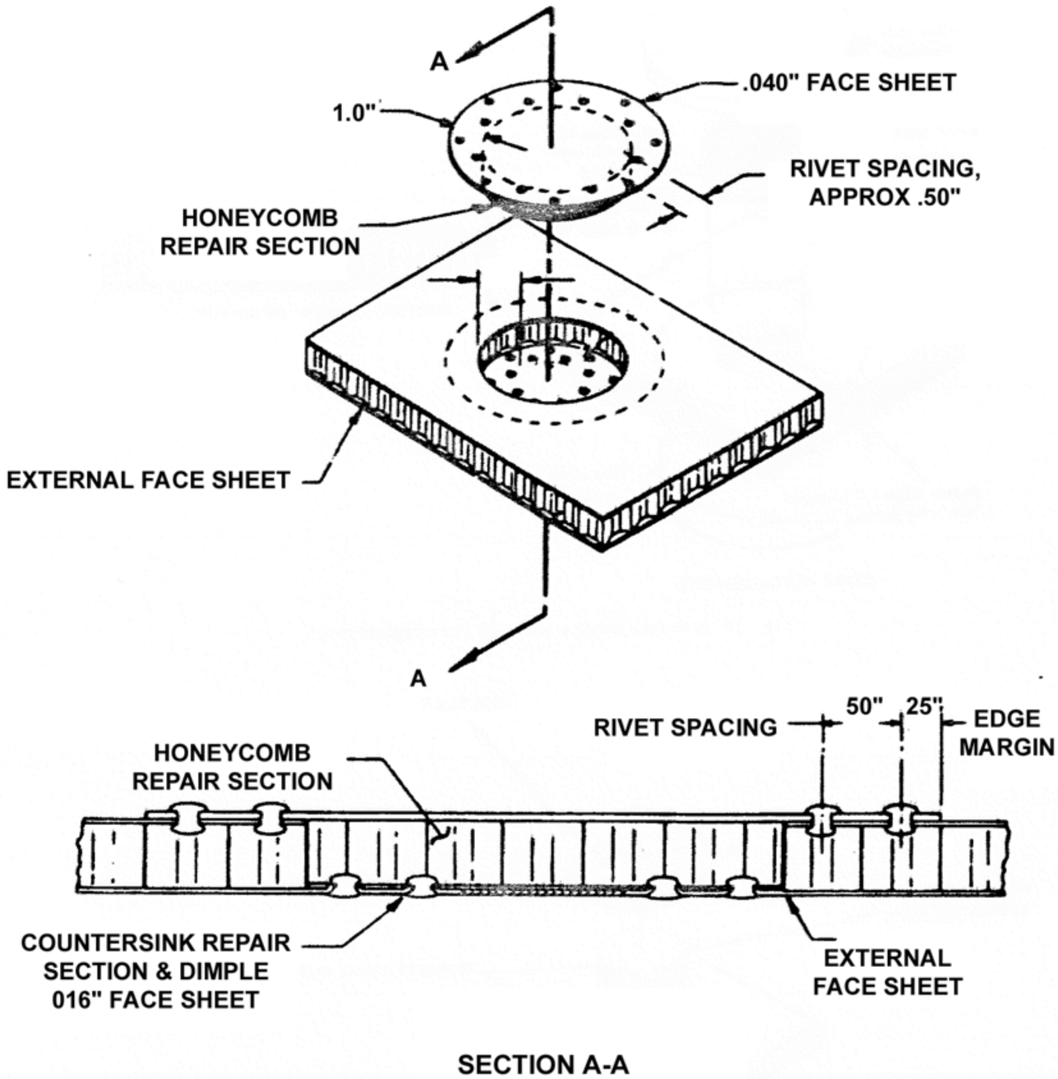

Fig. 12.13, A riveted plug repair.

Another method shown in Fig.12.13., 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. 12.14. A similar riveted repair is shown in Fig.12.15. 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

Hot Patch Bonding

Simply stated, a hot patch bonding machine performs two functions :

1. It applies atmospheric pressure by means of a vacuum pump.
2. It applies heat, usually in the form of a heat blanket. Hot patch bonding makes use of heat blankets which have electrical coils bonded into a rubber pad or blanket. The heat blankets can heat up quickly, unless they have a monitoring unit to control the rate of temperature rise and to set the temperature.

If the shape of the part to be cured is sharply contoured, instead of using a heat blanket with the hot bonding machine, in some instances a heat gun may be used. A tent of bagging film is attached to the part to hold the heat in around the part. The heat gun is monitored with a thermocouple and the controller of the hot bonding unit.

The monitor or controller is a device which will maintain a constant temperature, or will change the temperature at a specific rate. In working with composites, the temperature must be controlled both at a constant and at a specific rate of change. It is critical to perform these functions with a minimum of effort and a maximum of efficiency in order to achieve professional results. The simplest function the controller will do is to maintain a specified temperature for the repair.

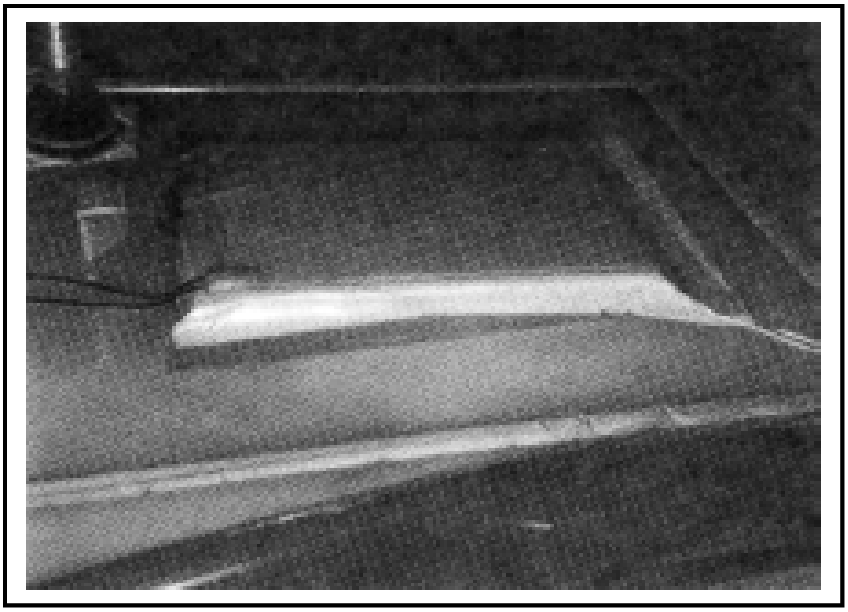

Fig. 12.14, Hot patch bonding is accomplished with a heat blanket, and is normally used in conjunction with a vacuum bag. Controller devices are used and the temperatures and times should be recorded.

The specified temperature is called the "setpoint" of the repair and when the controller is working in this mode it is called a setpoint controller.

Another function the controller may be able to perform is the "ramp and soak." The controller allows the temperature to slowly rise at a specific rate, then hold the temperature constant, then allows a slow decline of temperature at a specific rate.

Recording the temperatures of the curing process can be accomplished using hot bonding units which are equipped with a temperature recording unit. Such controllers may use a recorder that is included in the control unit, or as a separate unit. In any case, some manufacturers require that permanent records of the cure cycle be included in the log of the aircraft repairs. A note of warning : Don't become dependent on the recording record as an assurance that the part was repaired correctly. There are many aspects of a repair that need close monitoring. Just because the repair was cured at the proper temperature does not mean that the repair is airworthy.

To use a controller, a thermocouple is placed beside the repaired area, under a heat blanket, and under the bagging film to sense what temperature is being delivered to the part. The thermocouple sends the temperature information to the controller. The controller adds heat or stops heating depending on how the controller is set.

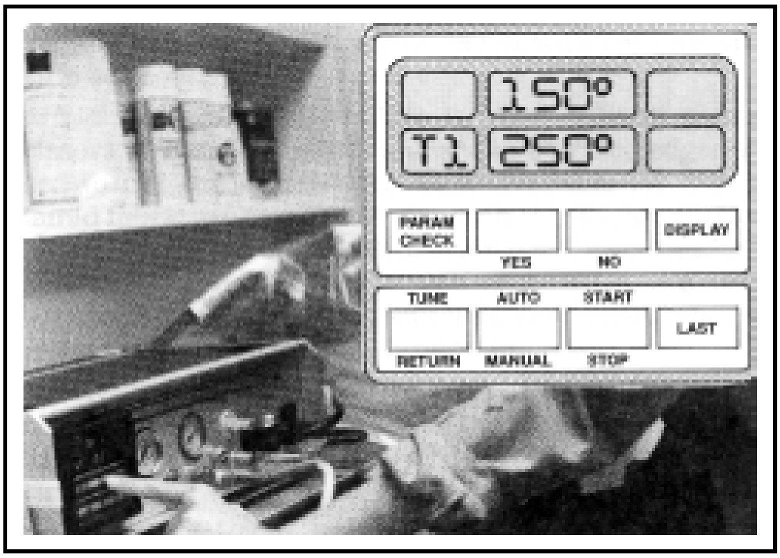

Fig. 12.15, controllers are actually fairly simple in their operation. Settings are straightforward, indicators are clearly represented, and programming is not complicated.

In the illustration of the controller face, the set pint is 250°F. If the thermocouple is only sensing 150°F, the controller will apply heat to the blanket or gun until the thermocouple senses 250°F. If the set point during the cooling down process is 150°F and the controller had previously been curing at 250°F, then the controller will not apply heat until the temperature dips slightly below 150°F.

To initially apply heat at the final cure temperature will not allow the resins enough time to flow properly before they go through their curing process. This may result in a resin rich area. For example, if 250°F is the final cure temperature and the controller applies heat, it will reach the 250°F is the final cure temperature and the controller applies heat, it will reach the 250°F mark as soon as it possibly can (usually within 30 seconds). The resin and catalyst mixtures need time to slowly start their chemical reaction before the final cure temperatures is reached.

It is also important to not turn off the heat and allow the part to cool too quickly, because composites gain much of their strength during the cooling down process which will also prevent the part from becoming brittle. A slow rate of temperature rise and decline is desirable, but can usually be achieved only if a monitor or controller is available.

A graph of the controller operating as a setpoint controller might look like figure 12.15 & 12.16. Here, the temperature climbs quickly from room temperature (T1) to a specified temperature (T2). There are many different ways in which a controller can be used.

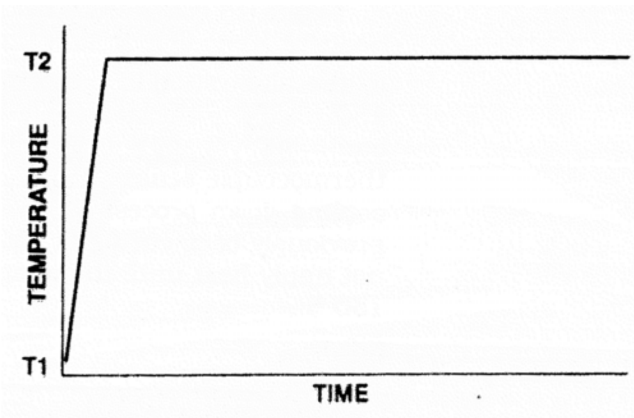

Fig. 12.16, The temperature rise from T1 (room temperature) to T2 (set point) would look like this graph.

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CHAPTER-13
CORROSION

INTRODUCTION
This chapter gives general guidance on the causes, appearance and prevention of corrosion which, if not detected in its early stages, can have disastrous consequences . Information on corrosion theory is included where it has bearing on the practical aspect of the inspection and maintenance of aircraft and the practical aspect of the inspection and maintenance of aircraft and aircraft parts.

All metals are subject to chemical and electro-chemical attack which converts them into metallic compounds such as oxides, hydroxides, carbonates, sulphates or other slats. Some metals resist attack better than others but the resistance of most metals may vary with such factors as physical environment, applied or internal stress, heat treatment state or working temperature. Although many of the metals used in aircraft construction have reasonable resistance to corrosion, it is essential that all possible action is taken to prevent its occurrence and to detect and remedy any corrosive attack, even if it appears to be insignificant.

As corrosion may arise from many different causes and can affect all kind of metallic structures and components, it is beyond the scope of this chapter to enumerate all the defects that may result from it. It is also impracticable to enumerate every remedy as the treatment of each affected part must be determined by its nature and its function in the particular aircraft. Guidance on the repair and re-protection of corroded parts should be obtained from the appropriate Manufacturer's Publications, but whenever doubt exists the Manufacturer should be consulted.

TYPE OF CORROSION
Corrosion is largely an electro-chemical phenomenons and is liable to occur whenever a difference in potential exists between two metals or a metal and substance in its vicinity in the presence of an electrolyte. It can also occur when a difference in potential exists between separate regions of a single piece of metal or between the different constituents of an alloy. The degree of which will be negligible; serious attack usually takes place only if moisture is present to act as an electrolyte between the poles created by any differences in potential. Two changes converted into a metallic compound, whilst the cathodic pole of the circuit may be reduced.

Direct Chemical Attack
When metals combine with atmospheric oxygen or are attacked by acids, the anodic and cathodic changes occur at the same point. Impurities in the atmosphere can be responsible for this type of corrosion. Thus, aircraft operating near the sea are affected by airborne salt particles, whilst the high sulphur content of industrial atmospheres has a markedly deleterious effect on some exposed metallic surfaces. There is also the possibility of accidental contact with harmful substances. Where this form of attack occurs, the attacked metal is converted into a chemical compound by the corrosive agent, e.g. aluminium may be converted to a aluminium sulphate by battery acids.

NOTE
On aircraft used for crop spraying, special care must be given to the inspection of the structure owing to the corrosive nature of some of the chemicals used.

Electro-chemical Attack
The close proximity of dissimilar metals in aircraft, aided by the presence of conductive media such as water, encourages the establishment of circuits and results in the metal which is anodic to the other being attacked. In some cases, such as when aluminium alloy and magnesium alloy are in contact, both metals may be corroded. Electro-chemical attack will be encouraged by the existence of stray currents from electrical apparatus or electrostatically-charged bodies.

Evidence of Attack
Both types of corrosive attack start on the surface of the metal but can work their way into the core if undetected. Evidence of corrosion will be indicated in the following manner.

(a) Aluminium Alloy
Corrosion of the aluminium surface is usually indicated by whitish powdery deposits with dulling of the surface on unpainted parts. The white powdery deposit also forms at discontinuities in protective coating and may spread beneath paint causing blistering or flaking. As the corrosion attack advances, the surface will appear mottled or etched with pitting. Swelling or bulging of skins, pulled or popped rivets are often visual indications of corrosion.

(b) Alloy and Carbon Steels

Corrosion is indicated by red rust deposits and pitting of the affected surfaces.

(c) Corrosion Resistant Steels

Corrosion is indicated by black pits or a uniform reddish-brown surface.

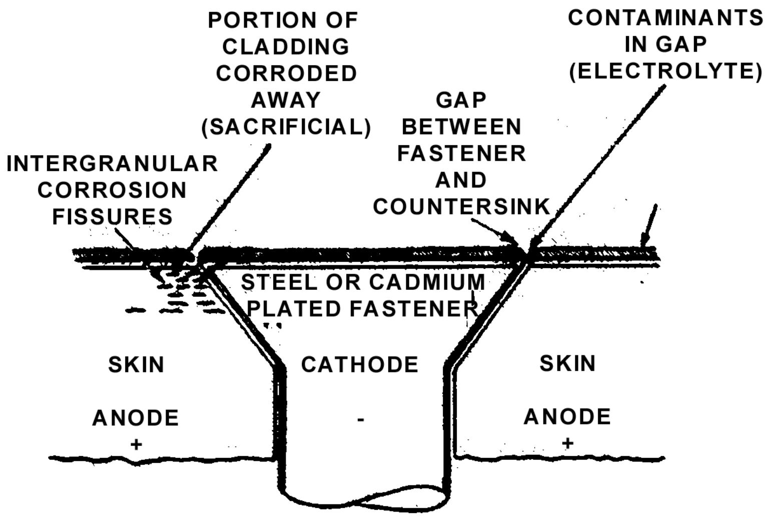

Fig. 13.1, Electrical Aspect of Corrosion

Terminology

The terminology used in describing corrosion is based on either the appearance of the corrosive attack or the mechanism associated with its formation. Frequently, several types of corrosion will occur simultaneously and it becomes difficult to determine the specific cause. The following types of corrosion are those most commonly experienced.

Surface Corrosion

This may take the form of a uniform etching of the surface, pitting or exfoliation of the surface grain boundaries. Light alloys are usually blotched by white or grey powdery deposits, whilst ferrous materials other than stainless steels become covered with reddish-brown rust, and a greenish powder forms on copper. Surface corrosion reduces the amount of sound material remaining and so weakens the structure but, since there is usually an indication of its existence, it is possible for it to be remedied by careful and systematic maintenance.

Note

In many instances the reduction in strength of a structure due to corrosion attack is out of all proportion to the reduction in thickness of the metal.

Intergranular Corrosion

The detection of this type of corrosion is difficult as the surface evidence may only be visible through a magnifying glass. Indications of the presence of corrosion can be obtained by anodising the part and examining for discoloration (black spots). Considerable experience is required for correct recognition, and often a metallurgical microsection examination will be necessary. The attack penetrates into the core of the material along the boundaries of the metal grains. As the material at the boundaries is usually anodic to the grain centres, the corrosion products often become concentrated at the boundaries, although sometimes the attack is transgranular and it is the material adjacent to the boundary which is attacked. The rate of attack is not limited by the lack of oxygen but is accelerated if applied or residual stress is present. Repeated tensile or fluctuating stresses encourage separation of the boundaries, so accelerating the spread of intergranular corrosion and giving rise to corrosion fatigue. As a result higher stress concentrations occur in the remaining sound material, cracks spread and complete failure follows. As there is no effective method of limiting or determining the loss of strength that occurs through this form of corrosion, material or parts showing any signs of it must be rejected immediately.

Pitting

Detected as a series of pits on the metal surface, usually in small, well defined local areas.

Filiform and Exfoliation (or Laminar) Corrosion

Filiform corrosion usually occurs under thin oil, grease or varnish films and is likely to be found on metal surfaces which have a protective film of any sort if there is evidence of a lack of adhesion of the protective film, and appears like 'worm-casts' on aluminium and magnesium alloys. Exfoliation appears as eruptions or flakiness on extruded alloys and can be a serious problem, although it is a relatively less harmful form of intergranular attack.

Note

Intergranular corrosion may occur without stress in the presence of acid chloride solutions or urine, etc., and the latter is often the cause of intergranular cracks which lead to component failure.

Galvanic

Galvanic corrosion is usually visible as pitting and is often referred to as dissimilar metal corrosion. However, it is not limited to just dissimilar metal couples. Various types of concentration cells, where electron flow occurs between areas or points of different electrical potential, are also examples of galvanic corrosion. Pitting results when in the presence of a conducting solution, electron flow occurs between different metals or between different points or areas on a metal surface exhibiting different electrical potential.

Microbial

Microbial (microbiological) corrosion occurs in integral fuel tanks and is caused by the presence of bacteria and fungus in aviation kerosene. The fungus grows at the fuel \ water interface, and the metabolic products formed corrode the metallic structure.

Stress Corrosion

This type of corrosion usually manifests itself as fine cracks. It occurs in alloys that are susceptible to cracking when exposed to a corrosive environment while under a tensile stress.

CONDITIONS CAUSING CORROSION

Because of the stringent weight limitations of aircraft, structural parts and components cannot be designed so that they are heavier than is dictated by the requirements of mechanical strength. Thus, any loss of strength through corrosion damage is more critical than in other forms of transport. Aircraft parts should therefore be manufactured, protected and assembled so that corrosion is unlikely to occur and, after entering service, every precaution should be taken to preserve the original finish. Cleaning and inspection, and when necessary re-protection, are essential at frequent intervals throughout the working lives of all components and parts.

Basic Factors of Material and Assembly

The following factors are important as a guide to the prevention of corrosion.

Selection of Materials

As material specification used in initial construction or for subsequent repair are chosen by the Manufacturer, who should make resistance to corrosion a factor in selecting the appropriate specification, maintenance responsibility is normally limited to ensuring that all instructions for handling, storage, heat treatment, assembly and protection are correctly carried out and that a close watch is maintained for sign of incipient corrosion.

Dissimilar Metals

The contact of dissimilar metals, which occurs in many parts of aircraft structures and in most accessories and components, is always likely to cause electro-chemical reaction, but in many instances such reaction can be prevented by maintaining protective or insulating layers between the metal surfaces. It should be remembered that parts to the same materials specification may have a relative difference in potential if their heat treatment states are compound, etc., as though they were dissimilar metals . Some examples of dissimilar metal contacts are quoted:

a. Steel bolts through aluminium alloy spares and structural members.
b. Steel brake components secured to magnesium alloy wheels.
c. Parts made of brass, steel, tungsten, etc., such as clips or brackets, attached to aluminium alloy structural members.
d. Aluminium alloy skin panels riveted to extruded stringers.
e. Steel levers, shafts and gears housed in castings of light alloy.

HEAT TREATMENT

Incorrect heat treatment may lower the corrosion resistance of the material treated, thus it is essential that all heat treatment should be applied strictly in accordance with approved specifications. The corrosion resistance of high-strength aluminium alloys is affected by their cooling rate; if this is rapid their susceptibility to intergranular corrosion is reduced, provided that locked-up quenching stresses are afterwards relieved.

NOTE
Heat is sometimes applied to structural parts for purposes other than the development of particular mechanical properties of the metal, e.g. when metal to metal joints are bonded by thermo-setting synthetic resins under the influence of heat and pressure. Since 'heat treatment' of this kind is not always covered by official specification, close adherence to the aircraft Manufacturer's instructions is essential to ensure that the corrosion resistance and other properties of the metal are not impaired.

Welding
Welded joints are sometimes subject to corrosion because the heated strip has been rendered anodic to the surrounding metal but the danger can be greatly reduced by the exercise of skill and care. It should be remembered that the fluxes used in welding are often corrosive and hence all residues from fluxes should be thoroughly cleaned off immediately after welding. Some stainless steels are particularly susceptible to intergranular attack in the welded region (weld decay), although the likelihood of this can be reduced if the part is annealed after welding or if the steel contains stabilizing elements such as titanium or niobium . Inert gas welding processes which do not require flux are sometimes used when the removal of flux would be difficult.

Fretting
This is a type of corrosion which can have serious consequences, as it reduces the fatigue strength of the structure; it occurs when parts are bolted tightly together and yet slip slightly on one another during flexing or other movements of aircraft parts. The heating caused by friction promotes oxidisation of steel parts and the oxide is then rubbed off to form dust frequently described as "cocoa". Fretting of aluminium alloys produces a black oxide. Structural assembly bolts should be inspected to ensure that the protective treatment plating is intact and should be assembled within the stipulated torque loading limits and in accordance with the Manufacturer's instructions.

Stress
Metals under stress generally corrode more rapidly than unstressed metals. The influence of stress on the development of intergranular corrosion is mentioned. Corrosion that is continuing on parts under repeated stress is very much more harmful than corrosion for the same length of time without stress, and can lead to rapid failure of the part from fatigue. In many cases, stress corrosion cracks have resulted from initial pits in the surface.

High Temperatures
Parts which become heated in service, such as brake drums, combustion chambers and exhaust pipes, tend to oxidise more rapidly than unheated parts. This tendency is reduced if the parts are made from alloys containing nickel or chromium, although the corrosive effects of the sulphur present in exhaust gases may still do harm to heated engine parts.

Electrical Equipment
Faults in the insulation of electrical equipment which lead to current leakage can cause the equipment itself to corrode or can encourage electro-chemical attack in the surrounding structure. Insulation should therefore be carefully tested as outlined. Sparking in confined spaces will produce nitric acid in the presence of moisture and this acid will then attack the surrounding material.. Nitric acid attack can be prevented by ensuring that the vents of such equipment as magnetos are kept clean so as to permit the escape of the oxides of nitrogen evolved. Certain insulating materials give off vapours which are corrosive, e.g. phenolic resin-bonded insulating materials give off vapours which corrode cadmium plate.

Factors Due to Environment and Operation
Corrosion can arise from many circumstances, some of which are unavoidable but many of which can be anticipated and controlled. When conditions that create corrosion are an inevitable accompaniment of storage or operation, the only safeguard is adequate maintenance.

Damage to Protective Coatings
Metallic surfaces protected by chemical films, metal plating or organic coatings, may suffer severe attack if the protective coat is physically damaged. Some protective coatings are susceptible to attack from certain types of lubricants, de-icing fluids or hydraulic fluids, but this danger can be reduced by selecting protectives that are specially resistant for the items that are likely to be in contact with these fluids. Scratches caused by careless handling and abrasion from grit or water striking the aircraft at high speed can provide starting points for corrosion, but the seriousness of such defects depends on the materials affected. Thus aluminium alloy sheet clad with pure aluminium is not much harmed by minor scratches since the aluminium cladding provides 'sacrificial protection'. On the other hand, chromium plated steel will rust readily if the chromium is damaged.

Surface Defects
Corrosion may arise from particles of foreign matter, such as rolling-mill scale or emery particles, which are embedded in the surface. Particular care is necessary after such operation as filing, grinding or abrasive grit blasting to ensure

that all particles are completely removed. A high polish is given to some components to enable them to resist attack, and this resistance will be lowered if polished surfaces are roughened or scores.

Crevice Corrosion

Intense corrosion is often found where non-conducting materials, such as plastics, glass-wool or upholstery, are in contact with metal. A similar effect may occur in inaccessible corners formed in metal parts. In such places, oxygen is replenished less quickly than elsewhere with the result that the crevice is rendered anodic to the surface outside and is therefore subject to electro-chemical attack. It follows that the contact of metals and non-conductors should be treated like the contact of dissimilar metals, and that all enclosed regions in aircraft structures should be vented and drained as adequately as possible. Ventilation also helps to prevent the accumulation of condensed moisture and discourages the growth of moulds and bacteria which can also promote corrosion.

Marine Corrosion

The salt present in sea water will attack many metals directly. Landplanes may be affected by airborne particles or spray droplets, whilst amphibians require constant attention to keep them free from the salt deposited by evaporated spray. If trapped in the aircraft structure, sea water will provide a particularly active electrolyte for electro-chemical action. Hulls are sometimes damaged because of the voluminous character of the corrosion products precipitated in crevices; as the material accumulates, plates may be bulged and rivets fractured. The inside of the chine members where the side sheeting joins the planing bottom is particularly vulnerable to corrosion because of its moisture trapping shape.

Fuels, Oils and other Liquids

Although petroleum products contain sulphur compounds and organic acids, they do not usually corrode fuel tanks, pipe-lines, etc., because of the resistant nature of the materials from which these items are made. The danger of corrosion chiefly arises from the water content of oils and fuels; the water acts as an electrolyte to promote combination with oxygen dissolved in the oil or fuel. This effect is most pronounced with leaded patrol, and light alloy tanks containing such fuels should be protected with inhibitor cartridges. Careful inspection of the external surfaces as well as the internal structure of the keel areas, particularly of pressurised aircraft, is necessary due to condensation and spillage from toilet and galley installations. Battery acids, de-icing fluids, disinfectants, water methanol spillage and urine can also cause extensive attack on structural parts and care should always be taken to wash off any of these fluids which may be spilt. Integral fuel tanks should be designed to give good water collection and drainage. Water in aviation kerosene may cause serious corrosion within the fuel system. It may be saline or brackish, which with other contaminants such as iron oxide, micro-biological organisms, etc., may have very serious effects.

NOTE

All aviation fuels absorb moisture from the air and the amount of dissolved water contained varies with the temperature of the fuel. When the temperature of the fuel decreases, some of the dissolved water comes out of solution and falls to the bottom of the tank. When the temperature of the fuel increases, water is drawn from the atmosphere to maintain a saturation solution. Changes in temperature, therefore, result in a continuous accumulation of water.

ORDER OF CORRODIABILITY IN METALS

1. Magnesium
2. Aluminium
3. Zinc
4. Iron
5. Cadmium
6. Nickle
7. Lead
8. Tin
9. Silver
10. Tungestun
11. Venadium
12. Chromium

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CHAPTER-14
FASTENERS

TURNLOCK FASTENERS

Turnlock fasteners are used to secure inspection plates, doors, cowlings, and other removable panels on aircraft. The most desirable feature of these fasteners is that they permit quick and easy removal of access panels for inspection and servicing purposes. Turnlock fasteners are manufactured and supplied by a number of manufacturers under various trade names. Some of the most commonly used are the Dzus, Airloc, and Camloc.

Dzus Fasteners

Cowling and other inspection access doors that must be opened frequently can be held with dzus fasteners that require only a quarter of a turn to lock or unlock. With a Dzus fastener a hard spring-steel wire is riveted across an opening on a fixed part of a fuselage, and a stud is mounted on the removable panel with a metal grommet. When the panel is closed, a slot in the stud straddles the spring. Turning the stud a quarter of a turn pulls the spring up into the slanted slot and locks it as the spring passes over the hump in the slot. (Fig. 14.1)

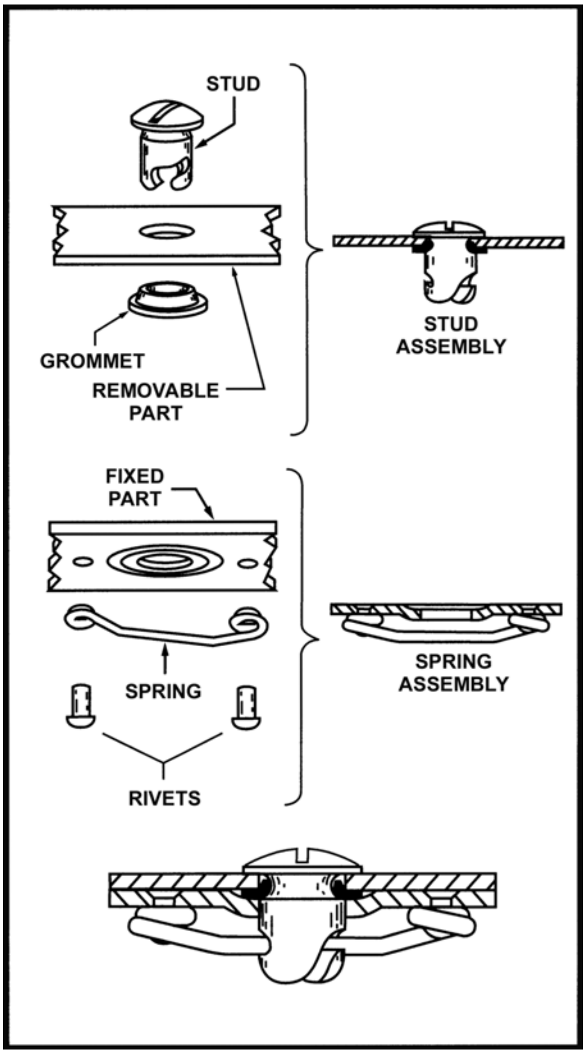

Fig.14.1, With a standard Dzus fastener, a slotted stud engages a spring mounted to the fuselage. As the stud is turned onequarter turn, the spring locks the fastener in place.

When something is fastened with Dzus fasteners, care must be taken that the stud in every fastener straddles each of the springs rather than passing beside them. In order to be sure that all of the fasteners are properly locked, the slots should all be lined up. Furthermore, when a Dzus fastener is fastened, a distinct click is heard when the spring drops over the hump into the locked position. To aid in assuring that no stud misses the spring, special receptacle-type fasteners are available that guide the stud over the spring. (Fig. 14.2).

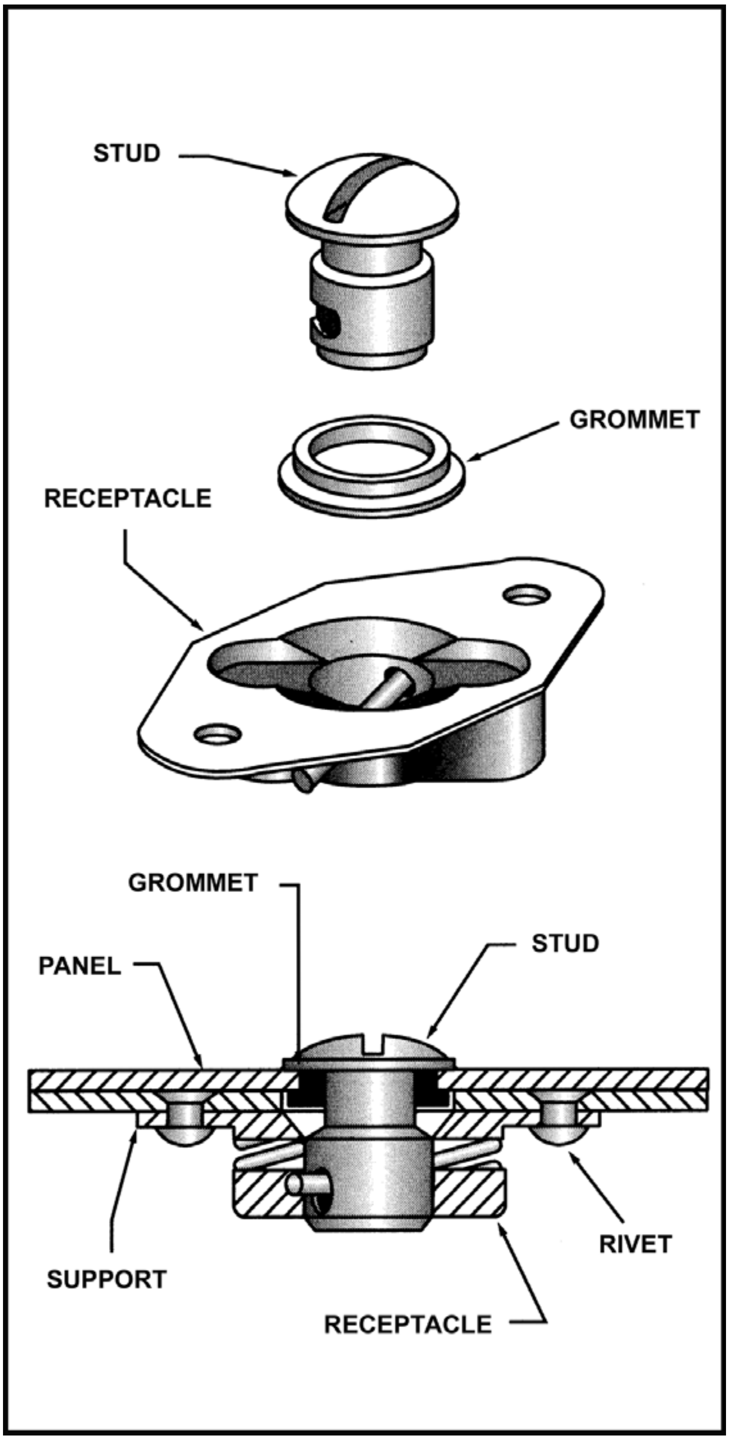

Fig.14.2, The receptacle of a receptacle-type Dzus fastener guides the stud to the exact location it needs to be prior to engaging the spring.

Airloc Fastener

An Airloc fastener consists of a steel stud and crosspin in a removable cowling or door and a sheet sprig-steel receptacle in the stationary member. To lock this type of fastener, the stud slips into the receptacle and is rotated a quarter of a turn. The pin drops into an indetation in the receptacle spring and hods the fastener locked. (Fig. 14.3).

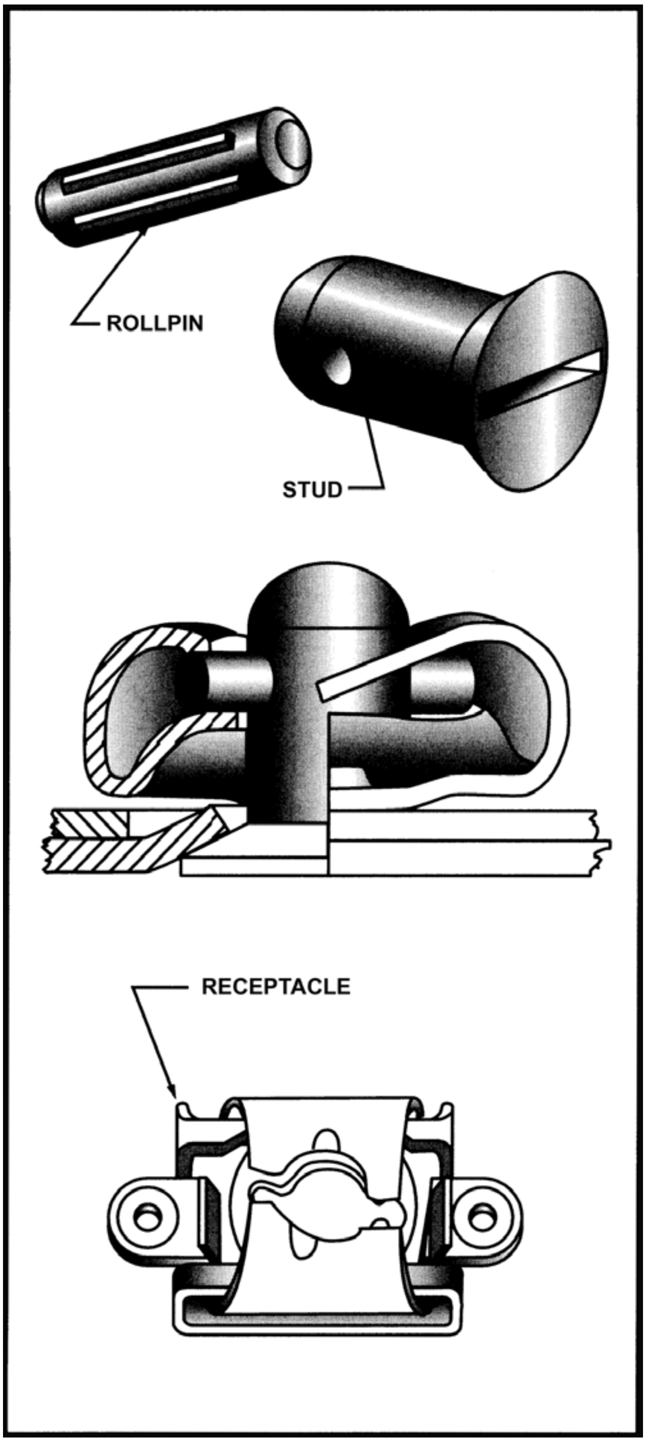

Fig.14.3, Airloc cowling fasteners are similar to Dzus fasteners and are used in many of the same applications

Camlock Fastener

The stud assembly of a Camlock fastener consists of a housing containing a spring and a stud with a steel pin. This assembly is held onto the removable portion of the cowling or access door with a metal grommet. The stud fits into a pressed steel receptacle, and a quarter of a turn locks the steel pin in a groove in the bottom of the receptacle (Fig. 14.4).

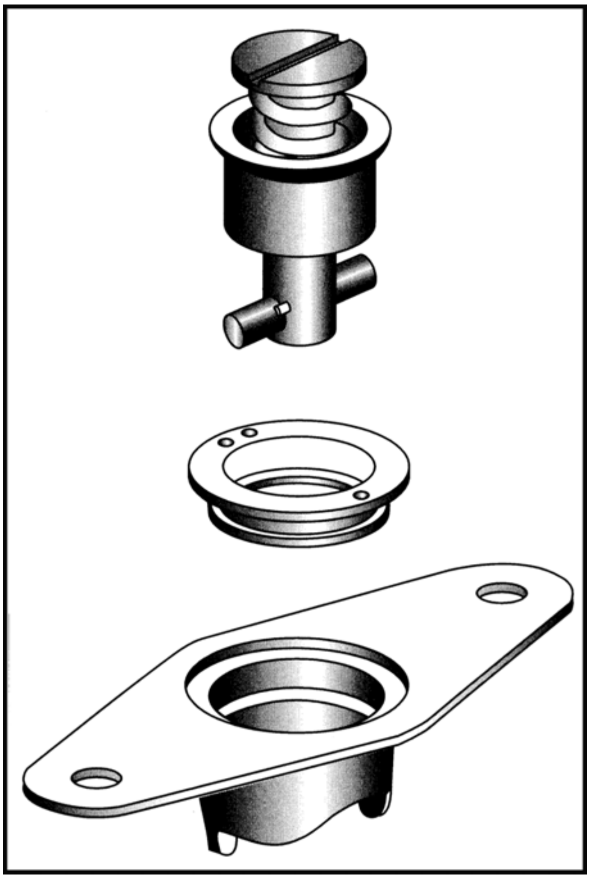

Fig.14.4, With a Camlock cowling fastener the stud assembly can be inserted into the receptacle when the pin is aligned with the slot in the slot in the receptacle.

MS FASTENERS

A wide variety of fasteners is available in the MS range. All of these fasteners are marked to show the material from which they are made or the MS specification to which they conform ; in addition, most fasteners are marked with the manufacturer's identification.

AN FASTENERS

These specifications are in two series. The early series has numbers from 3 to 9000, with the fasteners occupying a range from 3 to 1000; these fasteners are of comparatively low strength, and are manufactured in steel or aluminium alloy. The steel parts are generally manufactured from low-alloy steel, and if non-corrosion-resistant, are cadmium plated, whilst the aluminium parts are anodised. The later series parts have six figure numbers commencing with 1,000,000, are of more recent design and are generally manufactured from higher-strength materials

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CHAPTER-15
KNOWLEDGE OF VARIOUS TYPES OF THREADS, USED IN BRITISH & AMERICAN SYSTEM

SCREW THREADS

CLASSIFICATION OF TYPES OF THREADS

Type of V-threads

I. BS Whitworth Thread

This form of thread is also known as British Standard Whitworth (B.S.W.) thread and has been adopted as standard form in the United Kingdom.

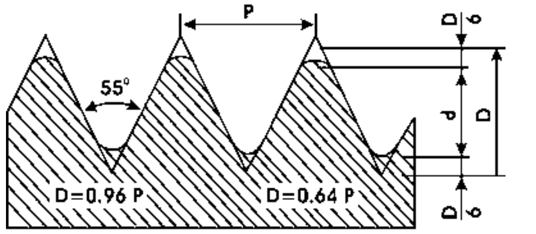

Fig. 15.1, Whitworth thread

The angle is 55°. The theoretical depth D = 0.96P, where P is the pitch of the thread. $\frac{1}{6}$ of the theoretical depth is rounded off at the top and at the bottom. Therefore, the actual depth d = 0.64P.

II. British Association Thread

It is generally used for small instrument screws. The angle of the thread is 47½°. 0.236 of the theoretical depth is rounded off at the top and at the bottom, leaving the actual depth equal to 0.6 P.

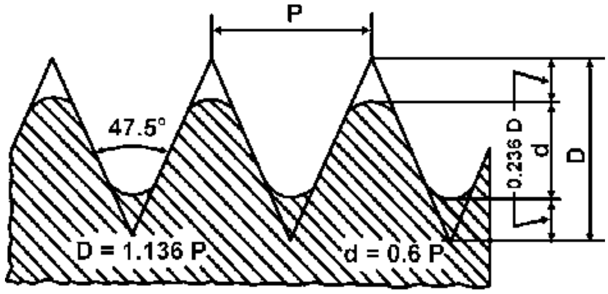

Fig. 15.2, British Association thread.

Theoretical depth, D = 1.136 P
Actual depth, d = 0.6 P.

III. British Standard Pipe Thread (B.S.P.) and British Standard Fine (B.S.F.)

These have the same Whitworth profile but their pitches are finer and hence, the depths smaller. Thus, they have large effective and core diameters than the B.S.W. thread. B.S.F. threads are generally used in automobile and aircraft work. B.S.P. threads are used for gas, steam or water pipes. They are specified by the bore of the pipe and not by the outside diameter. Thus, the outside diameter of a threaded pipe having a bore of 1" nominal diameter is 1.309". Pipes of 1" to 6" diameters have the same number of threads per inch.

IV. American Sellers Thread

This form of thread is adopted as a standard form in U.S.A. It has an angle of 60°. One-eighth of the theoretical depth is cut-off parallel to the axis of the screw at the top and at the bottom. The crests and the roots of this thread are therefore flat.

Theoretical depth, D = 0.866 P

Actual depth, $d = \frac{3}{4}$ D = 0.649 P.

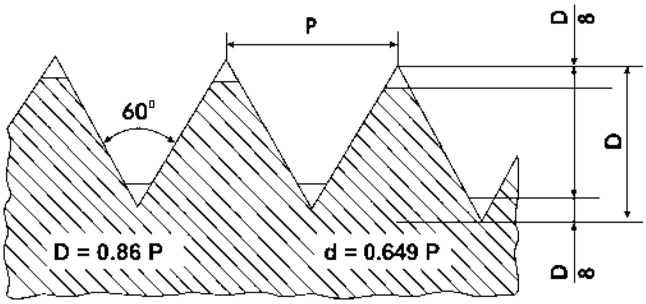

Fig. 15.3, American Sellers Thread

V. Unified Threads

In 1947, the International Organization for Standardization (I.S.O.) of which India, U.S.A., United Kingdom, Canada and a number of other countries are members, came into being, It decided to adopt the Unified screw thread profile as the I.S.O. basic profile. It also decided to recognize two separate I.S.O. series based on inch and metric systems of measurement, with this common basic profile for threads.

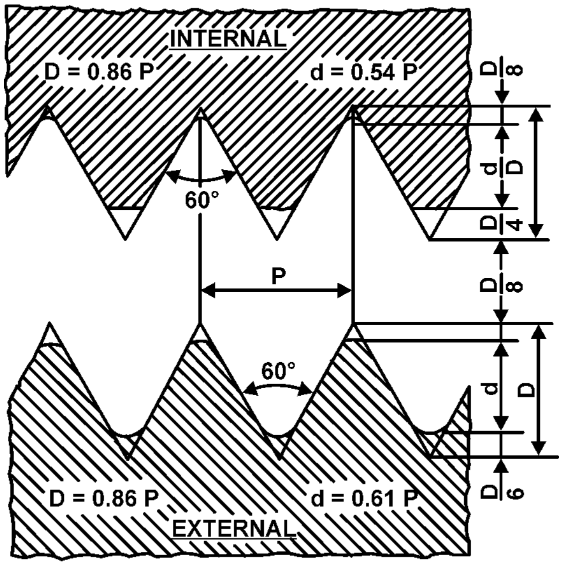

Fig. 15.4, Unified Thread

In this form of thread, the external thread (on a screw) varies slightly in shape from the internal thread (inside a nut) as can be seen from the figure. The angle of the thread is 60°. Roots of both - internal and external - threads are rounded, while the crests are cut parallel to the axis of the screw. The root of the internal thread is rounded within the depth of $\frac{D}{8}$ as shown in the figure.

External thread :

Theoretical depth, D = 0.866 P

Actual depth, $d = \frac{17}{24}$ D = 0.61 P.

Internal thread:

Theoretical depth, D = 0.866 P

Actual depth, $d = \frac{5}{8}$ D = 0.54 P.

The maximum depth of engagement between the external and the internal threads is $\frac{5}{8}$ D.

VI. Metric Threads

The Indian Standards Institution has recommended the adoption of the Unified screw thread profile based on metric system as a standard form for use in India, and has designated it as Metric screw thread with I.S.O. profile. In this system, the pitch of the thread (instead of the number of threads per unit length) is fixed.

Metric thread is designated by the letter M followed by the diameter, e.g. M 20, where 20 is the diameter of the screw in millimetres.

TYPES OF SQUARE THREADS

I. Square Thread

This thread has its flanks or sides normal to the axis and hence, parallel to each other. It is generally used for transmission of power. It is also used for obtaining larger axial movement of the nut or the screw per revolution. For the same nominal diameter of the screw, the pitch of the square thread is usually greater than that of the triangular thread. The depth and the thickness of the thread are each equal to half the pitch.

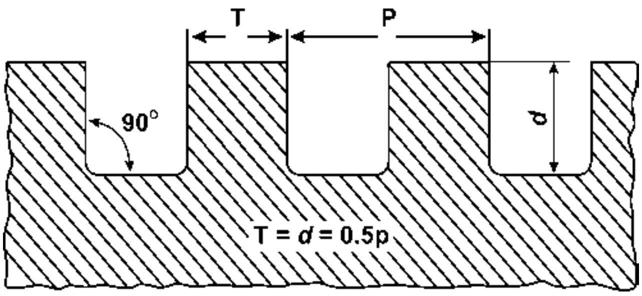

Fig. 15.5, Square thread

II. Butress Thread

This thread is a combination of the triangular and the square threads. One flank of the thread is perpendicular to the axis of the screw. The angle between its two flanks is 45°. The theoretical depth is equal to the pitch, one-eight of which, is cut-off parallel to the axis at the crest and at the root. This thread is suitable only when the force acts entirely in one direction as shown by the arrow F. Its use is commonly made in the screw of a bench-vice.

Theoretical depth, D = P

Actual depth, $d = \frac{3}{4} D = 0.75\,P.$

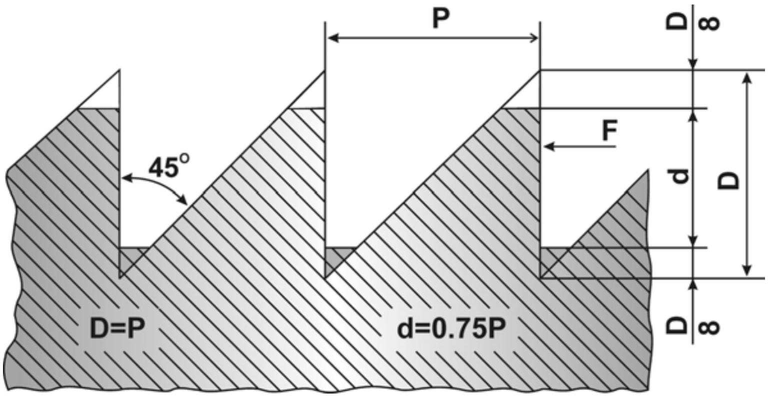

Fig. 15.6, Buttress Thread

III. Acme thread

This thread is a modification on the square thread. It is easier to cut and is stronger at the root than the square thread. It is particularly used where the nut, which is made in two parts, is required to engage with or disengage from a screw at frequent intervals as in the leading screw of the lathe. The thread angle is 29°. Depth d = ½P + 0.01" = 0.5 P + 0.25 mm. The thickness of the thread at the crest is equal to 0.3707 P.

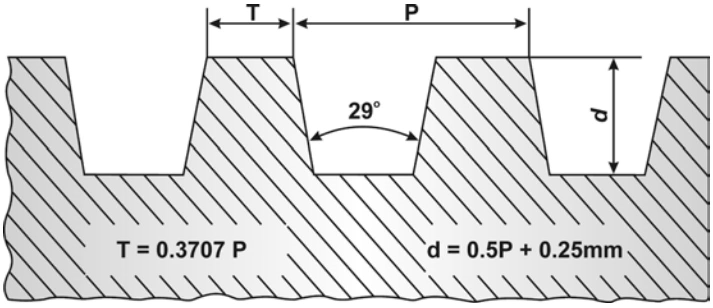

Fig. 15.7, Acme Thread

IV. Knuckle thread

This thread is also a modification of the squre thread. It is formed by rounding off the corners of the squre thread to such an extent that it has a completely rounded profile. Is section comprises of semi-circles of radious R = 0.25 P. The depth d = 0.5 P. This thread can withstand heavy wear and rough usage.

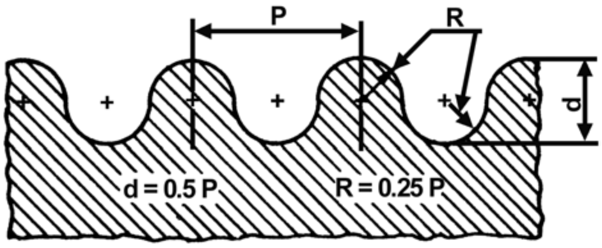

Fig. 15.8, Knuckle Thread.

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INTENTIONALLY BLANK

CHAPTER-16
THREAD FORM

THREADFORM

A standard gauging system is not in itself sufficient to verify completely the thread form, since the form at the crest and root is not controlled by the gauges. For this reason, and as a periodic check on the general quality of thread production, a supplementary inspection of the threads should be made, either by the use of optical instruments or by projecting the threads on to a screen at an appropriate magnification and comparing them with a standard line diagram representing the thread form, drawn to the same magnification. An optical examination or projection of the threads should be carried out on initial production to verify that a satisfactory screw production technique has been established. When checking external threads, this is a convenient point to confirm that the radius between the shank and the head is within permissible limits.

When internal threads are to be examined by a projection process, it will be necessary to take a cast of the threads, care being taken to ensure that the cast is a true reproduction of the thread form.

The form of the thread should be checked to ensure that it is regular and, where radiused roots and crests are specified, that these are correctly formed and blend uniformly with the flanks. When the threads have been truncated, it should be ascertained that the specified length of thread flank has been maintained.

STANDARDOFFINISH

The threads should be examined to ensure that the required standard of surface finish has been attained, and that there is no evidence of tearing or chatter; it is recommended that a magnifying glass of suitable magnification or some other suitable optical instrument is used for this purpose. The standard of finish is largely influenced by the type of material being threaded. One of the most difficult materials to thread is B.S.S. S80, but with a suitable combination of cutting speed, tool materials and angles, and cutting lubricants, a finish equal to the simpler materials can be achieved.

NOTESONUSINGGAUGES

Three types of gauges are in general use for checking external threads, i.e., roller type caliper gauges, anvil type caliper gauges, and ring gauges; of these, the two former types are usually preferred for general gauging.

Caliper gauges, which can be used for checking both left and right hand threads consist of two pairs of rollers or anvils, arranged as illustrated in Figure 16.1. The gauging elements can be adjusted to suit various diameters and are set by means of the special setting plugs. After setting, the adjusting mechanism of the gauge should be sealed to prevent unauthorised adjustments.

Caliper gauges, unlike ring gauges, permit the external threads to be checked for ovality and, threads should always be checked in two positions at right angles to each other.

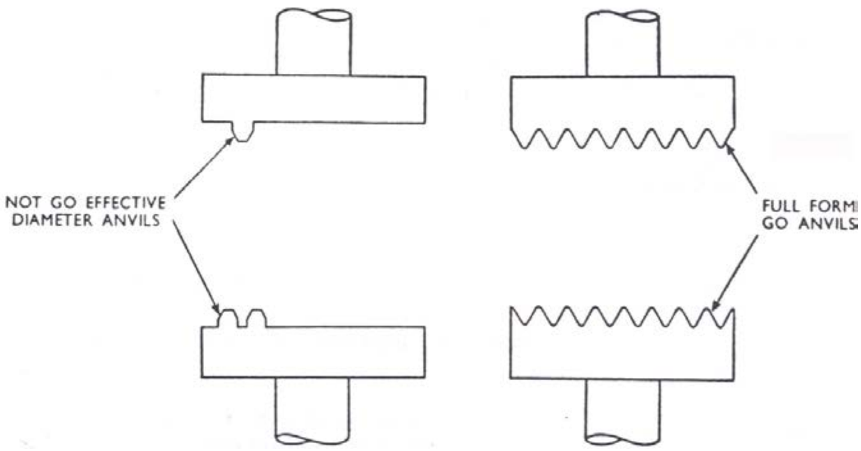

Fig. 16.1 Arrangement of Caliper Gauges

It is essential that the threads should be free of swarf and dirt before gauging is begun, and care should be taken to employ only a light pressure on the gauge to minimise the possibility of springing the frames. When anvil type gauges are used, the items to be checked should be applied from the front of the gauge, and should never be drawn through from the rear.

If the threads will not pass through the "Go" gauge, but will slip easily through the "Not Go" portion, this is indicative of an error in either the thread form of the pitch. The nature of the error can be established by trying the first thread only of the item into the "Go" gauge, and if the thread passes through, it can be assumed that the error is in the pitch, but if it fails to pass through then, assuming the major diameter to be correct, a serious error in flank angle, or malformation of the root or crest, will be indicated.

Ridging or flashes may occur on external threads which have been produced by a moulding or diecasting process, and it is recommended that threads produced by either of these methods should be checked for continuity with a ring gauge.

GENERAL INSPECTION

In addition to gauging the threads, the parts should be inspected for general dimensional accuracy. The majority of thread drawings specify that a "lead", or chamfer, should be applied to the first half or full thread, and this also should be checked for accuracy.

Bolts, and in particular those having short plain shanks, which are produced on automatic machines using automatic die chucks, should be checked to ensure that the final thread is correctly formed, since, for various reasons, the thread form cutter may fail to cut a full final thread.

Rolled threads may be affected by chips in rolling dies, which will produce similar identically repeated bumps on each thread produced from the dies. A proportion of the threads should be examined visually for such defects, since they may not necessarily be revealed by gauging.

UNIFIED THREAD FORM

The basic form of a Unified thread is illustrated in Figure 1 and is derived from an equilateral triangle with one side parallel to the axis of the thread. The triangle is truncated by an amount equal to $\frac{1}{8}$ of its height at the major diameter and $\frac{1}{4}$ of its height at the minor diameter.

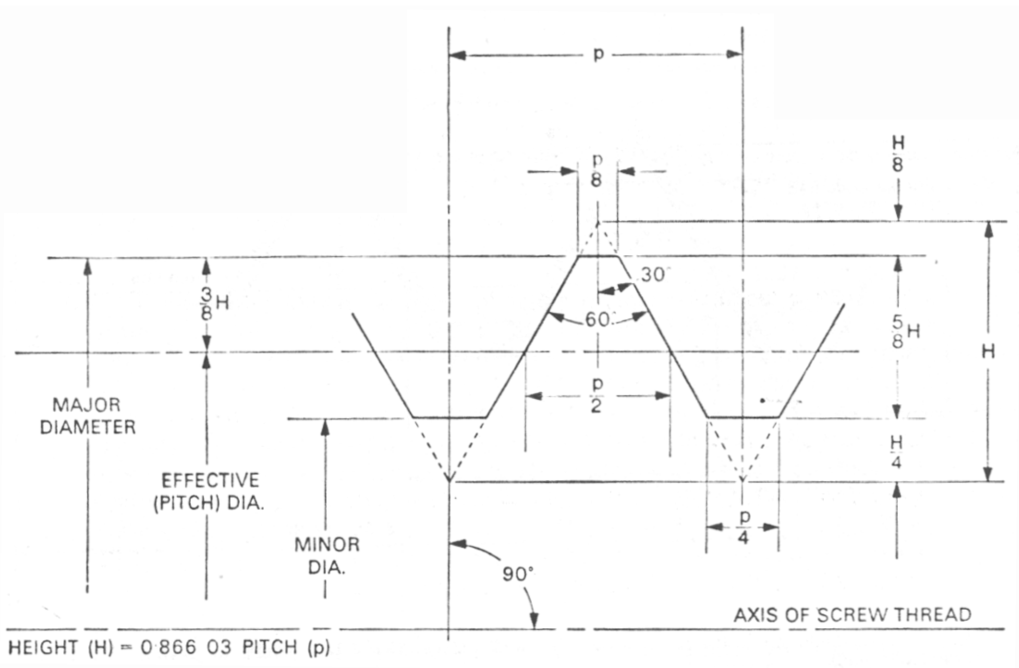

Fig. 16.2, Basic Form of Unified Thread

The design form of the thread (Fig. 16.3), i.e. the thread in its maximum metal condition, varies from the basic form in that the root of the external thread is rounded to a specified radius below the flat. The contact between the design forms of the external and internal thread is confined to the flank over a radial depth of $\frac{5}{8}$ the height of the basic triangle. In practice the root of the internal thread is rounded outside the major diameter to avoid sharp corners.

Modern mass production methods often result in partial or even complete rounding of the external thread crests, but this is not detrimental to the strength of the fastener and does not conflict with the checking methods used. It does render the thread less susceptible to damage and has the added advantage of minimising the plating faults which often occur at sharp corners.

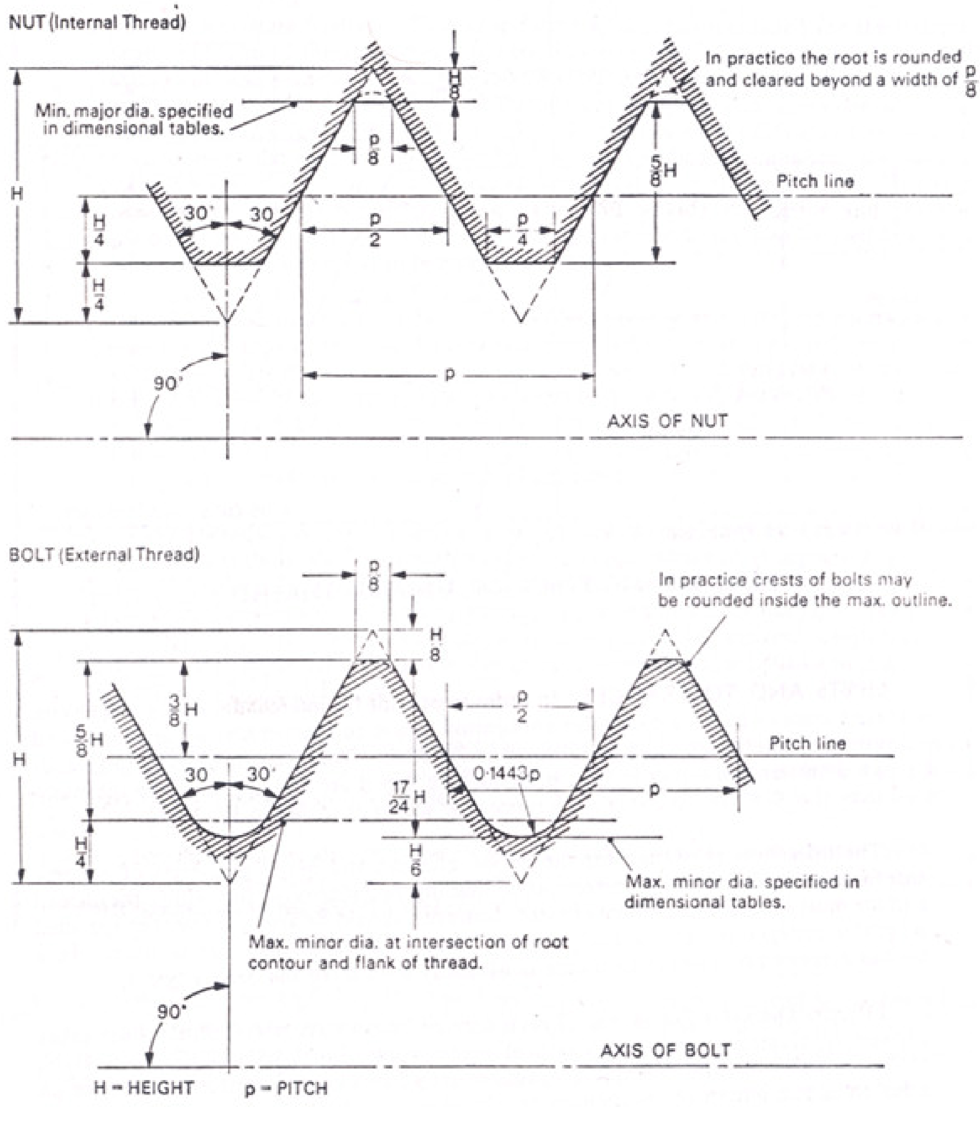

Fig.16.3, Design form of unified thread (Maximum Metal Condition)

LIMITS AND TOLERANCES

In order to provide for interchangeability and ensure the correct class of fit for a particular application, standard Unified threads are controlled by a system of tolerances which are defined in BS 1580. This Standard relates to threads of ¼ inch diameter and larger but the principles employed are also applicable to the numbered sizes (i.e. 8-80 to 10-32) the tolerances for which are listed in BS 3155.

The tolerances permitted for the major, effective and minor diameters of a screw thread provide, in effect, an envelope of limiting boundaries within which the thread surface must lie. The accuracy of pitch, however, should be assessed over the specified length of engagement of the mating parts, since no separate tolerance is given. In a similar manner no separate tolerance is normally quoted for the flank angle.

Effective Diameter Tolerance

This is derived from a three part formula which takes account of diameter, pitch and length of engagement. For UNC, UNF, UNJ, 4UN, 6UN and 8UN threads, a length of engagement equal to one diameter is used; for all other threads a length of engagement of 9 pitches is used.

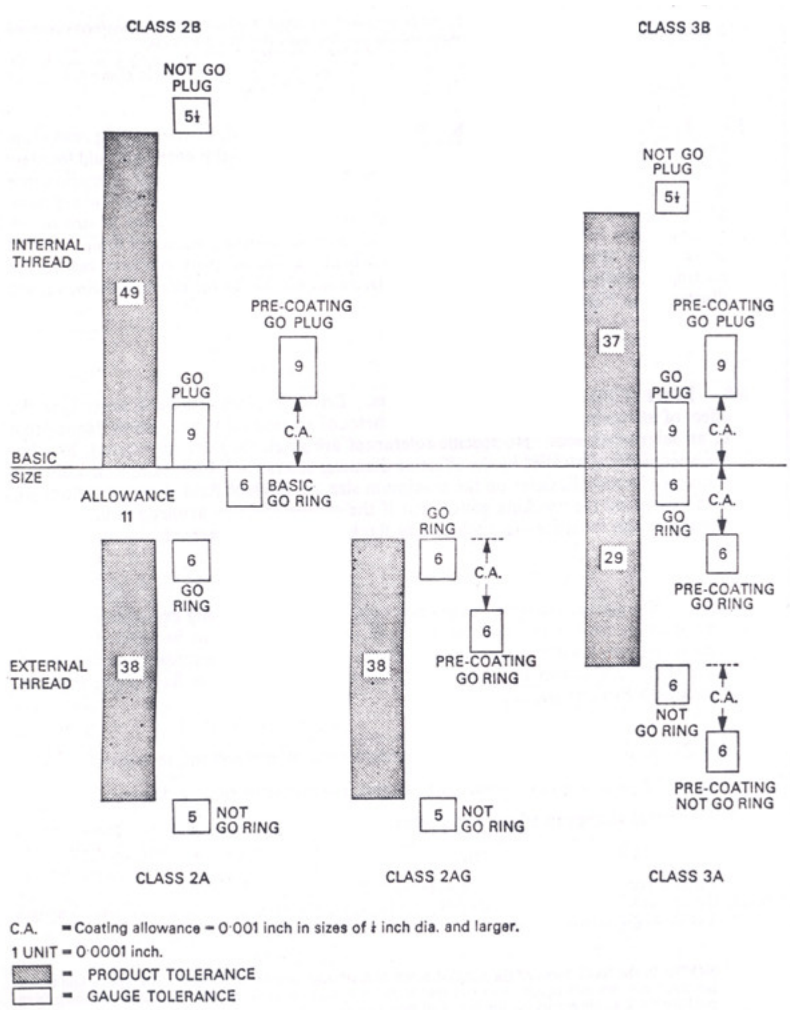

Fig.16.4, Effective Diameter Tolerances

Major Diameter Tolerance

With external threads the tolerance on major diameter is derived solely from a formula based on pitch. With internal threads no tolerance is quoted, it being considered that this dimension will be adequately controlled by the crests of the tap or cutting tool.

Minor Diameter Tolerances

The minor diameter tolerance on external threads is related directly to the effective diameter tolerance. The minor diameter of an internal thread is formed by an operation prior to threading ad the tolerance is related to pitch and diameter.

Depth of Engagement

The depth of engagement (i.e. radial amount of thread overlap) is 5H/8 for standard Unified threads and 9H/16 for UNJ threads when mating threads are in the maximum metal condition. This is reduced by the tolerances permitted on the major diameter of the external thread and the minor diameter of the internal thread.

Allowance

This is the design clearance permitted between mating threads and is deducted from the basic size of the external thread. The allowance for Class 1A and 2A threads is 30 per cent of the Class 2A effective diameter tolerance but there is no allowance permitted for Class 3A threads.

Note : Due to the tendency of close fitting fasteners of unplated stainless steel to seize when tightened it is recommended that stainless steel bolts should not be made to Class 3A limits.

Provision for Coated Threads

Where specified, a depth of coating (e.g., cadmium or tin) of 0.0002 inch is normally required on all threads and this coating would interfere with the thread tolerances if not taken into account during manufacture. The allowance for Class 2A threads is normally permitted to be absorbed by the coating and it is, therefore, unnecessary for the thread to be reduced in size before coating. For other external threads and all internal threads, diametral limits are laid down in the appropriate specification, to which the thread must conform before the coating is applied. The appropriate limits, as applicable to the effective diameter, are illustrated in Figure 16.4.

Effect of Pitch and Flank Angle Errors

Errors in pitch and flank angle have the effect increasing the simple effective diameter of an external thread and decreasing that of an internal thread. No specific tolerances are given for parameters, but they are adequately controlled by the effective diameter tolerance. For example, if a bolt has a simple effective diameter on the maximum size, no pitch or flank angle deviations will be accepted by the checking gauge, but if the simple effective diameter is of minimum size then some deviations in pitch and/or flank angle will be accepted.

Should the requisite gauges not be available, e.g. during experimental of preproduction conditions, and the accuracy of the threads is to be verified by direct measurement, it will be necessary to measure all elements of the threads and to compute the effective diameter in relation to possible errors in pitch or flank angle from the following formula:-

If Z = Maximum pitch error over specified length of engagement, in inches,
A_1 and A_2 = errors in opposite flank angles, regardless of sig n, in degrees,
E = Virtual change in effective diameter,
P = Basic pitch of thread, then,
Pitch Error = $E = 1.732 \times Z$
Flank angle error = $E = 0.01 \times P (A_1 + A_2)$

Note : In the basic from of the Unified screw thread, the lengths of straight flank above and below the pitch line are not equal. For this reason the virtual change in effective diameter resulting from positive flank angle errors on the bolt and negative flank angle errors on the nut will be slightly less than that resulting from negative flank angle errors on the bolt and positive flank angle errors on the nut. The factor 0.01 in the expression above is the mean value of the corresponding factors applying to these two sets of conditions and is sufficiently accurate for practical purposes.

CLASSIFICATION OF THREADS

Aircraft bolts, screws, and nuts are threaded in either the NC (American National Coarse) thread series, the NF (American National Fine) thread series, the UNC (American Standard Unified Coarse) thread series, or the UNF (American Standard Unified Fine) thread series. There is one difference between the American National series and the American Standard Unified series that should be pointed out. In the 1-inch-diameter size, the NF thread specified 14 threads per inch (1-14NF), while the UNF thread specifies 12 threads per inch (1-12 UNF). Both type threads are designated by the number of times the incline (threads) rotates around a 1-inch length of a given diameter bolt or screw. For example, a 4-28 thread indicates that a ¼-inch -diameter bolt has 28 threads in 1 inch of its threaded length.

DIMENSIONS AND TOLERANCE

Threads are also designated by Class of fit. The class of a thread indicates the tolerance allowed in manufacturing. Class 1 is a loose fit, Class 2 is a free fit, Class 3 is a medium fit, and Class 4 is a close fit. Aircraft bolts are almost always manufactured in the Class 3, medium fit.

A Class 4 fit requires a wrench to turn the nut onto a bolt, whereas a Class 1 fit can easily be turned with the fingers. Generally, aircraft screws are manufactured with a Class 2 thread fit for ease of assembly.

Bolts and nuts are also produced with right - hand and left - hand threads. A right - hand thread tightens when turned clockwise; a left - hand thread tightens when turned counterclockwise.

MEASUREMENT OF BRITISH ASSOCIATION AND WHITWORTH FORM SCREW THREADS

INTRODUCTION

The inspection of screw threads produced by recognised methods such as machining, dieing, tapping, rolling, etc. Where it is necessary to achieve the maximum resistance to fatigue, bolts produced by a rolling process are usually preferred.

The accuracy of screw threads should be verified by a system of gauging, and a suitable system, together with the ancillary checks considered necessary to ensure compliance with the specified drawing requirements.

SCREW THREAD SPECIFICATIONS

The specifications for screw threads of Whitworth form, i.e. British Standard Whitworth (B.S.W.), and British Standard Fine (B.S.F.), are defined in British Standard, No. 84 : 1956, whilst those for British Association (B.A.) threads are given in British Standard, No. 93 : 1951. The specifications for British Standard Pipe (B.S.P.) parallel threads were given in B.S. 84 : 1940, but are not included in the latest issue of this specification since they are now covered in B.S. 2779 : 1956 entitled "Fastening Threads of B.S.P. Sizes".

The above specifications define the basic series of diameters and corresponding pitches, together with recommended tolerances and limits. In B.S. 84 : 1956 there are also included recommended tolerances for other threads of Whitworth form up to twenty inches diameter.

There is no specification in the B.S. range dealing with brass threads, which are of Whitworth form, 26 threads per inch.

SCREW THREAD TERMINOLOGY

For the benefit of those not familiar with screw thread terminology, a glossary is given below.

Angle of Thread

The included angle between the flanks of a thread, measured in an axial plane section.

Axis of Thread

The longitudinal centre line through the threaded portion.

Basic Size

The nominal standard dimensions of the threads from which all variations are made.

British Association Threads

A system of metric threads, confined to small sizes ranging from 6 mm. to 0.25 mm. in diameter and from 1 mm. to 0.171 mm. pitch. The diameters are designated in numbers ranging from 0 to 25. The thread is of a symmetrical "V" formation of $47\frac{1}{2}°$ included angle, having its crests and roots rounded with equal radii, such that the basic depth of the thread is 0.60 of the pitch.

British Standard Fine

A thread of Whitworth form, but of a finer pitch for a given diameter.

British Standard Pipe

A thread of Whitworth form, designated originally by the bore of the pipe on which it was formed and not by its major diameter, which is a decimal size, slightly smaller than the outside diameter of the pipe.

British Standard Whitworth

The standard British thread. It is a symmetrical "V" thread of 55^0 included angle, with a radius at root and crest of 0.1373 x pitch. The pitch of the thread is standardised for given diameters.

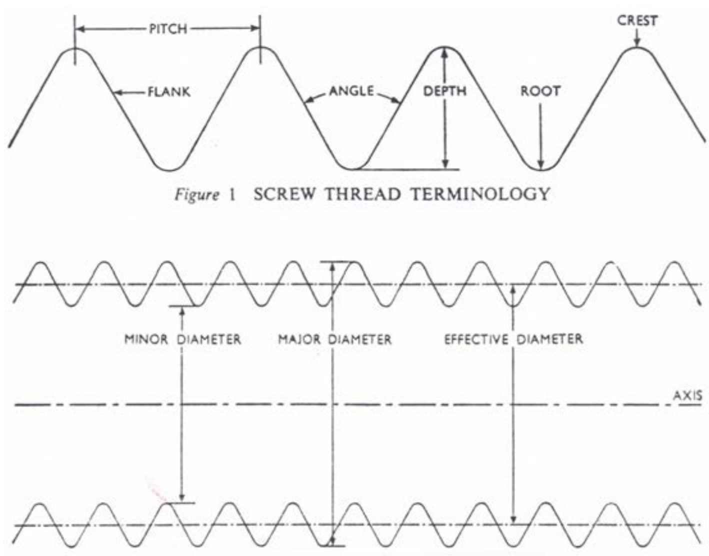

Fig. 16.5, Screw Thread Terminology

Crest
That part of the surface of a thread which connects adjacent flanks at the top of the ridge.

Depth of Thread
The distance between the root and crest, measured at right angles to the axis.

Effective Diameter
Simple Effective Diameter
The diameter of the pitch cylinder of the parallel thread or the pitch cone of a taper thread, in a specified plane normal to the axis. With Whitworth threads of nominal form, the simple effective diameter occurs halfway down the flanks and its nominal value may be obtained by subtracting one depth of thread from the nominal major diameter.

Virtual Effective Diameter
The effective diameter of an imaginary thread of perfect pitch and angle, having the full depth of flanks, but clear at the crests and roots, which would just assemble with the actual thread over the prescribed length of engagement. The virtual effective diameter exceeds the simple effective diameter with external threads, but is less than the simple effective diameter with internal threads, by an amount corresponding to the diametrical effects due to any errors in the pitch and/or flank angles of the thread.

Flank
The surface of the thread which connects the root and the crest.

Flank Angle
The angle between the flank of the thread and a line drawn perpendicular to the axis.

Lead
The distance a screw advances axially in one complete turn.

Length of Engagement
The axial distance over which two mating threads are designed to make contact.

Major Diameter
The largest diameter of the thread measured in a plane normal to the axis.

Minor Diameter
The smallest diameter of the thread measured in a plane normal to the axis.

Pitch
The distance from the centre of one crest to the centre of the next, measured parallel to the main axis.

Root
That part of the surface of the thread which connects adjacent flanks at the bottom of the groove.

Truncation
A truncated thread is one having flat crests, e.g. in the truncated Whitworth form thread, the basic rounded crests at the major diameter of an external thread and the minor diameter of an internal thread are removed at their junctions with the straight flanks of the basic thread form.

LIMITS AND TOLERANCES OF THREADS
To permit control of screw thread dimensions during production, drawings should stipulate the nominal size, specification reference and class, whilst for screw threads of special diameter/pitch relationships, or for interference fits, the drawings should specify the toleranced sizes for the major, effective and minor diameters. If such information is not given, the guidance of the designer should be sought.

The major diameter of internal threads is controlled in practice by the major diameters or the taps of screwing tools used to cut the threads, thus a tolerance is not usually specified, but only a minimum size, which should be the same as the basic major diameter. However, a sharp root radius should be avoided, and the screwing tools used should be capable for producing a root radius equal at least to one-half of the standard radius for the pitch concerned.

The tolerances permitted for the major, effective and minor diameters of a screw thread provide, in effect, an envelope of limiting boundaries within which the thread form must lie. The accuracy of pitch, however, should be assessed over the specified length of engagement of the mating parts, since no separate tolerance is given. In a similar manner, no tolerance is usually quoted for the flank angle.

Effect of Pitch and Flank Angle Errors
Errors in the pitch and flank angles of a thread virtually increase the effective diameter of an external thread, and decrease that of an internal thread. For threads to be acceptable, therefore, it is necessary to ensure that any compounding of the effective diameter by pitch and flank angle errors does not cause the upper limit of the effective diameter of external threads, or the lower limit of that of internal threads, to be exceeded.

The size of the effective diameter, whether or not influenced by pitch or flank angle errors, is automatically safeguard provided the thread is found to be acceptable by the gauging system. However, if the requisite gauges are not available, e.g. during experimental or pre-production conditions, and the accuracy of the threads is to be verified by direct measurement, it will be necessary to measure all elements of the threads, and to compute the effective diameter in relation to possible errors in the pitch and flank angles from the following formulae.

IF Z = maximum pitch error over specified length of engagement.
A_1 and A_2 = errors in opposite flank angles, regardless of sign, in degrees.
E = virtual change in effective diameter.
P = basic pitch of thread.

i. For Whitworth threads:
   - Pitch error .. .. $E = 1.921 \times Z$.
   - Flank angle error .. .. .. $E = 0.0105 \times P(A_1 + A_2)$.

ii. For B.A. threads:
   - Pitch error .. .. $E = 2.273 \times Z$.
   - Flank angle error .. .. .. $E = 0.0091 \times P(A_1 + A_2)$.

Classes of Fit
Whitworth Form Threads
Three classes of fit for external threads and two classes for internal threads are provided in B.S. 84 : 1956 and are as follows:

i. ***Close Class External Threads***
This class applies to threads where a good snug fit is required. It is obtainable consistently only by the use of the highest quality production equipment, supported by an accurate system of inspection and gauging. It is normally used for special work where refined accuracy of pitch and thread form is particularly required.

ii. ***Medium Class Internal and External Threads***
This class of fit applies to the better class ordinary interchangeable screw threads.

iii. ***Free Class External Threads***
This class applies to the majority of ordinary commercial quality bolts.

iv. ***Normal Class Internal Threads***
This class applies to the ordinary commercial quality nuts which are intended for use with medium or free class bolts.

B.A. Threads
Provision is made in B.S. 93 : 1951 for one class of fit for internal threads, size 0 B.A.. to 16 B.A., and two classes for external threads, i.e. close class for sizes 0 B.A. to 10 B.A.. and normal class for sizes 0 B.A. to 16 B.A. Close class fit are not given for external threads, sizes 11 B.A. to 16 B.A., since such bolts are not normally highly stressed.

i. ***Close Class External Threads***
This class applies to threads where a good snug fit is required. It is obtainable consistently only by the use of the highest quality production equipment, supported by an accurate system of inspection and gauging. It is normally used for special work where refined accuracy of pitch and thread form is particularly required.

ii. ***Normal Class External Threads***
This class applies to threads produced for general commercial use, and is suitable for general engineering purposes.

Plated Threads
In order to avoid any undue restriction of screwing tolerances, and also to prevent the removal of the plating during assembly, for threads which are plated with metals such as cadmium, nickel, etc., where the usual thickness of the plating is in the order of 0.0002 in., the following arrangements are permitted by B.S.. 84 : 1956 and B.S. 93 : 1951.

For Whitworth external threads of either medium or free class, it is necessary to ensure that the threads prior to plating are not undersize, and that the maximum sizes are not exceeded after plating. For external threads to the close class, the tolerances may be displaced by an amount not exceeding 0.001 in. before plating.

For B.A. external threads of normal class, sizes 11 B.A. to 16 B.A. and all close class threads, the lower limits of the minor, effective and major diameters may be reduced by an amount not exceeding 0.001 in. before plating.

Due to the tendency of class fitting bolts and nuts manufactured of stainless steel to seize when tightened together, it is recommended that Whitworth form bolts manufactured in this material, in sizes up to and including $\frac{3}{4}$ in., should not be made to “close” class limits before plating, but rather to the “medium” or “free” class limits for unplated bolts, whilst B.A. bolts made of stainless steel should be made to the “normal” class limits for unplated bolts.

INSPECTION OF SCREW THREADS
An inspection of the threads should be made to verify that the drawing requirements in respect of dimensional accuracy, thread form and standard of finish are met. Information on implementing these inspections is given in paragraph 7 to 11, whilst a description of the equipment to be used is given in the following paragraph.

THREAD GAUGES
The system of “Workshop” and “Inspection” grade gauges recommended in B.S. 919 : 1940 has been superseded in B.S. 919 : 1952 by a system of gauges designated “General” and “Reference” grade gauges. General and Reference grades are provided for “Go” screw plug, ring and caliper gauges and their associated setting plugs, but for “Not Go” screw gauges and “Go” and “Not Go” major diameter gap gauges and minor diameter plug gauges, B.S. 919 : 1952 recommends the use of General grade gauges only.

General Gauges
These gauges are so dimensioned as to control the thread flanks within the specified work limits, i.e., the gauge tolerances lie within the work limits. The use of General gauges is recommended for medium and free fit class Whitworth form threads and for all classes of B.A. threads.

Reference Gauges
These gauges are designed around the nominal size of the thread with a minimum encroachment into or outside the work tolerance. The principal uses of Reference gauges are as referees in case of doubt, thus serving as a check on the continued accuracy of General gauges, and for checking threads which have been manufactured to close class tolerances.

"Go" Gauges

These gauges are designed to control the maximum diameter and pitch of the external thread and the minimum diameter and pitch of the internal thread. The gauges are manufactured to the thread form and gauge length specified in B.S. 919:1952.

"Not Go" Gauges

"Not Go" effective diameter gauges are also designed to comply with the requirements of B.S. 919 : 1952, where it is specified that the threads should be cleared at the crests and roots in order to permit control of the effective diameter only. To minimise the possibility of pitch error affecting the result, the gauges embody not more than two or three turns of thread.

Accuracy of Gauges

It is important that all thread gauges should be checked periodically to ensure that they are not worn beyond permissible limits or are otherwise inaccurate. Checking is normally done by skilled inspectors, and if the gauges are in continuous use, a daily check is desirable. If the work is of an intermittent nature, a weekly check should suffice, but if the work is being handled in "short runs", a check before and after use is recommended.

Each gauge should bear a serial number, and records of all checks should be kept.

Where resetting is necessary in the instance of adjustable gauges, setting plugs of guaranteed accuracy should be used.

Setting Plugs

Setting plugs are screw plug gauges to which adjustable screw ring and clipper gauges are set. They have truncated crests and are cleared at the roots to ensure contact only with the flanks of the threads of the gauge being set. General setting plugs should be used for General "Go" gauges and Reference setting plugs should be used for Reference "Go" gauges.

General

It is recommended that the handles of the various types of gauges, i.e. general, reference, pre-plating, etc., should be painted in different colours to reduce the risk of an incorrect gauge being used.

GAUGINGSYSTEM

Gauging of External Threads

The following gauges should be used when checking external threads to ensure compliance with the drawing requirements.

A "Go" full form caliper or ring gauge to control the maximum diameter of the thread, and to ensure that the pitch is acceptable over the specified length of engagement.

A "Not Go" effective diameter thread caliper gauge to control the minimum effective diameter of the thread.

A "Not Go" major diameter gap gauge to control the minimum major diameter of the thread.

When truncated threads are to be checked, "Go" and "Not Go" major diameter gap gauges, specially dimensioned for truncated threads, should be used to control the major diameter.

Gauging Internal Threads

The following gauges should be used when checking internal threads to ensure compliance with drawing requirements.

A "Go" full form screw plug gauge to control the minimum diameter of the thread, and to ensure that the pitch is acceptable over the specified length of engagement.

A "Not Go" effective diameter screw plug gauge to control the maximum effective diameter of the thread.

A "Not Go" minor diameter plug gauge to control the maximum minor diameter of the thread.

When truncated threads are to be checked, "Go" and "Not Go" minor diameter plug gauges, specially dimensioned for truncated threads, should be used.

Observation should be made to ensure that the axis of the thread through the nut is at right angles to the end faces. This is particularly important in larger nuts which may be used at predetermined torque loadings on ground-threaded high tensile bolts or studs.

Gauging Plated Threads

External Threads

Prior to plating, the threads should be checked with a "Not Go" effective diameter caliper gauge to control the minimum effective diameter specified prior to plating, and a "Not Go" major diameter gap gauge, made to control the minimum major diameter specified prior to plating.

i. After plating, the threads should be checked with a "Go" full form thread caliper or ring gauge to control the maximum diameter of the thread.

ii. When plated truncated threads are to be checked, a "Go" major diameter gap gauge, specially dimensioned for truncated threads, should be used to control the major diameter.

Internal Threads

Prior to coating, the threads should be checked with a "Not Go" effective diameter screw plug gauge to control the maximum effective diameter specified prior to plating, and a "Not Go" minor diameter plug gauge, made to control the maximum minor diameter specified prior to plating.

i. After plating, the threads should be checked with a "Go" full form screw plug gauge to control the minimum diameter of the thread.
ii. When plated truncated threads are to be checked, "Go" minor diameter plug gauge, specially dimensioned for truncated threads, should be used to control the minor diameter.

Relaxation of Gauging

When a quantity of identical threads are to be produces, and it has been verified by inspection that a satisfactory production technique has been established, the gauging operations described above may be selectively applied at the discretion of the Chief Inspector. for rolled threads, evidence of identical conditions of manufacture would consist of ensuring that the machines producing the threads had been fed with blanks adequately controlled as to size and ductility, that the machines had been correctly set prior to each run, and that the threads produced by each machine had been checked periodically during each run to verify their continued dimensional accuracy.

AMERICAN THREAD

Aircraft bolts, screws and nuts are threaded in either the NC (American National Coarse) thread series, the NF (American National Fine) thread series, the UNC (American Standard Unified coarse) thread series or the UNF (American Standard Unified Fine) Thread Series. There is one difference between the American National Series and the American Standard Unified Series that should be pointed out. In the one inch diameter size, the NF thread specified 14 threads per inch (1 - 14 NF) while the UNF thread specifies 12 threads per inch (1 - 12 UNF). Both type threads are designated by the number of times the incline (threads) rotates around a one inch length of a given diameter bolt or screw. For example, a 4 - 28 thread indicates that a ¼ inch diameter bolt has 28 threads in one inch of its threaded length.

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CHAPTER-17
BOLTS AND SCREWS OF BRITISH MANUFACTURE
(IDENTIFICATIONMARKING)

INTRODUCTION

This chapter gives guidance on the identification of bolts and screws complying with British Standards 'A' Series of Aircraft Materials and Components and the Society of British Aerospace Companies 'AS' series of specification. The chapter does not include information on the 'AGS' series since these have been entirely superseded by other standards. Information on the manufacture and testing of bolts and screws will be found in British Standards A100 and A101m entitled ''General Requirements for Bolts and Nuts of Tensile Strength not exceeding 180000 lbf/in^2 (125 bar)'', and ''General Requirements for Titanium Bolts'', respectively.

The identification of bolts and screws located on aircraft may not always be an easy task since not all are marked to show the standard to which they conform. This chapter sets out to show the features from which positive identification may be made, but it should be understood that items exist, which although identical in appearance, may not be interchangeable. It is also important to understand the direction of stress in a particular bolt since a 'shear' bolt must not be used to replace a 'tension' bolt. If any doubt exists as to the identity of a particular item the appropriate Parts Catalogue should be consulted; replacement of an incorrect part may lead to failure in service.

It will be found that a number of Specifications are either obsolete or obsolescent, in some instances due to standardisation of a countersunk head of 100^0 included angle. The replacements are indicated in the tables.

A list of the abbreviations used in the chapter is given in at the end of this chapter.

BRITISH STANDARDS

a. **Bolts and Screws with BA or BSF Threads**

In this series, BSF threads are used on bolts of ¼-inch diameter and larger; smaller bolts and all screws have BA threads, except that grub screws are also supplied in ¼-inch BSF. BA sizes larger than 2 BA are not specified. Table 17.1 gives a list of the relevant Standards, superseding Standards and identification data appropriate to the series, and Figure 17.1 illustrates the types of head used. To find the Standard number of a given item proceed as follows:-

b. Identify the head from Figure 17.1, for example '(ℓ)'. Reference to Table 1 shows that '(ℓ)' refers to an A61 bolt. If the illustration applies to more than one specification, further information contained in the table, such as the type of finish, should enable the identification to be completed.

In some instances, e.g. A31 to A56 in Table 17.1, identification can only be effected from the finish applied (mechanical testing apart), or by the labelling on packages.

Code Systems for Bolts

The code system used for the identification of the bolts listed in Table 17.1 consists of the standard number followed by the part number of the particular bolt. The part number consists of a number indicating the nominal length of the plain portion of the shank in tenths of an inch, followed by a letter indicating the nominal diameter (Table 17.2). Example : The complete part reference number for a 3/8 inch A57 bolt of length L = 3.1 inch is A57 31J.

i. All bolts to British Standards A25, A26, A30, A57, A59, A60, and A61 of 1/4 inch nominal diameter and over are marked with the appropriate British Standard on the upper face of the head. Additionally, bolts of 7/16 inch nominal size and larger have the appropriate part number applied to the upper face of the head. Parcels of bolts have the number of the relevant British Standard and the appropriate part number clearly stated on the labels.

ii. The positions at which the plain length is measured on hexagon bolts and the overall lengths on various types of screws are indicated in Figure 17.2. It should be noted that with BA and BSF bolts, the plain portion of the shank includes the thread 'run-out'. A 'washer face' [e.g. Figure 17.1 (b)] on the under surface of a bolt head is not included in the plain length of the shank.

Code System for Screw (A31 to A46)

The code system used for the identification of the screw listed in Table 17.1 consists of the British Standard number followed by the part number of the particular screw. The part number consists of a number indicating the nominal length of the screw (in thirty-seconds of an inch) when measured as described below (see also Figure 17.2) preceded by a letter indicating the nominal diameter (Table 17.2). Example: The complete part referencing number for a 2 BA A41 countersunk head aluminium alloy screw 1/2 inch long, is A41 C16.

TABLE 17.1
BA AND BSF BOLTS AND SCREWS

Standard No.	Description	Material	Finish	Head (Fig. 1)	Remarks	Thread	Normal Size Range
A17	Hex. hd. bolt	Al Al	anodic	e or f	obsolescent	BA/BSF	6BA to 1 in BSF
A25	Hex. hd. bolt	HTS	cad	a,b,c or d	replaces A15Y	BA/BSF	6 BA to 1 in BSF
A26	Hex. hd. bolt	CRS	nat	a	replaces A15Z	BA/BSF	6BA to 1 in BSF
A28	Hex. hd. bolt	Al Al	anodic	g or h	obsolescent	BA/BSF	6 BA to 1 in BSF
A30	Hex. hd. c/t bolt	HTS	cad	i or j	cad h & t	BA/BSF	6 BA to 1 in BSF
A31	Cheese hd. screw	LTS	cad	o	replaces AGS 247	BA	12 BA to 2 BA
A32	Round hd. screw	LTS	cad	n	replaces AGS 245	BA	10 BA to 2 BA
A33	90° csk. hd. screw	LTS	cad	q	replaces AGS 249	BA	12 BA to 2 BA
A34	Raised csk. hd. screw	LTS	cad	p		BA	10 BA to 2 BA
A35	Cheese hd. screw	CRS	nat	o	replaces AGS 896	BA	12 BA to 2 BA
A36	Round hd. screw	CRS	nat	n	replaces AGS 967	BA	10 BA to 2 BA
A37	90° csk. hd. screw	CRS	nat	q	replaces AGS 968	BA	12 BA to 2 BA
A38	Raised csk. hd. screw	CRS	nat	p		BA	10 BA to 2 BA
A39	Cheese hd. screw	Al Al	anodic	o		BA	12 BA to 2 BA
A40	Round hd. screw	Al Al	anodic	n	replaces AGS 564	BA	10 BA to 2 BA
A41	90° csk. hd. screw	Al Al	anodic	q		BA	12 BA to 2 BA
A42	Raised csk. hd. screw	Al Al	anodic	p		BA	10 BA to 2 BA
A43	Cheese hd. screw	Brass	tinned	o	replaces AGS 246	BA	12 BA to 2 BA
A44	Round hd. screw	Brass	tinned	n	replaces AGS 244	BA	10 BA to 2 BA
A45	90°csk. hd. screw	Brass	tinned	q	replaces AGS 248	BA	12 BA to 2 BA
A46	Raised csk. hd. screw	Brass	tinned	p		BA	10 BA to 2 BA
A55	Grub screw	FCS	cad	none		BA/BSF	6 BA to ¼ BSF
A56	Grub screw	CRS	nat	none		BA/BSF	6 BA to ¼ BSF
A57	Hex. hd. shear bolt	HTS	cad	k	cad h & t only	BSF	¼ to ¾ in BSF
A59	Hex. hd. c/t bolt	HTS	cad	i		BA /BSF	6 BA to 1 in BSF
A60	Hex. hd. shear bolt	HTS	cad	k		BSF	¼ to ¾ in BSF
A61	Hex. hd. bolt	Al Al	anodic	l or m	replaces A28	BA/BSF	6 BA to 1 in BSF

TABLE 17.2
DIAMETERCODELETTERS

Code	Size	Code	Size
A	6 BA	P	$\frac{9}{16}$ in BSF
B	4 BA	Q	$\frac{5}{8}$ in BSF
C	2 BA	S	$\frac{3}{4}$ in BSF
E	¼ in BSF	U	$\frac{7}{8}$ in BSF
G	$\frac{5}{16}$ in BSF	W	1 in BSF
J	$\frac{3}{8}$ in BSF	X	12 BA
L	$\frac{7}{16}$ in BSF	Y	10 BA
N	½ in BSF	Z	8 BA

i. ***Cheese and Round Heads***
The nominal length is the distance measured from the surface of the head to the extreme end of the shank, including any chamfer or radius.

ii. ***Countersunk Heads***
The nominal length is the distance measured from the upper surface of the head to the extreme end of the shank, including any chamfer or radius.

iii. ***Raised Countersunk Heads***
The nominal length is the distance measured from the upper surface of the head (excluding the raised portion) to the extreme end of the shank, including any chamfer or radius.

Code System for Grub Screws Complying with A55-A56

The code system used for these screws consists of the British Standard number followed by the part number of the particular screw. The part number consists of a number indicating the overall length of the screw in sixteenths of an inch, preceded by a letter indicating the nominal diameter. Example: The complete part referencing number for a 1/4 inch diameter A55 screw, ½-inch long, would be A55 8.

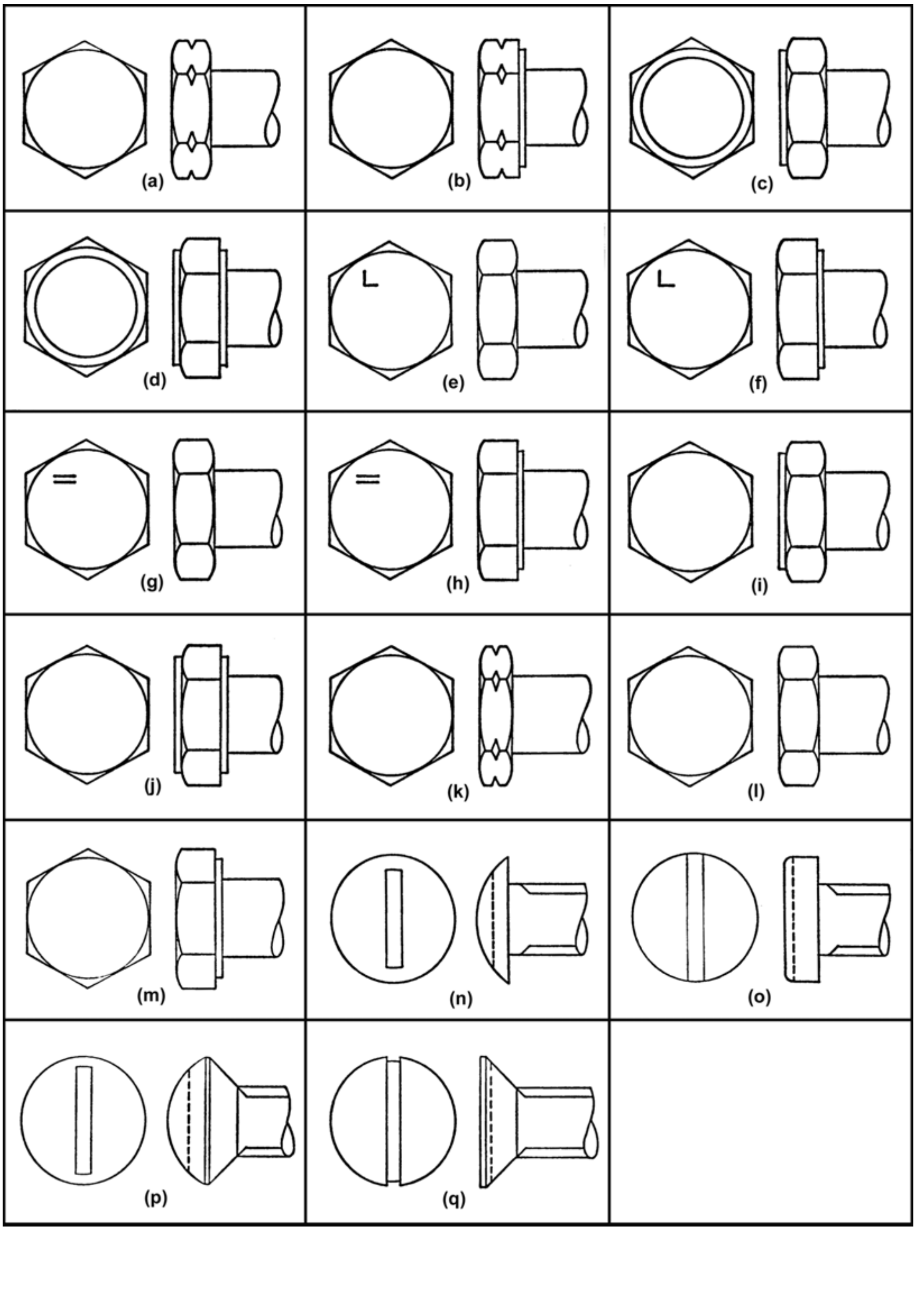


Fig. 17.1, Identification of British Standards BA/BSF Bolts and Screws.

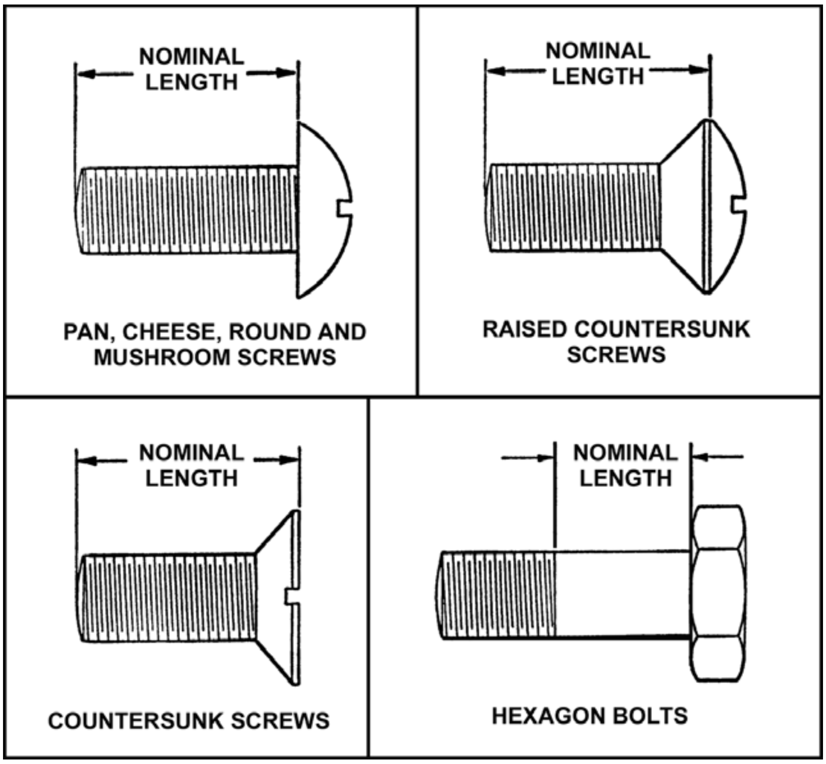


Fig. 17.2, Length of BA/BSF Bolts and all Screws.

Bolts and Screws Having Unified Threads

Table 17.3 gives a list of current and obsolescent bolts and screws in the Unified range. Figure 17.3 illustrates the type of head used in this range and also shows the general 'Unified' symbols, including (h) the cylindrical extension (dog point) sometimes used on parts not having hexagon shaped heads. It will be noticed that there are several shapes of hexagon head; these are alternative methods of manufacture and do not necessarily provide a means of identification, although A108 and A111 bolts, which have close tolerance shanks, have a cylindrical extension on top of the head and shear bolts always have thin heads. Bolts and screws of similar shape may be further identified by the material; aluminium alloy is dyed green, high tensile steel is cadmium plated and corrosion resistant steel or brass are normally uncoated. When the British Standard number is not marked on the bolt head, identification should be made as follows:-

Identify the head from Figure 17.3, for example (g). Reference to Table 17.3 shows that the bolt could be an A113, A114 or A170. Complete identification is possible in this example from the type of finish; in other instances it may be derived from further information, such as diameter or thread length, contained in Table 17.3.

Code System for Unified Bolts and Screws.

The code system used for the identification of the bolts and screws listed in Table 17.3 consists of the Standard number followed by the part number of the particular bolt. The diameter code shown in Table 17.4 is used on all parts but the measurement of length varies with different Standards as follows:-

i. All bolts from A102 to A212 inclusive, normal length in tenths of an inch followed by the diameter, e.g. an A102, 10-32 UNF bolt with plain length of one inch = A102-10D.

NOTE : Hexagon and mushroom head bolts are also supplied in lengths of 0.05 inch in some specifications, e.g. an A170-1/2D bolt has a plain length of 0.05 inch.

ii. All screws from A204 to A221 inclusive, diameter followed by length in thirty seconds of an inch, e.g. a4-40 UNC A217 screw 1 inch long = A217-A32.

iii All bolts from A226 to A232 inclusive, diameter followed by nominal length in sixteenths of an inch, e.g. a1/4 inch UNJF A229 bolt with plain length one inch = A229-e16.

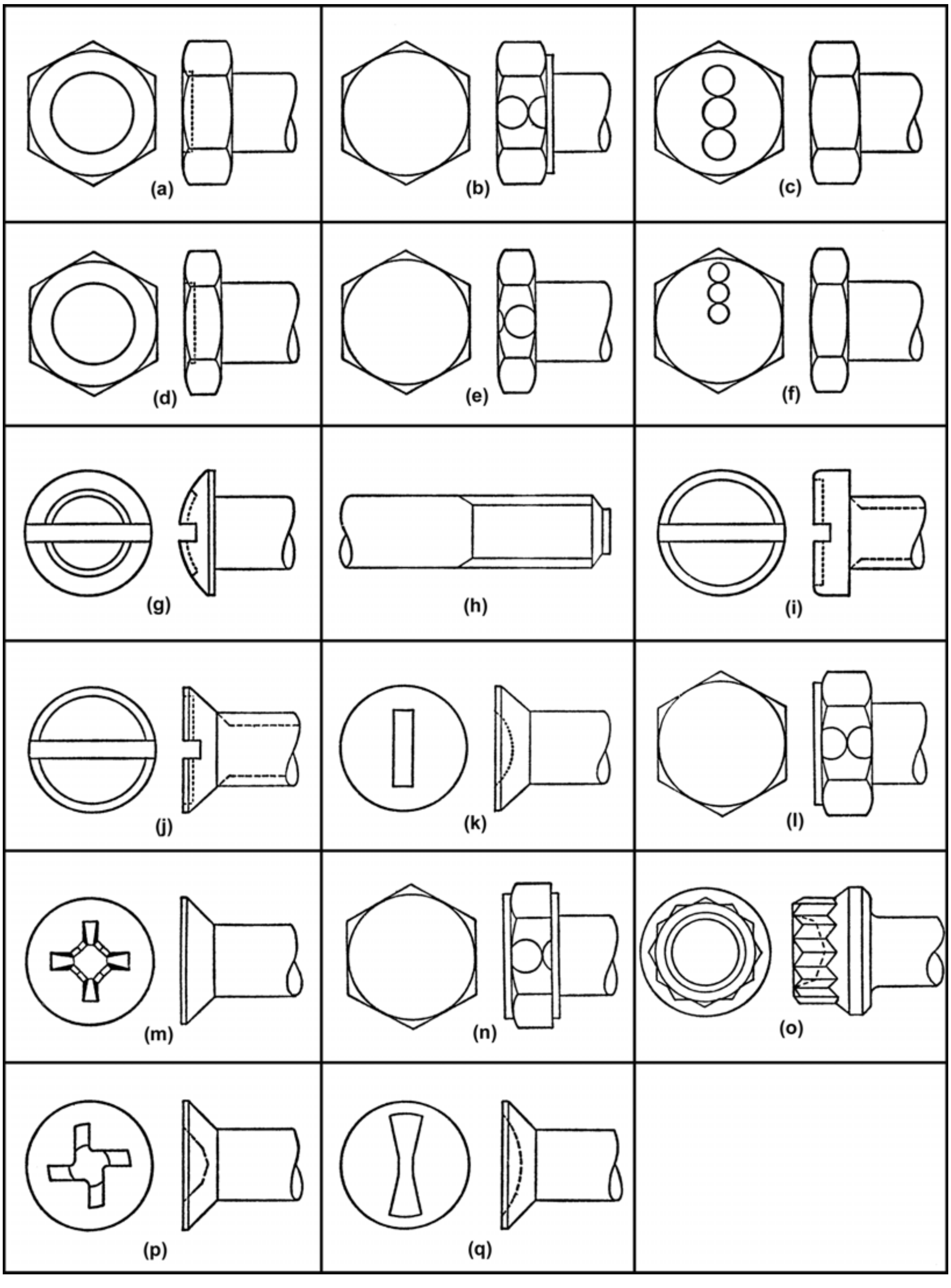


Fig. 17.3, Identification of British Standards Unified Bolts and Screws.

TABLE 17.3
UNIFIED BOLTS AND SCREWS

BS No.	Description	Material	Finish	Identi-fication (Fig. 3)	Remarks	Thread and Class	Normal Size Range
A102	Hex. hd. bolt	HTS	cad	a, b or c		Unified, 2A	4-40 to 1 in
A104	Hex. hd. bolt	CRS	nat	a, b or c		Unified, 2A	4-40 to 1 in
A108	Hex. hd. bolt	HTS	cad	l or n	cad hd. and	Unified, 2A	10-32 to ½ in
A109	Hex. hd. shear bolt	HTS	cad	d, e or f	thread only	Unified, 2A	¼ to $\frac{3}{4}$ in
A111	Hex. hd. c/t bolt	HTS	cad	l or n		Unified, 2A	10-32 to ½ in
A112	Hex. hd. shear bolt	HTS	cad	d, e or f		Unified, 2A	¼ to $\frac{3}{4}$ in
A113	Mush. hd. bolt	HTS	cad	g, h		Unified, 2A	6-32 to $\frac{5}{16}$ in
A114	Mush. hd. bolt	CRS	nat	g, h		Unified, 2A	6-32 to $\frac{5}{16}$ in
A116	Pan hd. bolt	HTS	cad	I, h		Unified, 2A	4-40 to $\frac{5}{16}$ in
A117	Pan hd. bolt	CRS	nat	i, h		Unified, 2A	4-40 to $\frac{5}{16}$ in
A119	90° csk. hd. bolt	HTS	cad	j	obsolescent	Unified, 2A	¼ to ½ in
A120	90° csk. hd. bolt	CRS	nat	j	obsolescent	Unified, 2A	¼ to ½ in
A169	Hex. hd. bolt	Al Al	green	b or c	replaces A106	Unified, 2A	6 -32 to $\frac{5}{8}$ in
A170	Mush. hd. bolt	Al Al	green	g	replaces A115	Unified, 2A	6 - 32 to $\frac{5}{16}$ in
A171	Pan hd. bolt	Al Al	green	i	replaces A118	Unified, 2A	4-40 to $\frac{5}{16}$ in
A172	90° csk. hd. bolt	Al Al	green	j, h	obsolescent	Unified, 2A	¼ to ½ in
A173	100° csk. hd. bolt	HTS	cad	k			8-32 to ½ in
A174	100° csk. hd. bolt	CRS	nat	k		Unified, 2A	8-32 to ½ in
A175	100° csk. hd. bolt	Al Al	green	k	replaces A172	Unified, 2A	8-32 to ½ in
A204	100° csk. hd. screw	LTS	cad	j,h		Unified, 2A	0-80 to 10-32
A206	100° csk. hd. screw	CRS	nat	j, h		Unified, 2A	4-40 to 10-32
A208	100° csk. hd. screw	Al Al	green	j, h		Unified, 2A	4-40 to 10-32
A211	100° csk. hd. bolt	HTS	cad	m		Unified, 2A	8-32 to ½ in
A212	Hex. hd. c/t bolt	HTS	cad	b or c	special quality	Unified, 3A	10-32 to ½ in
A217	Pan hd. screw	LTS	cad	i, h	replaces A205	Unified, 2A	0-80 to 10-32
A218	Pan hd. screw	CRS	nat	i, h	replaces A207	Unified, 2A	4-40 to 10-32
A219	Pan hd. screw	Al Al	green	i, h	replaces A209	Unified, 2A	4-40 to 10-32
A220	100° csk. hd. screw	Brass	nat	j, h		Unified, 2A	0-80 to 10-32
A221	Pan hd. screw	Brass	nat	i, h		Unified, 2A	0-80 to 10-32
A226	Hex. hd. bolt	HTS	cad	a, b or c	short thread	Unified, 3A	4-40 to 10-32
A227	Pan hd. bolt	HTS	cad	i, h	short thead	Unified, 3A	4-40 to 10-32
A228	Double hex. hd. c/t bolt	HTS	cad	o		UNJF, 3A	¼ to 1 in
A229	Hex. hd. c/t bolt	HTS	cad	a, b or c		UNJF, 3A	10-32 to ½ in
A230	Csk. hd. c/t bolt	HTS	cad	q		UNJF, 3A	10-32 to ½ in
A232	Csk. hd. c/t bolt	HTS	cad	p		UNJF, 3A	10-32 to ½ in

Extent of Marking

The marking actually applied to a bolt depend on the particular specification and whether marking is practical. Adding the code 'A217-Z32' to the head of a 2-64 UNF pan head screw (head diameter 0.0155 to 0.167 in), for example, would be very difficult, and having raised characters on a countersunk head bolt would, in certain circumstances, defeat the object of using that shape of head.

i. 'Unified' Marking

Most bolts, and screws 4-40 UNC and larger, are marked with a symbol to show that they have 'Unified' threads. The markings consist of continuous circles (hexagon headed bolts only), a recessed head or shank dog point, and are illustrated in Figure 17.3.

NOTE

At some future date, to be agreed, the 'Unified' marking of screws will be discontinued and identification of these items will be solely from the label on the package.

ii. Code Marking

Most hexagon head bolts 10-32 UNF and larger are marked with the full code, i.e. Standard plus size code, but pan and mushroom head bolts may only be marked with the bolt length and countersunk head bolts are not usually marked at all. The code is not applied to screws, or bolts smaller than 10-32 UNF.

TABLE 17.4
DIAMETER CODE LETTERS

Code	Size	Code	Size
Y	0 - 80 UNF	J	$\frac{3}{8}$ in UNF (UNJF)
Z	2 - 64 UNF	L	$\frac{7}{16}$ in UNF (UNJF)
A	4 - 40 UNC	N	$\frac{1}{2}$ in UNF (UNJF)
B	6 - 32 UNC	P	$\frac{9}{16}$ in UNF (UNJF)
C	8 - 32 UNC	Q	$\frac{5}{8}$ in UNF (UNJF)
D	10 - 32 UNF (UNJF)	S	$\frac{3}{4}$ in UNF (UNJF)
E	$\frac{1}{4}$ IN UNF (UNJF)	U	$\frac{7}{8}$ in UNF (UNJF)
G	$\frac{5}{16}$ in UNF (UNJF)	W	1 in UNF (UNJF)

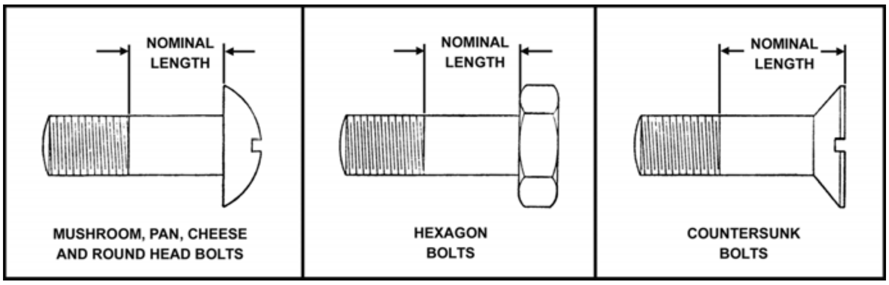


Fig. 17.4, Length of BS unified Bolts

'AS' BOLTS AND SCREWS

This paragraph is concerned with the identification of bolts and screws complying with the Society of British Aerospace Companies 'AS' series of specification. The specification provide a range of bolts and screws in sizes and head shapes not found in British Standards specification. Bolts manufactured from special materials (e.g. heat resistant steel) and having Unified threads are also included.

Table 17.5 shows the AS specification for bolts and screws with BA/BSF threads, together with complete identification details.

TABLE 17.5
'AS' NUMBERS OF BA/BSF BOLTS AND SCREWS

Head	Round	Mush-room	Raised Counter-sunk (90°)	Counter-sunk (90°)	Raised Counter-sunk (120°)	Counter-sunk (120°)	hexagon	Material	Finish
Bolts with screwdriver slot or hexagonal head	1247+	1249+	1245+	1243+				Al Al	Anodic
	4565	4566	4564	4563				Al Al	Blue
	1246	1248	1244+	1242			4569++	HTS	Cad.
	2922	2923	2921	2920				SS	Nat.
							2504++	HTS	Cad h & t
Bolts with phillips recess	3078*+ 4597**	3079*+ 4598**	3295**	3294**	3296**	3297**		HTS	Cad.
Screws with Phillips recess	2991	2992	2994	2993	2995	2996		Mild Steel	Cad.

* 1 dot on head
**2 dots on head

\+ obsolescent
\+ 2 BA only
\+

Table 17.6 shows the AS specification for 'round head' bolts with a locking flat and Unified threads. These bolts are manufactured from high tensile steel and are cadmium plated.

TABLE 17.6
'AS' NUMBERS OF ROUND HEAD BOLTS WITH FLAT (UNIFIED)

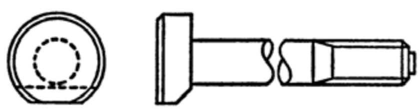
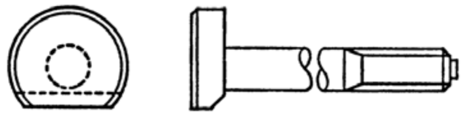
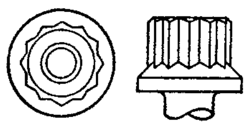
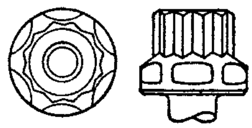
 Small head				 Large head			
10 - 32 UNF	¼ UNF	$\frac{5}{16}$ UNF	$\frac{3}{8}$ UNF	10 - 32 UNF	¼ UNF	$\frac{5}{16}$ UNF	$\frac{3}{8}$ UNF
6760 to 6804	6895 to 6939	7033 to 7077	7171 to 7215	6850 to 6894	6985 to 7032	7123 to 7170	7264 to 7308

Table 17.7 shows the AS specifications for double hexagon head bolts manufactured from heat resistant steel and having UNS of UNJF threads. Requirements for protective treatment vary between specifications, some bolts being silver plated while others have a natural finish.

TABLE 17.7
'AS' SPECIFICATIONS

Thread	Type	Material	HEADS SHAPE 	
UNS Threads (10-32 to $\frac{3}{8}$ - 24 UNS - 3A)	Plain	DTD 5066	13000 - 13399	17000 - 17399
		DTD 5026	13400 - 13799	17400 - 17799
		DTD 5077	13800 - 14199	17800 - 18199
	Externally Relieved Body	DTD 5066	14500 - 14899	18200 - 18599
		DTD 5026	14900 - 15299	18600 - 18999
		DTD 5077	15300 - 15699	19000 - 19399
	Close Tolerance Shank	DTD 5066	19400 - 19799	
		DTD 5026	19800 - 20199	
		DTD 5077	20200 - 20599	
UNJF Threads	Plain (8 - 36 to $\frac{3}{8}$ - 24 UNJF)	DTD 5066	20800 - 21299	
		DTD 5026	21300 - 21799	
		DTD 5077	21800 - 22299	
	Close Tolerance Shank (10 - 32 to $\frac{3}{8}$ - 24 UNJF)	DTD 5066	22400 - 22799	
		DTD 5026	22900 - 23299	
		DTD 5077	23400 - 23799	

NOTE

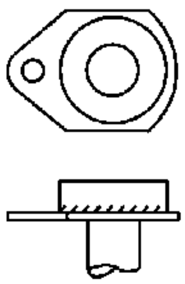
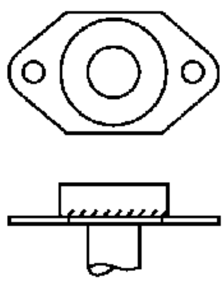
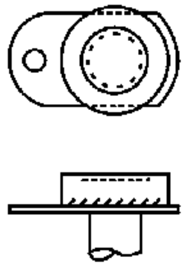
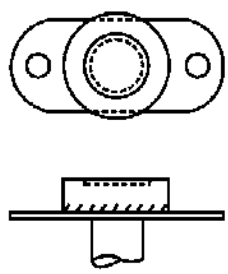
The UNS bolts listed in the table have reduced diameter threads for use in high temperature applications and should be fitted with nuts complying with specifications AS20620 to AS 20639.

For purposes of standardisation a further series of heat resistant bolts with UNJF threads is being introduced to replace those with UNS threads. Details of the AS numbers allocated to these bolts are not, as yet, available, but the method of identification will be the same as described for the bolts in Table 17.7.

Table 17.8 shows the AS specifications for anchor bolts manufactured from weldable steel.

ASI and AS2 are specifications for titanium bolts having Unified threads, with hexagon and 100^0 countersunk heads respectively. Both specifications are obsolescent but the bolts may be recognised by the material finish and the marking 'AS1' or 'AS2' on the head, as appropriate.

TABLE 17.8
'AS' NUMBERS OF ANCHOR BOLTS

BA/BSF		Unified	
			
4752	4753	6735	6736
Weldable bolt is AS 4754		Weldable bolt is AS 6737	

Identification Marking

AS1, AS2 and all the bolts listed in Table 17.7 are marked with the AS specification to which they conform. Other AS bolts are unmarked except for the 'Unified' symbol which is applied to anchor bolts (recessed head) and the round head bolts shown in Table 17.6 (shank dog point).

Code System

Although a large number of AS bolts and screws are not marked in any way, codes are necessary for ordering and storage purposes.

The code system used for the identification of the bolts and screws listed in Table 17.5 and 17.8, and for ASI and AS2 bolts, is the same as that used for British Standards bolts, i.e. AS number followed by a number indicating length in tenths of an inch and a letter indicating diameter (Tables 17.2 or 17.4 as appropriate). The length is measured in the same way as for British Standard parts.

NOTE

AS 2504 and 4569 bolts are only manufactured in 2 BA; the diameter code is therefore not required.

Reference to Table 17.6 shows that a batch of AS numbers is allocated to each diameter of bolt in this series. A separate number within each batch is reserved for a particular length of bolt so that a code system is unnecessary; any particular AS number in this series applies only to a bolt of specified length and diameter. The plain length is graduated in steps of 0.05 inch from 0.05 inch to 0.9 inch, and steps of 0.1 inch thereafter up to 3.4 inch. A 10-32 UNF bolt 1.2 inch long and having a small head will therefore be AS 6780

The bolts shown in Table 17.7 also have a batch of AS numbers allocated to each diameter but in this case the range of available lengths varies between specifications. The length of the bolt is taken as the whole length of the shank, including the thread in sixteenths of an inch up to 2 inches long, and eighths thereafter, each particular size having a unique reference number. It should be noted that this series of bolts has a threaded length greater than that normally found on aircraft fasteners. A minimum length of plain portion is also maintained, so that the thread length in the shorter bolts is reduced below the normal for the particular diameter.

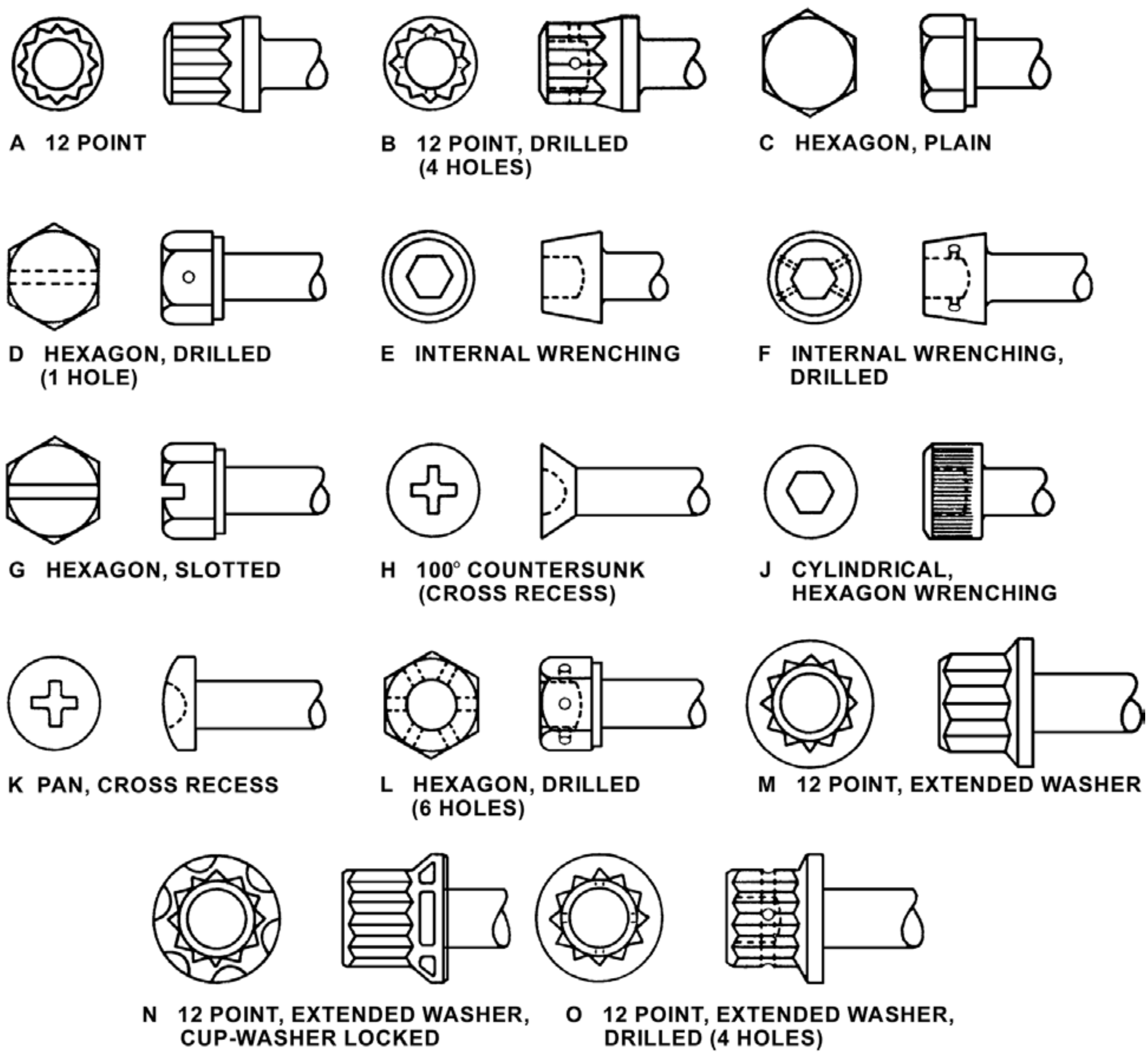


Fig.17.5, MS Bolts And Screws

MS Bolts

Table 17.9 lists a wide range of bolts and screws in the MS series. It should be noted, however, that the term 'bolt' is applied to the whole range of sizes in which a particular item is supplied. In the specifications, an item with a No. 8 or smaller thread is generally termed a 'screw', regardless of the fact that it is identical inshape and material to a larger item, which is termed a 'bolt'. However, in some cases the term 'bolt' is also applied to an item with a No. 8 thread.

Coding

For most of the items listed in Table 17.9, the MS number relates to an item of a particular diameter, and a table provide in the specification details the range of lengths available in that size. Length is indicated by a dash number, nut the length indicated by a particular dash number varies with the diameter, so that the complete part number of a particular item can only be determined by reference to the specifications.

With bolts in the ranges MS 20004 to 20024 and MS 20033 to 20046, the thread size is indicated by the part number as outlined, and the length is indicated by a dash number, which represents grip length in sixteenths of an inch.

TABLE 17.9, MS BOLTS AND SCREWS

MS Number	Type	Head Shape (Fig. 4)	Head Marking	Thread	Thread Size Range	Material*	Plating
9033 - 9038	Bolt, 12 point, heat resistant	A	EH 19	UNF	No. 10 - ½ in	AMS 5735	Nil
9060 - 9066	Bolt, 12 point, drilled, extended washer head	O	EH 19	UNF	No. 10 - ½ in	AMS 5735	Nil
9088 - 9094	Bolt, 12 point, drilled head	B	E 11	UNF	No. 10 - $\frac{9}{16}$ in	AMS 6322	Cad.
9110 - 9113	Bolt, 12 point, extended washer head	M	MS No.	UNF	No. 10 - $\frac{3}{8}$ in	AMS 5731	Nil
9146 - 9152	Bolt, 12 point	A	E 11	UNF	No. 10 - $\frac{9}{16}$ in	AMS 6322	Cad.
9157 - 9163	Bolt, 12 point	A	E 11	UNF	No. 10 - $\frac{9}{16}$ in	AMS 6322	Black oxide
9169 - 9175	Bolt, 12 point, drilled head	B	E 11	UNF	No. 10 - $\frac{9}{16}$ in	AMS 6322	Black oxide
9177 and 9178	Screw, 12 point, extended washer head	N	EH 19	UNF	No. 6 & No. 8	AMS 5735	Nil
9183 and 9184	Screw, 12 point, drilled head	B	E 11	UNF	No. 6 & No. 8	AMS 6322	Cad.
9185 and 9186	Screw, 12 point	A	E 11	UNF	No. 6 & No. 8	AMS 6322	Cad.
9189 and 9190	Screw, 12 point	A	E 11	UNF	No. 6 & No. 8	AMS 6322	Black oxide
9191 and 9192	Screw, 12 point, drilled head	B	E 11	UNF	No. 6 & No. 8	AMS 6322	Black oxide
9206 - 9214	Bolt, 12 point extended washer head	M	MS No.	UNJF	No. 6 - $\frac{9}{16}$ in	AMS 6304	Diffused nickel cadmium
9215 - 9222	Bolt, 12 point, extended washer, drilled head	O	MS No.	UNJF	No. 6 - ½ in	AMS 6304	Diffused nickel cadmium
9224	Bolt, 12 point, heat resistant	A	EH 19	UNF	$\frac{9}{16}$ in	AMS 5735	Nil
9281 - 9291	Bolt, hexagon head	C	MS No.	UNF	No. 4 - $\frac{3}{4}$ in	AMS 6322	Black oxide
9292 - 9302	Bolt, hexagon head, drilled	D	MS No.	UNF	No. 4 - $\frac{3}{4}$ in	AMS 6322	Black oxide
9438 - 9448	Bolt, hexagon head, drilled	D	MS No.	UNJF	No. 6 - $\frac{3}{4}$ in	AMS 6304	Diffused nickel cadmium
9449 - 9459	Bolt, hexagon head	C	MS No.	UNJF	No. 6 - $\frac{3}{4}$ in	AMS 6304	Diffused nickel cadmium
9487 - 9497	Bolt, hexagon head	C	MS No.	UNJF	No. 8 - $\frac{3}{4}$ in	AMS 5731	Nil
9498 - 9508	Bolt, hexagon head, drilled	D	MS No.	UNJF	No. 6 - $\frac{3}{4}$ in	AMS 5731	Nil
9516 - 9526	Screw, hexagon head	C	MS No.	UNJF	No. 4 - $\frac{3}{4}$ in	AMS 6322	Cad.
9527 - 9537	Screw, hexagon head, drilled	D	MS No.	UNJF	No. 4 - $\frac{3}{4}$ in	AMS 6322	Cad.
9554 - 9562	Bolt, 12 point, extended washer head, PD shank	M	MS No.	UNJF	No. 6 - $\frac{9}{16}$ in	AMS 5731	Nil
9563 - 9571	Bolt, 12 point, ext. washer, drilled head, PD shank	O	MS No.	UNJF	No. 6 - $\frac{9}{16}$ in	AMS 5731	Nil
9572 - 9580	Bolt, 12 point, extended washer head	M	MS No.	UNJF	No. 6 - $\frac{9}{16}$ in	AMS 5731	Silver plated
9583 - 9591	Bolt, hexagon head, drilled	L	MS No.	UNJF	No. 10 - $\frac{3}{4}$ in	AMS 5731	Nil

TABLE 17.9, (continued)

MS Number	Type	Head Shape (Fig. 4)	Head Marking	Thread	Thread Size Range	Material*	Plating
9676 - 9679	Bolt, 12 point; extended washer head, cupwasher locked	N	MS No.	UNJF	No. 10 - $\frac{3}{8}$ in	AMS 5731	Nil
9680 - 9683	Bolt, 12 point, extended washer head, cupwasher locked	N	MS No.	UNJF	No. 10 - $\frac{3}{8}$ in	AMS 6322	cad.
9694 - 9702	Bolt, 12 point, extended washer head	M	MS No.	UNJF	No. 4 - $\frac{9}{16}$ in	AMS 5708	Nil
9712 - 9720	Bolt, 12 point, extended washer, drilled	O	MS No.	UNJF	No. 4 - $\frac{9}{16}$ in	AMS 5708	Silver plated
9730 - 9738	Bolt, 12 point, extended washer, PD shank	M	MS No.	UNJF	No. 4 - $\frac{9}{16}$ in	AMS 5643	Nil
9739 - 9747	Bolt, 12 point, extended washer, drilled, PD shank	O	MS No.	UNJF	No. 4 - $\frac{9}{16}$ in	AMS 5643	Nil
9748 - 9756	Bolt, 12 point, extended washer head, PD shank	M	MS No.	UNJF	No. 4 - $\frac{9}{16}$ in	Titanium	Nil
9757 - 9765	Bolt, 12 point, extended washer, drilled head, PD shank	O	MS No.	UNJF	No. 4 - $\frac{9}{16}$ in	Titanium	Nil
9883 - 9891	Bolt, 12 point, extended washer head	M	MS No.	UNJF	No. 4 - $\frac{9}{16}$ in	AMS 5616	Nil
20004 - 20024	Bolt, internal wrenching	E or F	MS No.	UNF	¼ - 1½ in	Alloy steel	cad.
20033 - 20046	Bolt, hexagon head, 1200°F	C	1200	UNF	No. 10 - 1 in	corrosion- and heat-resisting steel	Nil
20073 & 20074	Bolt, hexagon head, drilled	D	X	-73 = UNF -74 = UNC	No. 10 - $\frac{3}{4}$ in	Alloy steel	cad.
21095	Bolt, self-locking, 250°F, hexagon head	C	-	UNF	No. 10 - 1¼ in	CRS	Nil
21096	Bolt, self-locking, 250°F, pan head + recess	K	Nil	4,6,8 = UNC, larger = UNF	No. 4 - ½ in	Alloy steel	cad.
21097	Bolt, self-locking, 250°F, pan head + recess	K	Nil	4,6,8 = UNC, larger = UNF	No. 4 - ½ in	CRS	Nil
21250	Bolt, 12 point, 180 000 lbf/in^2, drilled or plain	A or B	MS No.	UNF	¼ - 1½ in	Alloy steel	cad.
21277 - 21285	Bolt, 12 point, extended washer head	M	MS No.	MIL-S-8879	No. 4 - $\frac{9}{16}$ in	AMS 5735	Nil
21286 - 21294	Bolt, 12 point, extended washer, drilled	O	MS No.	MIL-S-8879	No. 4 - $\frac{9}{16}$ in	AMS 5735	Nil

* AMS 6304 and AMS 6322 are low alloy steels.
All other AMS specifications in the Table are corrosion and heat-resisting alloys.

With bolts in the MS 21250 series, the dash number indicates both diameter and length. The first two figure as indicate diameter in sixteenths of an inch, and the last two figures indicate grip length in sixteenths of an inch.

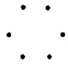
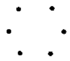
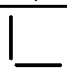
With the MS 20004 to 20024, and MS 21250, bolts, an H in place of the dash indicates a drilled-head bolt.

MS Screws

Table 17.10 lists a variety of the screws covered by MS specifications, and shows the features by which these screws may be partially identified.

Because the individual specifications vary, the screws listed in Table 17.10 should be fully identified by reference to the particular specification.

TABLE 17.10 MS SCREWS

MS Number	Type	Head Shape (Fig. 4)	Head Marking	Thread	Thread Size Range	Material	Plating
9122 and 9123	Screw, hex. head, slotted	G	E 11	UNF	No. 10 and ¼ in	AMS 6322	Cadmium
21262	Screw, cyl. head, 160 KSI int. wren. 250°F	J		4,6,8 = UNC larger = UNF	No. 4 - $\frac{5}{8}$ in	Alloy steel	Cadmium
21295	Screw, cyl. head, 160 KSI int. wren. 250°F	J		4,6,8 = UNC Larger = UNF	No. 4 - $\frac{5}{8}$ in	CRS	Nil
24693	Screw, flat 100° + recess	H	—	UNC 2A UNF 2A	No. 6 - $\frac{3}{8}$ in	CRS	Nil
24694	Screw, flat 100° + recess	H	—	UNC 3A UNF 3A	No. 6 - $\frac{9}{16}$ in	CRS	Nil
27039	Screw, pan head, + recess, structural	K	B/C	8 = UNC Larger = UNF	No. 8 - ½ in	Bronze Alloy steel CRS	Nil Cadmium Nil
35297	Screw, cap, hex. head	C		UNC 2A	¼ - 1¼ in	Carbon steel	Cad. or zinc
35299	Screw, cap, hex. head	C		UNC 2A	¼ - 1¼ in	Carbon steel	Phosphate
35307	Screw, cap, hex. head	C		UNC 2A	¼ - 1¼ in	CRS	Nil
35308	Screw, cap, hex. head	C		UNF 2A	¼ - 1¼ in	CRS	Nil
51095	Screw, cap, hex. head, drilled	D		UNC 2A	¼ - 1 in	Carbon steel	Cadmium
51096	Screw, cap, hex. head, drilled	D		UNF 2A	¼ - 1 in	Carbon steel	Cadmium
51099	Screw, cap, hex. head, drilled	D		UNC 2A	¼ - 1 in	CRS	Nil
51100	Screw, cap, hex. head, drilled	D		UNF 2A	¼ - 1 in	CRS	Nil
51105	Screw, cap, hex. head, drilled	D		UNC 2A	¼ - 1 in	Carbon steel	Cadmium
51106	Screw, cap, hex. head, drilled	D		UNF 2A	¼ - 1 in	Carbon steel	Cadmium
51107	Screw, cap, hex. head, drilled shank	C		UNC 2A	¼ - 1 in	Alloy steel	Phosphate
51108	Screw, cap, hex. head, drilled shank	C		UNF 2A	¼ - 1 in	Alloy steel	Phosphate
51109	Screw, cap, hex. head, drilled shank	C		UNC 2A	¼ - 1 in	CRS	Nil
51110	Screw, cap, hex. head, drilled shank	C		UNF 2A	¼ - 1 in	CRS	Nil
90726	Screw, cap, hex. head	C		UNF 2A	¼ - 1½ in	Carbon steel	Cadmium
90727	Screw, cap, hex. head	C		UNF 2A	¼ - 1½ in	Alloy steel	Cadmium
90728	Screw, cap, hex. head	C		UNC 2A	¼ - 1½ in	Alloy steel	Cadmium

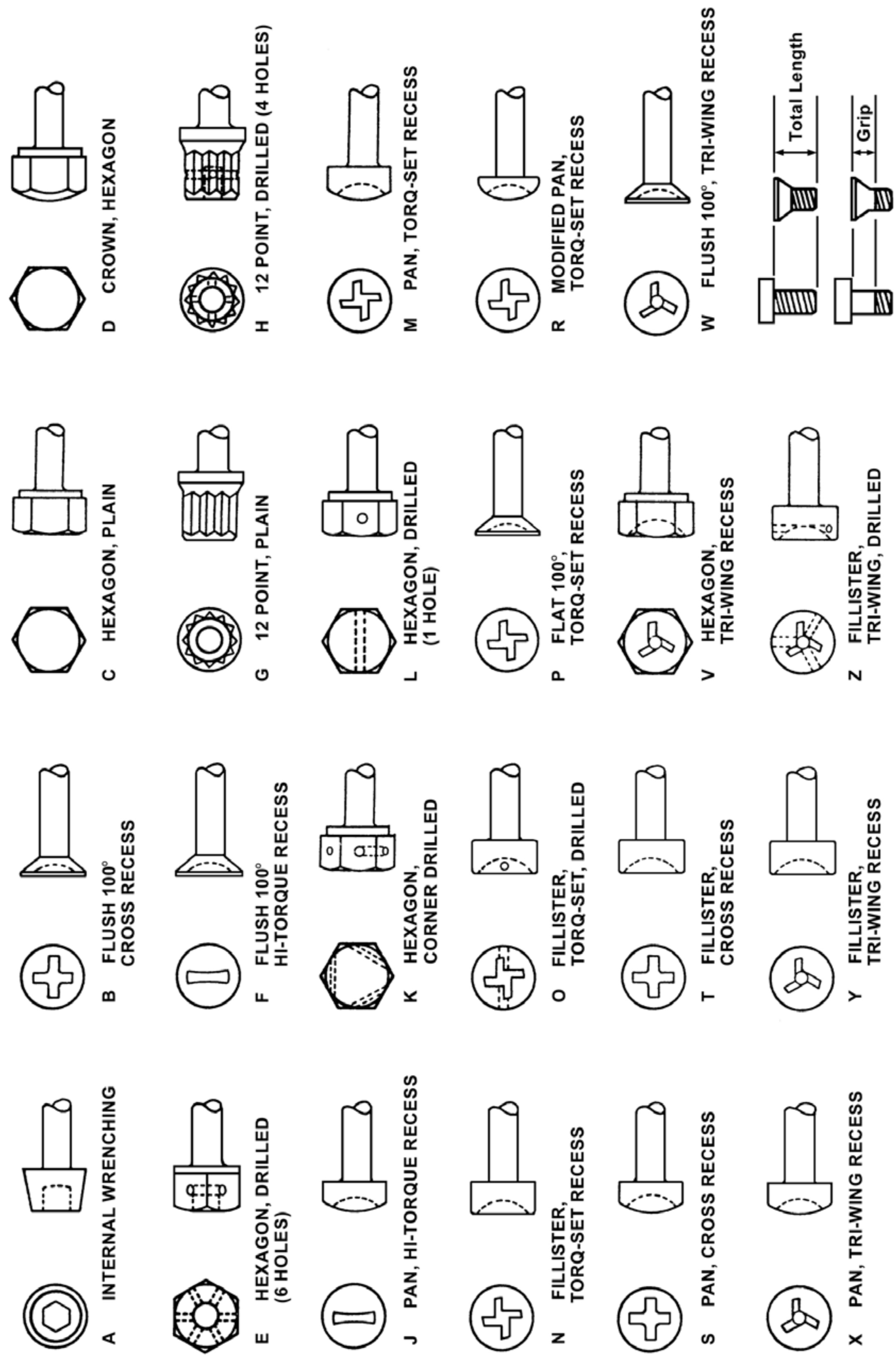


Fig. 17.6, NAS Bolts and Screws

Note

Provision is also made for including the manufacturer's identification mark on the head.

Coding

The bolts and screws listed in Table 17.11, are coded according to their type, diameter, length, type of plating and material. Where a component is made in more than one material, an alloy steel part is given the basic part number ; similarly, where applicable, the basic part number implies that the part is not drilled for locking purposes.

Diameter

Most bolts and screws are coded according to thread size in a similar way to AN and MS parts; however, there are some exceptions.

a. BAS 1261 to 1265 and NAS 1266 to 1270 are available in sizes 9/16 - 18, 5/8 - 18, 3/4 - 16, 7/8 - 14, and 1 - 12; they are coded in numerical order and indicated by an 'A' in Table 17.11.

b. For bolts and screws which are given a range of numbers [except as detailed in (d)], the last figure or two figures indicates the size as follows :-

NAS xxx0 = 4 - 40, xxx1 = 6 - 32, xxx2 = 8 - 32, xxx3 = 10 - 32, xxx4 = 1/4 - 28, xxx5 = 5/16 - 24, xxx6 = 3/8 - 24, xxx7 = 7/16 - 20, xxx8 = 1/2 - 20, xxx9 = 9/16 - 18, xx10 = 5/8 - 18, xx12 = 3/4 - 16, xx14 = 7/8 - 14, xx16 = 1 - 12, xx18 = 1 1/8 - 12, xx20 = 1 1/4 - 12.

The threads are usually UNC, UNF, UNJC or UNJF, but some bolts and screws are also available with American National threads, and these are coded separately. Those parts which comply with the Unified standard are indicated by a 'B' in Table 17.11.

c. For bolts and screws which are given a single NAS number, the diameter is given by the first dash number as follows:-

NAS xxxx - 02 = 2 - 56, xxxx - 04 = 4 - 40, xxxx - 06 = 6 - 32, xxxx - 08 = 8 - 32, xxxx - 3 = 10 - 32, xxxx - 4 = 1/4 - 28, and so on, in steps of 1/16 in, following the sizes given in (b). Parts following this code are marked 'C' in Table 15.15.

d. NAS 1271 to 1280 are available in sizes from 1/4 to 1 in, and are coded in numerical order.

Length

The length is indicated by the second dash number for parts with the 'C' diameter code, or the first dash number for all other parts. The length dash-number indicates the total length of a part with a full thread or the grip length of a part with a shorter thread (see Fig. 17.6), in sixteenths of an inch; exceptions are NAS 563 to 572, for which the length dash number represents thirty-seconds of an inch, and NAS 428, for which the dash number represents eighths of an inch as detailed in paragraph for AN parts.

TABLE 17.11, NAS BOLTS AND SCREWS

NAS No.	Type	Head (Fig.5)	Size Range	Material	Coding				Head Marking
					Dia.	Replacing Dash or First Dash	Replacing Second Dash	At End	
144–158	Bolt, internal wrenching	A	No.1 – $1\frac{1}{4}$ in	Alloy steel	B	A = drilled shank DH = drilled head Nil = undrilled			NAS No.
333–340	Bolt, flush 100°, close-tolerance	B	No.10 – $\frac{5}{8}$ in	Alloy steel	B	A = undrilled shank P = Phillips recess Nil = hex. socket C = cad. plated shank	–	See Specification for Length Code	NAS No. + △
428	Bolt, crown hex. head	D	No.10 – $\frac{3}{8}$ in	Alloy steel	C	H = drilled head K = slotted shank	–	–	NAS 1347 Type IV
464	Bolt, shear, close-tolerance	C	No.10 – 1 in	Alloy steel	C	P = cad. shank	A = undrilled shank		NAS No. + △
501	Bolt, hex. head, non-magnetic	C	No.10 – $1\frac{1}{4}$ in	CRS	C	A = undrilled shank H = drilled head	–	–	NAS No. + –
560	Screw, 100°, non-magnetic, structural	B	No.8 – $\frac{9}{16}$ in	CRS	C	C = low strength H = high temp. X = high strength	K = Phillips recess P = cad.plated	–	NAS No. +C, H or X
563–572	Bolt, full threaded, fully identified	E	No.10 – $\frac{3}{4}$ in	Alloy steel	B	–	–	–	NAS No. + dash no.
583–590	Bolt, 100°, close-tolerance, 160,000 lbf/in , Hi-Torque	F	No.10 – $\frac{5}{8}$ in	Alloy steel	B	–	–	–	NAS 1347 Type IV
624–644	Bolt, 12 point, 180,000 lbf/in	G or H	$\frac{1}{4}$ – $1\frac{1}{2}$ in	Alloy steel	B	H = drilled head	–	–	NAS No.
653–658	Bolt, hex. head, short thread, close-tolerance	C	No.10 – $\frac{1}{2}$ in	Titanium	B	V = titanium	–	D = drilled shank	NAS No. + dash no. + material
663–668	Bolt, 100°, close-tolerance long thread	F	No.10 – $\frac{1}{2}$ in	Titanium	B	V = titanium	–	HT = Hi-Torque	NAS 1347 Type IV
673–678	Bolt, hex. head, close-tolerance	C or K	No.10 – $\frac{1}{2}$ in	Titanium	B	V = titanium	–	D = drilled shank H = drilled head	NAS No. + dash no. + material
1003–1020	Bolt, hex. head, non-magnetic, heat-resistant	C or L	No.10 – $1\frac{1}{4}$ in	CRS	B	–	–	A = undrilled H = drilled head Nil = drilled shank	NAS No. + dash no.
1083–1088	Bolt, 100°, close-tolerance, short thread	F	No.10 – $\frac{1}{2}$ in	Titanium	B	V = 6AL-4V alloy T = 4AL-4MN alloy		Nil = Phillips HT = Hi-Torque	NAS 1347 Type IV

TABLE 17.11, NAS BOLTS AND SCREWS - CONTINUED

NAS No.	Type	Head (Fig. 5)	Size Range	Material	Coding				Head Marking
					Dia.	Replacing Dash or First Dash	Replacing Second Dash	At End	
1100	Screw, pan head, full thread, Torq-Set	M	No.0 — $\frac{3}{8}$ in	Alloy steel Titanium CRS	C	C = CRS 140 000 psi E = CRS 160 000 psi V = titanium	–	B = black plating P = type II plating W = type I plating	NAS No. + dash no. + material
1101	Screw, flat fillister, full thread, Torq-Set	N or O	No.0 — $\frac{3}{8}$ in	As 1100	C	As 1100	H = drilled head	As 1100	NAS No. + dash no. + material
1102	Screw, 100°, full thread, Torq-Set	P	No.2 — $\frac{3}{8}$ in	As 1100	C	As 1100	–	As 1100	NAS No. + dash no. + material
1103 – 1120	Bolt, shear, hex. head modified, short thread	C	No.10 — 1¼ in	Alloy steel	C	As 1100	–	As 1100 D = drilled	NAS No. + dash no. + material
1121 – 1128	Screw, flat fillister, close-tolerance, short thread	N or O	No.6 — ½ in	As 1100	B	As 1100	–	H = drilled head P and W as 1100	NAS No. + dash no. + material
1131 – 1138	Screw, pan head, close-tolerance, short thread	M	No.6 — ½ in	As 1100	B	C = CRS V and T as 1083	–	P and W as 1100	NAS No. + dash no. + material
1141 – 1148	Screw, pan head (mod), close-tolerance, short thread	R	No.6 — ½ in	As 1100	B	As 1100	–	P and W as 1100	NAS No. + dash no. + material
1151 – 1158	Screw, 100°, close-tolerance, short thread	P	No.6 — ½ in	As 1100	B	As 1131	–	D = Drilled shank P and W as 1100	NAS No. + dash no. + material
1161 – 1168	Screw, 100°, shear, self-locking	P	No.6 — ½ in	Alloy steel CRS	B	E as 1100	–	P and W as 1100 + locking code	NAS No. + dash no. + material + circle of dots
1171 – 1178	Screw, pan, shear, self-locking	M	No.6 — ½ in	Alloy steel CRS	B	E as 1100	–	P and W as 1100 + locking code	NAS No. + dash no. + material + circle of dots
1181 – 1188	Screw, flat fillister, shear, self-locking	N	No.6 — ½ in	Alloy steel CRS	B	C and E as 1100	–	P and W as 1100 + locking code	NAS No. + dash no. + material + circle of dots

TABLE 17.11, NAS BOLTS AND SCREWS - CONTINUED

NAS No.	Type	Head (Fig. 5)	Size Range	Material	Coding: Dia.	Coding: Replacing Dash or First Dash	Coding: Replacing Second Dash	Coding: At End	Head Marking
1189	Screw, 100°, full thread, self-locking, 250° F	B or P	No.2 — $\frac{3}{8}$ in	Alloy steel CRS	C	C as 1100	P = Phillips recess T = Torq-Set recess	W as 1100 + locking code	NAS No. + dash no. + circle of dots
1190	Screw, pan head, full thread, self-locking	M or S	No.2 — $\frac{3}{8}$ in	Alloy steel CRS	C	C and E as 1100	P = Phillips recess T = Torq-Set recess	H = type II plating W = type I plating + locking code	NAS No. + dash no. + circle of dots
1191	Screw, flat fillister, full thread, self-locking, 250° F	N or T	No.2 — $\frac{3}{8}$ in	Alloy steel CRS	C	C and E as 1100	P = Phillips recess T = Torq-Set recess	H and W as 1190 + locking code	NAS No. + dash no. + circle of dots
1202 — 1210	Bolt, 100°, close-tolerance, 160,000 lbf/in², short thread	B	No.8 — $\frac{5}{8}$ in	Alloy steel	B		—	D = drilled shank W as 1190	NAS 1347 Type IV
1216	Bolt, pan head, full thread, Hi-Torque	J	No.4 — $\frac{3}{8}$ in	Alloy steel CRS	C	—	CR = CRS 125,000 lbf /in² C = CRS 140,000 lbf /in²	B = black plating P = type II plating	NAS 1347 Type IV
1217	Bolt, pan head, short thread, Hi-Torque	J	No.8 — $\frac{3}{8}$ in	Alloy steel CRS	C	—	C and CR as 1216	B and P as 1216	NAS 1347 Type IV
1218	Bolt, pan head, long thread, Hi-Torque	J	No.4 — $\frac{3}{8}$ in	Alloy steel CRS	C	—	C and CR as 1216	B and P as 1216	NAS 1347 Type IV
1219	Bolt, 100°, full thread, Hi-Torque	F	No.4 — $\frac{3}{8}$ in	Alloy steel CRS	C	—	C and CR as 1216	B and P as 1216	NAS 1347 Type IV
1220	Bolt, 100°, short thread, Hi-Torque	F	No.8 — $\frac{3}{8}$ in	Alloy steel CRS	C	—	C and CR as 1216	B and P as 1216	NAS 1347 Type IV
1221	Bolt, 100°, long thread, Hi-Torque	F	No.4 — $\frac{3}{8}$ in	Alloy steel CRS	C	—	C and CR as 1216	B and P as 1216	NAS 1347 Type IV
1223 — 1235	Bolt, hex. head, close-tolerance, self-locking	C	No.10 — 1¼ in	Alloy steel CRS	B	C = CRS	—	W as 1190 + locking code	NAS 1347 Type IV + circle of dots
1243 1250	Bolt, 100°, close-tolerance, short thread, Hi-Torque, 0.0156 in oversize, 160,000 lbf/in² (a)	F	No.10 — $\frac{5}{8}$ in	Alloy steel	B	—	—	—	NAS 1347 Type IV
1253 — 1260	Bolt, 100°, close-tolerance, short thread, Hi-Torque, 0.0312 in oversize, 160,000 lbf/in² (a)	F	No.10 — $\frac{5}{8}$ in	Alloy steel	B		—	—	NAS 1347 Type IV

TABLE 17.11 , NAS BOLTS AND SCREWS - CONTINUED

NAS No.	Type	Head (Fig. 5)	Size Range	Material	Coding				Head Marking
					Dia.	Replacing Dash or First Dash	Replacing Second Dash	At End	
1261 — 1265	Bolt, hex. head, close-tolerance, short thread	C	$\frac{9}{16}$ — 1 in	Titanium	A	—	—	D = drilled shank	NAS 1347 Type IV
1266 — 1270	Bolt, hex. head, close-tolerance	C	$\frac{9}{16}$ — 1 in	Titanium	A	—		D = drilled shank	NAS 1347 Type IV
1271 — 1280	Bolt, 12 point	G or H	$\frac{1}{4}$ — 1 in	Titanium	D	H = drilled head	—		NAS 1347 Type IV
1303 — 1320	Bolt, hex. head, close-tolerance, 160,000 lbf/in^2	C or K	No.10 — $1\frac{1}{4}$ in	Alloy steel	B	—	—	D = drilled shank H = drilled head W = type I plating	NAS No. + dash no.
1503 — 1510	Bolt, 100°, close-tolerance, short thread, Hi-Torque, 160,000 lbf/in^2	F	No.10 — $\frac{5}{8}$ in	Alloy steel	B	—	—	W = type I plating	NAS No. + dash no.
1578	Bolt, pan head, shear, 1200°F	J or M	No.10 — $\frac{1}{2}$ in	C and HR steel (U—212)	C	—	T = Torq-Set recess H = Hi-Torque recess	—	NAS 1347 Type II
1579	Bolt, pan head, full thread, 1200°F	J or M	No.10 — $\frac{3}{8}$ in	C and HR steel (U—212)	C	—	T and H as 1578	—	NAS 1347 Type II
1580	Bolt, tension, 100°, 1200° F	F or P	No.10 — $\frac{5}{8}$ in	C and HR steel (U—212)	C	—	T and H as 1578	—	NAS 1347 Type II
1581	Bolt, shear, 100° reduced, 1200° F	F or P	No.10 — $\frac{5}{8}$ in	C and HR steel (U—212)	C	—	T and H as 1578	—	NAS 1347 Type II
1582	Bolt, 100° , full thread, 1200° F	F or P	No.10 — $\frac{3}{8}$ in	C and HR steel (U—212)	C	—	T and H as 1578	—	NAS 1347 Type II
1586	Bolt, tension, 12 point, 1200° F, external wrenching	G or H	$\frac{1}{4}$—$1\frac{1}{4}$ in	C and HR steel (U—212)	C	—	H = drilled head	—	NAS 1347 Type II
1588	Bolt, shear, hex. head, 1200° F	C	No.10 — 1 in	C and HR steel (U—212)	C	—	—	—	NAS 1347 Type II

TABLE 17.11, NAS BOLTS AND SCREWS - CONTINUED

NAS No.	Type	Head (Fig. 5)	Size Range	Material	Coding				Head Marking
					Dia.	Replacing Dash or First Dash	Replacing Second Dash	At End	
1603 — 1610	Bolt, 100°, close-tolerance, 0.0312 in oversize, 160,000 lbf/in² (b)	F or P	No.10 — $\frac{5}{8}$ in	Alloy steel	B	—	—	R = Phillips recess Nil = Hi-Torque	NAS 1347 Type IV
1620 — 1628	Screw, 100°, short thread, Torq-Set recess	P	No. 4 — $\frac{1}{2}$ in	Alloy steel CRS Titanium	B	C, E and V as 1100	—	D = drilled shank P = type II plating	NAS 1347 Type IV
1630 — 1634	Screw, pan head, short thread Torq-Set	M	No. 4 — $\frac{1}{2}$ in	Alloy steel CRS Titanium	B	C, E and V as 1100	—	D = drilled shank P = type II plating	NAS 1347 Type IV
1703 — 1710	Bolt, 100°, close-tolerance, 0.0156 in oversize, 160,000 lbf/in² (b)	B or F	No.10 — $\frac{5}{8}$ in	Alloy steel	B	—	—	R = Phillips recess Nil = Hi-Torque	NAS 1347 Type IV
2803 — 2810	Bolt, 100°, close-tolerance, 180,000 lbf/in², Torq-Set	P	No.10 — $\frac{5}{8}$ in	Alloy steel	B	—	—	—	NAS No. + dash no.
2903 — 2920	Bolt, shear, hex. head, 0.0156 in oversize (b)	C or K	No.10 — $1\frac{1}{4}$ in	Alloy steel	B	E = short thread	—	D = drilled shank H = drilled head W = type I plating	NAS No. + dash no.
3003 — 3020	Bolt, shear, hex. head, long or short thread, 0.0312 in oversize (b)	C or K	No.10 — $1\frac{1}{4}$ in	Alloy steel	B	E = short thread	—	D = drilled shank H = drilled head W = type I plating	NAS No. + dash no.
4104 — 4116	Bolt, 100°, close-tolerance, long thread, Tri-wing recess, self-locking and non-locking	W	$\frac{1}{4}$ — 1 in	Alloy steel	B	B = black plating D, L or P see (g)	—	X = 0.0156 in oversize Y = 0.0312 in oversize	NAS No. + dash no. (e) (f) (g)
4204 — 4216	Bolt, 100°, close-tolerance, long thread, Tri-wing recess, self-locking and non-locking	W	$\frac{1}{4}$ — 1 in	CRS (c)	B	U = unplated D, L or P see (g)	—	X and Y as 4104	NAS No. + dash no. (e) (f) (g)
4304 — 4316	Bolt, 100°, long thread, Tri-wing recess, self-locking and non-locking	W	$\frac{1}{4}$ — 1 in	Titanium (d)	B	U = unplated D, L or P see (g)	—	X and Y as 4104	NAS No. + dash no. (e) (f) (g)
4400 — 4416	Bolt, 100°, short thread, Tri-wing recess, self-locking and non-locking	W	No.4 — 1 in	Alloy steel	B	B = black plating D, L or P see (g)	—	X and Y as 4104	NAS No. + dash no. (e) (f) (g)

TABLE 17.11, NAS BOLTS AND SCREWS - CONTINUED

NAS No.	Type	Head (Fig. 5)	Size Range	Material	Coding				Head Marking
					Dia.	Replacing Dash or First Dash	Replacing Second Dash	At End	
4500—4516	Bolt, 100°, close-tolerance, short thread, Tri-wing recess, self locking or non-locking	W	No.4 — 1 in	CRS (c)	B	U = unplated D, L or P see (g)	—	X and Y as 4104	NAS No. + dash no. + C for CRS (e) (f) (g)
4600—4616	Bolt, 100°, close-tolerance, short thread, Tri-wing recess, self-locking and non-locking	W	No.4 — 1 in	Titanium (d)	B	U = unplated D, L or P see (g)	—	X and Y as 4104	NAS No. + dash no. + V for titanium (e) (f) (g)
4703—4716	Bolt, 100°, close-tolerance, short thread, reduced head, non-locking, Tri-wing recess	W	No.10 — 1 in	Alloy steel	B	D = drilled shank Nil = undrilled	—	X and Y as 4104	NAS No. + dash no. (e) (f)
4803—4816	Bolt, 100°, close-tolerance, short thread, reduced head, non-locking, Tri-wing recess	W	No.10 — 1 in	CRS (c)	B	D = drilled shank U = unplated	—	X and Y as 4104	NAS No. + dash no. + C for CRS (e) (f)
4903—4916	Bolt, 100°, close-tolerance, short thread, reduced head, non-locking, Tri-wing recess	W	No.10 — 1 in	Titanium (d)	B	D = drilled shank U = unplated	—	X and Y as 4104	NAS No. + dash no. + V for titanium (e) (f)
5000—5006	Bolt, pan head, close-tolerance, short thread, Tri-wing recess, self-locking and non-locking	X	No.4 — $\frac{3}{8}$ in	Alloy steel	B	B = black plating L or P see (g)	—	X and Y as 4104	NAS No. + dash no. (e) (f) (g)
5100—5106	Bolt, pan head, close-tolerance short thread, Tri-wing recess, self-locking and non-locking	X	No.4 — $\frac{3}{8}$ in	CRS (c)	B	U = unplated L or P see (g)	—	X and Y as 4104	NAS No. + dash no. + C for CRS (e) (f) (g)
5200—5206	Bolt, pan head, close-tolerance, short thread, Tri-wing recess, self-locking and non-locking	X	No.4 — $\frac{3}{8}$ in	Titanium (d)	B	U = unplated L or P see (g)	—	X and Y as 4104	NAS No. + dash no. + V for titanium (e) (f) (g)
5300—5360	Screw, flat fillister head, full thread, Tri-wing recess, self-locking and non-locking	Y or Z	No.4 — $\frac{3}{8}$ in	Alloy steel	B	H = drilled head B = black plating L or P see (g)	—	—	NAS No. + dash no. (f) (g)

TABLE 17.11, NAS BOLTS AND SCREWS - CONTINUED

NAS No.	Type	Head (Fig. 5)	Size Range	Material	Coding				Head Marking
					Dia.	Replacing Dash or First Dash	Replacing Second Dash	At End	
5400 – 5406	Screw, flat fillister head, full thread, Tri-wing recess, self-locking and non-locking	Y or Z	No.4 — $\frac{3}{8}$ in	CRS (c)	B	H = drilled head U = unplated L or P see (g)	–	–	NAS No. + dash no. + C for CRS (f) (g)
5500 – 5506	Screw, flat fillister head, full thread, Tri-wing recess, self-locking and non-locking	Y or Z	No.4 — $\frac{3}{8}$ in	Titanium (d)	B	H = drilled head U = unplated L or P see (g)	–	–	NAS No. + dash no. + V for titanium (f) (g)
5600 – 5606	Screw, 100°, full thread, Tri-wing recess, self-locking and non-locking	W	No.4 — $\frac{3}{8}$ in	Alloy steel	B	B = black plating L or P see (g)	–	–	NAS No. + dash no. (f) (g)
5700 – 5706	Screw, 100°, full thread, Tri-wing recess, self-locking and non-locking	W	No.4 — $\frac{3}{8}$ in	CRS (c)	B	B = black plating U = unplated L or P see (g)	–	–	NAS No. + dash no. + C for CRS (f) (g)
5800 – 5806	Screw, 100°, full thread, Tri-wing recess, self-locking and non-locking	W	No.4 — $\frac{3}{8}$ in	Titanium (d)	B	U = unplated L or P see (g)	–	–	NAS No. + dash no. + V for titanium (f) (g)
6000 – 6003	Screw, hex. head, full thread, Tri-wing recess	V	No.4 to No.10	CRS (c)	B	U = unplated	–	–	NAS No. + dash no. + C for CRS (f)
6100 – 6103	Screw, hex. head, full thread, Tri-wing recess	V	No.4 to No.10	Titanium (d)	B	U = unplated	–	–	NAS No. + dash no. + V for titanium
6203 – 6220	Bolt, hex. head, short thread, close-tolerance, self-locking and non-locking	C or K	No.10 — $1\frac{1}{4}$ in	Alloy steel	B	D, L or P see (g)	–	X or Y as 4104 D = drilled shank H = drilled head	NAS No. + dash no. (e) (g)
6303 – 6320	Bolt, hex. head, short thread, close-tolerance, self-locking or non-locking	C or K	No.10 — $1\frac{1}{4}$ in	CRS (c)	B	U = unplated L or P see (g)	–	X or Y as 4104 D = drilled shank H = drilled head	NAS No. + dash no. (e) (g)
6403 – 6420	Bolt, hex. head, short thread, close-tolerance, self-locking and non-locking	C or K	No.10 — $1\frac{1}{4}$ in	Titanium (d)	B	U = unplated L or P see (g)	–	X or Y as 4104 D = drilled shank H = drilled head	NAS No. + dash no. (e) (g)

TABLE 17.11 , NAS BOLTS AND SCREWS - CONTINUED

NAS No.	Type	Head (Fig. 5)	Size Range	Material	Coding				Head Marking
					Dia.	Replacing Dash or First Dash	Replacing Second Dash	At End	
6604 6620	Bolt, hex. head, long thread, close-tolerance, self-locking and non-locking	C or K	$\frac{1}{4}$—$1\frac{1}{4}$ in	Alloy steel	B	D = drilled shank H = drilled head L or P see (g)	—	X or Y as 4104	NAS No. + dash no. (e) (g)
6704 — 6720	Bolt, hex. head, long thread, close-tolerance, self-locking and non-locking	C or K	$\frac{1}{4}$—$1\frac{1}{4}$ in	CRS (c)	B	D = drilled shank H = drilled head U = unplated L or P see (g)	—	X or Y as 4104	NAS No. + dash no. (e) (g)
6804 — 6820	Bolt, hex. head, long thread, close-tolerance, self-locking and non-locking	C or K	$\frac{1}{4}$—$1\frac{1}{4}$ in	Titanium (d)	B	D = drilled shank H = drilled head U = unplated L or P see (g)	—	X or Y as 4104	NAS No. + dash no. (e) (g)

NOTES :
(a) For repair work only, replacing NAS 1503 to 1510.

(b) For repair work only.

(c) Cadmium plated CRS bolts have green dye or paint on the end of the shank.

(d) Cadmium plated titanium bolts have red dye or paint on the end of the shank.

(e) Oversize bolts are marked with 'X' or 'Y' (see code).

(f) Heads are also marked with an encircled number, to indicate the size of the Tri-wing recess, in accordance with NAS 4000.

(g) Method of locking, included in code and marked on head, is as follows:
D = drilled shank. L = locking element is optional. P = patch type locking element.

Plating

Alloy-steel bolts and screws are normally cadmium plated in accordance with QQ-P-416 Type II Class 3. If a different plating is used, or if CRS or titanium parts are plated, the following code may be used :-

W = QQ-P-416 Type I Class 3 plating.
B = Blackened Type II plating.
H = CRS with Type II plating.
P = CRS or titanium with Type II plating.
U = Unplated.
A = Aluminium coating to NAS 4006.

Type of Locking

Unless otherwise noted in Table 17, the type of locking is indicated as follows :

D = Drilled shank.
H = Drilled head.
L = Nylon strip locking element.
N = Nylon button or pellet locking element.
LK = KEL-F strip locking element.
NK = KEL-F pellet locking element
K = KEL-F locking element, type optional.

Note

The lack of a letter for a self-locking bolt indicates that the type of locking element is unimportant.

Type of Recess

Where a choice of wrenching recesses is available, the following code is used to indicate the type required :

T = Torque - set.
H = Hi-Torque
P or R = Phillips (cruciform).

Note

The type of recess indicated by the lack of a code letter is shown in Table 17.11.

Type of material

The NAS fasteners listed in Table 17.11 are manufactured from alloy steel, corrosion-resistant steel (CRS), corrosion-and heat-resistant (C and HR) steel, and titanium alloy. Except in the case of titanium alloy, which is sometimes indicated by a 'V' (see Table 17.11), the type of material is not specified unless the fastener is made in more than one material. The basic code applies to alloy steel, and the following code indicates other materials :-

CR = corrosion-resistant steel, 125,000 lbf/in^2
C = corrosion-resistant steel, 140,000 lbf/in^2
E = corrosion-resistant steel, 160,000 lbf/in^2
V = titanium alloy.

Examples of coding

a.	NAS 564-15	is full-threaded bolt in cadmium-plated alloy steel, with 1/4 - 28 thread, and length of 15/32 in.
b.	NAS 1146E12P	is a screw with a modified pan head, close-tolerance shank and Torque-Set recess, made from CRS (160,000 lbf/in^2), with Type II plating. It has a 3/8 - 24 thread and a 3/4 in grip length.
c.	NAS 1189-3T8L	is a self-locking screw with a 100° countersunk head and full thread. It has a 10-32 thread, is 1/2 in long, and is in alloy steel with Type II plating. It has a strip-type nylon locking element and a Torque-Set recess.
d.	NAS 6804D10X	is a hexagon head, close-tolerance bolt in titanium alloy, with a long thread, It has a 1/4-28 thread and 5/8 in grip length, and a drilled shank which is 0.0156 in oversize.

FUTURE TRENDS

Because of the importance of reducing weight in the construction of an aircraft, designers are constantly seeking means of using higher strength or lighter alloys for structural purposes. This trend applies particularly to fasteners and it is apparent that the use of smaller diameter bolts and miniature anchor nuts will become more widespread. It will be accompanied by the use of threads of UNJF from.

In the field of light alloys, specifications for titanium bolts are being prepared and will probably be drawn up in accordance with existing American practice, within the framework of British Standard A101, entitled ''General Requirements for Titanium Bolts''

Because of the vast experience gained, particularly in America, in the use of both standard and miniature components, it has been internationally agreed to use Unified inch threads on fasteners. However, with the introduction of metric dimensions in other fields, it is probable that a metric thread series will eventually be accepted.

As far as identification features are concerned it appears likely that the system used for recent specifications will continue; bolts in the AS series will be marked with a number which will be unique for a particular diameter and length, and bolts in the BS series will use the code at present applied to bolts with UNJ threads.

NOTE

There is no symbol used to differentiate between threads of standard unified or UNJ form.

ABBREVIATIONS

The following is an alphabetical list of abbreviations used in this Leaflet:-

AGS	Aircraft General Standards
AS	Aircraft Standards
Al Al	Aluminium alloy
BA	British Association
blue	dyed blue over anodic film
BSF	British Standards Fine
cad.	cadmium plated all over
cad. h & t	cadmium plated head and thread only
csk.	countersunk
c/t	close tolerance
CRS	corrosion resisting steel
FCS	free-cutting steel
green	dyed green over anodic film
hd.	head
hex.	hexagon
HTS	high tensile steel
LTS	low tensile steel
mush.	mushroom
nat.	natural finish
SS	stainless steel
UNC	Unified coarse thread
UNF	Unified fine thread
UNS	Unified special thread
UNJF	Unified fatigue-resistant fine thread

AIRCRAFT BOLTS

Most, but not all, aircraft bolts are designed and fabricated according to government standards with the following specifications :

1. ***AN, Air Force/Navy :*** Comes in three head styles - Hex Head - Clevis Nd Eye Bolts.
2. ***NAS, National Aerospace Standards :*** are available in Hex Head, Internal wrenching and Countersunk.
3. ***MS, Military Standards :*** are in Hex head and Internal Wrenching.

BOLT TYPES, SPECIFICATION AND IDENTIFICATION

General - Purpose Bolts

The hex-head aircraft bolt (AN-3 through AN-20) is an all - purpose structural bolt used for general applications involving tension or shear loads where a light-drive fit is permissible (0.006-inch clearance for a 5/8-inch hole, and other sizes in proportion). They are fabricated from SAE 2330 nickel steel and are cadmium plated and anodized aluminium alloys. Most bolts used in aircraft structures are either general purpose, AN bolts or NAS internal wrenching or close tolerance bolts or M.S. bolts.

Alloy steel bolts smaller than No. 10-32 (3/16-inch diameter, AN-3) and aluminum alloy bolts smaller than 1/4-inch diameter are not used in primary structures. Aluminum alloy bolts and nuts are not used where they will be repeatedly removed for purposes of maintenance and inspection.

The AN 73-AN81 (MS20073-MS20074) drilled-head bolt is similar to the standard hex-bolt, but has a deeper head that is drilled to receive wire for safetying. The AN 3-AN 20 and the AN-73, AN-81 series bolts are interchangeable, for all practical purposes, from the standpoint of tension and shear strengths.

AN3-AN20 AIRFRAME BOLTS

Application

These bolts may be used for either tensile or shear loads.

Material

Cadmium plated nickel alloy steel : No letter designation - Head marked with cross or asterisk.

Corrosion resistant steel (CRES) : C - Head marked with single dash.

Aluminum alloy (2024-T4) : DD-Head marked with two dashes.

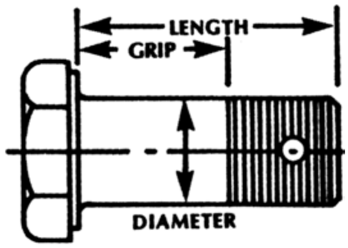


Fig.17.7 AN3 - AN20 Airframe Bolts.

Diameter

The AN number denotes the diameter of the shank in 1/16-inch increments :
Example 3 = 3/16".

Length

The dash number denotes the length in eighths of an inch up through 7/8. For lengths greater than one inch, the first digit is the number of inches and the second digit is the number of eighths.

Example

12 = 1 inch + 2/8 or 1-1/4 inch long.

Thread

Class 3NF

Safety Provisions

1. This bolt was originally designed to be used with a castle nut and cotter pin wherein the shank is drilled for the pin.
2. If a self-locking nut is to be used, the shank should be undrilled. This is designated by the letter A following the dash number.

   Example AN4-6A.
3. If the bolt is used in a blind hole and safetied with wire through the head, the head is drilled and designated by the letter H used in place of the dash.

TABLE 17.12 NUT AND COTTER PIN SIZES

AN Number	Diameter	Plain Nut AN Number	Castle Nut AN Number	Cotter Pin MS Number
AN3	3/16	AN315-3R	AN310-3	MS24665-132
AN4	1/4	AN315-4R	AN310-4	MS24665-132
AN5	5/16	AN315-5R	AN310-5	MS24665-132
AN6	3/8	AN315-6R	AN310-6	MS24665-283
AN7	7/16	AN315-7R	AN310-7	MS24665-283
AN8	1/2	AN315-8R	AN310-8	MS24665-283

a. Hexagonal Headed Bolt

Bolts that are typically used for airframe structural applications have hex heads and range in size from AN3 to AN20.

b. Clevis Bolt

The head of a Clevis Bolt is round and is either sloted to receive a common screw driver or recess to receive a cross point screw driver. This type of bolt is used only where sheet loads occur and never in tension. it is often inserted as a mechanical pins in a controle system.

AN21-AN36 CLEVIS BOLTS

Application

These bolts are used for shear loads only.

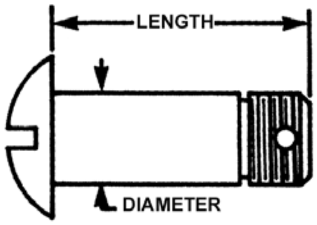


Fig.17.8 AN21 - AN36 Clevis Bolts

Material

Nickel steel alloy, SAE 2330.

Diameter

AN21 - AN23 - the second digit denotes the fine thread machine screw size.

Example

21 is 6-40, 22 is 8-36; 23 is 10-32.

AN 24-AN36- the second digit denotes the diameter in 1/16th-inch increments.

Example

AN25 has a diameter of 5/16th -inch.

Length

The dash number indicates the length in 1/16th-inch increments.

Example

9 = 9/16-inch, -26/16 or 1-5/8 inches long.

Thread

Class 3NF

Safety Provisions

This bolt is designed to be used with a shear castle nut, safetied with a cotter pin. In the event a self-locking nut is used, the bolt should not be drilled. This is designated by the letter A following the dash number.

Example

AN 24-16A.

TABLE 17.13, NUT AND COTTER PIN SIZES
To Use With Each Clevis Bolt Size

AN Number	Diameter & Threads Per Inch	Self-Locking Nut	Castle Shear Nut	Cotter Pin
AN21	6 - 40	- - - - - - - - - - -	AN320 - 1	MS24665 - 3
AN22	8 - 36	- - - - - - - - - - -	AN320 - 2	MS24665 - 132
AN23	10 - 32	MS20364 - 1032	AN320 - 3	MS24665 - 132
AN24	1/4 - 28	MS20364 - 428	AN320 - 4	MS24665 - 132

TABLE 17.14, DASH NUMBER - NOMINAL LENGTH

-8 1/2	-14 7/8	-20 1 - 1/4
-9 9/16	-15 15/16	-21 1-5/16
-10 5/8	-16 1	-22 1-3/8
-11 11/16	-17 1-1/16	-23 1-7/16
-12 3/4	-18 1-1/8	-24 1-1/2
-13 13/16	-19 1-3/16	-25 1-9/16

Clevis Bolt & Eye Bolt

Aircraft bolts are fabricated from cadmium - or zinc-plated corrosion-resistant steel, unplated corrosion-resistant steel, and anodized aluminum alloys. Most bolts used in aircraft structures are either general-purpose, AN bolts, or NAS internal-wrenching or close-tolerance bolts, or MS bolts. In certain cases, aircraft manufacturers make bolts of different dimensions or greater strength than the standard types. Such bolts are made for a particular application, and it is of extreme importance to use like bolts in replacement. Special bolts are usually identified by the letter "S" stamped on the head.

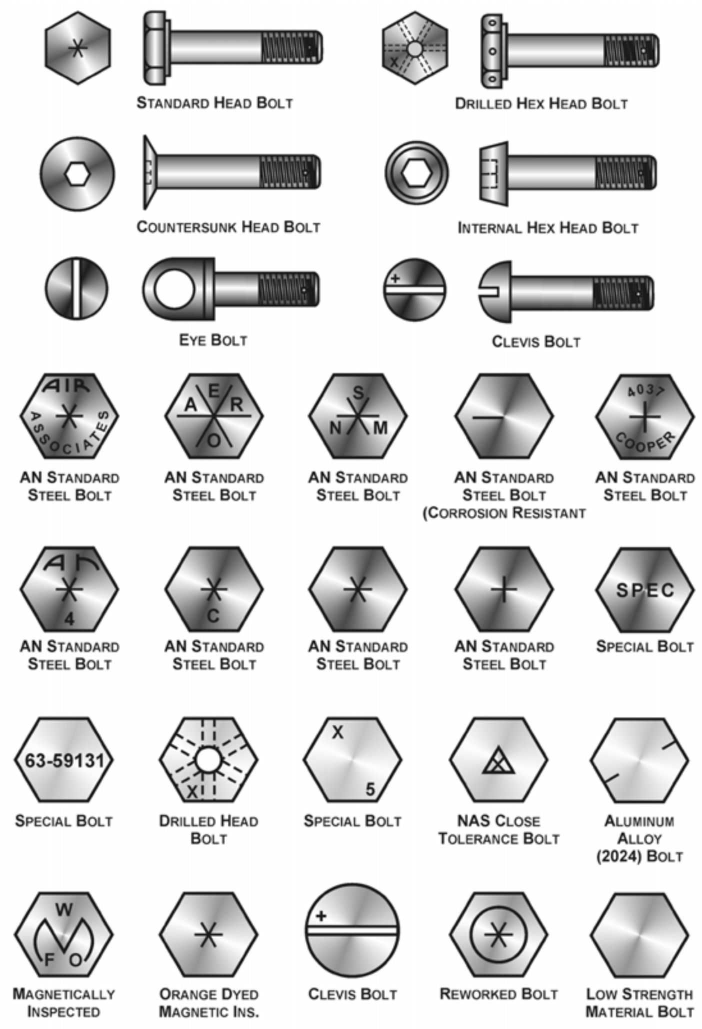


Fig.17.9, Aircraft Bolt Identification.

AN bolts come in three head styles - hex-head, clevis, and eyebolt (See figure 17.9). NAS bolts are available in hex-head, internal-wrenching, and countersunk head styles. MS bolts come in hex-head and internal-wrenching styles.

c. Eye Bolt

This type of special purpose bolt is used where external tension loads are to be applied. The eye bolt is designed for the attachment of such devices as the fork of a turn buckle, a clevis or a cable shackle . The treated end may or may not be drilled for safetying.

d. Drilled - Head Engine Bolts

AN73 through AN81 bolts are hex-headed nickel steel bolts that are similar in appearance to the AN3 through AN20 series. However, unlike standard bolts, drilled-head engine bolts have a thicker head that is drilled with a small hole in each of the flats and in the center of the head. As with most bolts, the diameters of drilled-head engine bolts are in 1/16 increments while bolt lengths are in 1/8 inch increments. The diameter is indicated by the second number following the "AN" designation while the bolt length is indicated by a dash number. For example, a drilled-head engine bolt designated as AN74 -6 has a diameter of ¼ inch and a length of 3/4 inch.

An advantage of drilled-head engine bolts is that they are made with either fine of course threads. A fine threaded bolt is identified by the absence of an "A" preceding the dash number, while a course threaded bolt is identified by the presence of the letter "A" before the dash number. As an example, a drilled-head engine bolt with an AN75A7 designation has a diameter of 5/16 inch, a length of 7/8 inch, and course threads. On the other hand, the designation AN75-7 identifies a bolt with the same dimensions and fine threads.

Under MS standards, AN73 through AN81 drilled-head engine bolts have been superseded by MS20074. In this case, MS20073 bolts have fine threads while MS20074 bolts have course threads. The diameter of MS20073 and MS20074 bolts is identified by a dash number. For example, a MS20073-05 identifies a fine threaded bolt with a diameter of 5/16 inch. Diameters are in 1/16 inch increments and range from -03 (3/16 inch) up to -12, (3/4 inch). Bolt length, on the other hand, is indicated by a second dash number whose value is indicated in a chart. This second dash number can range from -02 (.344 inch) to -60 (6.062 inches).

e. Counter Sunk Head Bolt

NAS bolts are available in countersunk head style also. Countersunk head bolts is flat topped and beveled towards the shank so that if fits into a countersunk hole and is flush with the material surface.

f. Drilled Hex Head Bolt

MS20073 - MS20074 DRILLED HEAD BOLTS

Application

Primarily in high stress areas where the bolt is screwed into a blind hole and safetied with lock wire. An example of the use of this bolt is to attach a propeller to a flanged shaft.

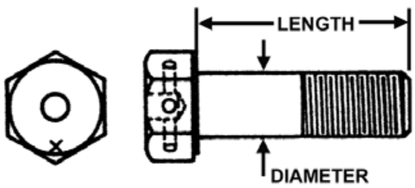


Fig. 17.10, MS20073 - MS20074 Drilled Head Bolts.

Materials

-03 through - 12
MS20073 has from 10-32 to 3/4-16 threads
MS20074 has from 10-24 to 3/4-10 threads

Length

The dash number denotes the length in eighths of an inch up through 7/8-inch. For lengths greater than one inch, the first digit is the number of inches and the second digit is the number of eighths.
Example : MS20073-7-7 is 3/8-inch diameter, 7/8-inch long.
MS20073-5-33 is 5/16-inch diameter, 3-3/8 inches long.

Thread

The MS20073 has a national fine thread and is designed to be used with nuts or screwed into a steel part. MS20074 is national course threaded and is principally used in aluminum or magnesium castings.

Safety provisions
All of these bolts have their drilled hole for safety wire with no hole in the shank for a cotter pin.

g. Internal Hex Head Bolt
These bolts, (MS-20004 through MS-20024 or NAS - 495) are fabricated from high-strength steel and are suitable for use in both tension and shear applications. When they are used in steel parts, the bolthole must be slightly countersunk to seat the large corner radius of the shank at the head. In Dural material, a special heat-treated washer must be used to provide an adequate bearing surface for the head. The head of the internal-wrenching bolt is recessed to allow the insertion of an internal wrench when installing or removing the bolt. Special high-strength nuts are used on these bots. Replace an internal-wrenching bolt with another internal-wrenching bolt. Standard AN hex-head bolts and washers cannot be substituted for them as they do not have the required strength.

h. AN Standard Steel Bolt
Made of corrosion resistance stainless steel. They are marked with either a raised dash or asterisk; corrosion resistant steel is indicated by a single raised dash.

i. Special Bolt
Bolts designed for a particular or use are classified as special purpose bolts, Clevis Bolts, Eye Bolts, Jo-Bolts and Lock Bolts are special purpose bolts.

j. Drilled Head Bolt
It is similar to standard hex bolts but has a deeper head, which is drilled to receive wire for safetying. The AN-3 ad AN-73 series bolts are interchangeable, for all practical purposes, from the stand point of tension and sheer strength.

k. NAS Close Tolerance Bolt
Close tolerance NAS bolts are marked with either a raised or recessed triangle. The material markings for NAS bolts are the same as AN bolts. Any time a bolted joint is subjected to pounding loads or if bolts are used in the same joint, the bolts should fit the hole with a tightfit. These bolts are ground to a tolerance of to .00005 and are protected from rust by greasing instead of plating.

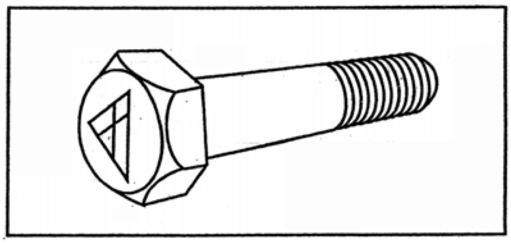


Fig. 17.11, Close tolerance bolts carry a triangle mark on their heads and are ground to a much tighter tolerance than standard bolts.

l. Al. Alloy bolt
An Aluminium alloy bolts are marked with two raised dashes. Additional information such as bolt diameter, bolt length and grip length may be obtained from the bolt part number. For example in the bolt part number AN3DD5A. The AN designates that it is an AIFFORCE - NAVY standard bolt. 3 indicates the diameter in sixteenths of an inch (3/16”) the DD indicates the material is 2024 aluminium alloy letter “C” in place of DD indicates corrosion resistant steel and absence of letter indicates cadmium plated steel. The 5” indicates the length in eights of an inch (5/8”) and the ‘A’ indicates shank is undrilled. If the letter ‘H’ preceded the “5” in addition to the “A” following it, the head would be drilled for safetying.

m. Magnetically Inspected Bolt
Bolts inspected magnetically (Magnaflux) or by fluorescent means (zyglo) are identified by means of colored lacquer, or a head marking of a distinctive type.

n. Orange Dyed
The bolt has got a low weight of just 29 grams (1 ounce) made possible by a highly innovative combination of carbon and an extremely durable aluminium alloy.

Another highlight is the newly developed ‘advanced airflow system’ which optimises the airflow in the bolt thus making it even more efficient.

o. Reworked Bolts & Low strength Bolt

Alloy steel bolts smaller than no. 10-32 and aluminium alloy bolts smaller than ¼" diameter are not used in primary structures. Al. alloy bolts and nuts are not used where they will be repeated by removed for purpose of maintenance and inspection. Al. alloy nuts may be used with cadmium plated steel bolts loaded in sheer on land airplane but are not used on sea plane due to the increased possibility of dissimilar metal corrosion.

LOCKBOLT TYPE

Jo-Bolt

Jo-bolt is a trade name for an internally threaded three-piece rivet. The Jo-bolt consists of three parts - a threaded steel alloy bolt, a threaded steel nut, and an expandable stainless steel sleeve. The parts are factory preassembled. As the Jo-bolt is installed, the bolt is turned while the nut is held. This causes the sleeve to expand over the end of the nut, forming the blind head and clamping against the work. When driving is complete, a portion of the bolt breaks off. The high-shear and tensile strength of the Jo-bolt makes it suitable for use in cases of high stresses where some of the other blind fasteners would not be practical. Jo-bolts are often a part of the permanent structure of late-model aircraft. They are used in areas which are not often subjected to replacement or servicing. (Because it is a three-part fastener, it should not be used where any part, in becoming loose, could be drawn into the engine air intake). Other advantages of using Jo-bolts are their excellent resistance to vibration, weight saving, and fast installation by one person.

Presently, Jo-bolts are available in four diameters : The 200 series, approximately 3/16 - inch in diameter; the 260 series, approximately ¼-inch in diameter; the 312 series, approximately 5/16 - inch in diameter; and the 375 series, approximately 3/8 - inch in diameter. Jo-bolts are available in three head styles which are : F (flush), P (hex-head), and FA (flush millable).

Lockbolts

The lockbolt combines the features of a high-strength bolt and rivet, but it has advantages over both. The lockbolt is generally used in wing-splice fittings, landing-gear fittings, fuel-cell fittings, longerons, beams, skin-splice plates, and other major structural attachments. It is more easily and quickly installed than the conventional rivet or bolt and eliminates the use of lockwashers, cotter pins, and special nuts. Like the rivet, the lockbolt requires a pneumatic hammer or "pull gun" for installation; when installed, it is rigidly and permanently locked in place. Three types of lockbolts are commonly used, the pull type, the stump type, and the blind type. (See figure 17.12).

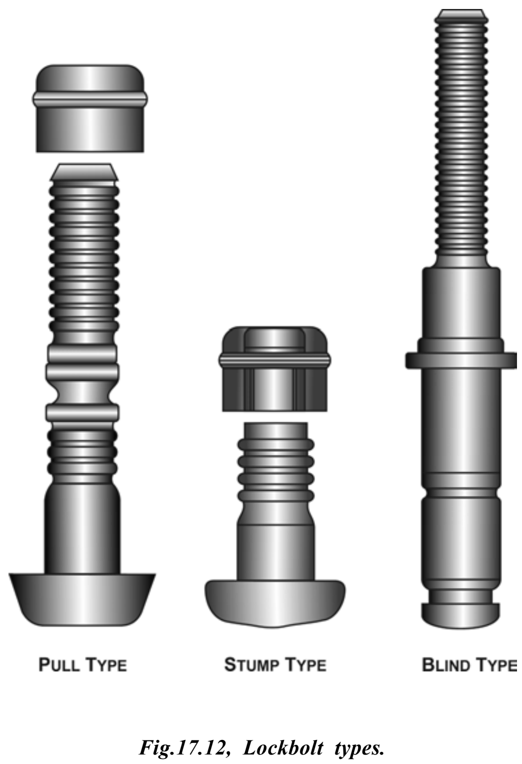


Fig.17.12, Lockbolt types.

Pull type

Pull-type lockbolts are used mainly in aircraft primary and secondary structures. They are installed very rapidly and have approximately one-half the weight of equivalent AN steel bolts and nuts. A special pneumatic "pull gun" is required to install this type of lockbolt. Installation can be accomplished by one person since bucking is not required.

Stump type

Stump-type lockbolts, although they do not have the extended stem with pull grooves, are companion fasteners to pull-type lockbolts. They are used primarily where clearance will not permit installation of the pull-type lockbolt. A standard pneumatic riveting hammer (with a hammer set attached for swaging the collar into the pin-locking grooves) and a bucking bar are tools necessary for the installation of stump-type lockbolts.

Blind type

Blind-type lockbolts come as complete units or assemblies. They have exceptional strength and sheet pull-together characteristics. Blind lockbolts are used where only one side of the work is accessible and, generally, where it is difficult to drive a conventional rivet. This type of lockbolt is installed in the same manner as the pull-type lockbolt.

Common features

common features of the three types of lockbolts are the annular locking grooves on the pin and the locking collar which is swaged into the pin's lock grooves to lock the pin in tension. The pins of the pull - and blind - type lockbolts are extended for pull installation. The extension is provided with pulling grooves and a tension breakoff groove.

LOCK BOLT NUMBERING SYSTEM

Numbering System

The numbering systems for the various types of lockbolts are explained by the following breakouts (see figure 17.13)

Safetying of Bolts and Nuts

It is very important that all bolts or nuts, except the self-locking type, be safetied after installation. This prevents them from loosening in flight due to vibration.

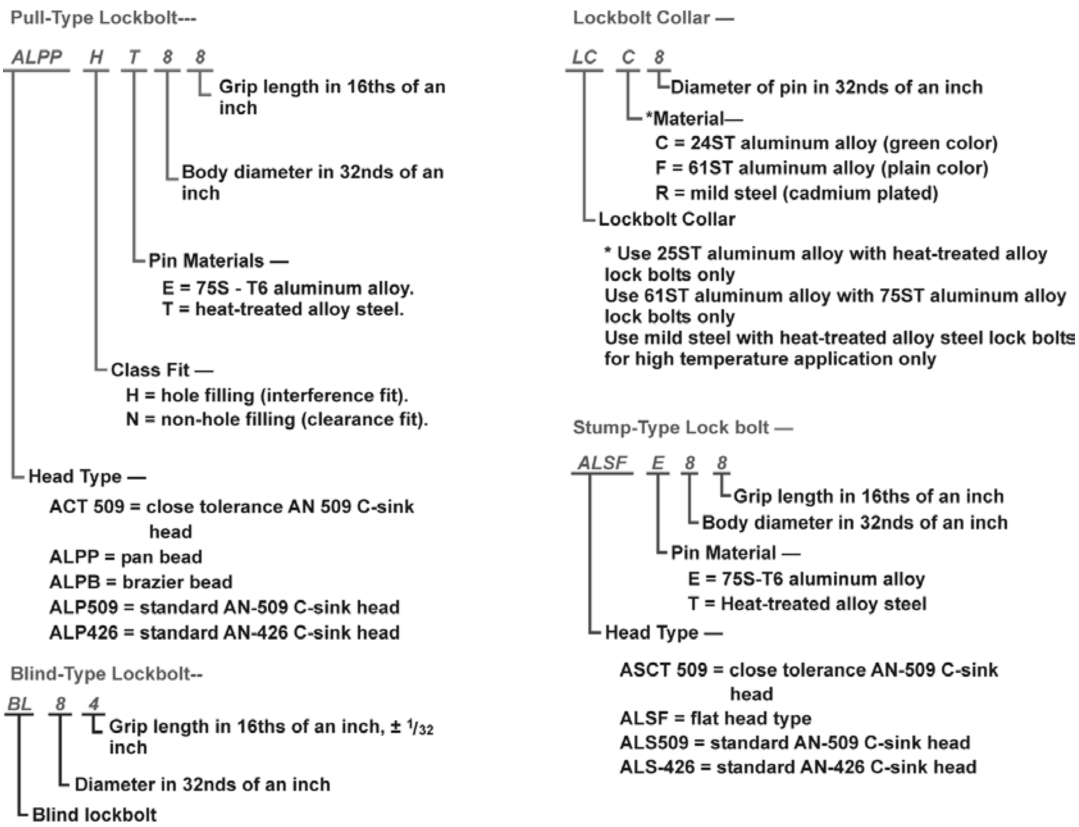


Fig.17.13, Lockbolt numbering system.

AN173-AN186 CLOSE TOLERANCE BOLT

Application

Any time a bolted joint is subject to pounding loads or if bolts and rivets are used in the same joint, the bolts should fit the hole with a tight fit. These bolts are ground to a tolerance of +0.0005" and are protected form rust by greasing instead of plating.

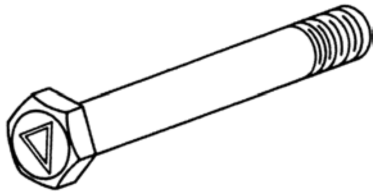


Fig.17.14, AN173 - AB186 Close Tolerance Bolt

Material
SAE 2330 nickel alloy steal.

Diameter
The last digit in the AN number denotes the diameter in sixteenth-inch increments added to the basic 17.
Ex. AN176 is 6/16 - of 3/8-inch diameter, AN182 is 12/16 - or 3/4 - inch diameter.

Length
The dash number denotes the length in eights of an inch. Bolts longer than one inch use two digits - the first indicating the number of inches, and the second, the number of eighths of an inch.

Example
AN175-22 = 5/16 diameter close tolerance bolt 2–1/4 inches long.

Thread
Thread is NF.

Safety provision
The standard bolt is drilled for a cotter pin, but if it is desired that the shank be undrilled so a self-locking nut may be used, the letter A is added to the end of the number : AN174-12A. If it is desired that the head be drilled to accept safety wire, the letter H is inserted in place of the dash.

Example
AN173H4A.

Early Series AN Bolts
Table 17.12 gives a list of the early series AN Bolts, and Fig.17.15, shows the types of heads and the identification marking used to indicate the material from which the parts are made.

TABLE 17.15, EARLY SERIES AN BOLTS

AN Number	Type	Material	Process	Nominal Range of Thread Sizes	Thread
3 - 20	Bolt, hexagon head	Steel	Cad. plated	No. 10 to 1¼ in	UNF
		CRS*	Nil		
		Al. alloy	Anodised		
21 - 36	Bolt, clevis	Steel	Cad. plated	No. 6 to 1 in	UNF
42 - 49	Bolt, eye	Steel	Cad. plated	No. 10 to $\frac{9}{16}$ in	UNF
73 - 81	Bolt, hexagon, drilled head	Steel	Cad. plated	No. 10 to $\frac{3}{4}$ in	UNF or UNC
173 - 186	Bolt, close-tolerance	Steel	Cad. plated thread and head	No. 10 to 1 in	UNF
		CRS*	Nil		
		Al. alloy	Anodised		

* CRS = Corrosion-resistant steel.

All of the bolts listed in Table 17.15 may be identified as to type by reference to the head marking or position of the locking wire holes. Diameter may be identified by experience, or by measurement and reference to the specification. Other dimensions such as grip length, head size and thread length, must be obtained from the specification.

Coding

For identification purposes the AN number is used to indicate the type of bolt and its diameter, and a code is used to indicate the material, length and thread (where these vary) and the position of the locking wire or cotter pin (split pin) hole.

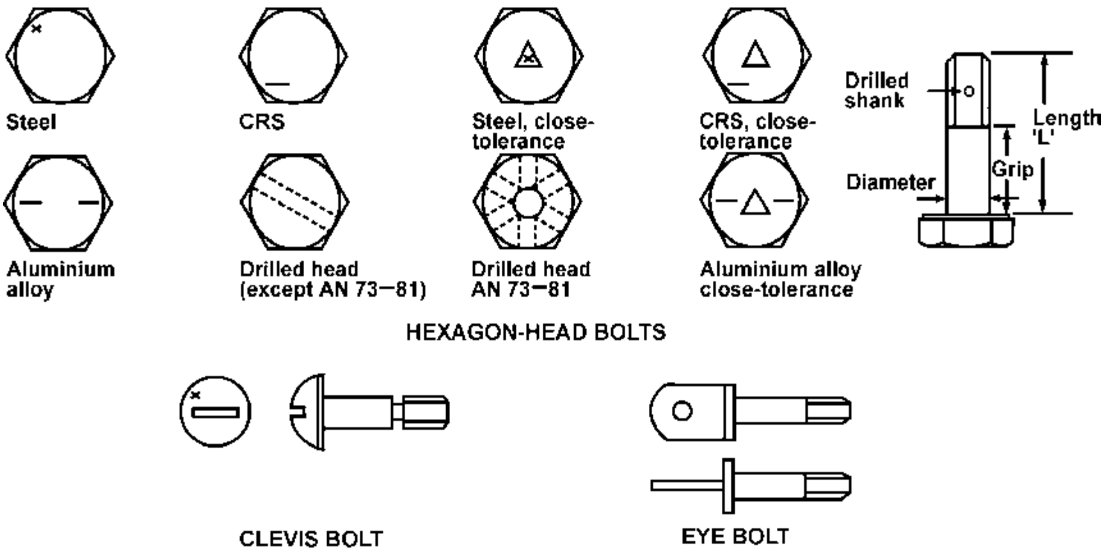


Fig. 17.15, Early Series AN Bolts

TABLE 17.16, LATE SERIES AN BOLTS

AN Number	Type	Material	Identification
101001 - 101900	Bolt, hexagon head	Alloy steel (AMS 6322) cadmium plated	
101901 - 102800	Bolt, hexagon head, drilled shank		
102801 - 103700	Bolt, hexagon head, drilled head (1 hole)		
103701 - 104600	Bolt, hexagon head, drilled head (6 hole)		
104601 - 105500	Bolt, hexagon head	Corrosion-resistant steel (AMS 7472)	
105501 - 106400	Bolt, hexagon head, drilled shank		
106401 - 107300	Bolt, hexagon head, drilled head (1 hole)		
107301 - 108200	Bolt, hexagon head, drilled head (6 holes)		

a. Diameter

The last figure or last two figures of the AN number indicate the diameter of the thread. 1 = No. 6, 2 = No. 8, 3 = No. 10, and 4 = 1/4 in, and subsequent numbers indicate the diameter in 1/16 in increments ; above 5/8 in the available sizes are in 1/8 in steps, but are still coded in sixteenths. Thus an AN 4 is a hexagon head bolt with 1/4 in thread, an AN 14 is a hexagon head bolt with a 7/8 in (14/16) thread and an AN 182 is a close-tolerance bolt with a 3/4 in (12/16) thread (the numbering in this case starting at 173). An exception to this is the eye bolt, where different diameter pin holes affect the coding ; AN 42 is No.10, AN 43 is 1/4 in, AN 44 is 5/16 in with a 1/4 in diameter pin hole, and AN 45 is 5/16 in with a 5/16 in diameter pin hole.

b. Length

The length of a bolt as quoted in the specifications, is the overall length from under the head to the end of the shank (L in Fig. 17.15), but the length is generally regarded as from under the head to the first full thread (excluding the chamfer) and is quoted in 1/8 in increments as a 'dash' number. The last figure of the dash number represents eights of an inch, and the first figure of the dash number represents inches. Thus an AN 4 - 12 is a 1/4 in hexagon - head bolt 1 1/4 in (i.e. 1 2/8) long, and an AN 12 - 24 is a 3/4 in hexagon-head bolt 2 1/2 in long. The total lengths quoted in the specifications for these bolts, is actually 1 9/32 in and 2 21/32 in, respectively. Clevis bolts (AN 21 to 36) do not follow this coding, but the length is indicated in 1/16 in increments by the dash number ; thus an AN 29-9 is 9/16 in long.

c. Position of Drilled Hole.

Bolts are normally supplied with a hole drilled in the threaded part of he shank, but different arrangements may be obtained by use of the following code :-

Drilled shank = normal coding, e.g. AN 24 - 15.

Undrilled shank = A added after dash number, e.g. AN 24 - 15 A

Drilled head only = H added before dash number (replacing the dash sign) and A added after dash number, e.g. AN 6H10A.

Drilled head and shank = H added before dash number, e.g. AN 6 H 10.

d. Material

The standard coding applies to a non-corrosion-resistant, cadmium-plated steel bolt. Where the bolt is supplied in other materials, letters are placed after the AN number as follows :-

C = corrosion-resistant steel (CRS)
DD = aluminium alloy, e.g. AN 6 DD 10.

e. Thread

Where the bolt is supplied with either UNF or UNC threads, a UNC thread is indicated by placing an 'A' in place of the dash, e.g. AN 74A6.

■■■

CHAPTER-18
AIRCRAFT NUTS

AIRCRAFT NUTS

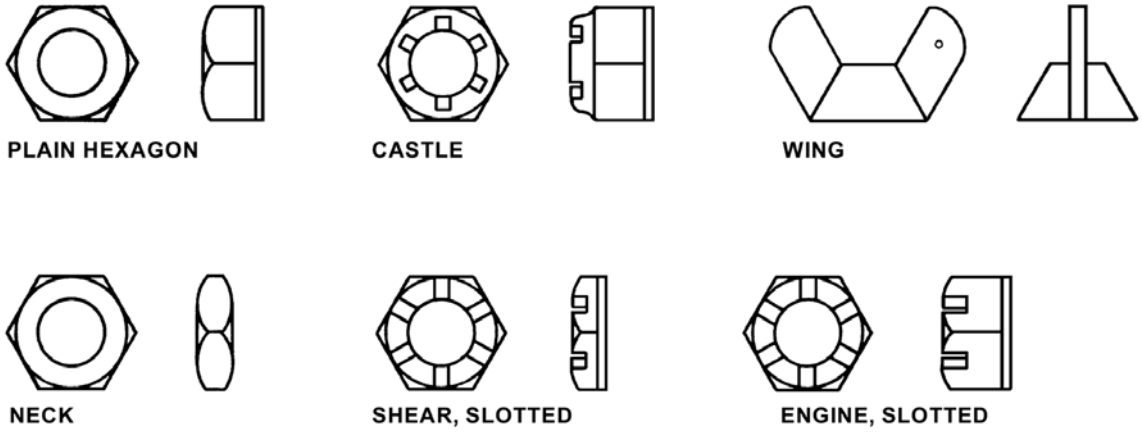


Fig. 18.1, Early Series AN Nuts.

Aircraft nuts are manufactured in a variety of shapes and sizes, made of alloy steel, stainless steel, aluminum alloys or titanium. No identification marks or letters appear on nuts. They can be identified only by the characteristic metallic luster or by color of the aluminum, brass, or the insert, when the nut is of the self-locking type. They can be further identified by their construction.

Like aircraft bolts, most aircraft nuts are designed and fabricated in accordance with AN, NAS, and MS standards and specifications.

Aircraft nuts can be divided into two general groups; non-self-locking and self-locking nuts. Non-self-locking nuts (Fig. 18.2) must be safetied by external locking devices, such as cotter pins, safety wire, or locknuts. Self-locking nuts contain the locking feature as an integral part. Self-locking nuts can be further subdivided into low temperature (250° F or less) Fig. 18.3 and high temperature (more than 250° F) Fig. 18.4.

NON-SELF LOCKING NUTS
Most of the familiar nuts (plain, castle, castellated shear, plain hex, light hex, and plain check) are the non-self-locking type (Fig. 18.2).

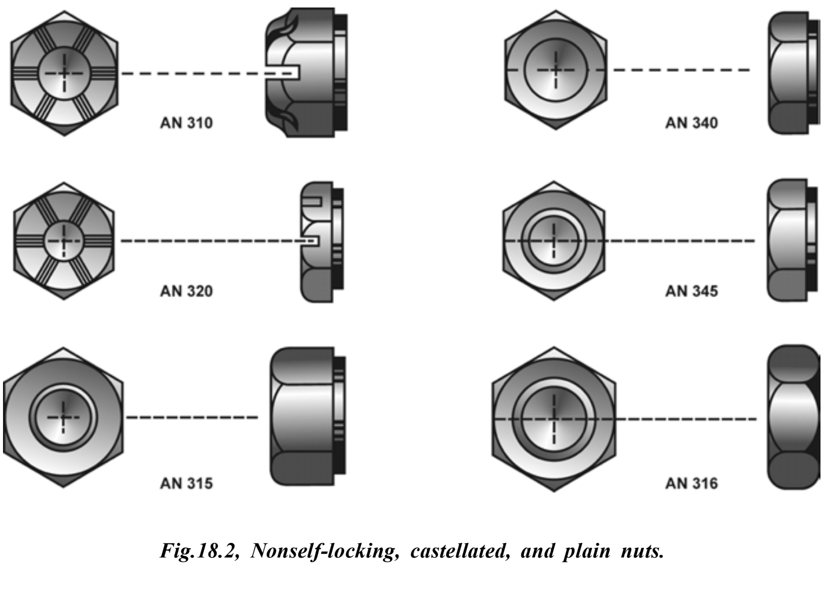


Fig.18.2, Nonself-locking, castellated, and plain nuts.

The castle nut, AN 310, is used with drilled-shank AN hex head bolts, clevis bolts, eyebolts, drilled head bolts, or studs. It is fairly rugged and can withstand large-tension loads. Slots (castellations) in the nut are designed to accommodate a cotter pin or lock wire for safety. The AN310 castellated, cadmium-plated steel nut is by far the most commonly used airframe nut.

The castellated shear nut, AN320, is designed for use with devices (such as drilled clevis bolts and threaded taper pins) that are normally subjected to shearing stress only. Like the castle nut, it is castellated for safetying. Note, however, that the nut is not as deep or as strong as the castle nut; also notice that the castellations are not as deep as those in the castle nut.

(1) AN310 CASTLE NUT

These fine-thread nuts are designed to fit on a standard airframe bolt with a Class 3 fit, and are used when the bolt is subjected to either shear or tensile loads. The size of a nut is indicated in the part code by a dash number which denotes the size of the bolt it fits. For example, an AN310-6 nut fits an AN6 bolt which has a diameter of 3/8 inch. Castle nuts are available in cadmium-plated nickel steel, corrosion-resistant steel, and 2024 aluminum alloy. Unless specified, a castle nut is made of cadmium-plated nickel steel. A corrosion resistant nut, on the other hand, is identified by the letter "C" inserted before the dash number in the part code. Aluminum alloy nuts are identified by the letter "D". For example, the part code AN310D-6 identifies an aluminum alloy nut that has an inside diameter of 6/16 (3/8) inch.

(2) AN315 AND AN335 PLAIN HEX NUT (FINE AND COARSE THREAD)

The AN315 plain nut has no castellations and, therefore, cannot be held in place using a cotter pin. Since these fine-thread nuts have no locking provisions, a spring-type lock washer must be used in combination with the nut. The lock washer applies a spring force to prevent the nut from shaking loose. AN315 nuts are used with either tensile or shear loads and are made of either nickel steel, corrosion-resistant steel, and aluminum alloy. The type of material used is indicated in the designation code in the same way it is for bolts. In other words, the absence of an additional letter identifies nickel steel, whereas the letter "C" preceding the dash number identifies corrosion resistant steel, and a "D" identifies 2024 aluminum alloy. Furthermore, plain nuts are made with both right and left-hand threads. For example, an AM315-7R is a nickel steel nut with right-hand threads that fits an AN7 bolt. An AN315C-4L, on the other hand, is a 1/4 inch diameter corrosion-resistant steel plain nut with left-hand threads.

(3) AN316 CHECK NUT

In some instances a plain nut is locked in place using a check nut. A check nut is simply a second nut that is tightened against the primary nut so it cannot turn off. An AN316 check nut is made of cadmium-plated steel and is available in both right and left-hand threads. An AN316-4R is a right-hand check nut that fits a quarter-inch thread, while a AN316-4L has a left-hand thread.

(4) AN320 SHEAR CASTLE NUT

The AN320 shear castle nut is made of the same material and has the same type of thread as AN310 nut. However, shear castle nuts are much thinner than standard castle nuts and, therefore, are used only for shear loads on clevis bolts. An AN320-6 nut is a shear castle nut that is used on an AN26 clevis bolt. An aluminum alloy (2024) nut is identified as an AN320D6.

(5) AN340 MACHINE SCREW NUTS

AN340 machine screw nuts are made in machine screw sizes from number 2 up through 1/4 inch and have coarse threads. They are available in carbon steel, corrosion-resistant steel (C), brass (B), and 2024 aluminum alloy (DD). A nut identified as a AN340B-6 is a brass nut that fits a 6-32 machine screw. An AN340DD-416 is an aluminum alloy nut that fits a 1/4-20 thread.

(6) AN 345 MACHINE SCREW NUT

These nuts are similar to AN340 nuts except they have national-fine series threads. They are available in cadmium-plated carbon steel, corrosion-resistant steel (C), commercial brass (B), and 2024 aluminum alloy (DD). An AN345DD-416 is an aluminum alloy nut that fits a 1/4-28 thread per inch machine screw.

(7) AN355 SLOTTED ENGINE NUT

This nut is designed for use on an aircraft engine and is not approved for airframe use. It is made of heat-treated steel and has national fine threads that produce a Class 3 fit. It is available in sizes from AN355-3 (3/16 inch) to AN355-12 (3/4 inch) and has slots cut in it for a cotter pin.

(8) AN360 PLAIN ENGINE NUT

This engine nut is similar to the AN355 in that it is approved for use on engines only. However, an AN360 differs from an AN355 in that it does not have cotter pin slots and has a black rustproof finish. An AN360-7 is a plain engine nut that fits a 7/16 inch bolt.

(9) AN350 WING NUT

Wing nuts are used when it is necessary to remove a part frequently without the use of tools. Aircraft wing nuts are made of either cadmium-plated steel or brass and are available in sizes to fit number six machine screws up to 1/2 inch bolts. All of these nuts have national fine threads that produce a Class 2 fit. Nuts for machine screw sizes are designated by the series number. However, nuts used on bolts have a bolt size given in 1/16 inch increments followed by the number 16. For example, with an AN350-616 wing nut, the -6 indicates that the nut will fit a 3/8 (6/16) inch bolt.

SELF-LOCKINGNUTS

As their name implies, self-locking nuts need no auxiliary means of safetying but have a safetying feature included as an integral part of their construction. Many types of self-locking nuts have been designed and their use has become quite widespread. Common applications are : (1) Attachment of antifriction bearings and control pulleys; (2) Attachment of accessories, anchor nuts around inspection holes and small tank installation openings; and (3) Attachment of rocker box covers and exhaust stacks. Self-locking nuts are acceptable for use on certificated aircraft subject to the restrictions of the manufacturer.

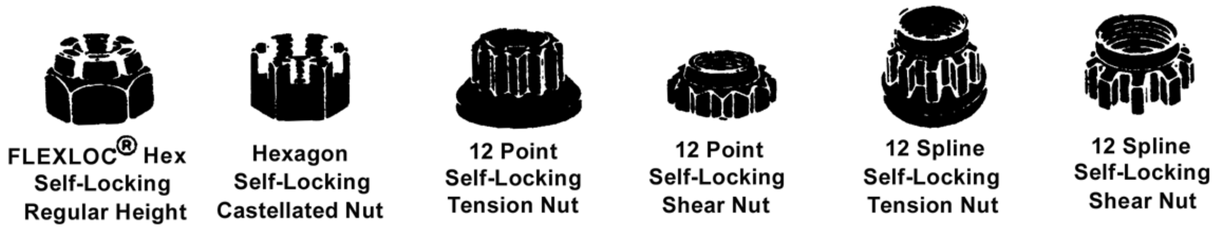


Fig.18.3, High-temperature (more than 250°F) self-locking nuts.

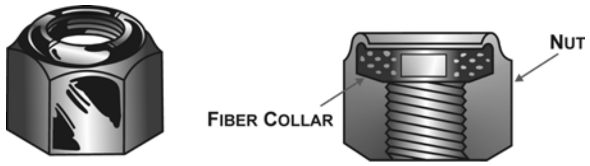


Fig. 18.4, Low-temperature (250°F or less) self-locking nut (elastic stop nut, AN 365, MS20365)

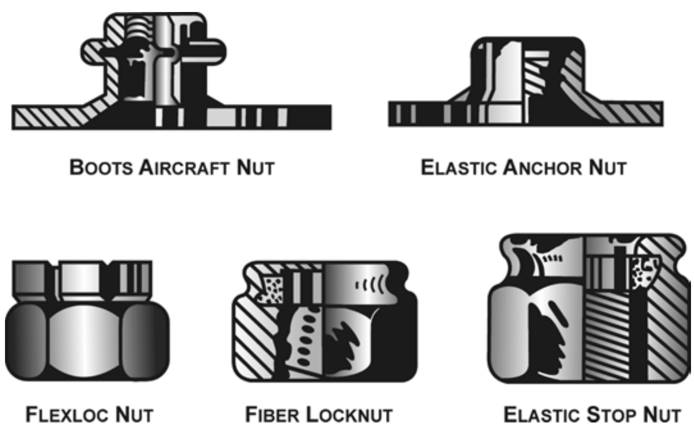


Fig. 18.5, Self-locking nuts

Self-locking nuts are used on aircraft to provide tight connections which will not shake loose under severe vibration. Do not use self-locking nuts at joints which subject either the nut or bolt to rotation. They may be used with antifriction bearings and control pulleys, provided the inner race of the bearing is clamped to the supporting structure by the nut and bolt. Plates must be attached to the structure in a positive manner to eliminate rotation or misalignment when tightening the bolts or screws.

The two general types of self-locking nuts currently in use are the all-metal type and the fiber-lock type. For the sake of simplicity, only three typical kinds of self-locking nuts are considered in this handbook : The Boots self-locking and the stainless steel self-locking nuts, representing the all metal types; and the elastic stop nut, representing the fiber-insert type.

Hexagonal

Like aircraft bolts most aircraft nuts are designed and fabricated in accordance with AN, NAS, and MS standards and specifications. In hexagonal shape which gives better grip while loosening and tightening and provided face for tabwasher locking. The hex corner provides hole for wirelocking.

Flange Nut

A flange nut has a wide flange at one end that acts as an integrated, non-spinning washer. This serves to distribute the pressure of the nut over the part being secured, reducing the chance of damage to the part and making it less likely to loosen as a result of an uneven fastening surface.

Palnuts

Palnut is a registered trademark of Trans Technology and is the most common name used for these stamped sheet metal check-nuts. They work in a very similar manner as a jam or checknut but their construction allows them to distort under load and return to their original shape in the threaded area because the are made form a spring like steel. They are also lighter than standard jam nuts. be advised they are not a substitute for a positive lockign device such as a castle nut and cotter pin or a corner drilled nut for safety wire. The Palnuts we stock are commercial versions of MS27151 series. The main difference is that the MS parts are Cadmium Plated and the Commercial ones we stock are Zinc Plated.

Dome Nut

A self-aligning dome nut having a base member for connection into a hole or aperture of a mounting plate by a pressing operation. The base member has a neck portion on one side for connection into the hole and a cavity on its other side into which a nut member. The dome is connected to the base member to leave an exposed portion on its other side for direct application of a clamping force during attachment of the dome nut to the support member. An insulting washer is disposed around the neck portion of the base member between it and the mounting plate, the insulating washer is sized to electrically isolate the nut from the support member and preclude electrical arcing there between.

Boots Self-Locking Nut

The Boots self-locking nut is of one-piece, all metal construction, designed to hold tight in spite of severe vibration. Note in Figure 18.5 that it has two sections and is essentially two nuts in one, a locking nut and a load-carrying nut. The two sections are connected with a spring which is an integral part of the nut. The spring keeps the locking and load-carrying sections such a distance apart that the two sets of threads are out-or-phase ; that is, so spaced that a bolt which has been screwed through the load-carrying section must push the locking section outward against the force of the spring to engage the threads of the locking section properly.

Thus, the spring, through the medium of the locking section, exerts a constant locking force on the bolt in the same direction as a force that would tighten the nut. In this nut, the load-carrying section has the thread strength of a standard nut of comparable size, while the locking section presses against the threads of the bolt and locks the nut firmly in position. Only a wrench applied to the nut will loosen it. The nut can be removed and reused without impairing its efficiency.

Boots self-locking nuts are made with three different spring styles and in various shapes and sizes. The wing type, which is the most common, ranges in size for No. 6 up to ¼ - inch, the Rol-top ranges from ¼ - inch to 9/16 inch, and the bellows type ranges in size from No. 8 up to 3/8 inch. Wing-type nuts are made of anodized aluminum alloy, cadmium plated carbon steel, or stainless steel. The Rol-top nut is cadmium-plated steel, and the bellows type is made of aluminum alloy only.

Stainless Steel Self-Locking Nut

The stainless steel self-locking nut may be spun on and off with the fingers, as its locking action takes place only when the nut is seated against a solid surface and tightened. The nut consists of two parts; a case with a beveled locking shoulder and key, and a threaded insert with a locking shoulder and slotted keyway. Until the nut is tightened it spins on the bolt easily, because the threaded insert is the proper size for the bolt. However, when the nut is seated against a solid surface

This action compresses the threaded insert and causes it to clench the bolt tightly. The cross-sectional view in figure 18.6 shows how the key of the case fits into the slotted keyway of the insert so that when the case is turned the threaded insert is turned with it. Note that the slot is wider than the key. This permits the slot to be narrowed and the insert to be compressed when the nut is tightened.

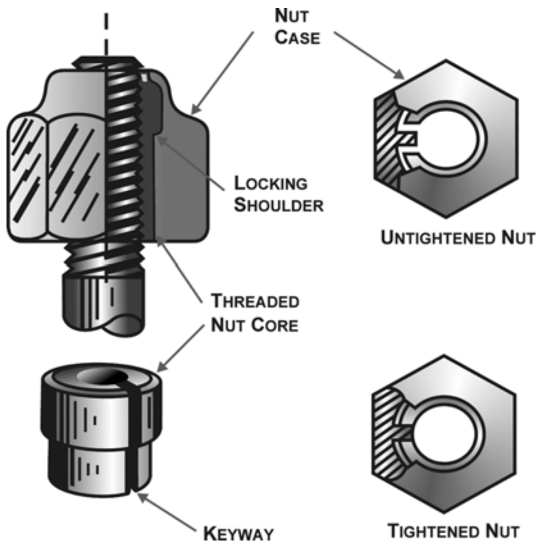


Fig. 18.6, Stainless steel self-locking nut.

Elastic Stop Nut

The elastic stop nut is a standard nut with the height increased to accommodate a fiber-locking collar. This fiber collar is very tough and durable and is unaffected by immersion in hot or cold water or ordinary solvents such as ether, carbon tetrachloride, oils, and gasoline. It will not damage bolt threads or plating.

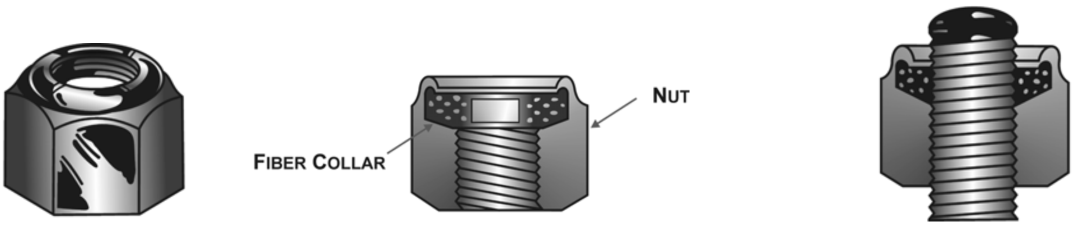


Fig. 18.7, Elastic stop nut.

As shown in figure 18.7, the fiber-locking collar is not threaded and its inside diameter is smaller than the largest diameter of the threaded portion or the outside diameter of a corresponding bolt. When the nut is screwed onto a bolt, it acts as an ordinary nut until the bolt reaches the fiber collar. When the bolt is screwed into the fiber collar, however, friction (or drag) causes the fiber to be pushed upward. This creates a heavy downward pressure on the load-carrying part and automatically throws the load-carrying sides of the nut and bolt threads into positive contact. After the bolt has been forced all the way through the fiber collar, the downward pressure remains constant. This pressure locks and holds the nut securely in place even under severe vibration.

Nearly all elastic stop nuts are steel or aluminum alloy. However, such nuts are available in practically any kind of metal. Aluminum alloy elastic stop nuts are supplied with an anodized finish. Steel nuts are cadmium plated.

Normally elastic stop nuts can be used many times with complete safety and without detriment to their locking efficiency. When reusing elastic stop nuts, be sure the fiber has not lost its locking friction or become brittle. If a nut can be turned with the fingers, replace it.

After the nut has been tightened, make sure the rounded or chamfered end of the bolts, studs, or screws extends at least the full round or chamfer through the nut. Flat end bolts, studs, or screws should extend at least 1/32 inch through the nut. Bolts of 5/16 inch diameter and over with cotter pin holes may be used with self-locking nuts, but only if free from burrs around the holes. Bolts with damaged threads and rough ends are not acceptable. Do not tap the fiber-locking insert. The self-locking action of the elastic stop nut is the result of having the bolt threads impress themselves into the untapped fiber.

Do not install elastic stop nuts in places where the temperature is higher than 250° F., because the effectiveness of the self-locking action is reduced beyond this point. Self-locking nuts may be used on aircraft engines and accessories when their use is specified by the engine manufacturer.

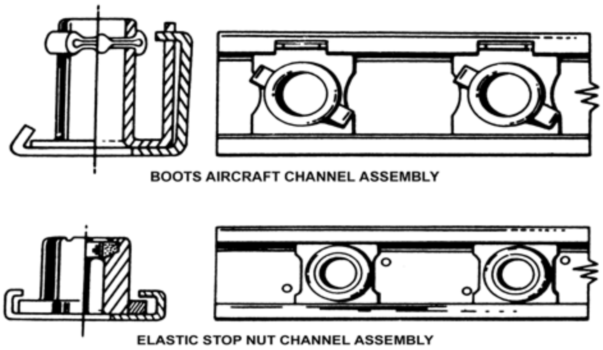


Fig. 18.8, Self-locking nut bases.

Self-locking nut bases are made in a number of forms and materials for riveting and welding to aircraft structure or parts. (See figures 18.8.) Certain applications require the installation of self-locking nuts in channels, an arrangement which permits the attachment of many nuts with only a few rivets. These channels are tack-like bases with regularly spaced nuts which are either removable or nonremovable. The removable type carries a floating nut, which can be snapped in or out of the channel, thus making possible the easy removal of damaged nuts. Nuts such as the clinch-type and spline-type which depends on friction for their anchorage are not acceptable for use in aircraft structures.

Self-Locking Nuts to 250°F

The elastic stop nut is essentially a standard hex nut that in-corporates a fiber or nylon insert (Fig. 18.9). The inside diameter of the red insert is deliberately smaller than the major diameter of the matching bolt. The nut spins freely on the bolt until the bolt threads enter the locking insert, where they impress, but do not cut, mating threads in the insert. This compression forces a metal-to-metal contact between the top flanks of the nut threads and the bottom flanks of the bolt threads. This friction hold plus the compression hold of the insert essentially "locks" the nut anywhere on the bolt.

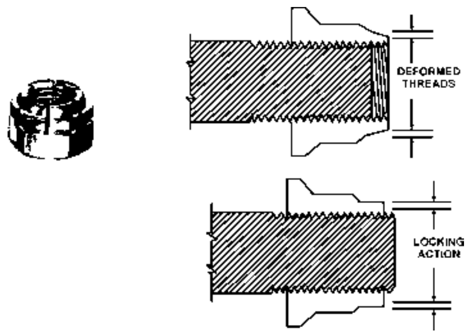


Fig. 18.9, The Boot's self-locking, all-metal nut.

After the nut has been tightened, the rounded or chamfered end of bolts, studs, or screws should extend at least the full round or chamfer through the nut. Flat-end bolts, studs, or screws should extend at least 1/32" through the nut. When fiber-type self-locking nuts are reused, the fiber should be carefully checked to be sure that it has not lost its locking friction or become brittle. Locknuts should not be reused if they can be run up to a finger-tight position. Bolts 5/16" diameter and larger, with cotter pin holes, can be used with self-locking nuts, but only if they are free from burrs around the holes. Bolts with damaged threads and rough ends are not acceptable.

Self-locking nuts should not be used at joints that subject either the nut or the bolt to rotation. They can be used with antifriction bearings and control pulleys, provided that the inner face of the bearing is clamped to the supporting structure by the nut and bolt.

High-Temperature Self-Locking Nuts

All-metal locknuts are constructed with either the threads in the locking insert out-of-phase with the load-carrying section (Fig.18.9) or with a saw-cut insert with a pinched-in thread in the locking section. The locking action of the all-metal nut depends upon the resiliency of the metal when the locking section and load-carrying section are engaged by screw threads.

Anchor Nuts

Anchor nuts are permanently mounted nut plates that enable inspection plates and access doors to be easily removed and installed. To make the installation of an access door easier where there are a great number of screws, a floating anchor nut is often used. With a floating anchor nut the nut fits loosely into a small bracket which is riveted to the skin. Since the nut is free to move within the bracket it aligns itself with a screw. To speed the production of aircraft, ganged anchor nuts are installed around inspection plate openings. These are floating-type anchor nuts that are installed in a channel that is riveted to the structure. Each nut floats in the channel with enough play so that a screw can move the nut enough to align it. [Figure 18.10]

Tinnerman nuts

Tinnerman nuts are cost-economical nuts that are stamped out of sheet metal. Because of their semi-rigid construction, tinnerman nuts can be adapted for use in many situations. For example, tinnerman nuts are commonly used on light aircraft to mount instruments to the instrument panel as well as attach inspection panels and cowlings.

Tinnerman nuts used to mount instruments can either be installed in an instrument panel or in the instrument case itself. To reduce the chance or magnetic interference, the nuts are made of brass and the cage that holds the nut is constructed of phosphor bronze. If the instrument is rear mounted, the legs of the nut are long enough to pass through the instrument case. If the instrument is front mounted, the nut fastens into the screw hole in the instrument panel. [Figure 18.11]

On many light aircraft where cost is a major factor, tinnerman-type anchor nuts are riveted to a structure to hold screws used to secure inspection plates. Although these nuts lack the strength of a regular threaded nut plate, they are approved for nonstructural inspection plates where their use protects aircraft skin from damage by repeated insertion and removal of self-tapping screws. [Figure 18.12]

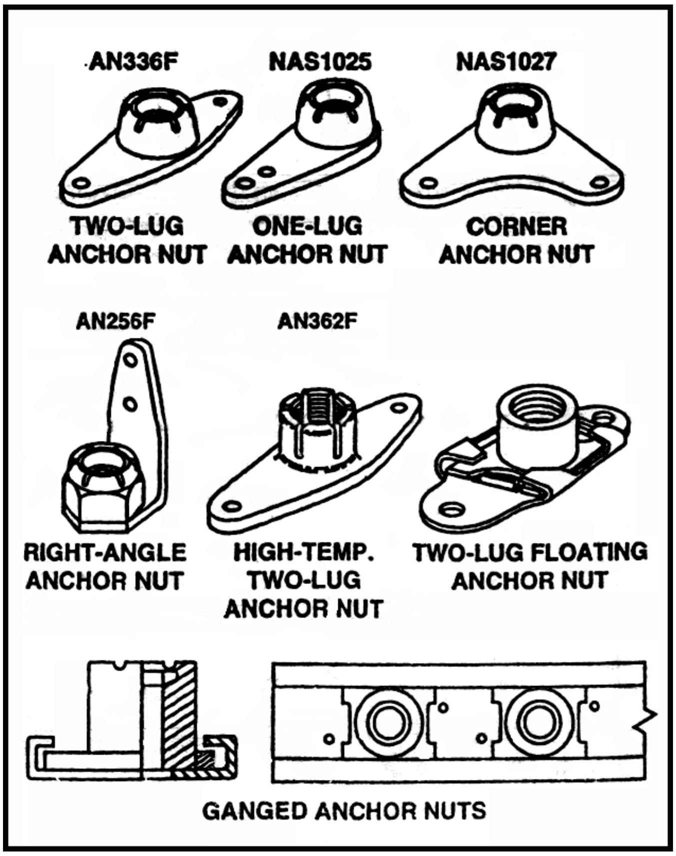


Fig. 18.10, Anchor Nuts

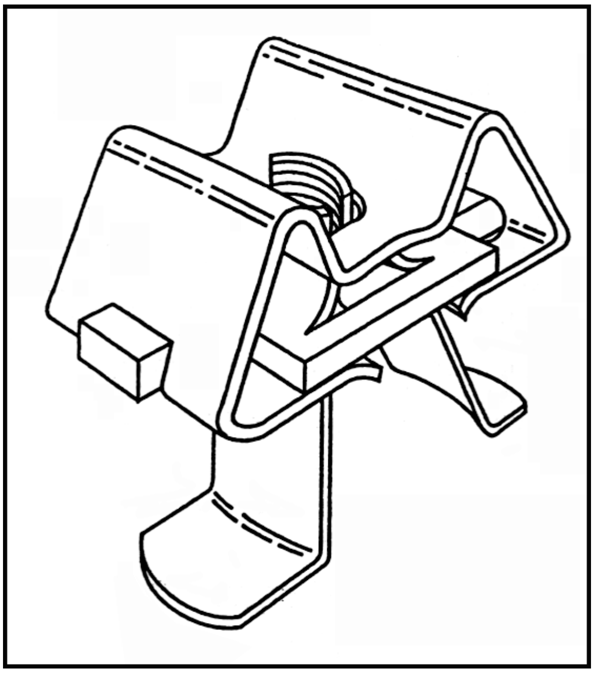


Fig. 18.11, To reduce magnetic influences in the cockpit, nonmagnetic mounting nuts secure instruments in a control panel.

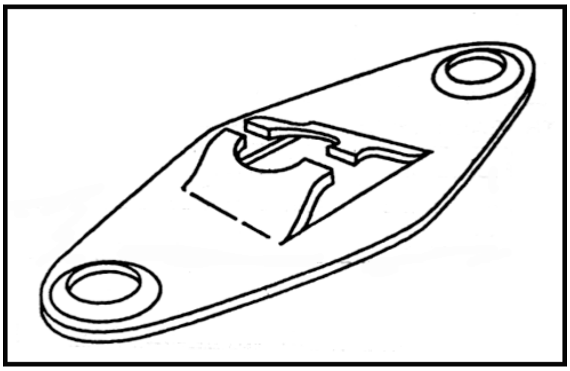


Fig. 18.12, Anchor type tinnerman nuts are suitable for nonstructural applications.

The cowlings on some light aircraft are held on with self-tapping sheet metal screws. To prevent the sheet metal screws from enlarging the holes in the cowling by repeated insertion and extraction, a U-type Tinnerman nut is slipped over the edge of the inside cowling so that it straddles the screw hole. When a screw is tightened into the nut, the spring action of the nut holds the screw tight. [Figure 18.13]

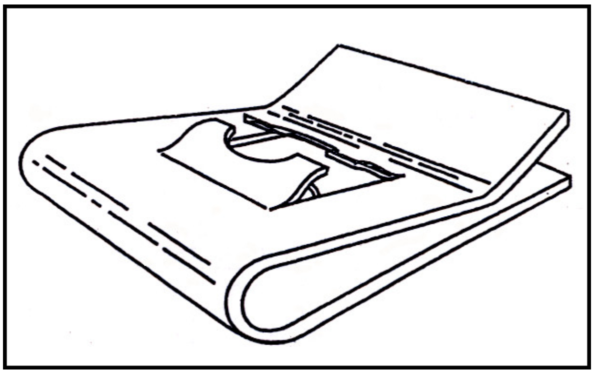


Fig. 18.13, U-type Tinnerman nuts provide convenient anchor points for cowlings, fairings, and panels.

TYPES OF NUTS

Self-locking nut bases are made in a number of forms and materials for riveting and welding to aircraft structure or parts. Certain applications require the installation of self-locking nuts in channels, an arrangement that permits the attachment of many nuts with only a few rivets. These channels are track-like bases with regularly spaced nuts that are either removable or nonremovable. The removable type carries a floating nut that can be snapped in or out of the channel, thus making possible the easy removal of damaged nuts. Clinch and spline nuts, which depend on friction for their anchorage, are not acceptable for use in aircraft structures.

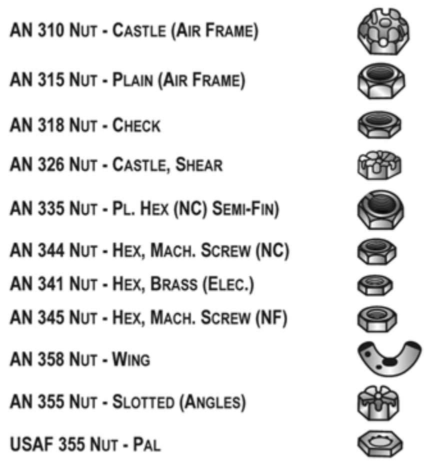


Fig. 18.14, Types of Nuts.

Various types of anchor nuts (Fig. 18.15) are available for riveting to the structure for application as removable panels.

Sheet spring nuts, sometimes called speed nuts, are used with standard and sheet-metal self-tapping screws in nonstructural locations. They find various used in supporting line clamps conduit clamps, electrical equipment access doors, etc., and are available in several types. Speed nuts are made from spring steel and are arched prior to tightening. This arched spring lock prevents the screw from working loose. These nuts should be used only where originally used in fabrication of the aircraft (Fig. 18.14).

Fig. 18.15, Various types of anchor nuts.

ii. **Castle Nuts**

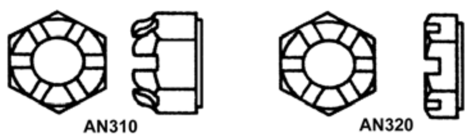


Fig.18.16, AN310 Castle Nut

Application

These nuts are used for tension loads on drilled-shank bolts and are safetied with a cotter pin

Material

Cadmium plated alloy steel : No letter designation.
Aluminium alloy (2024 - T4) : D in place of dash
Aluminium alloy (2024 - T4) : D in place of dash
Corrosion resistant steel : C in place of dash.

Size

These nuts all have National Fine threads and the dash number denotes the diameter of the bolt they fit, in 1/16ths of an inch.

Example

AN310C12 = corrosion resistant steel castle nut to fit a 3/4 - 16 bolt.

Thread

Class 3NF.

Table 18.1, CASTLE NUTS

DASH NUMBER	DIAMETER & THREAD	COTTER PINS USED WITH AN310 & AN320
-3	No. 10-32	AN380-2-2
-4	1/4-28	AN380-2-2
-5	5/16-24	AN380-2-2
-6	3/8-24	AN380-3-3
-7	7/16-20	AN380-3-3
-8	1/2-20	AN380-3-3
-9	9/16-18	AN380-4-4
-10	5/8-18	AN380-4-4
-12	3/4-16	AN380-4-5

AN320 SHEAR CASTLE NUT

Application

These nuts are used on drilled shank clevis bolts for shear loads, and safetied with a cotter pin.

Material

Cadmium plated alloy steel : No letter designation
Aluminum alloy (2024 - T4) : D in place of dash
Corrosion resistant steel : C in place of dash

Size

The size is indicated by the dash number. -1 fits a 6 -40 machine screw, -2 fits an 8 - 36 screw. Other dash numbers indicate the diameter in sixteenths of an inch of the fine thread bolt the nut fits.

Example

AN320 -6 fits a 3/8" clevis bolt (AN26).

Thread

Class 3NF.

MS21078 TWO LUG ANCHOR NUT

MILITARY NUMBERS	THREAD SIZE
MS21078-06	6-32
-08	8-32
-3	10-32
-4	1/4-28
-5	5/16-24

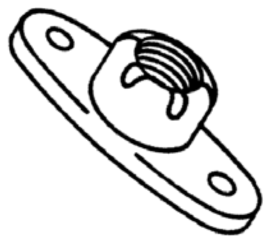


Fig.18.17

MILITARY NUMBERS	THREAD SIZE
MS21080-06	6-32
-08	8-32
-3	10-32
-4	1/4-28

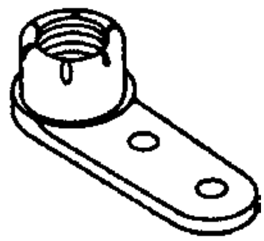


Fig.18.18

MS21081 CORNER ANCHOR NUT

MILITARY NUMBERS	THREAD SIZE
MS21081-06	6-32
-08	8-32
-3	10-32

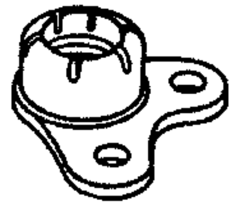


Fig.18.19

AN315-316 PLAIN AND CHECK NUTS

DASH NUMBER	DIAMETER & SIZE
-3	No. 10-32
-4	1/4-28
-5	5/16-24
-6	3/8-24

Add "L: after dash for left-hand thread.

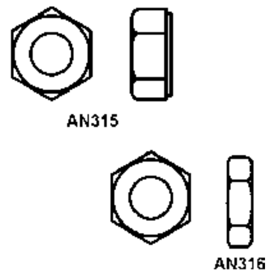


Fig.18.20

MS20341 ELECTRICAL NUT

PART NUMBER	THREAD SIZE
MS20341-6	6 - 32
MS20341-8	8 - 32
MS20341-10	10 - 32

Fig.18.21

NAF213790 BRASS MANIFOLD NUT

PART NUMBER	"AC" NUMBER	SIZE & THREAD
NAF213790-4	AC36A6203-4	1/4-28
NAF213790-5	AC36A6203-5	5/16-24

Fig.18.22

HIGH TEMPERATURE SELF-LOCKING NUT

MILITARY NUMBER	THREAD SIZE
AN363C-832	8-32
AN363C-1032	10-32
AN363C-428	1/4-28
AN363C-524	5/16-24
AN363C-624	3/8-24

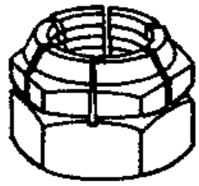


Fig.18.23

MS20364 THIN SELF-LOCKING NUT

MILITARY NUMBER	THREAD SIZE
MS20364-632	6-32
MS20364-832	8-32
MS20364-1032	10-32
MS20364-428	1/4-28
MS20364-524	5/16-24
MS20364-624	3/8-24

Fig.18.24

PART NUMBER	OLD "AC" PART NO.	SIZE & THREAD
MS27151-6	AC356-832	8-32
-7	-1032	10-32
-13	-428	1/4-28
-16	-524	5/16-24
-19	-624	3/8-24
-21	-720	7/16-20
-24	-820	1/2-20

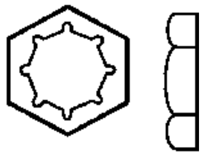


Fig.18.25

MS20365 SELF-LOCKING NUT

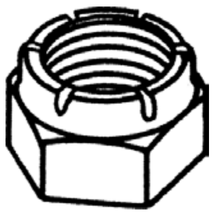


Fig. 18.26

Material

Cadmium plated alloy steel : No. letter designation
Aluminum alloy (2024 - T4) : D in place of dash
Brass : B in place of dash

Size

These nuts are available in both National Fine and National Coarse threads. The size and number of threads is denoted by the dash number.

Other dash numbers denote the diameter in sixteenth-inch increments and the number of threads per inch :

Example

AN365C428 = High temperature self-locking nut, 1/4 - inch diameter, with 28 threads per inch.

AN365B632 - Low temperature regular hex self-locking nut made of brass that fits a 6 - 32 machine screw.

Coding

The nuts listed in Table 18.2 are coded according to the type and size of thread, by a dash number placed after the AN number. Those nuts which are intended for use with AN bolts have the same code as the bolts, i.e. a number indicating thread diameter in sixteenths of an inch, and No.6, No.8 and No.10 threads being -1, -2 and -3, respectively. Those nuts intended for use with machine screws (AN 340 and 345) are coded according to the code for screws. The code represents the thread number (-0 to -10) or the diameter in sixteenths of an inch (-416, -516, etc.) designation (-640, -832, etc.) or thread diameter in fraction sizes (-4 = 1/4 in, -5 = 5/16 in, etc.). Material is indicated by a letter placed in the code instead of the dash ; C = corrosion-resistant steel, DD = aluminium alloy, machine-screws nuts, D = other aluminium alloy nuts, B = brass, and the absence of a letter indicates a non-corrosion-resistant steel nut. With AN 315 and 316 nuts, 'L' or 'R' is added after the code to indicate left - or right-hand threads. Examples of this coding are ; AN 350B4 is a brass wing nut to fit a 1/4 in bolt, and AN 316-6L is a steel check nut to fit a 3/8 in bolt with a left-hand thread.

TABLE 18.2, EARLY SERIES AN NUTS

AN Number	Type	Material	Process	Nominal Range of Thread Sizes	Thread
310	Nut, castle	Steel CRS Al. alloy	Cad. plated Nil Anodised	No. 10 to 1¼ in	UNF
315	Nut, plain	Steel CRS Al. alloy	Cad. plated Nil Anodised	No. 6 to 1¼ in (also left-hand thread)	UNF
316	Nut, check	Steel	Cad. plated	¼ to 1 in (also left-hand thread)	UNF
320	Nut, castle, shear	Steel CRS Al. alloy	Cad. plated Nil Anodised	No. 6 to 1 ¼ in	UNF
340	Nut, machine screw, hexagon	Steel CRS Brass Al. alloy	Cad. plated Nil Nil Anodised	No. 2 to ¼ in No. 2 to ¼ in No. 2 to No. 6 No. 6 to $\frac{3}{8}$ in	UNC
345	Nut, machine screw, hexagon	Steel CRS Brass Al. alloy	Cad. plated Nil Nil Anodised	No. 0 to ¼ in No. 0 to ¼ in No. 0 to No. 10 No. 10 to ¼ in	UNF
350	Nut, wing	Steel Brass	Cad. plated Nil	NO. 6 to ½ in	UNF
355	Nut, engine, slotted	Steel	Cad. plated	No. 10 to $\frac{3}{4}$ in	UNF
360	Nut, engine, plain	Steel	Cad. plated	No. 10 to $\frac{3}{4}$ in	UNF

IDENTIFICATION MARKING NUTS OF BRITISH MANUFACTURE

Introduction

This chapter gives guidance on the identification of nuts complying with British Standards 'A' Series of Aircraft Materials and Components, with AGS Specifications and with certain specifications in the Society of British Aerospace Companies 'AS' Series.

Failure of a fastener through the use of an incorrect nut could cause malfunction and, in certain circumstances, lead to the jamming of controls. It is most important, therefore, that engineers and inspectors should be acquainted with the features by which any particular type of nut may be identified. A nut may have the correct type of thread but it may be unsuitable for some other reasons such as material, temperature classification or length of thread; it is also possible to fit a nut of incorrect size, e.g. a 10-32 UNF nut may fit an 8-32 UNC screw. These dangers may be minimised by constant vigilance during servicing operations.

For the benefit of engineers engaged on the maintenance of older types of aircraft, information on obsolescent Standards is also included in this chapter, together with details of replacement Standards.

Information on the identification of bolts and screw of British manufacture is given in chapter before.

A list of abbreviations and terms used in this chapter is given at the end.

TABLE 18.3, LATE SERIES AN NUTS

AN Number	Type	Material	Sizes	Identification
121501 - 121525	Nut, hexagon, plain	Alloy steel (AMS 6322) cadmium plated	No. 10 to 1 in UNF	
121551 - 121575	Nut, hexagon, castle			
121526 - 121550	Nut, hexagon, plain	Corrosion-resistant steel (AMS 7472)		
121576 - 121600	Nut, hexagon, castle			
150401 - 150425	Nut, hexagon, check	Alloy steel (AMS 6320) cadmium plated	No. 10 to $\frac{3}{4}$ in UNF	
150426 - 150450	Nut, hexagon, shear, slotted			

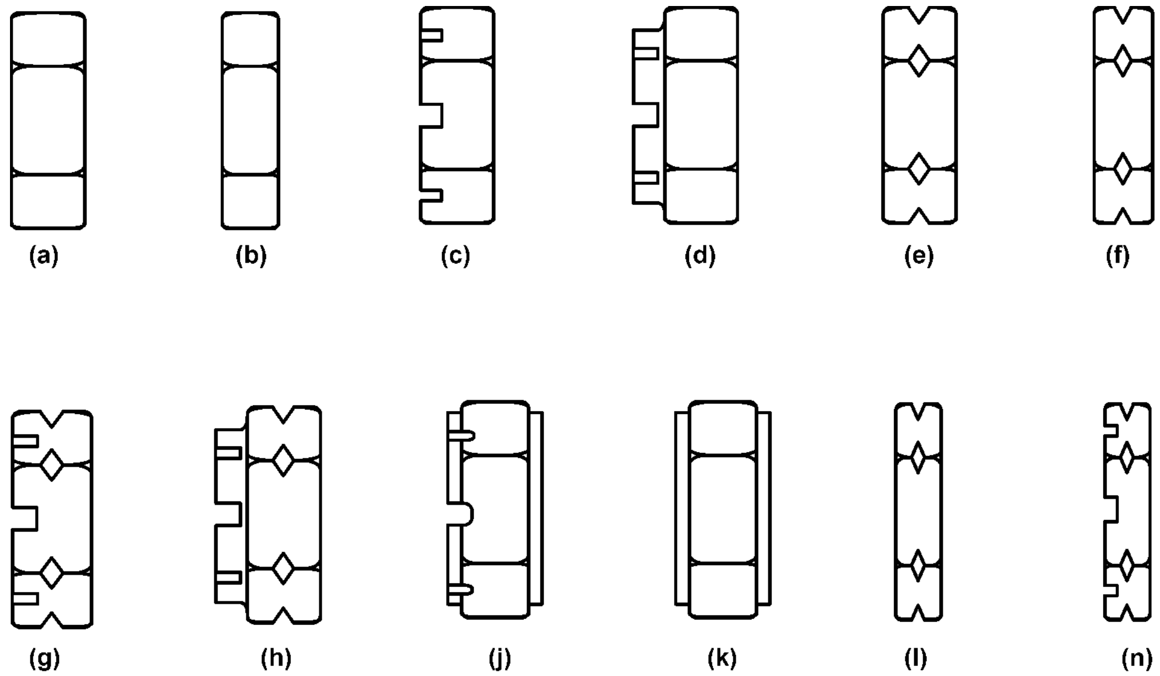
BRITISH STANDARDS NUTS HAVING BA OR BSF THREADS

Table 18.4 gives a list of relevant Standards and superseding Standards. Identification details are included in the table and the different nuts included in this range are illustrated in Figure 18.23.

TABLE 18.4
BA AND BSF HEXAGON NUTS

BS No.	Types (para. 2.2)	Material	Finish	Remarks	Identi-fication (Fig. 1)*	Size Range
A14	P and T	Brass	cad or natural	obsolescent	a or b	(i) 10 BA to 0 BA (ii) 4 BA to 1¼ BSF
A24	P, T, S and C	HTSS	natural	replaces A16 Z	e, f, g or h	6 BA to 1 in BSF
A27	P, T, S and C	HTS	cadmium	replaces A16 Y	e, f, g or h**	6 BA to 1 in BSF
A29	P and S	Al Al	anodic	replaces A18	j or k	6 BA to 1 in BSF
A47	P	LTS	cadmium	order as A27 in	a	12 BA to2 BA
A48	T	LTS	cadmium	2, 4 and 6 BA	b	8 BA to 2 BA
A49	P	SS	natural		a	12 BA to 2 BA
A50	T	SS	natural		b	8 BA to 2 BA
A51	P	Al Al	anodic		a	12 BA to 2 BA
A52	T	Al Al	anodic		b	8 BA to 2 BA
A53	P	Brass	tinned	replaces A14 P	a	12 BA to 2 BA
A54	T	Brass	tinned	replaces A14 T, 2 and 4 BA	b	8 BA to 2 BA
A58	T or TS	HTS	cadmium	shear nut	l or n	¼ to $\frac{3}{4}$ in BSF

* The BS number is marked on all nuts larger than $\frac{3}{4}$ inch BSF.
** a, b, c or d in sizes below ¼ inch BSF.



NOTE : Shear nuts (l) and (n) are 0 - 2 in thick in all sizes.

Fig. 18.27, Identification Features BA/BSF Nuts.

Identification

Identification of a particular nut may be effected from its shape and anti-corrosive treatment; in addition, all nuts larger than 3/8 inch BSF are marked with the British Standards number, and parcels of nuts are labelled with the complete part number.

Code System for Nuts

The code system used for the identification of the nuts listed in Table 18.4 (with the exception of A14) consists of the Standards number followed by a letter indicating the size of the thread (Table 18.5), followed by a letter indicating the type of nut, i.e. P (ordinary nut), S (slotted nut), c (castle nut), and T (thin nut). These type letters are not, however, applied to the nuts. For example, the complete part referencing number used on the drawing, or when ordering 7/16 inch ordinary A27 nuts is A27LP, but the corresponding marking of the nuts will be A27L.

TABLE 18.5
DIAMETERCODELETTERS

Code	Size	Code	Size
A	6 BA	P	$\frac{9}{16}$ in BSF
B	4 BA	Q	$\frac{5}{8}$in BSF
C	2 BA	S	$\frac{3}{4}$in BSF
E	¼ in BSF	U	$\frac{7}{8}$in BSF
G	$\frac{5}{16}$ in BSF	W	1 in BSF
J	$\frac{3}{8}$ in BSF	X	12 BA
L	$\frac{7}{16}$ in BSF	Y	10 BA
N	$\frac{1}{2}$ in BSF	Z	8 BA

Where nuts have a left-hand thread the letter ‘L’ is added to the part number, thus the above example with a left-hand thread would have the part number A27LPL. The letter ‘L’ is marked on of the hexagonal surfaces of the nut.

Code System for BS A14 Brass Nuts

In the obsolescent British Standard A14 two ranges of nuts are covered, viz. O BA plain and 4 BA to 1.1/4 inch BSF thin.

i. In the former (which is superseded by A53) the diameter is indicated by the BA number, and the part number consists of the Standard number followed by the diameter number and the letter 'B'. For example, the complete part reference number used on the drawing or when ordering 4 BA plain nuts, is A14 4B.

ii. In the second range the 4 and 2 BA nuts are superseded by British Standard A54, but the coding system is similar to that in Table 18.29, with the exceptions that 'X' and 'Y' are used to denote 1.1/3 inch BSF and 1.1/4 inch BSF nuts respectively, and the letter 'B' is substituted for the usual letter 'T'. For example, a 1/4 inch thin nut has a reference number A14 EB.

iii. Both ranges include nuts with left-hand threads .

BRITISH STANDARDS NUTS HAVING UNIFIED THREADS

Table 18.6 gives a list of the relevant Standards and superseding Standards for ordinary hexagon nuts and Table 18.7 gives the Standards applicable to stiff nuts of various types. The nut are illustrated in Figures 18.24 and 18.25 respectively.

TABLE 18.6
UNIFIED HEXAGON NUTS

BS No.	Type (para. 3.2)	Material	Finish	Remarks	Identification (Fig. 2)*	Size Range
A 103	P, T, S or C	HTS	cad		a, b, c or d	4 - 40 UNC to 1 in UNF
A 105	P, T, S, or C	CRS	natural	marked with 'Z'	a, b, c or d	4 - 40 UNC to 1 in UNF
A 107	P or S	Al Al	green		a or c	4 - 40 UNC to 1 in UNF
A 110	T or TS	HTS	cad	shear nut	e or f	¼ to $\frac{3}{4}$ in UNF
A 222	P	LTS	cad		a	0- 80 and 2 - 64 UNF
A 223	T	LTS	cad		b	0 - 80 and 2 - 64 UNF
A 224	P	Brass	tinned		a	0 - 80 and 2 - 64 UNF
A 225	T	Brass	tinned		b	0 - 80 and 2 - 64 UNF

* The BS number is marked on all nuts larger than $\frac{3}{8}$ inch UNF.

IDENTIFICATION

Nuts with Unified threads may be identified by their shape, type of finish and thread size. Additionally, all nuts other than anchor nuts, 8-32 UNC and larger, are marked with the 'Unified' symbol of continuous circles. The identification of smaller nuts may be more difficult, for example, an A222, 2-64 UNF nut is similar to an A47, 8 BA nut, and it may be necessary to try the nut on a bolt of known thread to achieve positive identification.

Nuts listed in Table 18.6, larger than 3/8 inch diameter, are marked with the British Standard number. Stiff nuts 1/4 inch UNF and larger which are manufactured from corrosion resisting steel, are marked with the letter 'Z' either on one flat or on the base plate; when the nut is also silver plated, the letter 'X' is added to or replaces the 'Z'.

Brass anchor nuts are marked with the letter 'B' and all hexagon brass stiff nuts have a washer face (Figure 18.29).

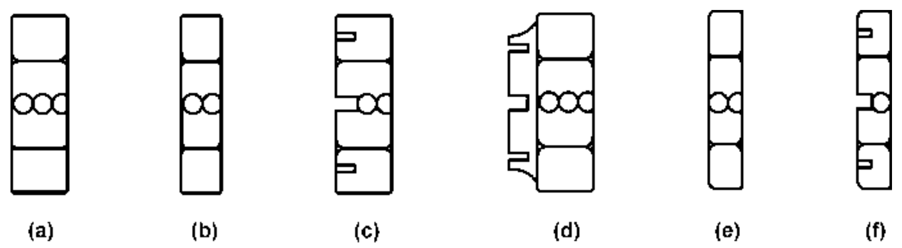
NOTE

The shape of the friction element on a stiff nut should not be taken as an identification feature. These are usually patented devices and depend on the design favoured by the particular manufacturer. Nut specifications normally only quote the maximum dimensions of the friction element and the frictional unscrewing torque required.

TABLE 18.7
UNIFIED STIFF NUTS

Basic Type		Attach-ment plate material	Temperature Classification, Nut Material and Coating				
			- 75°C to + 125°C		- 75°C to + 200°C		- 75°C to + 425°C
			Al Al*	Brass or Bronze††	Steel*	CRS**	
			Anodised	Tinned	Cad plated		Silver Plated
Hexagon	Ordinary thin cap		A 129 A 130 A 214	A 131 A 132 —	A 125 A 126 A 213	A 127 A 128 —	A 180 A 181 —
Clinch			A 124	A 123	A 122	—	—
Single lug fixed anchor	ordinary thin		A 161 A 162	A 163 A 164	A 157 A 158	A 159 A 160	A 200 A 201
Double lug fixed anchor	ordinary thin cap		A 140 A 141 A 216	A 142 A 143 —	A 136 A 137 A 215	A 138 A 139 —	A 186 A 187 —
Double lug floating anchor	ordinary thin	Al Al	A 153 A 154	— —	A 151 A 152	— —	— —
	ordinary thin	Brass	— —	A 155 A 156	— —	— —	— —
	ordinary thin	Steel	— —	— —	A 147 A 148	— —	— —
	ordinary thin	CRS	— —	— —	— —	A 149 A 150	A 192 A 193
Strip	ordinary thin		A 167 A 168	— —	A 165 A 166	— —	— —

* Nut body is made from S 92, S 112, S 113, S 114 or S 117 depending on the size of the nut. Base plate is made from S 510 or S 511 and attachment plate from S 511 or L 72.
** Nut body is made from S 80, base plate and attachment plate from S 521.
† Nut body is made from L 65, base plate and attachment plate from L 72.
†† Nut body is made from B 11, BS 249, BS 250, BS 251 or BS 369. Base plate and attachment plate are made from BS 267 or BS 409.



NOTE : Sheat nuts (e) and (f) are 0.2 in thick in all sizes

Fig.18.28, Unified Nuts.

Code System

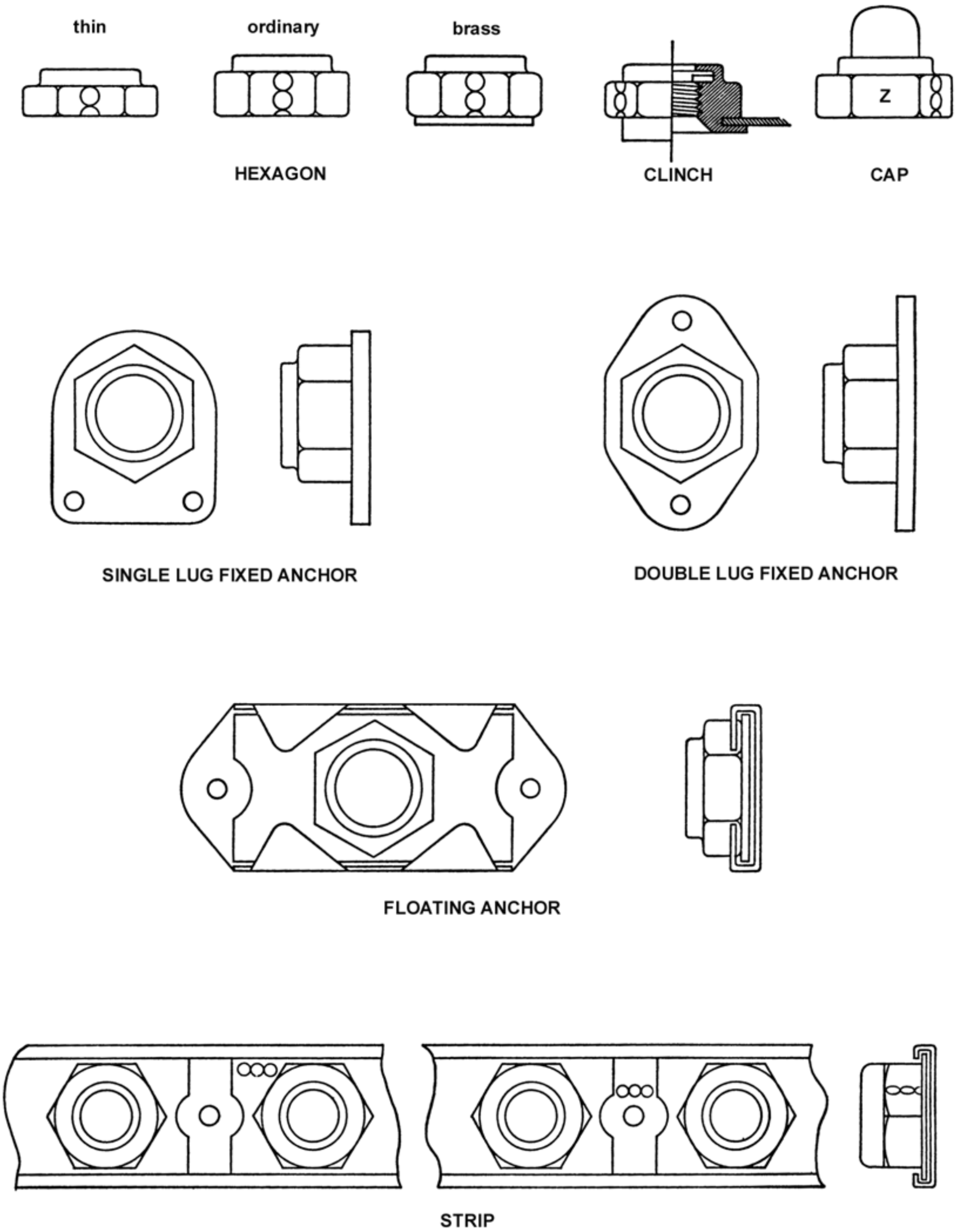
The code system used for the identification of nuts having Unified threads consists of the British Standard number followed by a letter indicating the size of thread (Table 18.8), followed, when appropriate, by a letter indicating the type of nut, i.e. P (ordinary nut), S (slotted nut), C (castellated nut) and T (thin nut). These letters are not, however, applied to the nut. For example, the complete part number used on drawings or when ordering a 7/16 inch UNF ordinary A 107 nut is A107 nut is A107 LP but the nut is only marked ‘A 107’. Where stiff nuts are concerned the part number is not marked on nuts of any size, but over 3/8 inch diameter a letter indicating thread size is applied.

Clinch Nuts, A122 to A124

A choice of three spigot length is specified of each size of nut, depending on the thickness of material through which the nut is to be clinched.

Stiff nuts

As mentioned in paragraph above, hexagon, clinch and strip stiff nuts are marked with a 'Unified' symbol to show the type of thread used. Anchor nuts (fixed or floating) are not so marked as the shape of the base plates is considered to be adequate for recognition purposes; there are much smaller and less angular than those fitted to similar stiff nuts with a BA of BSF threads in the AGS range of specifications. In the Unified stiff nuts the base plate is integral with the nut body, but the nut portion of an AGS stiff nut is retained inside a cage.



NOTE : The nut body of any anchor stiffnut may be either hexagonal or round.

Fig. 18.29, Identification Features, Unified Stiffnuts.

When it is necessary to differentiate on the drawing or order between metallic and nonmetallic friction element stiff nuts in the steel and corrosion-resisting steel (-75^{0}C to +200^{0}C) ranges, the suffix '/66' or '/77' respectively is added to the part reference. For example, the complete part reference for a 1/4 inch UNF steel nut with a metallic friction element is A125 E/77. A part reference with out such a suffix indicates that either type of nut may be used.

Stiff nuts complying with British Standards A 180, A 181, A 186, A 187, A 192, A193, A200 and A201 may be supplied unplated for use in that condition, or for subsequent plating by the user for applications where plating other than silver is required. When ordering such nuts, '/UP' should be added to the reference number. For example, a 16 inch UNF corrosion-resisting Steel, thin double-lug, floating anchor nut unplated, is A 193 G/UP.

Left-Hand Threads

Left-Hand threads in nuts are indicated by the use of the suffix letter 'L'. Thus the reference number for a 4-40 UNC ordinary brass nut complying with BS A210 would be A210 APL, i.e. the Standard number + the diameter letter + the nut type + left-hand thread. The letter 'L' is also applied to one of the hexagon faces of the nut. There is no provision made for left-hand threads in the specifications relating to stiff nuts.

TABLE 18.8
DIAMETER CODE LETTERS
UNIFIED THREADS

Code	Size	Code	Size
Y	0 - 80 UNF	J	$\frac{3}{8}$ in UNF
Z	2 - 64 UNF	L	$\frac{7}{16}$ in UNF
A	4 - 40 UNC	N	$\frac{1}{2}$ in UNF
B	6 - 32 UNC	P	$\frac{9}{16}$ in UNF
C	8 - 32 UNC	Q	$\frac{5}{8}$ in UNF
D	10 - 32 UNF	S	$\frac{3}{4}$ in UNF
E	¼ in UNF	U	$\frac{7}{8}$ in UNF
G	$\frac{5}{16}$ in UNF	W	1 in UNF

'AS' NUTS

Double hexagon Stiff nuts

A range of double-hexagon stiff nuts manufactured from heat resistant steel and having UNJF threads, is provided in the SBAC, AS series 20623 to 20630, representing thread sizes 8-36 UNJF to 9/1618 UNJF. These nuts are specified for use on the AS series of heat resistant bolts with UNJF threads, and may be identified from the AS number marked on the extended washer portion of the nut. They are illustrated in Figure 18.30.

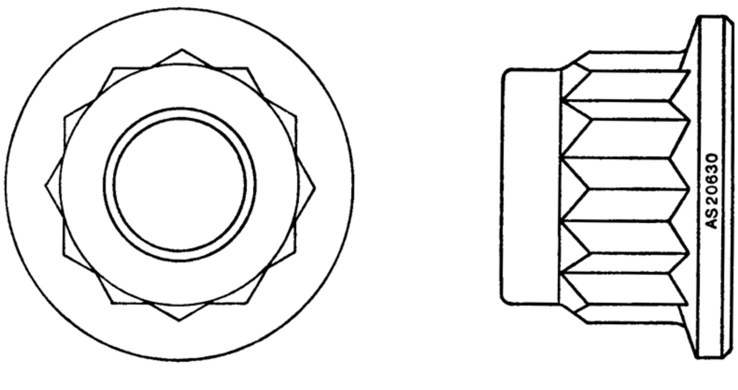


Fig. 18.30, 'AS' Double Hexagon Stiffnuts.

Ordinary and Anchor Stiff nuts

A Series of AS specifications for lightweight hexagon and anchor stiff nuts has been produced in the range AS 8600 to 8661 (see Table 18.9). These nuts are manufactured from high tensile steel and are considerably lighter than conventional nuts; all are now manufactured with UNJ threads.

No markings are applied to the nuts but they are quite different from either the BS or AGS stiff nuts and may be identified purely from their shape (see Figure 18.31). For storage and ordering purposes the nuts are identified by the AS number, followed by a size code letter as shown in Table 18.8. A further code is necessary for ordering strip nuts, and this consists of a number representing the distance between nut centres in eighths of an inch, followed by an additional number representing the number of nuts required in a strip. A 10-32 UNF strip nut with 0.75 inch nut spacing and having 10 mm nuts would therefore be, AS 8612/D/6/10.

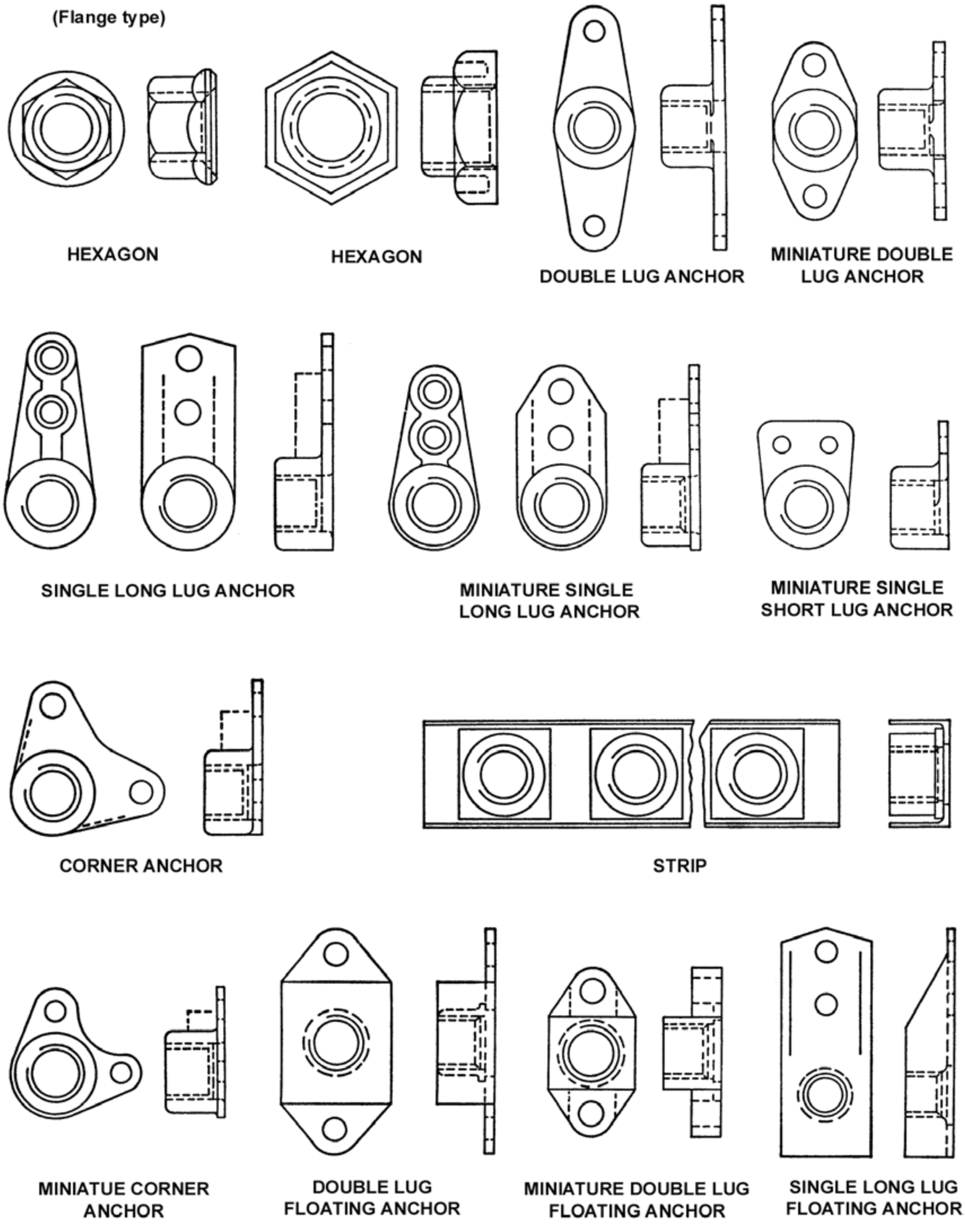


Fig. 18.31, Typical 'AS' Lightweight Stiffnuts.

As with the BS and AGS stiff nuts, the shape of the friction device is optional, the specification merely stating the maximum or minimum limits as appropriate. A further stipulation with this series of nuts is the maximum permissible weight per 100 units (and weight per inch for strip nut channels).

TABLE 18.9
'AS' LIGHTWEIGHT STIFF NUTS

	AS Numbers		
Material	HTS	CRS	CRS
Max. rated temperatures	250°C	450°C	250°C
Finish	Cad.	Silver	Natural
Hexagon, flange type	8600	8623	8650
Hexagon	8601	8624	8651
Double lug anchor	8602	8625	8652
Miniature double lug anchor	8603	8626	8653
Single long lug anchor	8604	8627	8654
Miniature single long lug anchor	8605	8628	8655
Miniature single short lug anchor	8606	8629	8656
Corner anchor	8607	8630	8657
Miniature corner anchor	8608	8631	8658
Double lug floating anchor	8609	8632	8659
Miniature double lug floating anchor	8610	8633	8660
Single large lug floating anchor	8611	8634	8661
Strip	8612		

Stiff nuts

Table 18.10 gives a list of the relevant AGS numbers for the various types of stiff nuts in this series; the nuts are illustrated in Figure 18.32 to show the differences from British Standards stiff nuts AGS stiff nuts have BA or BSF threads

TABLE 18.10
AGS STIFF NUTS

Type	AGS Number				
	Stan-dard	Thin	Csk	Cap	Csk cap
Hexagon	2001	2002	2003	2021	2024
Single anchor, single fixing	2004*	2005*	2006*		
Single anchor, double fixing	2018	2019	2020		
Double anchor	2007	2008	2009	2023	
Floating	2012	2013	2014		
Strip	2015	2016	2017		
Clinch	2011				

* Obsolescent

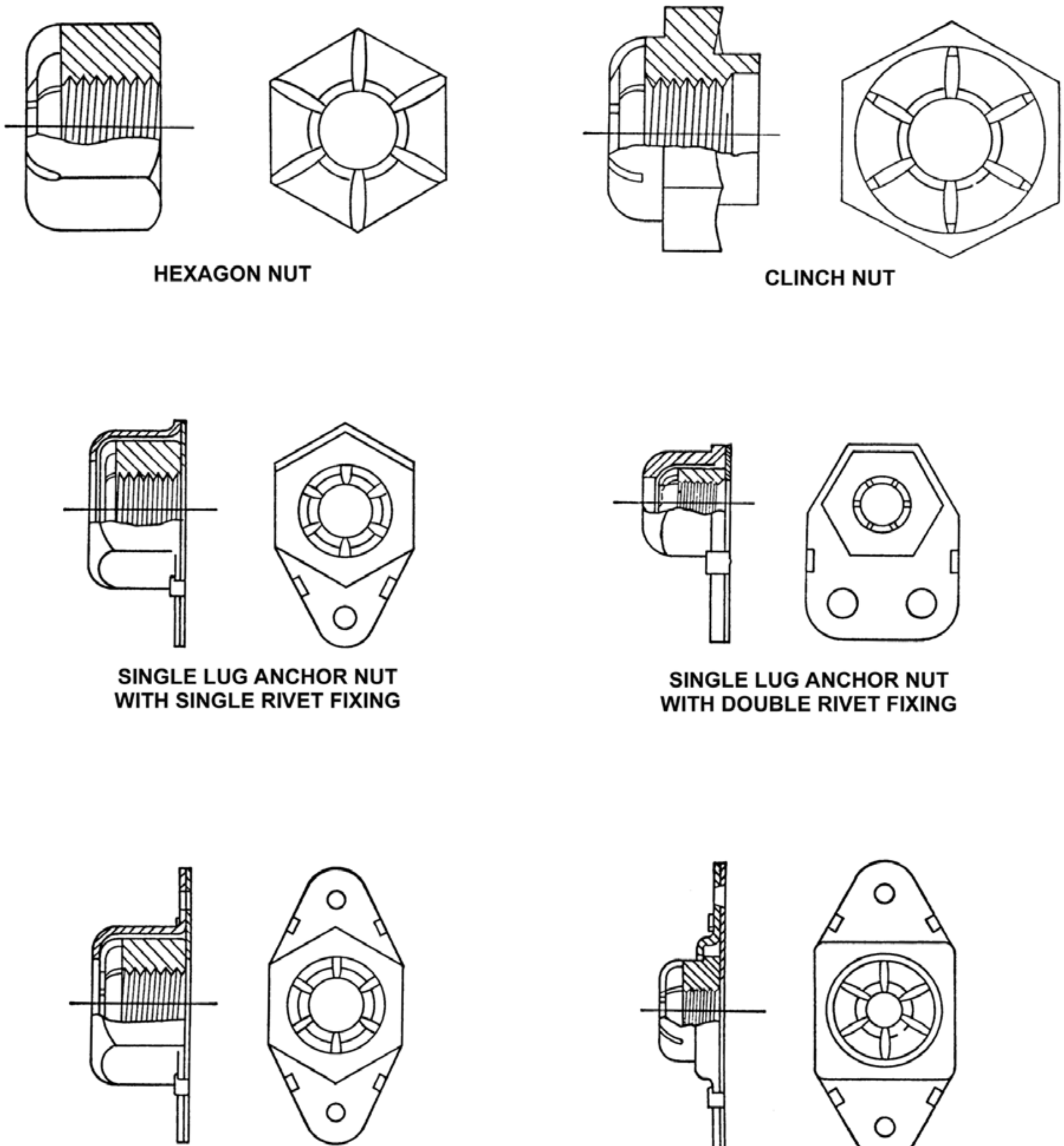


Fig.18.32, Typical AGS Stiffnuts.

Code Systems

The part referencing system consists of the AGS number, followed by a letter indicating the thread size, followed by a number indicating the material Floating anchor nuts are referenced with two material numbers, the first for the attachment plate and the second for the nut. The complete part number for a 5/16 inch BSF countersunk floating anchor nut with mild steel base plate and light alloy nut would be, AGS 2014/G/13. The diameter code letters are the same as those shown in Table 18.5 and the material code is as follows:-

1 Mild steel, cad. plated
2. CRS or monel, cad. plated
3. Light Alloy, anodised and dyed blue
4. Brass or bronze, electro-tinned.

TABLE 18.11
WINGNUTS

Code	Size	Code	Size
A	6 BA (AGS 113 only)	D	$\frac{11}{32}$ in BSF (AGS 120 only)
B	4 BA (AGS 113 only)	E	$\frac{3}{8}$ in BSF (AGS 120 only)
C	2 BA (AGS 113 only)	F	$\frac{13}{32}$ in BSF (AGS 120 only)
A	¼ in BSF (AGS 120 only)	G	$\frac{7}{16}$ in BSF (AGS 120 only)
B	$\frac{9}{32}$ in BSF (AGS 120 only)	H	$\frac{1}{2}$ in BSF (AGS 120 only)
C	$\frac{5}{16}$ in BSF (AGS 120 only)		

AGS NUTS - VARIOUS

Wing Nuts AGS 113 AGS 120 (Brass Cadmium Coated)

AGS 113 relates only to BA sizes, whilst 120 relates only to BSF sizes. The coding system for these nuts consists of the AGS number followed by a letter indicating the size of thread. Example: A¼- inch BSF brass wing nut would be AGS 120/A.

Wing Nuts AGS 3413

These are cadmium coated brass wing nuts with Unified threads in the sizes 4-40 UNC to ½- inch UNF. The coding system consists of the AGS number followed by a letter indicating the thread size (Table 18.8).

BSP Union Lock Nuts, AGS 207 (Mild steel, cad. plated), AGS 224 (Brass cad. plated) and AGS 957 (Al anodised)

The coding system used for these nuts consists of the AGS number (which indicates the type of material), followed by a letter indicating the thread size. The letters A to E are used, representing the sizes 1/8 inch BSP to 5/8 inch BSP in steps of 1/8 inch BSP brass lock nut would therefore be AGS 224/D.

Thin Nuts BSP and Whitworth Form, AGS 1148 (Al anodised)

The coding system used for these nuts consists of the AGs number, followed by a letter indicating the thread size (Table 18.12). ***Example:*** A 1/2 inch BSP nut would be AGS 1148/D.

TABLE 18.12
THINNUTS

Code	Size	Code	Size
A	$\frac{1}{8}$ in BSP	F	$\frac{3}{4}$ in BSP
B	$\frac{1}{4}$ in BSP	G	$\frac{7}{8}$ in BSP
BB	19 t.p.i. Whit. Form 0.60 o/d	H	1.0 in BSP
C	$\frac{3}{8}$ in BSP	J	$1\frac{1}{4}$ in BSP
CC	14 t.p.i. Whit. Form 0.75 o/d	K	$1\frac{1}{2}$ in BSP
D	$\frac{1}{2}$ in BSP	L	$1\frac{3}{4}$ in BSP
E	$\frac{5}{8}$ in BSP	M	2.0 in BSP

Union Nuts AGS 1187 (Al Anodised), AGS 1216 (Mild Steel, Cadmium treated) and AGS 1217 (Brass, cadmium treated)

The coding system used for these nuts consists of the AGS number, followed by a letter indicating the thread size (Table 18.12). Example: 1/4 inch BSP union nut made of brass would be AGS 1217/B.

L.T. Union Lock Nut, AGS 1710 (Brass, tinned)
This nut is made in one size only, i.e. 1/2 inch × 26 t.p.i. Whitworth form.

FUTURE TRENDS
The need for saving weight on aircraft structures has led to the widespread use of lightweight fasteners of all types, particularly of self-locking nuts and anchor nuts. The use of lightweight and miniature stiff nuts was pioneered in the United States and although these nuts are readily available in this country, very few of British design are, as yet, manufactured in Great Britain

Aircraft manufacturers are tending to make greater use of the UNJ thread form because of its high resistance to fatigue. All future specifications for aircraft fasteners are expected to stipulate this thread and some existing specifications for nuts contain a clause requiring the thread to be of UNJ form after a specified date. Nuts with UNJ threads are fully interchangeable with nuts having standard Unified threads of the same class, the only difference being a slight increase in the minor diameter to accommodate the increased root radius of the external thread.

In view of the general acceptance of metric dimensions in other fields, it seems likely that the metric thread of UNJ form will eventually be used internationally and result in further specifications for nuts in both the AS and BS series. It is expected that fasteners having metric threads will be identified by marking with the letter 'M'.

ABBREVIATIONS AND TERMS USED

AGS	Aircraft General Standards
Al	Aluminium Alloy.
AS	Aircraft Standards of the SBAC.
Attachment Plate	The formed sheet metal plate of a floating anchor nut which is riveted to the structure. It retains the nut body and base plate, allowing a specified amount of movement in relation to the structure.
BA	British Association
Base Plate	The plate, normal to the axis of the nut, which forms the riveting lugs of a fixed anchor nut. In a floating anchor nut it remains the nut body in the attachment plate.
BS	British standard.
BSF	British standard fine.
BSP	British standard pipe.
Cap Nut	A stiff nut, the threaded bore of which is sealed by a metal cap to prevent the leakage of fluid.
Clinch Nut	A self retaining nut having a spigot at the bearing face which is spread to hold the nut in position.
Fixed Anchor Nut	A stiff nut which is rigidly attached to the structure.
Floating Anchor Nut	A stiff nut which has a limited amount of movement in a plane normal to the axis of the nut for purposes of alignment. Friction Element
HTS	High tensile steel.
HTSS	High tensile stainless steel.
LTS	Low tensile steel.
MTS	Medium tensile steel.
Nut Body	The portion of a stiff nut containing the screw thread.
SS	Stainless steel.

Stiff nut	A nut body surmounted by a device which imposes friction between the nut and the thread on which it is mounted so that no other form of locking is required.
Strip Nuts	A row of stiff nuts mounted on a common attachment plate in the form of a continuous strip.
t.p.i.	Thread per inch.
UNC	Unified Coarse thread.
UNF	Unified fine thread.
UNJ	Unified thread with increased root radius for added fatigue resistance. Ranges of fine threads (UNJF) and coarse threads are provided in this series.
UNS	Threads of basically Unified form but differing slightly from the standard Unified series.
Whit.	Whitworth.

■■■

CHAPTER-19
AIRCRAFT SCREWS

AIRCRAFT SCREWS

Screws are the most commonly used threaded fastening devices on aircraft. They differ from bolts in as much as they are generally made of lower strength materials. They can be installed with a loose-fitting thread, and the head shapes are made to engage a screwdriver or wrench. Some screws have a clearly defined grip or unthreaded portion while others are threaded along their entire length.

Several types of structural screws differ from the standard structural bolts only in head style. The material in them is the same, and a definite grip length is provided. The AN525 washer-head screw and the NAS220 through NAS227 series are such screws.

Commonly used screws are classified in three groups : (1) Structural screws which have the same strength as equal size bolts; (2) machine screws, which include the majority of types used for general repair; and (3) self-tapping screws, which are used for attaching lighter parts. A fourth group, drive screws, are not actually screws but nails. They are driven into metal parts with a mallet or hammer and their heads are not slotted or recessed.

STRUCTURAL SCREWS

Structural screws are made of alloy steel, are properly heat treated, and can be used as structural bolts. These screws are found in the NAS204 through NAS235 and AN509 and AN525 series. They have a definite grip and the same shear strength as a bolt of the same size. Shank tolerances are similar to AN hex-head bolts, and the threads are National Fine. Structural screws are available with round, brazier, or countersunk heads. The recessed head screws are driven by either a Phillips or a Reed and Prince screwdriver.

The AN509 (100°) flathead screw is used in countersunk holes where a flush surface is necessary.

The AN525 washer-head structural screw is used where raised heads are not objectionable. The washer-head screw provides a large contact area.

SELF-TAPPING SCREWS

Self-tapping screws have coarse-threads and are used to hold thin sheets of metal, plastic, or plywood together. The type-A screw has a gimlet (sharp) point, and the type B has a blunt point with threads that are slightly finer than those of a type-A screw.

There are four types of heads available on self-tapping screws : a round head, truss head, a countersunk head, which is flat on top, and the countersunk oval screw. The truss-head is rounded, similar to the round head screw, but is considerably thinner [Fig. 19.1].

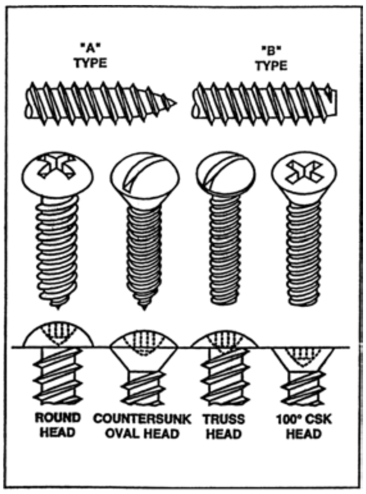


Fig. 19.1, Self-tapping sheet metal screws are useful for attaching trim and upholstery.

DRIVE SCREWS

Drive screws, AN535, correspond to the Parker-Kalon U-type. They are plain-head self-tapping screws used as capscrews for attaching nameplates in castings and for sealing drain holes in corrosion proofing tubular structures. They are not intended to be removed after installation.

FLAT-HEAD SCREWS

Structural flat-head screws have an MS24694 part number and are made of heat-treated carbon steel that is cadmium plated. They are distinguished from 100 degree flat-head machine screws by the “X” marked on their head.

ROUND-HEAD MACHINE SCREWS

The MS35206 round-head machine screw is made of cadmium-plated carbon steel and has either a slotted or recessed head. This screw is also available in brass and is identified by the part designation MS35214. The brass screws are typically coated with a black oxide and are sometimes used to mount instruments. Like most other screws, the round-head machine screw is available with either fine or coarse threads.

WASHER-HEAD SCREWS

These structural screws have a washer formed onto their head to increase the screw’s holding ability. This added bearing area is required when used with some thinner materials. Washer-head screws are made of cadmium-plated highstrength steel [Fig. 19.2]

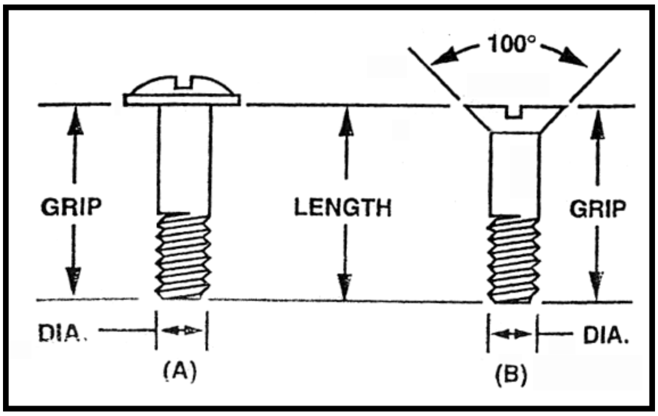


Fig. 19.2, Washerhead screws are available with both protruding and countersunk heads.

HEADLESS SCREWS

They are known as drive screws, actualy they are not screws but nails. They are driven into metal parts with a mallet or hammer. They are not slotted or recessed.

FILLISTER-HEAD SCREWS

The fillister-head structural screw is similar in appearance to the fillister-head machine screw except for the cross on its head indicating that it is made of high-strength steel. Structural fillister-head screws carry an AN502 part code if they have coarse threads and AN503 if they have fine threads.

TRUSS HEAD AND ALL MACHINE SCREWS

The AN526 truss-head machine screw has a large head that provides good holding ability on thin pieces of metal. This screw is available in cadmium-plated carbon steel in either slotted or cross-recessed heads.

Early Series AN Machine Screws

Screws differ from bolts in being made from a lower strength material, having a looser fit (class 2A thread instead of class 3A) and having a slotted or a cruciform-recessed head, for rotation by a suitably-shaped screwdriver. The thread is usually continued up to the head, but the shank of 'structural' screws (i.e. AN 509 and 525) has a plain potion and may be used in locations where shear loading is present. Some screw heads are marked to indicate the material from which they are made, and these markings are listed in Table 19.1. The markings, head shape and material will enable identification of a particular screw to be made. Table 19.1 lists the AN machine screws, and Fig. 19.3 illustrates the various head shapes. It should be noted that some of these screws are obsolescent, and may not be available in the full range of sizes.

TABLE 19.1, EARLY SERIES AN MACHINE SCREWS

AN Number	Type	Material	Process	Head Marking*	Nominal Range of Thread Sizes	Thread
500	Screw, fillister head	Steel	Cad. plated		No. 2 to $\frac{3}{8}$ in	UNC
		CRS	Nil			
		Brass	Nil			
501	Screw, fillister head	Steel	Cad. plated		No. 0 to $\frac{3}{8}$ in	UNF
		CRS	Nil			
		Brass	Nil			
502	Screw, fillister head (drilled)	Steel	Cad. plated	X X	No. 10 to $\frac{5}{16}$ in	UNF
503	Screw, fillister head (drilled)	Steel	Cad. plated	X X	No. 6 to $\frac{5}{16}$ in	UNC
505	Screw, flat 82°	Steel	Cad. plated	- -	No. 2 to $\frac{3}{8}$ in	UNC
		CRS	Nil			
		Brass	Nil			
		Al. alloy	Anodised			
507	Screw, flat 100°	Steel	Cad. plated		NO. 6 to ¼ in	UNC and UNF
		CRS	Nil	- -		
		Brass	Black oxide			
		Brass	Nil			
		Al. alloy	Anodised			
509	Screw, flat 100° structural	Steel	Cad. plated	X X	No. 8 to $\frac{5}{16}$ in	UNF
		Al. alloy	Anodised			
		Bronze	Cad. plated	= =		
		Bronze	Nil	= =		
510	Screw, flat 82°	Steel	Cad. plated		No. 5 to ¼ in	UNF
		CRS	Nil	- -		
		Brass	Nil			
		Al. alloy	Anodised			
515	Screw, round head	Steel	Cad. plated		No. 5 to $\frac{3}{8}$ in	UNC
		CRS	Nil	- -		
		Brass	Nil			
		Al. alloy	Anodised			
520	Screw, round head	Steel	Cad. plated		No. 5 to ¼ in	UNF
		CRS	Nil	- -		
		Brass	Nil			
		Al. alloy	Anodised			
525	Screw, washer head	Steel	Cad. plated		No. 8 to ¼ in	No. 8 UNC & UNF No. 10 UNF ¼ in UnF
526	Screw, truss head	Steel	Cad. plated		No. 6 to ¼ in	UNF and UNC
		CRS	Nil	- -		
		Al. alloy	Anodised			

* Only one symbol may be found on some screw heads

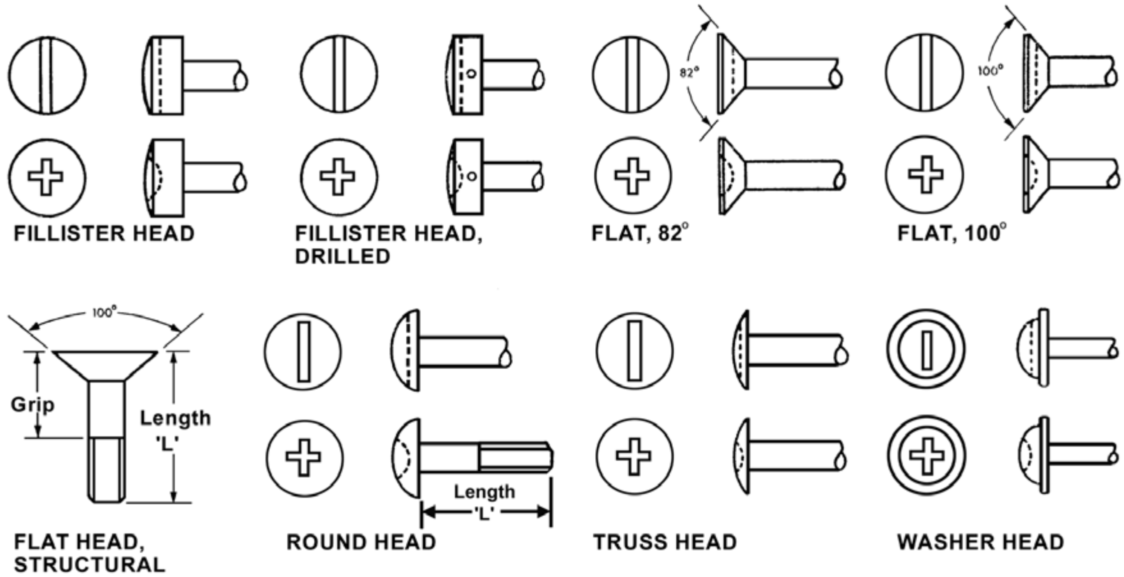


Fig.19.3, Early Series AN Screws.

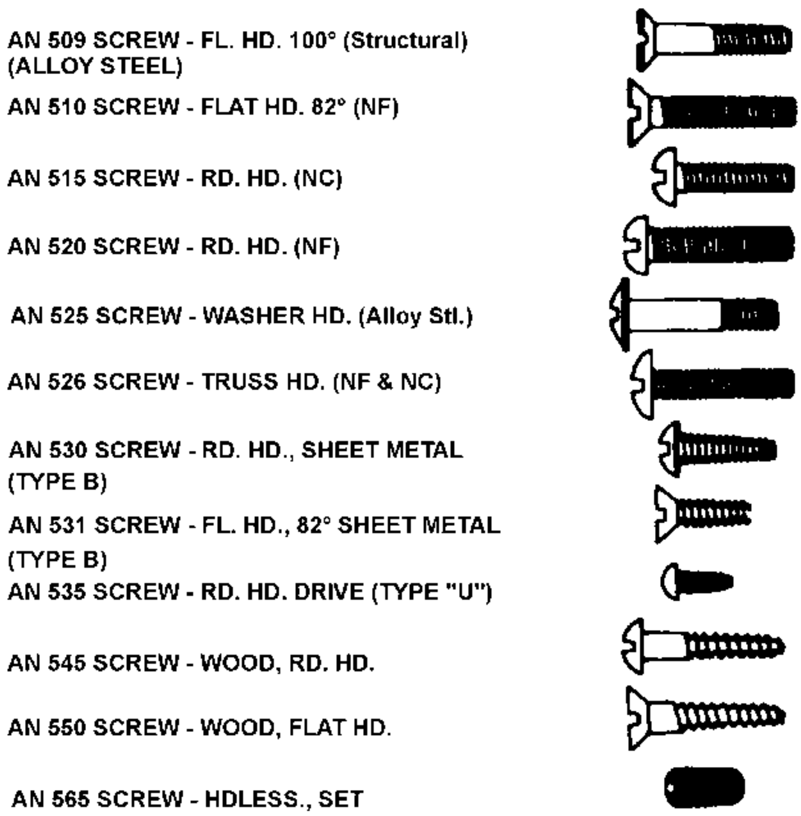
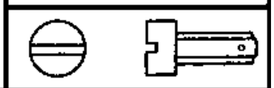


Fig.19.4, Aircraft Screws

TABLE 19.2, LATE SERIES AN SCREWS

AN Number	Type	Material	Sizes	Identification
116901 - 116912	Screw, oval fillister	Carbon steel (AMS 5061) cadmium plated	4 - 40	
116913 - 116924	Screw, oval fillister, drilled		4 - 40	
116925 - 116960	Screw, oval fillister		6 - 32	
116961 - 117000	Screw, oval fillister, drilled		6 - 32	
117001 - 117040	Screw, oval fillister		8 - 32	
117041 - 117080	Screw, oval fillister, drilled		8 - 32	
115401 - 115600	Screw, flat fillister	Alloy steel (AMS 6322) cadmium plated	UNF No. 10 to $\frac{3}{8}$ in	
115601 - 115800	Screw, flat fillister, drilled shank			
115801 - 116150	Screw, flat fillister, drilled head		No. 10 UNF ¼ to $\frac{3}{8}$ in UNF ¼ to $\frac{3}{8}$ in UNC	

Coding
Screws are coded by the AN number, to indicate the type (e.g. round head), letters to indicate material (and in some cases the shape of the screwdriver recess), and two dash numbers indicating diameter and length. In addition, some are coded to indicate whether the head is drilled or not.

a. Diameter
The coding for the diameter depends on whether the screw is available with only fine or coarse threads, or with either type of threads. Diameter is indicated by the first dash number.

i. Screws available with only one type of thread are coded by the thread number or diameter in sixteenths of an inch. For example, No. 4 (UNC or UNF) = -4, No. 10 (UNC or UNF) = - 10, 1/4 in (UNC or UNF) = -416, 5/16 in (UNC or UNF) = -516, etc.

ii. Screws available with both coarse and fine threads (AN 525 and AN 526) are coded by the thread number or diameter in sixteenths of an inch, followed by the number of threads per inch. For example, No. 6-32 (UNC) = -632, No. 8-36 (UNF) = -836, 1/4 - 28 (UNF) = -428, etc.

iii. AN 525 screws are available in only one coarse thread size (No.8) and this is coded - 832. The remaining sizes are coded in accordance with (i).

b. Length
The second dash number indicates the length (L in Fig. 19.4) of a screw in sixteenths of an inch. AN 509 screws are an exception to this rule, the actual length of the screw being 1/32 in longer than the size indicated by the code.

c. Material
Material is indicated by a letter (or letters) placed after the AN number as follows :-

Steel	=	no letter
CRS	=	C
Brass (unplated), AN 507	=	UB, and other screws = B
Brass (black oxide), AN 507	=	B
Aluminium alloy, AN 507, 509 and 526	=	DD, and other screws = D
Bronze (cad. plated), AN 509	=	P
Bronze (unplated), AN 509	=	Z

d. Head Recess

Where a screwdriver slot is required the basic code only is used. Where a cruciform recess is required, 'R' is added instead of the second dash.

e. Drilled Head

AN 500 and 501 screws are provided with a plain or drilled heads. The letter A before the first dash number indicates a screw with a drilled head.

f. Examples of Coding

i. An AN 500A6 -32 is a fillister head screw with a locking wire hole. It is made of cadmium-plated steel, has a No.6 (UNC) thread, has a slotted head and is 2 in long.

ii. An AN 507C832R8 is a 100° flat head screw in corrosion-resistant steel. It has a No.8-32 (UNC) thread, has a cruciform recessed head and is 1/2 in long.

iii. An AN 509DD416-20 is a 100° flat head, structural screw in aluminium alloy. It has a 1/4 in (UNF) thread, has a slotted head and is 9/32 in long.

DIFFERENT TYPES OF STUDS AND THEIR USES

Introduction

Studs are metal rods, threaded at both ends. Where it is not desirable, or possible, to drill through the parts for the fitting of bolts, studs are used to locate and secure the component. One end of the stud is screwed to the end of its thread into a tapped hole in one of the parts, and the other part is held in position by a nut screwed on to the other end of the stud.

Material & Size

They are made of high tensile steel in the sizes of 2 B.A. ¼" B.S.F., 5/16 B.S.F. & 3/8" B.S.F."

Types

3. The different types of studs normally used are described below:-

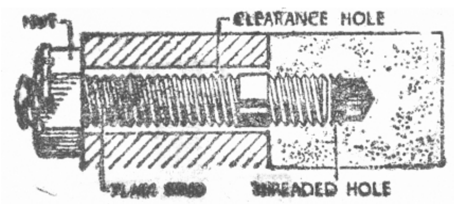


Fig.19.5 Standard Stud

a. Standard Studs

These are plain rods with threads cut on both ends.

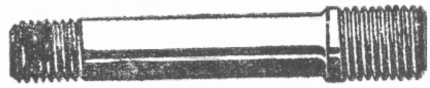


Fig.19.6, Wais Ed Stud

b. Waisted Studs

The diameter of the plain unthreaded portion of the waisted is reduced to the core diameter of its threaded ends, thereby making the stud lighter in weight without impairing its ultimate strength.

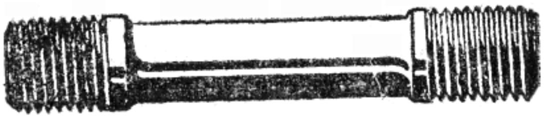


Fig.19.7, Stepped Stud

c. Stepped Studs

This type of stud is made with one threaded end of larger diameter than the other. The larger end screws into the component which is usually of softer material; thereby providing greater holding power. They are also used to replace broken studs, there tapped hole has been retapped to a larger size.

d. Shouldered Studs

These have integral shoulder on the plain portion of the stud, which seats firmly on the surface of the component into which the stud is screwed, thereby providing a more rigid assembly than could be obtained by the use of an ordinary stud.

Fig.19.8, Shouldered Stud

Classification

4. Studs are classified by the material, diameter, overall length and type

Fitting of Studs

5. The stud should be a good fit in the tapped hole and should remain in position when the nut is removed. Studs may be inserted by using a stud box and spanner or by fitting lock nuts and using a spanner on the upper nut or by using a stud inserting tool.

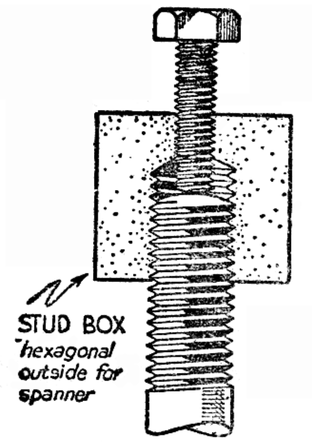


Fig.19.9, Stud Box

6. Stud Box

The stud box has different size of thread at each end and is suitable, therefore, for the insertion of two size of studs.

7. Stud Inserting Extracting Tool

Fig. 19.10, shows an exploded view of stud inserting extracting tool. When assembled, the cam followers are contained within the cage and are free to move radially within the limits of the slotted holes. The end plate is pressed into the end of the tool and located by peening. The stud, to be inserted or extracted, is passed through the hole in the cage. The locating screw is adjusted to prevent further entry of the stud into the tool. When the tool body is rotated, the cage tends to remain stationary owing to the light frictional grip of the cam followers on the stud shank. The rotating cam faces force the followers inwards, thus providing a tight grip on the shank. The stud then turns with the tool in the direction of rotation.

REMOVAL OF UNDAMAGED OR LOOSE STUD

8. Unbroken or loose stud may be removed by using locknuts and spanner, or by stud inserting and removing tool.

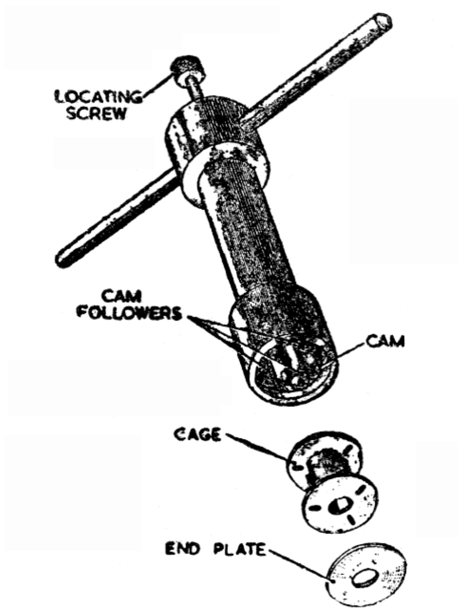


Fig.19.10, Stud Inserting And Extracting Tool

Removal of damaged or Broken Stud

9. When the stud is broken above the surface of the component to which it is screwed file two flats on the projecting part and using a spanner, or tap wrench unscrew the stud.

Removal of studs broken flush with or below the surface

10. One of the following methods should be adopted for removing studs broken flush with or below the surface:-

a. Centre pop the centre of the stud; drill a hole of half the stud diameter centrally in the stud, lightly drive a square taper drift until its edges just cut into the stud. Unscrew the stud using a spanner on the squared end of the drift.

Note :

The drift should not be tool hard as that may expand the stud and make it tighter.

b. Drill as described in (a) above, a tapping size hole. Tap with a thread of opposite hand to that of the damaged stud. Insert a bolt into the tapped hole and unscrew by a spanner.

c. An 'Ezy Out" extractor may be used for removal of a broken stud. "Ezy out" rather reassemble coarse, left-handed taper tap. This acts as in (b) above but bolt is not used.

d. When it is not possible to remove the damaged stud by the methods quoted above, drill right through with a drill just slightly smaller than the stud's core diameter and very carefully re-tap the hole exercising care to pick up the original thread.

SELF-TAPPING SCREW & DOWELS

Refer Chapter - 19 (Screws)

DOWELS

Dowel is a small projection of a shaped smooth nail on a plane flange of the component to align with the hole provided on the opposite flange of the component for correct alignment while fitment or installation of the component. In its original manufactured form dowel is called dowel rod. Dowel rod is often cut into short lengths, called dowel pins which are used to secure two objects together with precise alignment in a dowel join. A hole is bored on one flange of component and a small dowel pin is provided on opposite base flange to align, it with the hole for correct fitment. In other case a hole is bored in both objects and the dowel pin is inserted into aligned holes to restrict the moment.

■■■

CHAPTER-20
LOCKING DEVICES (AIRCRAFT WASHERS)

AIRCRAFT WASHERS

Aircraft washers used in airframe repair are plain, lock, or special washers.

a. Plain Washers

The plain washer, AN960 (Fig. 20.1), is used under hex nuts. It provides a smooth bearing surface and acts as a shim in obtaining correct grip length for a bolt and nut assembly. It is used to adjust the position of castellated nuts with respect to drilled cotter pin holes in bolts. Plain washers should be used under lock washers to prevent damage to the surface material.

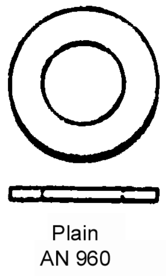


Fig.20.1, Plain washers

b. Special Washers

Some high-strength internal wrenching bolts have a radius between their shaft and the underside of the bolt head. To provide a tight mating surface, MS20002C countersunk washers are used under the heads of internal wrenching bolts. These washers have a countersunk edge to accommodate the radius on the bolt head. When these bolts are used in aluminum alloy structures, a countersunk washer is used under the bolt head and a plain type washer is used under the nut. Countersunk washers are made of heat-treated steel and are cadmium plated.

Finishing washers are often used in aircraft interiors to secure upholstery and trim. These washers have a countersunk face to accommodate flush screws. Finishing washers bear against a large area to avoid damaging fragile interior components.

Occasionally a nut or bolt cannot be safetied by conventional means. In many instances, keyed washers can be used as a safety device. Keyed washer have small keys or probations to enagage slots cut into bolts or panels. In addition, they have tab that can be bent up against a nut or bolt head to keep it from rotating.

c. Spring Washers

These consist of a single coil of square section spring with sharp corners, or a double coil of flat spring. They are placed under the nut and compressed on tightening, thus tending to prevent the nut from slackening. The sharp corners types has the advantage of biting into the metal and nut, which increases its locking properties. Spring washers may be used again, if still springy and retaining their sharp corners.

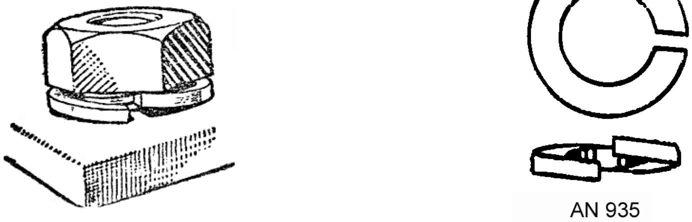


Fig.20.2, Spring Washer

d. Taper Pin Washers

Both the plain and threaded taper pin are used in aircraft structures to make a joint that is designed to carry shear loads. This type of pin does not allow any loose motion or play. The AN385 plain taper pin is forced into a hole that has been reamed with a Morse standard taper pin reamer and is held in place by friction. It can be safetied by passing safety wire around the shaft and through a hole drilled in its large end. An 386 taper pin is similar to the AN 385 except that its small-end is threaded to accept either a self-locking shear nut (AN 364) or a shear castle nut (AN320).

e. Star Lock Washer or Shake Proof Washer - Round washers designed with labs and lips

These washers are the thinner AN936 shake proof lockwashers which is available with both internal and external teeth. They are used with machine screws or bots where the selflocking or castellated type nut is not appropriate. They are designed with tabs or tips. They are bent upward across the sides of a hex nut or bolt to lock.

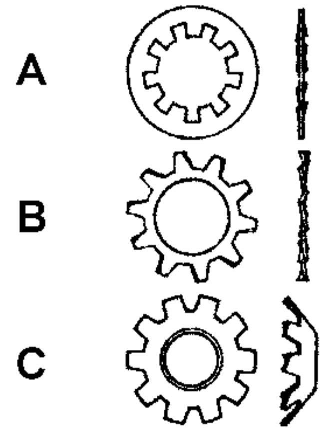


Fig.20._, Star Lock Waxher or Shake Proof Washer

f. Locking plates

These are thin metal plates, fitted round the nut after it has been tightened, and retained against rotation by a small set-screw. The hole in the plate is usually twelve sided to allow for close adjustment. Sometimes they are made double-ended to lock two nuts. Locking plates may be used again if they are a good fit on the nut. The set-screw securing locking plate is locked with a spring washer.

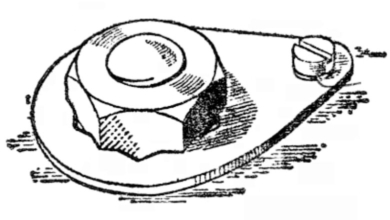


Fig.20.3, Locking Plate

g. Split pin

These are mild steel or nickel alloy pins, which pass through a slot in the nut and a hole in the bolt or stud. They are used with slotted or castle nuts and must be a good fit in both slot and hole; the width of the slot determines the diameter of the split pin to be used. For case of inspection of airframe split-pinning, the legs of the split pin are opened and bent round the nut. In an aeroengine, to maintain the clearance between moving parts, the legs of the split pin are bent in line with the axis of the bolt or stud over to the bolt end and side of the nut. Each pin must be used once only. The size of a split pin is determined by its diameter and overall length.

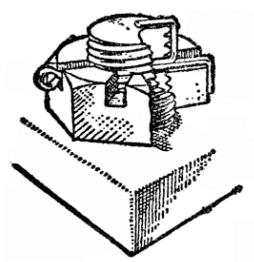


Fig.20.4, Split Pin

h. Pal Nut

Pal nut is a plain thin nut which is used for locking an other nut which has no provision of locking.

i. Safety wiring (Wire Locking)

Safety wiring is the most positive and satisfactory method of safetying capscrews, studs, nuts, boltheads, and turnbuckle barrels which cannot be safetied by any other practical means. It is a method of wiring together two or more units in such a manner that any tendency of one to loosen is counteracted by the tightening of the wire.

Safety wiring for nuts, bolts and screws

Nuts, bolts, and screws are safety wired by the single-wire or double-twist method. The double-twist method is the most common method of safety wiring. The single-wire method may be used on small screws in a closely spaced closed geometrical pattern, on parts in electrical systems, and in places that are extremely difficult to reach.

Fig. 20.5 is an illustration of various methods which are commonly used in safety wiring nuts, bolts, and screws. Careful study of Fig. 20.5 shows that :

a. Examples 1,2, and 5 illustrate the proper method of safety wiring bolts, screws, squarehead plugs, and similar parts when wired in pairs.
b. Example 3 illustrates several components wired in series.
c. Example 4 illustrates the proper method of wiring castellated nuts and studs. (Note that there is no loop around the nut).
d. Examples 6 and 7 illustrate a single-threaded component wired to a housing or lug.
e. Example 8 illustrates several components in a closely spaced closed geometrical pattern, using a single-wire method.

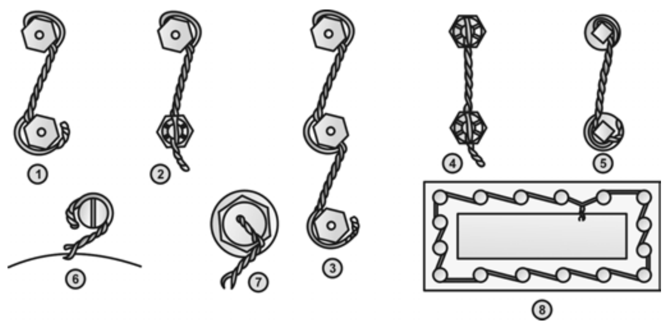


Fig. 20.5, Safety wiring methods.

When drilled-head bolts, screws, or other parts are grouped together, they are more conveniently safety wired to each other in a series rather than individually. The number of nuts, bolts, or screws that may be safety wired together is dependent on the application. For instance, when safety-wiring widely spaced bolts by the double-twist method, a group of three should be the maximum number in a series.

When safety-wiring closely spaced bolts, the number that can be safety-wired by a 24-inch length of wire is the maximum in a series. The wire is arranged so that if the bolt or screw begins to loosen, the force applied tot he wire is in the tightening direction.

Parts being safety-wired should be torqued to recommend values and the holes aligned before attempting the safetying operation. Never over torque or loosen a torqued nut to align safety wire holes.

Safety wiring for oil caps, drain cocks and Valves

These units are safety wired as shown in Fig. 20.6. In the case of the oil cap, the wire is anchored to an adjacent fillister head screw.

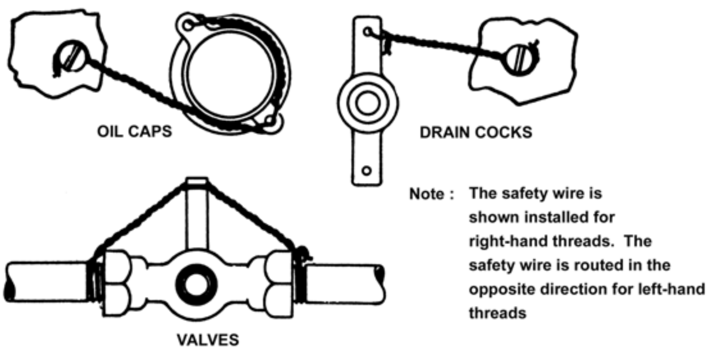


Fig. 20.6, Safety wiring oil caps, drain cocks, and valves.

This system applies to any other unit which must be safety wired individually. Ordinarily, anchorage lips are conveniently located near these individual parts. When such provision is not made, the safety wire is fastened to some adjacent part of the assembly.

j. Quick Release Fasteners

Introduction

1. Special types of fasteners have been designed for use on components such as cowlings fairings and inspection panels. They hold the component securely in position whilst at the same time allow for rapid attachment and detachment. The fasteners in common use are described below.

2. Dzus Fastener.

This fastener consists of a catch and a spring. The catch i held in position on the detachable component by a grommet, and the spring is riveted to the inner side of the fixed component. A helical slot in the body of the catch engages with the centre of the spring, drawing it when the catch is given a quarter turn in a clockwise direction. The fastener is unlocked by a quarter turn in anti-clockwise direction.

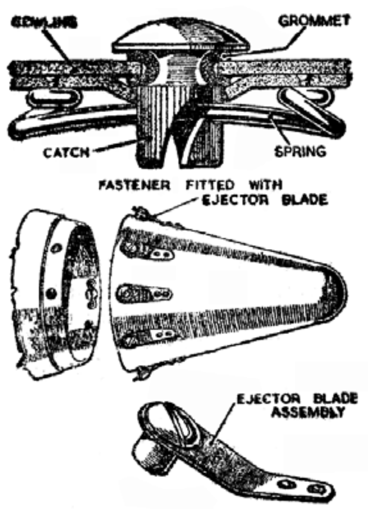


Fig.20.7, Dzus Fastener

3. Oddie Fastener

This comprises a central stud held in position in the outer component by a rubber washer or coil spring, and a two legged spring clip, riveted to the inner component. The stud is bullet shaped and has two diametrically opposed recesses near its pointed end. The fastener is locked by positioning the recesses on the stud in line with the spring legs, and pressing the stud with the finger. There must be a definite click as the fastener engages. The fastener is unlocked by turning the stud a quarter turn in either direction, thus turning the recesses out of engagement with the legs of the spring.

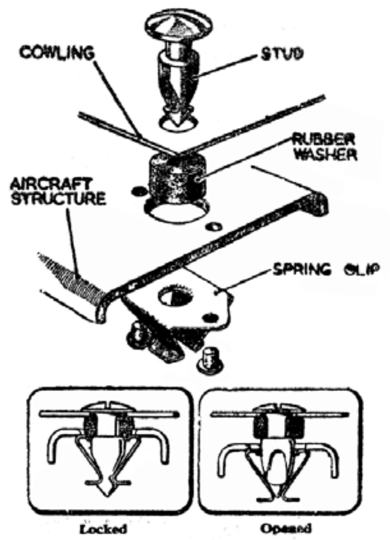


Fig. 28.8, Oddie Fastener

4. Amal Fastener

This type of fastener consists of a body (housing a spring loaded clock washer, a cotter, located by slots in the body, and centrally threaded to take a locking crew: and a back anchor plate riveted or welded to the inner component. When locked, the body is turned so that the ends of the cotter are positioned between the projecting legs of the anchor plate, and the locking screw tightened, to hold the inner and outer components securely together. The fastener is unlocked by first unscrewing the locking screw about two turns, then pressing the locking screw inwards to free the cotter from the legs on the anchor plate. They body is then turned a quarter turn in an a anti-clockwise direction to free the fastener.

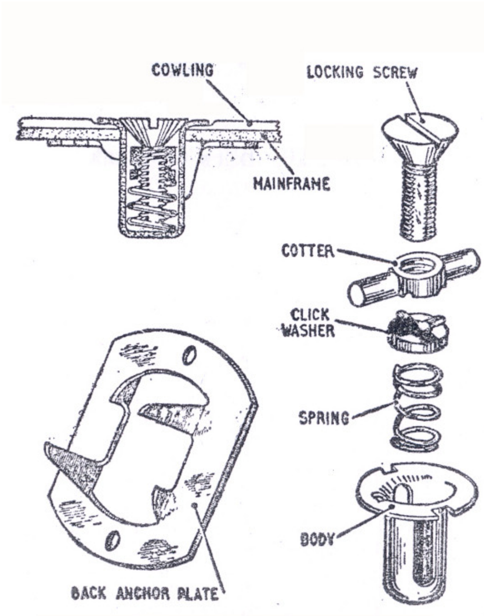


Fig. 20.9, Amal Fastener

5. Hawker Toggle Type Panel Fastener

The Hawker Toggle Type Panel fastener is used to secure the larger sizes of detachable panels and cowling, particularly where considerable pressure is likely to be exerted, either from the outside of the aircraft, or, as in the case of engine cowlings, from the inside. The toggle type fastener consists of two major parts, a double threaded adjusting link and fairing piece, and a toggle lever to which is attached a spring loaded catch plate. The fastener is contained in a lower and an upper toggle housing, and is mounted in the lower housing so that it cab be swivelled and locked into be upper housing. In general, the upper toggle housing is fitted into the detachable panel and the lower toggle housing is fitted to the component to which the panel is to be fastened, but the positions may be reversed.

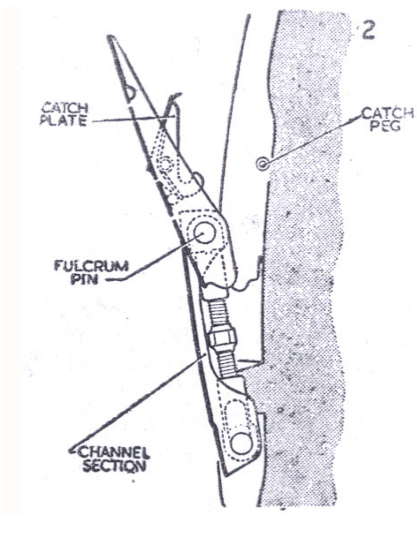


Fig.20.10, Hawker Toggle Type Panel Fastener

k. Key Circlip

These are made of spring steel and are used lock round shaped threaded parts. The circular portion of the circlip fits into a groove on one of the threaded parts, and the short bent end enters drilled holes in both threaded parts thus providing a lock. A circlip may also be used to prevent end wise movement by being sprung into a groove from which it partially projects. Each circlip must be used once.

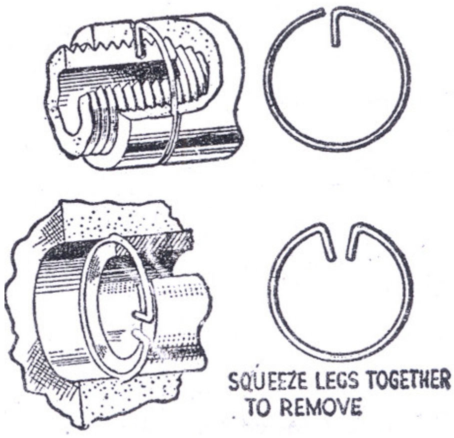


Fig.20.11, Circlips

l. Cotter pins

The AN380 cadmium-plated, low-carbon steel cotter pin is used for safetying bolts, screws, nuts, other pins, and in various applications where such safetying is necessary. The AN381 corrosion-resistant steel cotter pin is used in locations where nonmagnetic material is required, or in locations where resistance to corrosion is desired.

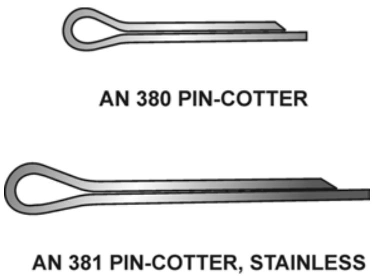


Fig. 20.12, Cotter Pins

Lock Washers

Lock washers (AN-935 and AN-936) can be used with machine screws or bolts whenever the self-clocking or castellated nut is not applicable. They are not to be used as fastenings to primary or secondary structures, or where subject to frequent removal or corrosive conditions.

AN standards include three types of washers, and, although these have been replace in later aircraft designs by MS washers, they may still be found on some older types of aircraft and are included for reference. These washers are listed and illustrated in Table 20.1.

Coding

Washers are identified by the AN number, a dash number to indicate size, and letters to indicate material and finish.

a. Size

The size of a washer is related to the size of bolt it is designed to fit, and the dash number is in accordance with the code.

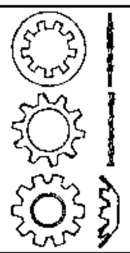
b. Material

Material is indicated in the code by adding the letters shown in Table 20.1.

c. Thickness

AN 935 and 960 washers may be available in light or regular thickness, the light washer being indicated by an 'L' at the end of the code. Actual thicknesses should be obtained from the AN Standard.

TABLE 20.1, EARLY SERIES AN WASHERS

AN Number	Type	Shape	Material	Process	Material Code
935	Washer, lock spring		Steel Bronze CRS	Cadmium plated NIl	Nil B C
936	Washer, shake-proof	A B C 	Steel Bronze	Cadmium plated Tinned	Nil B
960	Washer, plain		Steel CRS Brass Al. alloy Al. alloy	Cadmium plated Nil Nil Nil Anodised	Nil C B D PD

d. Examples

i. AN 936A416B is a style A regular shakeproof washer designed to fit a 1/4 in bolt and is made of bronze.

ii. AN 960 C-616L is a light plain washer in corrosion-resistant steel, for a 3/8 in bolt.

Fig. 20.13, Aircraft Washers.

■■■

CHAPTER-21
AIRCRAFT RIVETS

SOLID RIVETS

Introduction

This chapter gives guidance on the various types of solid rivets used in aircraft structures. It includes tables of the principal types of British and American rivets and gives guidance on the heat treatment of aluminium alloy rivets.

General

Rivets are designed to be strong in shear and should not be subjected to excessive tension loads. The two main groups of solid rivets are those with protruding heads, mostly used in the interiors of aircraft, and those with countersunk heads which are used on exterior surfaces where a flush finish is required. If protruding rivets are used externally they are usually of the mushroom (Figures 21.1 and 21.2) or universal (Figure 21.3) head types.

British and American rivets are not manufactured to identical specifications nor from identical materials but, since American rivets are not always available, it is often necessary to repair American-built aircraft using British rivets. Unless there are specific instructions to the contrary the information given in paragraph 5 may be used as a guide in choosing British substitutes for American rivets. When American rivets are available, all protruding-head rivets in American-built aircraft may be replaced by universal head rivets which have now been adopted as the standard for protruding-head rivets in that country.

NOTE

Deviations from the original repair scheme approved for an aircraft type, e.g. use of rivets of a different material, may only be made if written authority is obtained from an approved design organisation. The possibility of electro-chemical reaction between rivets and the surrounding material must always be considered.

Both British and American rivets are identified by head or shank end markings except where a material is easily identified by its natural colour or weight. Certain British rivets are also coloured all over to enable them to be more readily distinguished.

NOTE

Identification colouring requirements for British aluminium or aluminium alloy rivets are contained in Specification DTD 913.

Some aircraft manufacturers specify rivets made to the standards of their own companies, and may also use a different colour identification for standard rivets.

BRITISH SOLID RIVETS

Standards for British rivets are issued by the Society of British Aerospace Companies (AS series) and the British Standards Institute (SP series).

Rivets are identified by a Standard number and a part number. The Standard number identifies the head shape, material and finish, and the part number indicates the size in terms of shank diameter (thirty-seconds of an inch or millimetres 10) and length (in sixteenths of an inch or millimetres). For example, an AS162 rivet 1/8 inch diameter and 1/2 inch long would be AS162-408 and an SP160 rivet 4 mm in diameter and 16 mm long would be SP 160-40-16.

NOTE

'AS' close tolerance rivets are supplied in length graduations of 1/32 inch. The part number system remains the same, however, and odd 1/32 inches in length are shown by the addition of '5' after the normal part number.

Materials

The materials used for the manufacture of British rivets comply with DTD or British Standards (BS) Specifications, the actual material being quoted in the relevant tables. Rivets now manufactured from BS L86 were, until September 1961, manufactured from BS L69. Where the rivets require heat treatment, i.e. all BS L37 rivets, this is also indicated in the tables by the symbols and the procedures explained in the topic of Heat Treatment.

'AS' Rivets

Table 21.1 gives a list of the solid rivets which conform to the Aircraft Standards of the Society of British Aerospace Companies; these rivets are made in a range of sizes from 1/16 inch diameter and from 1/8 inch to 2 inches long except that copper rivets to AS 469 are only made in diameters up to 1/4 inch. Figure 21.1 illustrates the AS solid rivets and indicates the method of measuring the length 'L'. It will be seen from the Table that most of these rivets are obsolescent and have been replaced by rivets conforming to SP Standards.

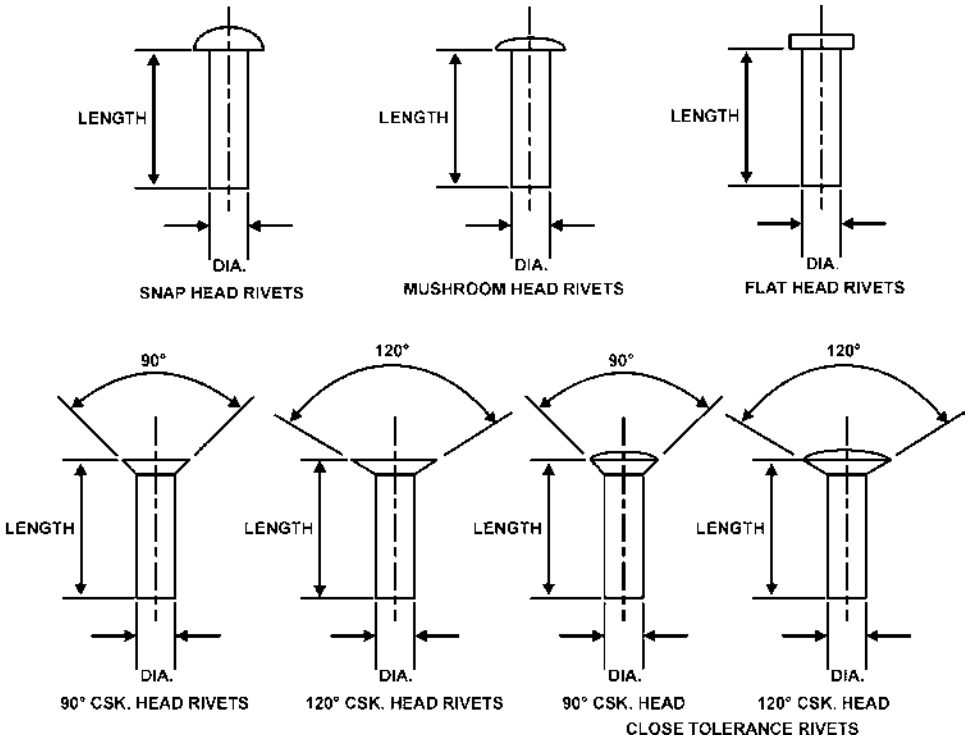


Fig. 21.1, 'AS' Rivets.

TABLE 21.1

AIRCRAFT STANDARD NUMBER	MATERIAL	MATERIAl SPECI-FICATION	HEAD TYPE	FINISH	IDENTI-FICATION MARK ON END OF SHANK	REMARKS
AS 155*	aluminium	L 36	snap	black anodic	A	superseded by SP 77
AS 156*	aluminium alloy	L 37**	snap	natural	D	superseded by SP 78
AS 157*	aluminium alloy	L 58	snap	green anodic	X	superseded by SP 79
AS 455*	mild steel	BS 1109	snap	cadmium		superseded by SP 76
AS 457*	monel	DTD 204	snap	natural	M	superseded by SP 81
AS 458*	tungum	DTD 367	snap	cadmium		
AS 459	copper		snap	natural		non-magnetic
AS 2227*	aluminium alloy	L 86	snap	violet anodic	S	superseded by SP 80
AS 4694*	monel	DTD 204	snap	cadmium	M	superseded by SP 82
AS 158*	aluminium alloy	L 37**	mushroom	natural	D	superseded by SP 83
AS 159*	aluminium alloy	L 58	mushroom	green anodic	X	superseded by SP 84
AS 2228*	aluminium alloy	L 86	mushroom	violet anodic	S	superseded by SP 85
AS 160*	aluminium	L 36	90°csk.	black anodic	A	
AS 161*	aluminium alloy	L 37**	90°csk.	natural	D	

TABLE 21.1 - CONTINUED

AIRCRAFT STANDARD NUMBER	MATERIAL	MATERIAI SPECI-FICATION	HEAD TYPE	FINISH	IDENTI-FICATION MARK ON END OF SHANK	REMARKS
AS 162*	aluminium alloy	L 58	90°csk.	green anodic	X	
AS 460	mild steel	BS 1109	90°csk.	cadmium		magnetic
AS 462	monel	DTD 204	90°csk.	natural	M	
AS 466*	tungum	DTD 367	90°csk.	cadmium		
AS 467	copper		90°csk.	natural		non-magnetic
AS 2229*	aluminium alloy	L 86	90°csk.	violet anodic	S	
AS 4695	monel	DTD 204	90°csk.	cadmium		
AS 4645	aluminium alloy	L 86	90°csk.	violet anodic	S	shank $\frac{1}{64}$ in. oversize, "R" on head
AS 4646	aluminium alloy	L 37††	90°csk.	plain anodic	D	
AS 163*	aluminium	L 36	120°csk.	black anodic	A	
AS 164*	aluminium alloy	L 37††	120°csk.	natural	D	
AS 165*	aluminium alloy	L 58	120°csk.	green anodic	X	
AS 463	mild steel	BS 1109	120° csk.	cadmium		magnetic
AS 465	monel	DTD 204	120° csk.	natural	M	
AS 468*	tungum	DTD 367	120° csk.	cadmium		
AS 2230*	aluminium alloy	L 86	120° csk.	violet anodic	S	
AS 4696	monel	DTD 204	120° csk.	cadmium	M	
AS 4647	aluminium alloy	L 86	120° csk.	violet anodic	S	shank $\frac{1}{64}$ in. oversize, "R" on head
AS 4648	aluminium alloy	L 37††	120° csk.	plain anodic	D	
AS 469	copper		flat	natural		non-magnetic
AS 2918	aluminium alloy	L 37††	90° raised csk.	natural		close tolerance
AS 3362	aluminium alloy	L 86	90° raised csk.	violet anodic		close tolerance
AS 2919	aluminium alloy	L 37††	120° raised csk.	natural		close tolerance
AS 3363	aluminium alloy	L 86	120° raised csk.	violet anodic		close tolerance

* Obsolescent
†† Require heat treatment before driving.

'SP' Inch Size Rivets

Table 21.2 give a list of the solid rivets which conform to the British Standards Institute Aerospace Standards for rivets in inch sizes. These rivets are made in a range of size from 1/16 inch to 3/8 inch in diameter and from 1/8 inch to 3 inches long, and are illustrated in Figure 21.2.

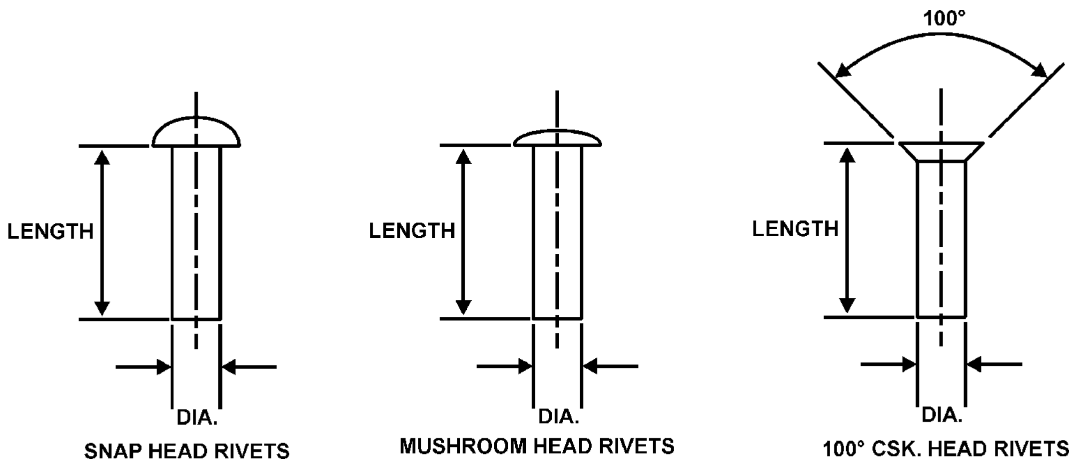


Fig. 21.2, 'SP' Inch Size Rivets.

TABLE 21.2

BRITISH STANDARD NUMBER	MATERIAL	MATERIAL SPECIFI-CATION	HEAD TYPE	FINSIH	IDENTIFI-CATION MARK**	REMARKS
SP 68	aluminium	L 36	100° csk.	black anodic	I*	
SP 69	aluminium alloy	L 37††	100° csk.	natural	7	
SP 70	aluminium alloy	L 58	100° csk.	green anodic	8	
SP 71	aluminium alloy	L 86	100° csk.	violet anodic	O+	
SP 76	steel	BS 1109	snap	cadmium		magnetic, superseding AS 455
SP 77	aluminium	L 36	snap	black anodic	I	superseding AS 155
SP 78	aluminium alloy	L 37††	snap	natural	7	superseding AS 156
SP 79	aluminium alloy	L 58	snap	green anodic	8	superseding AS 157
SP 80	aluminium alloy	L 86	snap	violet anodic	O	superseding AS 2227
SP 81	monel	DTD 204	snap	natural	M	superseding AS 457
SP 82	monel	DTD 204	snap	cadmium	M	non-magnetic, superseding AS 4694
SP 83	aluminium alloy	L 37††	mushroom	natural	7	superseding AS 158
SP 84	aluminium alloy	L 58	mushroom	green anodic	8	superseding AS 159
SP 85	aluminium alloy	L 86	mushroom	violet anodic	O	superseding AS 2228
SP 86	steel	BS 1109	100°csk.	cadmium		magnetic
SP 87	monel	DTD 204	100°csk.	natural	M	non-magnetic
SP 88	monel	DTD 204	100°csk.	cadmium	M	non-magnetic

* SP 68 rivets, prior to Amendment No. 1 to the Standard, published in September, 1959, bore no identification marks.

\+ SP 71 rivets, prior to Amendment No. 1 to the Standard, published in September, 1959, bore the identification mark '9' to signify manufacture from L 69 material.

†† Require heat treatment before use.

** May be on head or shank end, depending on rivet size.

'SP' Metric Size Rivets

Table 21.3 gives a list of rivets which conform to the British Standards Institute Aerospace Standards for rivets in metric sizes. These are confined, at present, to universal head and 100° countersunk truncated radius head rivets in diameters of 2.4 to 9.6 mm and lengths of 4 to 60 mm. The identification marks listed in the table are applied the matric size rivets shank end only.

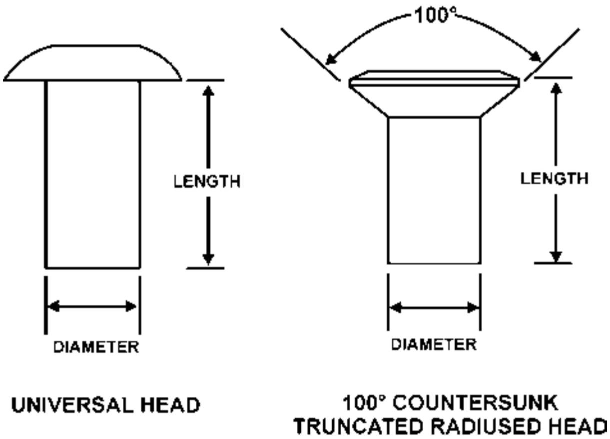


Fig. 21.3, 'SP' Metric Size Rivets.

TABLE 21.3

BRITISH STANDARD NUMBER	MATERIAL		HEAD TYPE	FINISH	IDENTIFICATION
	TYPE	SPECIFICATION			
SP 142	al. alloy	L 86	100° csk.†	violet anodic	indented dot
SP 157	al. alloy	L 86	universal	violet anodic	indented dot
SP 158	monel	DTD 204	universal	natural	two indented dots
SP 159	monel	DTD 204	universal	cadmium	nil
SP 160	al. alloy	L 58	universal	green anodic	raised cross
SP 161	al. alloy	L 58	universal	plain anodic	raised cross
SP 162	al. alloy	L 37††	universal	natural	raised broken line and centre point
SP 163	al. alloy	L 86	universal	plain anodic	indented dot

† 100° countersunk, truncated radiused head.
†† Required heat treatment before driving.

AMERICAN SOLID RIVETS

American rivets in general use are listed in Table 21.4, together with the means of identification which, since all the aluminium alloy rivets are

, is by means of head alloy anodic head markings rather than colour. The code used for the classification of American rivets is similar to that used for British rivets and is best illustrated by an example such as MS 20470 AD 5-12, which has the following meaning:

i. MS Signifies Military Standard
ii. 20470 is a code for the head shape and basic material (aluminium universal head in this instance).
iii. AD is a code for the rivet material (2117 aluminium alloy in this instance, see next paragraph.
iv. 5 is the diameter in thirty seconds of an inch
v. 12 is the length in sixteenths of an inch.

American wrought aluminium and aluminium alloys are identified by a four digit index system. The first digit indicates the main alloying element, the second indicates modifications to the original alloy and the last two indicate the aluminium purity or the specific alloy. These numbers are followed by a letter indicating the temper condition. Table 21.5 shows the aluminium and aluminium alloys used in the manufacture of rivets and the condition in which they are normally supplied to the user. Further information on temper designations is contained in next page under heading "American Temper Designations".

TABLE 21.4

RIVET AND MATERIAL CODE	MATERIAL	MATERIAL SPECIFI-CATION	HEAD TYPE	IDENTIFICATION MARK ON HEAD	REMARKS
MS 20426A	aluminium	1100	100° csk.	nil	supersedes AN 426 A
MS 20426B	aluminium alloy	5056	100° csk.	raised cross	supersedes AN 426B
MS 20426AD	aluminium alloy	2117	100° csk.	dimple	supersedes AN 426AD
MS 20426DD	aluminium alloy	2024††	100° csk.	raised double dash	supersedes AN 426DD
MS 20426D	aluminium alloy	2017**	100° csk.	raised dot	supersedes AN 426D
MS 20427	carbon steel	QQ-W-409 or QQ-S-633	100° csk.	recessed triangle	supersedes AN 427
MS 20427F	corrosion resistant steel	QQ-W-423	100° csk.	recessed dash	supersedes AN 427F
MS 20427M	monel	QQ-N-281	100° csk.	nil	supersedes AN 427M
MS 20427C	copper	QQ-W-341	100° csk.	nil	supersedes AN 427C
MS 20470A	aluminium	1100	universal	nil	supersedes AN 470A
MS 20470B	aluminium alloy	5056	universal	raised cross	supersedes AN 470 B
MS 20470AD	aluminium alloy	2117	universal	dimple	supersedes AN 470AD
MS 2047ODD	aluminium alloy	2024††	universal	raised double dash	supersedes AN 470DD
MS 20470D	aluminium alloy	2017††	universal	raised dot	supersedes AN 470 D
MS 20613 P/Z	carbon steel	QQ-S-633	universal	recessed triangle	supersedes MS 20435
MS 20613 C	corrosion resistant steel	QQ-W-423	universal	nil	supersedes MS 20435
MS 20615 M	monel	QQ-N-281	universal	double dimple	supersedes MS 20435
MS 20615CU	copper	QQ-W-341	universal	nil	supersedes MS 20435

NOTE : For MS 20613 rivets the letter P is added to indicate cadmium plated carbon steel and the letter Z to indicate zinc plated carbon steel.

** Require heat treatment before use.

TABLE 21.5

SPECIFICATIONS OF ALUMINIUM / ALLOY	CONDITION IN WHICH NORMALLY SUPPLIED
1100	— F as fabricated
2017	— T4 solution heat-treated
2024	— T4 solution heat-treated
2117	— T4 solution heat-treated
5056	— H32 strain hardened and then stabilised

MS Standards provide for two types of rivets, i.e. the universal head which is standard for protruding head rivets, and the 100° countersunk head which is standard for all flush head rivets.

American Temper Designations

American aluminium alloy rivets are given a temper designation to signify their condition. Non heat-treatable alloys such as 5056 have attained their maximum strength by working and are driven in the 'as received' condition. Of the heat-treatable alloys, 2117 does not benefit from further heat treatment and is driven in the 'as received' condition, 2024 must be solution treated before use and it is recommended that 2017 rivets of 3/8 inch diameter and larger are also solution treated to prevent cracking. Heat-treatable alloy rivets are supplied in the T4 condition (solution treated by the rivet manufacturer); when solution treated by the user before driving the final temper is T31 and when driven 'as received' the final temper is T3.

AN470 - Universal Headed

It is a combination of the roundhead, flathead, and brazier head. It is used in aircraft construction and repair in both interior and exterior locations. When replacement is necessary for protruding head rivets - roundhead, flathead, or brazier head - they can be replaced by universal head rivets.

Material	Head Marking	AN Material Code	AN425 78° Counter-Sunk Head	AN426 100° Counter-Sunk Head MS20426*	AN427 100° Counter-Sunk Head MS20427	AN430 Round Head MS20470*	AN435 Round Head MS20613* MS20615	AN441 Flat Head	AN442 Flat Head MS20470*	AN455 Brazier Head MS20470	AN456 Brazier Head MS20470	AN470 Universal Head MS20470*	Heat Treat Before Using	Shear Strength P.S.I.	Bearing Strength P.S.I.
1100	Plain	A	X	X		X			X	X	X	X	No	10000	25000
2117T	Recessed Dot	AD	X	X		X			X	X	X	X	No	30000	100000
2017T	Raised Dot	D	X	X		X			X	X	X	X	Yes	34000	113000
2017T-HD	Raised Dot	D	X	X		X			X	X	X	X	No	38000	120000
2024T	Raised Double Dash	DD	X	X		X			X	X	X	X	Yes	41000	130000
5056T	Raised Cross	B		X		X			X	X	X	X	No	27000	90000
7075-T73	Three Raised Dashes		X	X		X			X	X	X	X	No		
Carbon Steel	Recessed Triangle				X		X MS20613*	X					No	35000	90000
Corrosion Resistant Steel	Recessed Dash	F			X		X MS20613*						No	65000	90000
Copper	Plain	C			X		X	X					No	23000	
Monel	Plain	M			X			X					No	49000	
Monel (Nickel-Copper Alloy)	Recessed Double Dots	C					X MS20615*						No	49000	
Brass	Plain						X MS20615*						No		
Titanium	Recessed Large and Dmall Dot			MS20426				X					No	95000	

* New specifications are for Design purposes

Fig.21.4, Rivet Identification Chart

AN430 - Round Headed

Roundhead rivets are used in the interior of the aircraft, except where clearance is required for adjacent members. The roundhead rivet has a deep, rounded top surface. The head is large enough to strengthen the sheet around the hole and, at the same time, offer resistance to tension.

AN441 - Flat Headed

The flathead rivet, like the roundhead rivet, is used on interior structures. It is used where maximum strength is needed and where there isn't sufficient clearance to use a rounded rivet. It is seldom, if ever, used on external surfaces.

The brazier head rivet has a head of large diameter, which makes it particularly adaptable for riveting thin sheet stock (skin). The brazier head revet offers only slight resistance to the airflow, and because of this factor, it is frequently used for riveting skin on exterior surfaces, especially on aft sections of the fuselage and empennage. It is used for riveting thin sheets exposed to the slipstream. A modified brazier head rivet is also manufactured; it is simply a brazier head of reduced diameter.

AN425 - Counter-Sunk Head

The countersunk head rivet is flat topped and beveled toward the shank so that it fits into a countersunk or dimpled hole and is flush with the material's surface. The angle at which the head slopes may vary from 78° to 120°. The 100° rivet is the most commonly used type. These rivets are used to fasten sheets over which other sheets must fit. They are also used on ecxterior surfaces of the aircraft because they offer only slight resistance to the slipstream and help to minimize turbulent airflow.

SELECTION OF RIVETS

The following paragraphs give general guidance on the factors which must be considered when rivets of either British or American manufacture are specified for a particular application.

The rivet material must be compatible with the material in which it is to be used, for reasons of strength and resistance to corrosion. L 58 (or 5056) rivets must be used in magnesium structures, monel rivets in titanium and stainless steel, and aluminium or copper rivets in parts of similar or nonmetallic materials in non-structural applications. The type of aluminium alloy rivets to be used for a particular repair depends on the strength of the alloy with which it is used. Table 21.6 indicates the shear strengths of various rivet materials. Rivets of less shear strength than those specified in a Repair Manual drawing should not be used without the approval of the manufacturer. L 37 (or 2024) rivets require heat treatment before use and if they are to be replaced by L 86 (or 2117) rivets through lack of treatment facilities, the number of rivets must be increased to provide the same shear strength. Cadmium plated rivets should not be used in areas where temperatures of 250^{o}C or more are likely to be encountered.

The shear strength of the rivets used is not the only factor which determines the strength of a riveted joint. Generally, if the thickness of the sheets is less than half the diameter of the rivets used, failure of the joint will depend on the bearing stress rather than on the shear stress in the rivets.

The diameters and types of rivets to be used in repairs are normally specified either in the Repair Manual or in the repair scheme, but in the absence of specific instructions, 3/32 inch rivets should be used for 24 and 22 s.w.g. material, 1/8 inch rivets for 20 and 18 s.w.g. material and 5/32 inch for 16 s.w.g. If rivets of reduced diameter have to be substituted during repair work, the total number of rivets must be increased to provide equivalent cross-sectional area. Where 22 s.w.g. and thinner material is concerned, an there are no specific instructions regarding repair after a riveting failure, the substitution of mushroom head rivets for snap head rivets should be considered.

NOTE

Shear strength of a rivet is proportional to its cross-sectional area and not its diameter. Thus four rivets 1/16th inch diameter must be used to replace one rivet 1/8 inch diameter.

Where a large diameter rivet is used with thin sheet metal, the pressure required to close the rivet generally causes an undesirable bulging of the sheet around the rivet head. A diameter/thickness ratio not exceeding 3 is satisfactory for protruding head rivets but for countersunk rivets this ratio should not exceed 1.5.

When British rivets have to be used in American-built aircraft, rivets of the material with the nearest equivalent shear strength to the material of the original American rivets should be selected. If, as occurs in some instances, the available British rivets have lower shear strengths than the American rivets, either the total number of rivets should be increased or rivets of larger diameter should be used to make the strength of the joint in bearing and shear not less than it was originally. However, it should be borne in mind that an increase in the size of the rivets does not necessarily increase the strength of a joint; indeed, if the rivet sizes are increased beyond a certain amount, a reduction in strength will result.

TABLE 21.6

AMERICAN RIVET MATERIALS			BRITISH RIVET MATERIALS		
Material Specifi-cation	Tensile Strength lb/in²	Shear Strength lb/in²	Material Specifi-cation	Tensile Strength lb/in²	Shear Strength lb/in²
5056 - H32	38000	24000	L 58	35500	28500
2117 - T4	38000	26000	L 86	38000	29500
2017 - T4	55000	33000	L 37	56000	36000
2024 - T4	62000	37000	L 37	56000	36000

To ensure correct seating, countersunk head rivets should always be installed in dimples or countersunk holes of the same angle as the rivet head. Rivets with countersunk heads of 70° or 82° included angle are often used in positions where sealing is of primary importance, such as in integral fuel tanks, and when these rivets require replacement care is necessary to ensure that rivets with the correct angle heads are selected.

BLIND RIVETS

The blind rivets discussed in this paragraph are all closed by pulling a mandrel through the bore. In some cases the mandrel also plugs the rivet, but in others a separate sealing pin must be driven in after the rivet has been closed.

Chobert Rivets

Chobert rivets are manufactured with either snap or countersunk heads and are normally supplied in tubes for ease of assembly on the mandrel. The action of closing a Chobert rivet is shown in Figure 21.5, initial movement of the mandrel down the tapered bore forming the head and subsequent movement expanding the shank to fill the rivet hole. Sealing pins are an interference fit in the rivet bore and, apart from increasing shear strength, will prevent the ingress of moisture.

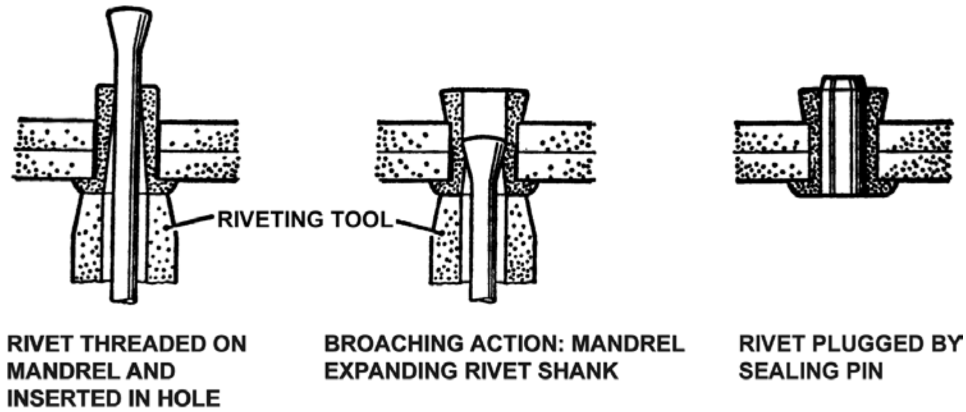


Fig.21.5, Closing Chobert Rivets

The Chobert rivets which have been given AGS numbers by the Society of British Aerospace Companies are shown in Table 21.7, but many other types are suitable for use on aircraft, full detail of materials, size an grip length being quoted in the manufacture's literature. For ordering purpose Chobert rivets may be identified by either the AGS number or a four figure code number assigned to it by the manufacture. This is followed by a further four figures indicating the size of the rivet. The first two figures of the size code indicate the diameter and the second two the length (both in thirty seconds of an inch), expect that if the AGS number is being quoted a zero in the diameter code is disregarded. As an example, a steel snap head rivet, $\frac{5}{32}$ inch diameter and $\frac{3}{8}\left(\frac{12}{32}\right)$ inch long , would be known by the manufacturer as 1201-0512, but the same rivet could also be ordered as AGS 2040\512.

NOTE

The length referred to for ordering purposes is the length of the rivet as supplied (i.e. shank length of snap head rivets and total length of countersunk rivets) and not the thickness to be riveted (i.e. grip)

The size code used for sealing pins fitted to snap head rivets is the same as the code used for the rivet itself, but if a sealing pin is to be fitted to a countersunk rivet the preceding length should be quoted. For example, a sealing pin for an AGS 2045\512 rivet (snap head) would be AGS 2047\512 but sealing pin for an AGS 2068/512 rivet (countersunk 100°) would be AGS 2047/510.

TABLE 21.7
CHOBERT RIVETS

AGS Number	Maker's Code	Head Type	Material Spec.	Anti-corrosive treatment	Identification
2040	1201	snap	DTD 720	cad. plated	magnetic
2045	1211	snap	L86	anodised	dyed violet
2041	1203	120° countersunk	DTD 720	cad. plated	magnetic
2046	1213	120° countersunk	L86	anodised	dyed violet
2067	1204	100° countersunk	DTD 720	cad. plated	magnetic
2042	1281	sealing pin	DTD 904	cad. plated	magnetic
2047	1282	sealing pin	L64	anodised	plain

A range of Chobert rivets with oversize shanks is also available and a may be used for repair work on aircraft. This is an advantage when rivets have been removed, since the increase in diameter is of the order 0.015 to 0.020 inches, depending on rivet size, so that repositioning of holes or re-stressing of joints is unnecessary.

Avdel Rivets

These rivets are similar to Chobert rivets, but each is fitted with its own stem (mandrel), the component parts being referred to; as the body and stem respectively. The stem is pulled into the body to close the rivet and, at a predetermined load, breaks proud of the manufactured head, leaving part of the stem inside the body in the form of a plug. Excess stem material may be nipped off and milled flush with the rivet head when required, e.g. on external surfaces, but stainless steel and titanium rivet stems break flush with the rivet head at the maximum grip range limit, and milling may not be necessary. The action of closing an Avdel rivet is shown in Figure 21.6.

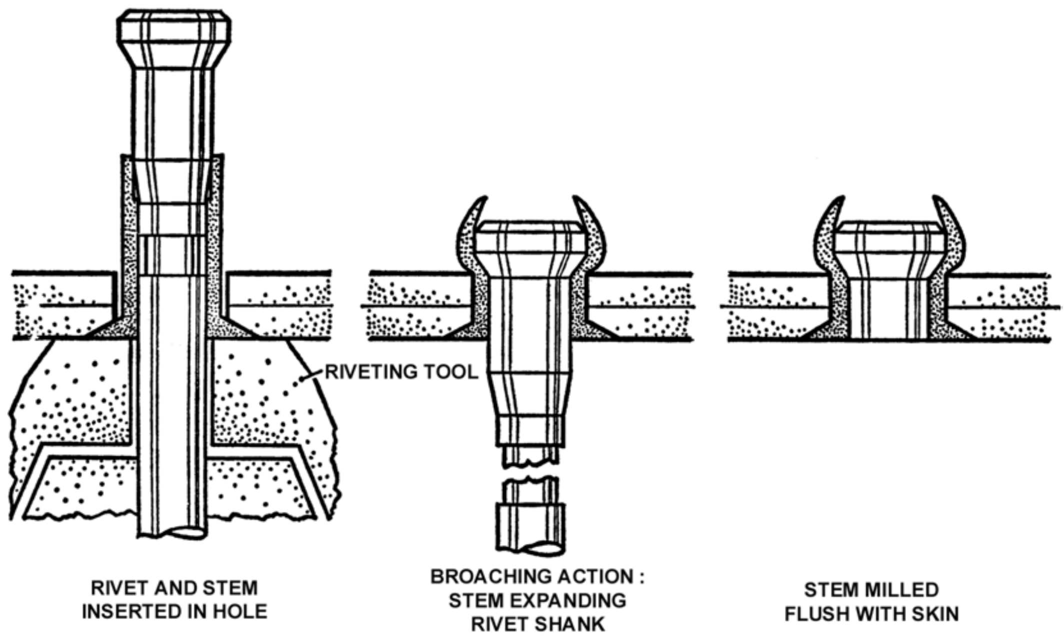


Fig. 21.6, Closing Avdel Rivets.

The Avdel rivets which have been given AGS number are shown in Table 21.8, and some of the more common rivets which may be used on aircraft, but do not have AGS numbers, are also included.

The code used for the identification Avdel rivets is the same as that used for Chobert rivets, i.e. the AGS number or the manufacturer's product code, followed by the size code.

The oversize rivets listed in Table 21.8 are used for repair purposes. The increases in diameter is similar to that quoted for Chobert rivets, and the same advantages apply.

Avdel rivets are lubricated by the manufacture to facilitate forming the rivet and on no account should the rivets be cleaned in solvent before use. These lubricants used are specially prepared for each type to obtain consistent results.

TABLE 21.8
AVDEL RIVETS

AGS Number	Master's code	Head Type	Material spec.		Finish	Remarks
			Body	Stem		
2065	4022	snap	L86	DTD 5074	anodised	-
2066	4032	100° countersunk	L86	DTD 5074	anodised	stem dyed red
-	4102	snap	L86	DTD 5074	anodised	oversize rivet, stem dyed violet
-	4132	100° countersunk	L86	DTD 5074	anodised	oversize rivet, stem dyed green
3920	4051	snap	DTD 189	FV 448	plain	stainless steel
3921	4057	100° countersunk	DTD 189	FV 448	plain	stainless steel
3922	4061	snap	DTD 189	FV 448	body cad. plated	stainless steel
3923	4067	100° countersunk	DTD 189	FV 448	body cad. plated	stainless steel
-	4074	universal	I.M.I. 230	I.M.I. 138 A	plain	titanium
-	4077	100° countersunk	I.M.I. 230	I.M.I. 138 A	plain	titanium

NOTE

Until recently all Avdel rivets manufactured from L 86 were dyed violet. This practice has been discontinued because of the frequent need to use these rivets in exterior aluminium surfaces which are not subsequently painted. The stems only are now dyed for identification purposes.

The shear strength of Avdel rivets is similar to that of slid rivets and is somewhat greater than that of Chobert rivets of similar material and size.

Tucker 'POP' Rivets

Tucker 'pop' rivets are manufactured with either domed or countersunk heads, and are supplied threaded on individual mandrels. There are, basically, two different types of rivets, known as 'standard' (open) and 'sealed'. The action of closing both types of rivet is shown in figure 21.7.

The mandrels of standard type rivets are of two; types, namely break head and break stem. With the former type the mandrel head separates from the formed rivet, but with the latter the heads retained in the rivet bore and provides a measure of sealing. The break head rivets are not widely used on aircraft due to ;the difficulty of recovering broken mandrel heads.

These mandrels of sealed type rivets are also of two types, the short break and the long break. The short break mandrel breaks immediately under the head, but the long break mandrel breaks outside the rivet has greatly increasing shear strength of the rivet and providing a flush finish when the protruding stem is nipped off.

A wide variety of tools is available for closing 'pop' rivets, ranging from pillar type hand tools to pneumatically or hydraulically operated power tools. A range of interchangeable heads for these tools permits closing the rivets where access is restricted.

The manufacture's identification code varies according to the type of rivet (i.e. standard or sealed) but similar letters are used to indicate material and head shape as follows:-

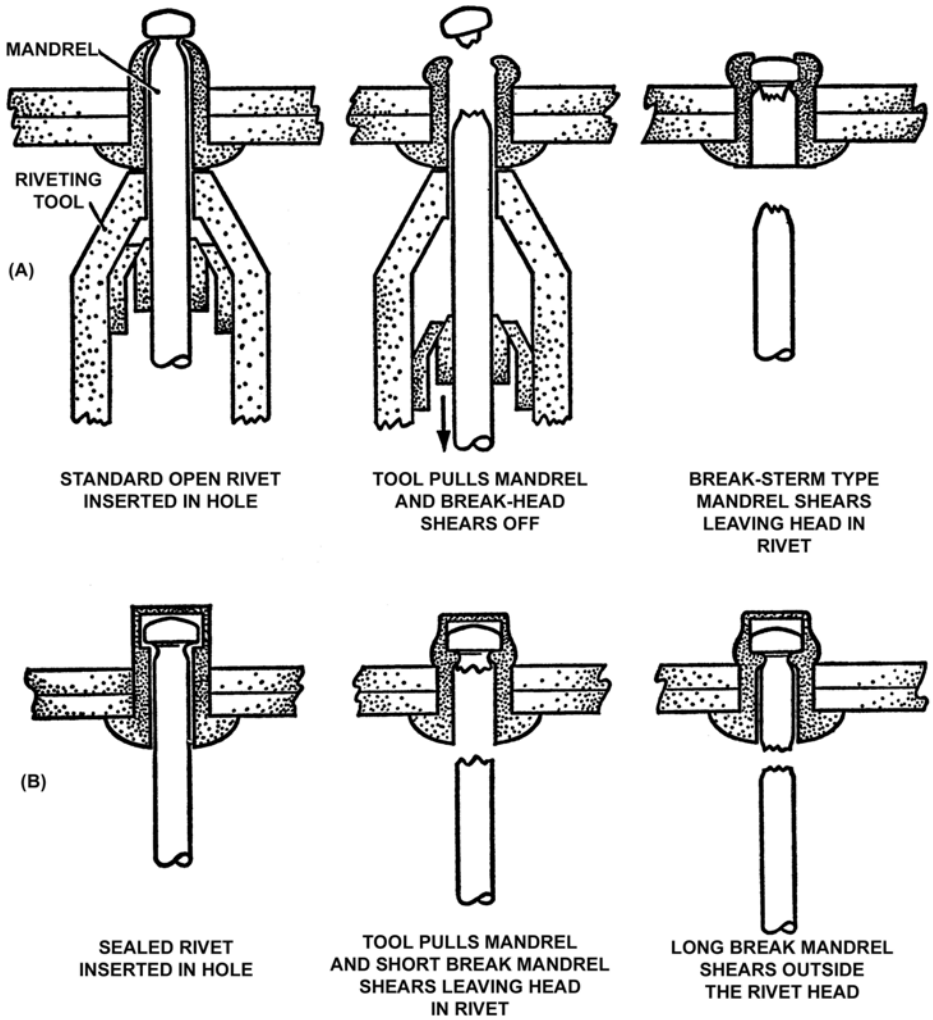


Fig. 21.7, Closing Tucker 'Pop' Rivets

i. Standard rivets

T	=	Tucker
L,A,S or C	=	Monel (DTD 10B), steel (E.N.2a) or copper respectively.
P	=	'pop' rivet
D or K	=	domed or countersunk head (120°) respectively.
BH or BS	=	break head or break stem respectively.

Size is indicated by three figures, the first indicating diameter and the last two the length of shank.

Thus a rivet coded TAP\K 412 BH would be a Tucker, L58, ; pop; rivet, with a countersunk head, 4\32 (1\8) inch diameter with a shank length of 0.12 inch and a break head mandrel.

ii. Sealed rivets

A or C	=	L58 of copper respectively.
D or K	=	Domed or countersunk head (120°) respectively.
R	=	Reinforced (i.e. long break mandrel).

Size is indicated by two or three figures, the first indicating diameter and the remainder the maximum riveting thickness.

Thus a rivet coded AD q would be an L58, domed head rivet, 4\32 $\left(\frac{1}{8}\right)$ inch thick and having a long break mandrel.

NOTE 1

The above details apply to the majority of aircraft rivets but rivets of different materials and head shapes are also available.

NOTE 2

Mandrels are normally of steel but are also available in different materials .

AGS numbers have been given to some of the standard 'pop' rivets and the most common are as follows:-

AGS 2048, L58 domed head
AGS 2049, L58 120° countersunk head.
AGS 2050, Monel (DTD 10B) domed head
AGS 2051, Monel (DTD 10B)120° countersunk head
AGS 2070, Monel (DTD 10B) 100° countersunk head

The AGS number is followed by the manufacture's coding for size and mandrel type as discussed in the previous paragraph.

iii. Cherry Rivets

These are rivets of American manufacture and are very similar to Avdel rivets, except that the stem is positively locked in the rivet bore. During the final stages of forming, a locking collar, located in a recess in the rivet head, is forced into a groove in the stem, and the finished blind head is flatter and broader than the standard head. The action of closing a Cherry rivet is shown in figure 21.8.

After forming, the stem protrudes slightly beyond the rivet head and this excess, plus part of the locking collar, may be milled off to provided a flush finish.

Cherry rivets are installed using hand or power operated tools and it is important that the tools are fitted with the correct type of head for the particular size or type of rivet. Details are normally supplied by either the aircraft or tool manufacturer.

Cherry rivets are identified by a four figure number followed by a figure indicating the diameter in thirty-seconds $\left(\frac{1}{32}\right)$ of an inch and further figure indicating the maximum grip in sixteenths of an inch. As an example , CR 2162-3-6 refers to a Cherry rivet in aluminium alloy, with a countersunk head and standard stem, 3\32 inch diameter and a maximum grip of 3\8 inch. Table 21.9 shows some of more common Cherry rivets, together with identification details.

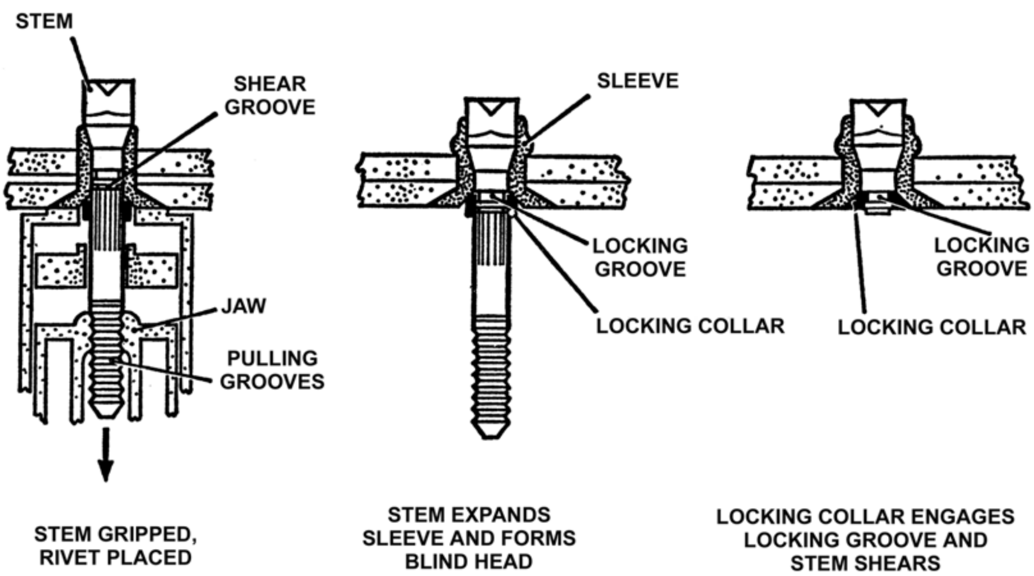


Fig. 21.8, Closing Cherry Rivets.

TABLE 21.9
CHERRYRIVETS

Code	Type	Head	Material		Finish	
			Rivet	Stem	Rivet	Stem
CR 2162	standard	countersunk	2017	7075	205 Alumite	1200 Alodine
CR 2163	standard	universal	2017	7075	205 Alumite	1200 Alodine
CR25625	standard	countersunk	monel	monel	silver plate	natural
CR25635	standard	universal	monel	monel	silver plate	natural
CR 2662	standard	countersunk	st. steel	st. steel	dry film	natural
CR 2663	standard	universal	st. steel	st. steel	dry film	natural
CR 2248	bulbed	countersunk	5056	steel	anodised	cad. plate
CR 2249	bulbed	universal	5056	steel	anodised	cad. plate

NOTE : A figure indicating maximum grip is marked on the rivet head.

MECHANICALLY EXPANDED RIVETS

Two classes of mechanically expanded rivets will be discussed here :

1. Non-structural
a. Self-plugging (friction lock) rivets
b. Pull-thru rivets
2. Mechanical lock, flush fracturing, self-plugging rivets.

Self-Plugging

The self-plugging (friction lock) blind rivets are manufactured by several companies : the same general basic information about their fabrication, composition, uses, selection, installation, inspection, and removal procedures apply to all of them.

Self-plugging (friction lock) rivets are farbricated in two parts : A rivet head with a hollow shank or sleeve, and a stem that extends through the hollow shank. Figure 21.9 illustrates a proturding head and a countersunk head self-plugging rivet produced by one manufacturer.

Several events, in their proper sequence, occur when a pulling force is applied to the stem of the rivet : (1) The stem is pulled into the rivet shank; (2) the mandrel portion of the stem forces the rivet shank to expand; and (3) when friction (or pulling action pressure) becomes great enough it will cause the stem to snap at a breakoff groove on the stem. The plug portion (bottom end of the stem) is retained in the shank of the rivet giving the rivet much greater shear strength than could be otained from a hollow rivet.

Self-plugging (friction lock) rivets are fabricated in two common head styles : (1) A protruding head similar to the MS20470 or universal head, and (2) a 100° countersunk head. Other head styles are available from some manufacturers.

The stem of the selfplugging (friction lock) rivet may have a knot or knob on the upper portion, or it may have a serrated portion as shown in figure 21.9.

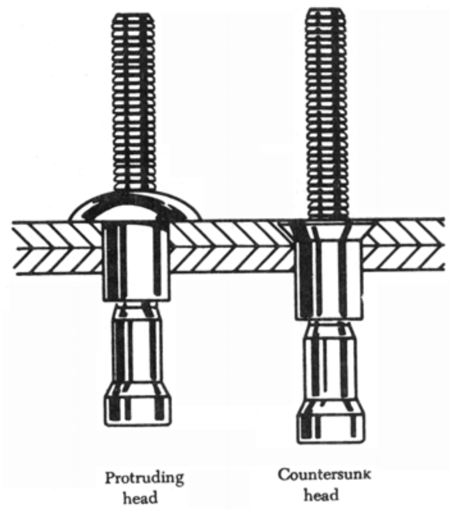


Fig. 21.9, Self-plugging (friction lock) rivets.

Self-plugging (friction lock) rivets are fabricated from several matrials. rivets are available in the following material combinations: stem 2017 aluminum alloy and sleeve 2117 aluminum alloy; stem 2017 aluminum alloy and sleee 5056 aluminum alloy; and stem steel and sleeve steel.

Selfplugging (friction lock) rivets are designed so that installation requires only one person; it is not necessary to have the work accessible from both sides. The pulling strength of the rivet stem is such that a uniform job can always be assured. Because it is not necessary to have access to the opposite side of the work, self-plugging (friction lock) rivets can be used to attach assemblies to hollow tubes, corrugated sheet, hollow boxes, etc. Because a hammering force is not necessary to install the rivet, it can be used to attach assemblies to plywood or plastics.

Factors to consider in the selection of the correct rivet for installation are: (1) Installation location, (2) composition of te material being riveted, (3) thickness of the material being riveted, and (4) strength desired.

If the rivet is to be installed on an aerodynamically smooth surface, or if clearance for an assembly is needed, countersunk head rivets should be selected. In other areas where clerance of smoothness is not a factor, the protrucing head type rivet may be utilized.

Mateial composition of the rivt shank will depend upon the type of material being riveted. Aluminum alloy 2117 shank rivets can be used on most aluminum alloys. Aluminum alloy 5056 shank rivets should be used when the material being riveted is magnesium.. Steel rivets should always be selected for riveting assemblies fabricated from steel.

The thickness of the material being riveted determines the overall length of the shank of the rivet. As a general rule, the shank of the rivet should extend beyound the material thickness approximatel $\frac{3}{64}$ inch to $\frac{1}{8}$ inch before the stem is pulled (see figure 21.10).

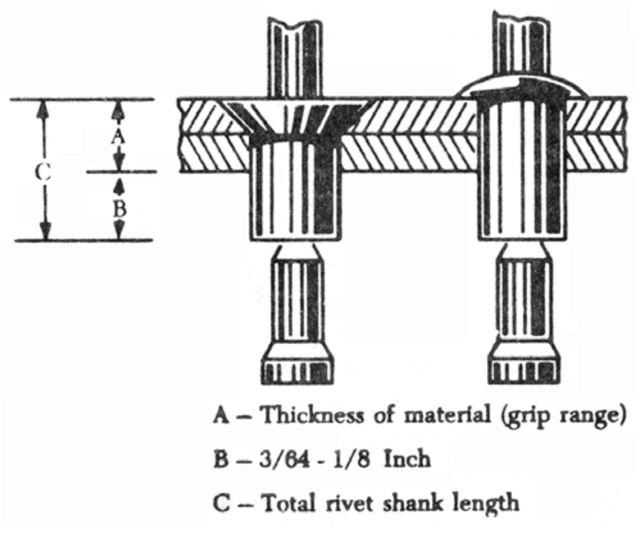


Fig. 21.10, Determining length of friction lock rivets

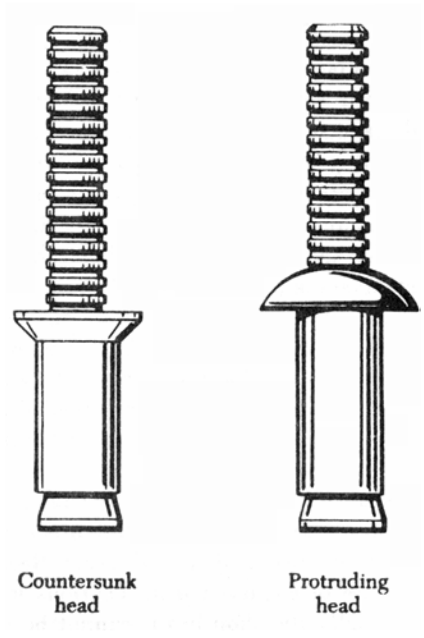


Fig. 21.11, Pullthru rivets

Pull-Thru Rivets

The pull-thru blind rivts are manufactured by severl companies; the same general basic information about their fabriction, composition, uses selection, installation, inspection, and removal procedures apply to all of them.

Pull-thru rivets are farbicated in two parts : A rivet head with a hollow shank or sleeve and a stem that extends through the hollow shank. Figure 21.11 illustrates a protruding head and a counter sunk head pull-thru rivet.

Several events, in their proper sequence, occur when a pulling force is applied to the stem of the rivet : (1) The stem is pulled thru the rivet shank ; (2) the mandrel portion of the stem forces the shank to expand forming the blind head and filling the hole.

Pull-thru rivets are fabricated in two common head styles : (1) Protruding head similar to the MS20470 or universal head, and (2) a 100° countersunk head. Other head styles are available from some manufacturers.

Pull-thru rivets are fabricated from seveal materials. Following are the most commonly used : 2117 - T4 aluminum alloy, 5056 aluminum alloy, monel.

Pull-thru rivets are designed so that installation requires only one person; it is not necessary to have the work accessible from both sides.

Factors to consider in the selection of the correct rivet for installation are : (1) Installation location, (2) composition of the material being riveted, (3) thickness of the material being riveted, and (4) strength desired.

The thickness of the material being riveted determines the overall length of the shank of the rivet. As a general rule, the shank of the rivet should extend beyond the material thickness approximately $\frac{3}{64}$ inch to $\frac{1}{8}$ inch before the stem is pulled. See figure 21.12.

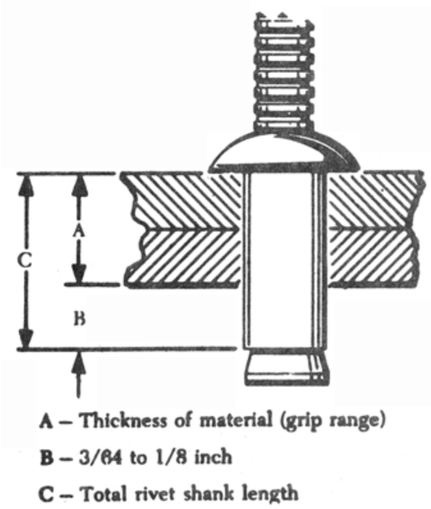


Fig. 21.12, Determining length of pull-thru rivets.

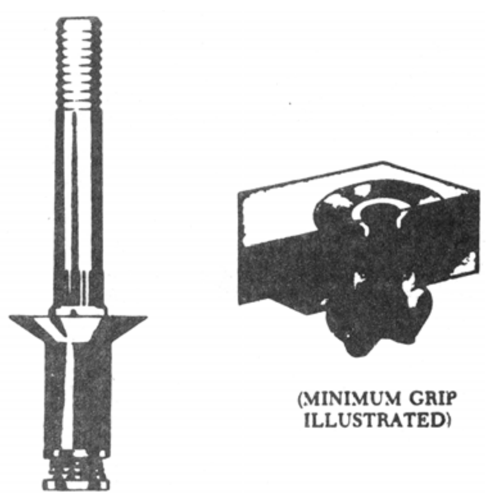


Fig. 21.13, Bulbed cherrylock rivet

Each company that manufactures pull-thru rivets has a code number to help users obtain corret rivet for the grip range of a particular installation. In adition, MS numbers are used for identification purposes. Numbers are similar to those shown on the preceding page.

Self-Plugging Rivets

Self-plugging (mechanical lock) rivets are similar to self-plugging (friction lock) rivets, except for the manner in which the stem is retained in the rivet sleeeve. This type of rivet has a positive mechanical locking collar to resist vibrations that cause the friction lock rivets to loosen and possibly fall out. (See figure 21.15). Also, the mechanical locking type rivet stem breaks off flush with the head and usually does not require further stem trimming whe properly installed. Self-plugging (mehanical lock) rivets dispaly all the strength characteristics of solid shank rivets and in most cases can be substituted rivet for rivet.

Bulbed Cherrylock Rivets

The large blind head of this fastener introduced the word "bulb" to blind rivet terminology. In conjuction with the unique residual preload developed by the high stem break load, its proven fatigue strength makes it the only blind rivet interchangeable structurally with solid rivets (figure 21.13).

Wiredraw Cherrylock Rivets

A wide range of sies, materials and strength levels to select from. This fastener is especially suited for sealing application sand joints requiring an excessive amount of sheet take-up (figure 21.14).

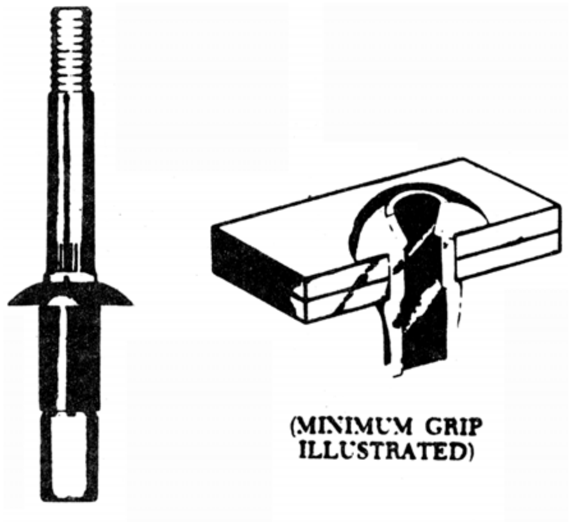


Fig. 21.14, Wiredraw cherrylock rivet

Huck Mechanical Locked Rivets

Self-plugging (mechanical lock) rivets are farbicated in two sections - a head and shank (includeing a conical recess and locking collar in the head),and a serrated stem that extends through the shank. Unlike the friction lock rivet, the mechanical lock rivet has a locking collar that forms a ppositive lock for retention of the stem in the shank of the rivet. This collar is seated in position during the installation of the rivet.

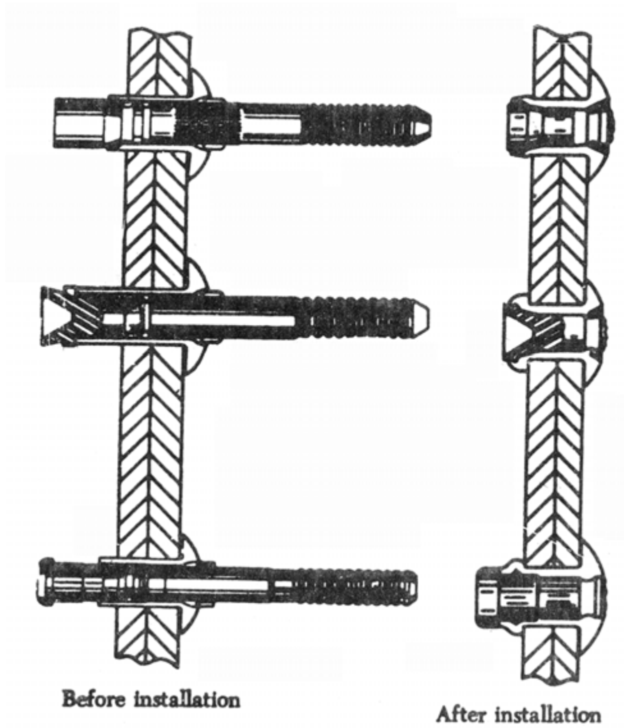


Fig. 21.15, Self-plugging (mechanical lock) rivets.

Material

Self-plugging (mechanical lock) rivets are farbicated with sleeves (rivet shanks) of 2017 and 5056 aluminum alloys, monel, or stainless steel.

The mechanical lock type of self-plugging rivet can be used in the same applications as the friction lock type of rivet. In addition, because of its greate stem retention characteristic, installation in areas subject to considereable vibration is recommended.

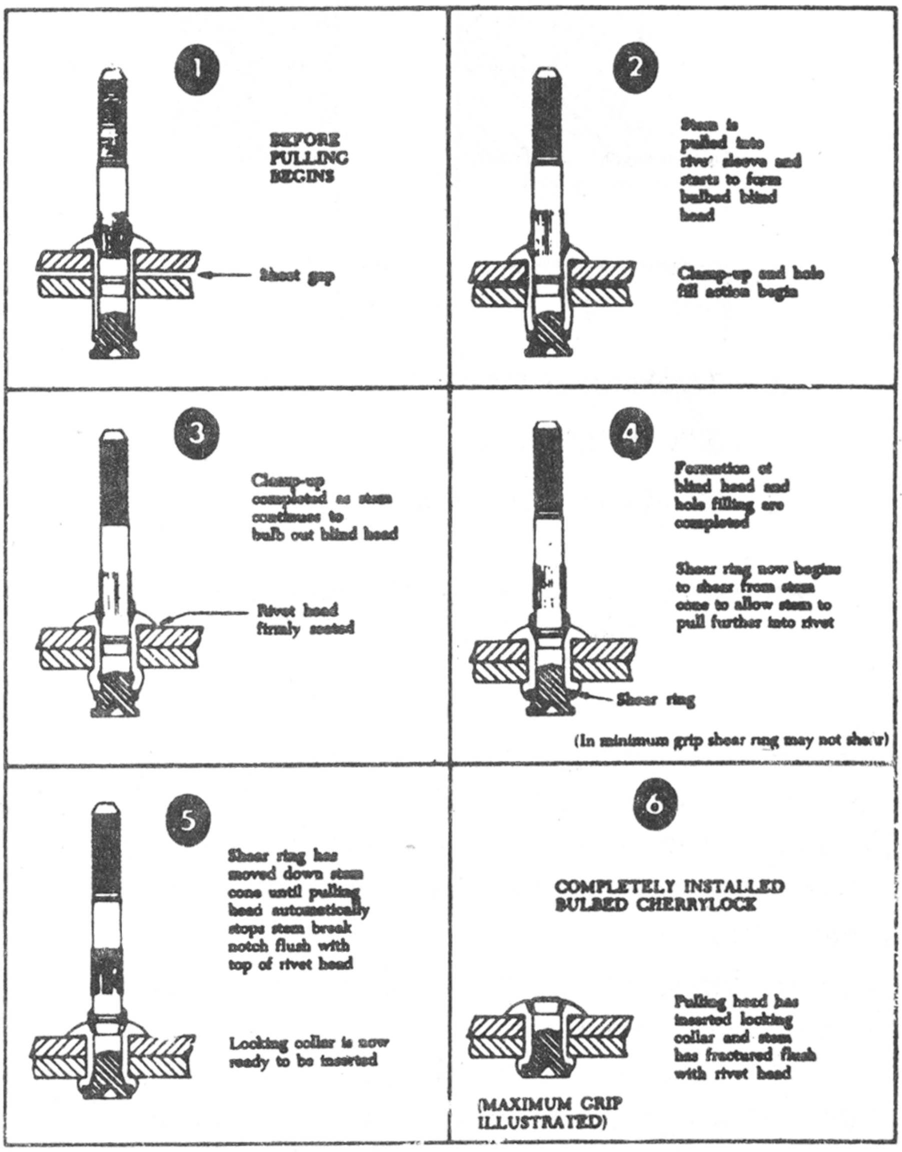


Fig. 21.16, Cherrylock rivet installation

The same general requirements must be met in the selection of the mechanical lock rivet as for the friction lock rivet. Composition of the material being joined together determines the composition of the rivet sleeve, for example, 2017 aluminum alloy rivets for most aluminum alloys and 5056 aluminum rivets for magnesum.

Figure 21.16 depicts the sequences of a typical mechanically locked blind rivet. The form and function may vary slightly between blind rivet styles and specifics should be obtained from manufacturers.

Head Styles
Self-plugging mechanical locked blind rivets are available in several head styles (figure 21.17) depending on the installation requirements.

Diameters
Shank diameters are measured in 1/32 inch increments and are generally identified by the first dash number : 3/32 diameter = -3; 1/8 diameter = -4; etc.

Both nominal and 1/64 inch oversize diameters are available.

Grip Length

Grip length refers to the maximum total sheet thickness to the riveted and is measured in 1/6 of an inch. This is generally identified by the second dash number. Unless otherwise noted, most blind rivets have their grip lengths (maximum grip) marked on the rivet head and have a total grip range of 1/16 inch. figre 21.18 demonstrates a typical grip accommodation.

To determine the proper grip rivet to use, measure the material thikness with a grip selection gage (available from blind rivet manufacturers). The proper use of a grip selector gage is shoen in figure 21.19.

The thickness of the material being riveted determines the overall length of the shank of the rivet. As a general rule, the shank of the rivet should extend beyond the material thickness approximately 3/64 ich to 1/8 inch before the stem is pulled (see figure 21.20).

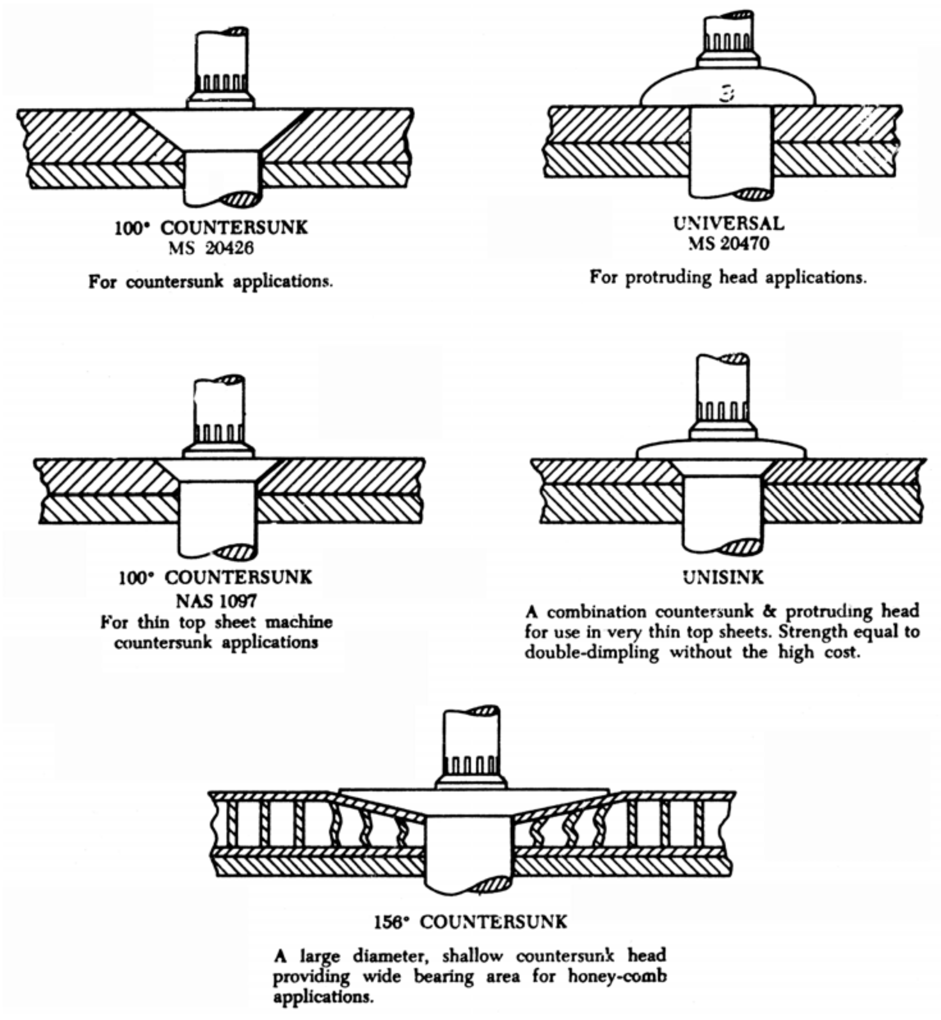


Fig. 21.17, Cherrylock rivet heads.

Rivet Identification

Each company that manufacturers self-plugging (friction lock) rivets has a code number to help users obtain the correct rivet for the grip range or material thickness of a particular installation. In addition, MS numbers are used for identification purposes. The following examples of part numbers for self-plugging (riction lock) rivets are representative of each.

Rivnuts

This is the trade name of a hollow, blind rivet made of 6053 aluminum alloy, counterbored and threaded on the inside. Rivnuts can be installed by one person using a special tool which heads the rivet on the blind side of the material. The Rivnut is threaded on the mandrel of the heading tool and inserted in the rivet hole.

The heading tool is held at right angles to the material, the handle is squeezed, and the mandrel crank is turned clockwise after each stroke. Continue squeezing the handle and turning the mandrel rank of the heading tool until a solid resistance is felt, which indicates that the rivet is set.

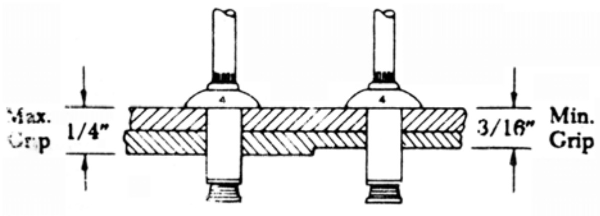


Fig. 21.18, Typical grip length

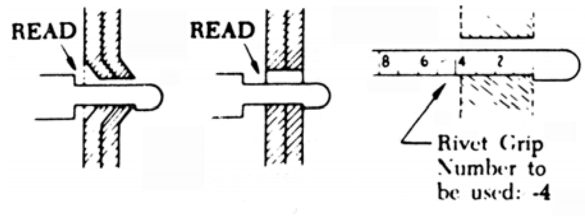
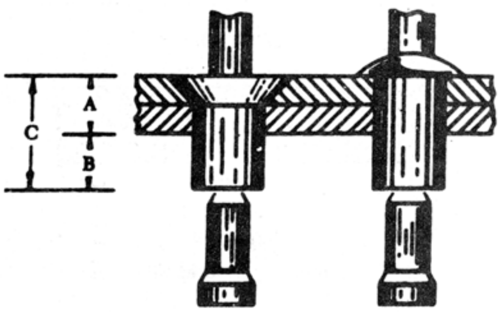


Fig. 21.19, Grip gage use.

The Rivnut is used primarily as a nut plate and in the attachment of deicer boots to the leading edges of wings. It may be used as a rivet in secondary structures or for the attachment of accessories such as brackets, instruments, or soundproofing materials.



A – Thickness of material (grip range)

B – 3/64 to 1/8 inch

C – Total rivet shank length

Fig. 21.20, Determining rivet length

Rivnuts are manufactured in two head types, each with two ends; the flat head with open or closed end, and the countersunk head with open or closed end. All Rivnuts, except the thin-head countersunk type, are available with or without small projections (keys) attached to the head to keep the Rivnut from turning. Keyed Rivnuts are used as a nut plate, while those without keys are used for straight blind riveting repairs where no torque loads are imposed. A keyway cutter is needed when installing Rivnuts which have keys.

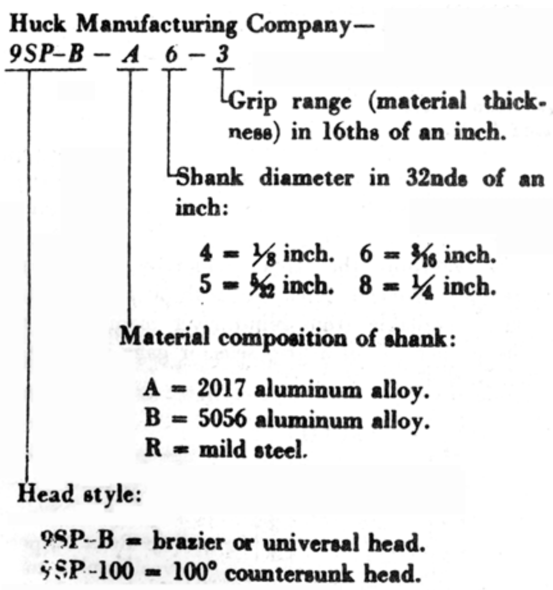


Fig. 21.21

Olympic Screw and Rivet Corporation—

RV 2 0 0 – 4 – 2

- 2 — Grip range in 16ths of an inch.
- 4 — Shank diameter in 32nds of an inch:
  - 4 = 1/8 inch. 6 = 3/16 inch.
  - 5 = 5/32 inch. 8 = 1/4 inch.
- 0 — Head style:
  - 0 = universal head.
  - 1 = 100° countersunk.
- 0 — Material composition of shank:
  - 0 = 2017 aluminum alloy.
  - 5 = 5056 aluminum alloy.
  - 7 = mild steel.
- 2 — Rivet type:
  - 2 = self-plugging (friction lock).
  - 5 = hollow pull-thru.
- RV — Manufacturer: Olympic Rivet and Screw Corporation.

Fig. 21.22

Townsend Company, Cherry Rivet Division—

CR 163 – 6 – 6

- 6 — Grip range (material thickness): knob stem in 32nds of an inch; serrated stem in 16ths of an inch.
- 6 — Rivet shank diameter in 32nds of an inch:
  - 4 = 1/8 inch. 6 = 3/16 inch.
  - 5 = 5/32 inch. 8 = 1/4 inch.
- 163 — Series number: Designates rivet material, type of rivet, and head style (163 = 2117 aluminum alloy, self-plugging (friction lock) rivet, protruding head).
- CR — Cherry Rivet.

Fig. 21.23

Military Standard Number—

MS 20600 B 4 K 2

- 2 — Grip range (material thickness) in 1/6ths of an inch.
- K — Type of stem:
  - K = knot head stem.
  - W = serrated stem.
- 4 — Shank diameter in 32nds of an inch:
  - 4 = 1/8 inch. 6 = 3/ inch.
  - 5 = 5/32 inch. 8 = ,4 inch.
- B — Material composition of sleeve:
  - AD = 2117 aluminum alloy.
  - B = 5056 aluminum alloy.
- 20600 — Type of rivet and head style:
  - 20600 = self-plugging (friction lock) protruding head.
  - 20601 = self-plugging (friction lock) 100° countersunk head.
- MS — Military Standard.

Fig. 21.24

The countersunk style Rivnut is made with two different head angles; the 100° with .048 and .063 - inch head thickness, and the 115° with .063 - inch head thickness. Each of these head styles is made in three sizes, 6-32, 8-32, and 10-32. These numbers represent the machine screw size of the threads on the inside of the Rivnut. The actual outside diameters of the shanks are 3/16 inch for the 6-32 size, 7/32 inch for the 8-32 size, and ¼ inch for the 10-32 size.

Open-end Rivnuts are the most widely used and are recommended in preference to the closed-end type wherever possible. However, closed-end Rivnuts must be used in pressurized compartments.

Rivnuts are manufactured in six grip ranges. The minimum grip length is indicated by a plain head, and the next higher grip length by one radial dash mark on the head. Each succeeding grip range is indicated by an additional radial dash mark until five marks indicate the maximum range.

Flat—0.32 Head Thickness		
6-45	6-75	6-100
8-45	8-75	8-100
10-45	10-75	10-100
6B45	6B75	6B100
8B45	8B75	8B100
10B45	10B75	10B100
6K45	6K75	6K100
8K45	8K75	8K100
10K45	10K75	10K100
6KB45	6KB75	6KB100
8KB45	8KB75	8KB100
10KB45	10KB75	10KB100
100°—0.48 Head Thickness		
6-91	6-121	6-146
8-91	8-121	8-146
10-91	10-121	10-146
6B91	6B121	6B146
8B91	8B121	8B146
10B91	10B121	10B146
100°—0.63 Head Thickness		
6-106	6-136	6-161
8-106	8-136	8-161
10-106	10-136	10-161
6B106	6B136	6B161
8B106	8B136	8B161
10B106	10B136	10B161
6K106	6K136	6K161
8K106	8K136	8K161
10K106	10K136	10K161
6KB106	6KB136	6KB161
8KB106	8KB136	8KB161
10KB106	10KB136	10KB161

Fig. 21.25, Rivnut data chart

Notice in figure 21.25 that some part number codes consist of a "6", an "8", or a "10", a "dash", and two or three more numbers. In some, the dash is replaced by the letters "K" or "KB". The first number indicates the machine screw size of the thread, and the last two or three numbers indicate the maximum grip length in thousandths of an inch. A dash between the figures indicates that the Rivnut has an open end and is keyless; a "B" in place of the dash means it has a closed end and is keyless; and a "KB" indicates that it has a closed end and a key. If the last two or three numbers are divisible by five, the Rivnut has a flathead; if they are not divisible by five, the Rivnut has a countersunk head.

An example of a part number code is :

10 KB 106
- **10** — Screw and thread size.
- **KB** — Closed end and key.
- **106** — Grip length.

Dill Lok-Skrus and Dill Lok-Rivets

Dill "Lok-Skru" and "Lok-Rivet" (see figure 21.26) are trade names for internally threaded rivets. They are used for blind attachment of such accessories as fairings, fillets, access door covers, door and window frames, floor panels, and the like. Lok-skrus and Lok-Rivets are similar to the Rivnut in appearance and application; however, they come in two parts and require more clearance on the blind side than the Rivnut to accommodate the barrel.

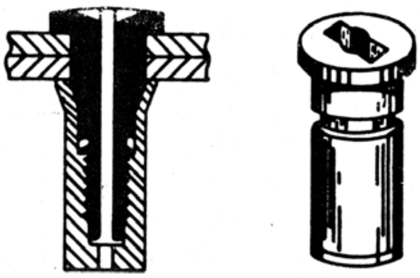


Fig. 21.26, Internally threaded rivet

The Lok-Rivet and the Lok-Skru are alike in construction, except the Lok-Skru is tapped internally for lastening an accessory by using an attaching screw, whereas the Lok-Rivet is not tapped and can be used only as a rivet. Since both Lok-Skrus and Lok-Rivets are installed in the same manner, the following discussion for the Lok-Skru also applies to the Lok-Rivet.

The main parts of a Lok-Skru are the barrel, the head and an attachment screw. The barrel is made of aluminum alloy and comes in either closed or open ends. The head is either aluminum alloy or steel, and the attachment screw is made of steel. All of the steel parts are cadmium plated, and all of the aluminum parts are anodized to resist corrosion. When installed, the barrel screws up over the head and grips the metal on the blind side. The attaching screw is then inserted if needed. There are two head types, the flathead and the countersunk head. The Lok-Skru is tapped for 7-32, 8-32, 100-32, or 10-24 screws, and the diameters vary from .230 inch for 6-32 screws, to .292 inch for 10-32 screws. Grip ranges vary from .010 inch to .225 inch.

Deutsch Rivets

This rivet is a high-strength blind rivet used on late model aircraft. It has a minimum shear strength of 75,000 p.s.i., and can be installed by one man.

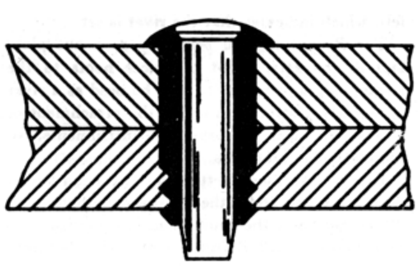


Fig. 21.27, Deutsch rivet

The Deutsch rivet consists of two parts, the stainless steel sleeve and the hardened steel drive pin (see figure 21.27). The pin and sleeve are coated with a lubricant and a corrosion inhibitor.

The Deutsch rivet is available in diameters of 3/16, 1/4, or 3/8 inch. Grip lengths for this rivet range from 3/16 to 1 inch. Some variation is allowed in grip length when installing the rivet; for example, a rivet with a grip length of 3/16 inch can be used where the total thickness of materials is between 0.198 and 0.228 inch.

When driving a Deutsch rivet, an ordinary hammer or a pneumatic rivet gun and a flathead set are used. The rivet is seated in the previously drilled hole and then the pin is driven into the sleeve. The driving action causes the pin to exert pressure against the sleeve and forces the sides of the sleeve out. This stretching forms a shop head on the end of the rivet and provides positive fastening. The ridge on the top of the rivet head locks the pin into the rivet as the last few blows are struck.

Pin Rivets

Pin (Hi-shear) rivets are classified as special rivets but are not of the blind type. Access to both sides of the material is required to install this type of rivet. Pin rivets have the same shear strength as bolts of equal diameters, are about 40 percent of the weight of a bolt, and require only about one-fifth as much time for installation as a bolt, nut, and washer combination. They are approximately three times as strong as solid-shank rivets.

Pin rivets are essentially threadless bolts. The pin is headed at one end and is grooved about the circumference at the other. A metal collar is swaged onto the grooved end effecting a firm, tight fit (see figure 21.28).

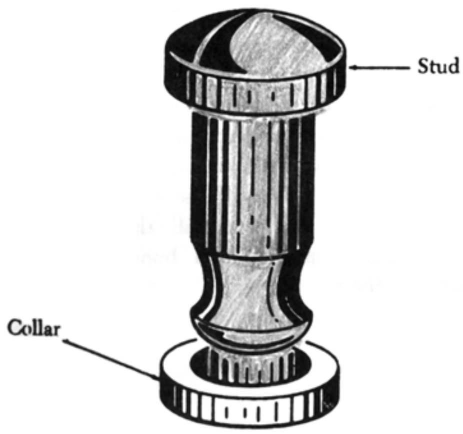
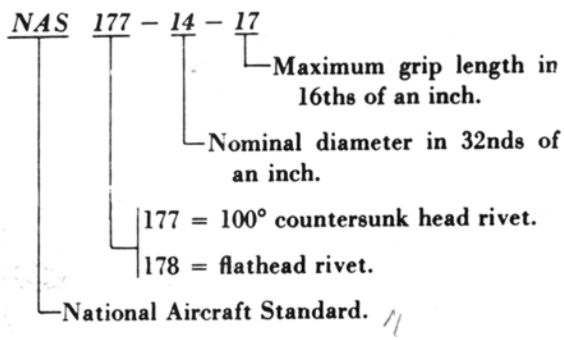


Fig. 21.28, Pin (Hi-shear) rivet.

Pin rivets are fabricated i a variety of materials but should be used only i shear applications. They should never be used where the grip length is less than the shank diameter.

Part numbers for pin rivets can be interpreted to give the diameter and grip length of the individual rivets. A typical part number breakdown would be :



MECHANICAL-LOCK RIVETS

Mechanical-lock rivets were designed to prevent the center stem of a rivet from falling out as a result of the vibration encountered during aircraft operation. Unlike the center stem of a friction-lock rivet, a mechanical-lock rivet permanently locks the stem into place and vibration cannot shake it loose.

Huck-Loks

Huck-lok rivets were the first mechanical-lock rivets and are used as structural replacements for solid shank rivets. However, because of the expensive tooling required for their installation, Huck-Loks are generally limited to aircraft manufacturers and some large repair facilities.

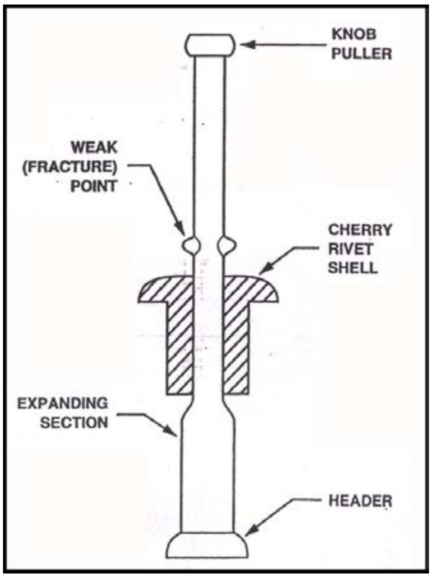


Fig. 21.29, The friction-lock rivet assembly consists of a shell and mandrel or pulling stem. The stem is pulled until the header forms a bucktail on the blind side of the shell.

Huck-Loks are available in four standard diameters, 1/8, 5/32, 3/16, and 1/4 inch, and come in three different alloy combinations : a 5056 sleeve with a 2024 pin, an A-286 sleeve with an A-286 pin, and a Monel 400 sleeve with an A-286 pin. [Fig 21.30].

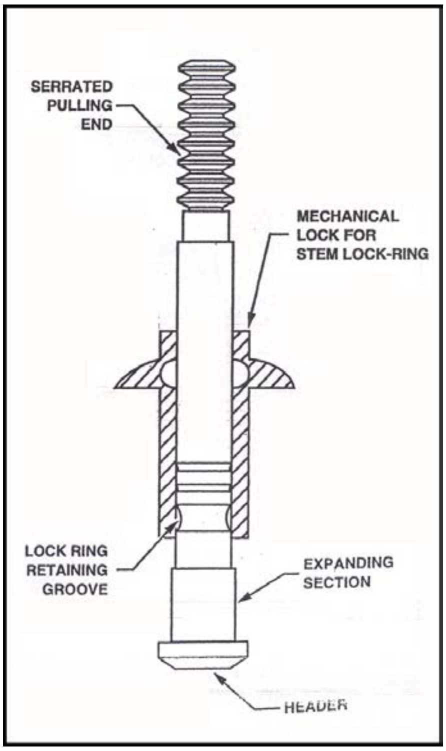


Fig. 21.30

Cherry Loks

The Cherry Mechanical Lock rivet, often called the bulbed Cherry Lock, was developed shortly after the Huck-Lok. Like the Huck-Lok, the Cherry Lock rivet is an improvement over the friction lock rivet because its center stem is locked into place with a lock ring. This results in shear and bearing strengths that are high enough to allow Cherry Locks to be used as replacements for solid shank rivets. [Fig. 21.31].

Cherry Lock rivets are available with two head styles, 100 degree countersunk and universal. Like most blind rivets, Cherry locks are available with diameters of 1/8, 5/32, and 3/16 inch, with an oversize of 1/64 inch for each standard size. The rivet, or shell, portion of a cherry Lock may be constructed of 2017 aluminum alloy, 5056 aluminum alloy, Monel, or stainless steel. Installation of Cherry Lock rivets requires a special pulling tool for each different size and head shape. However, the same size tool can be used for an oversize rivet in the same diameter group.

One disadvantage of a Cherry Lock i that if a rivet is too short for an application, the lock ring sets prematurely resulting in a malformed shank header. This fails to compress the joint, leaving it in a weakened condition. To avoid this, always use the proper rivet length selection gauge and follow the manufacturer's installation recommendations.

Olympic Loks

Olympic lok blind fasteners are light weight, mechanically locking spindle type blind rivets. Olympic loks come with a lock ring stowed on the head. As an Olympic lok is installed, the ring slips down the stem and locks the center stem to the outer shell. These bond fasteners require a specially designed set of installation tools. [Fig. 21.32]

Olympic-lock rivets are made with three head styles : universal, 100 degree flush, and 100 degree flush, and 100 degree flush shear. Rivet diameters of 1/8, 5/32 and 3/16 inch are available in eight different alloy combinations of 2017-T4, A-286, 5056 and Monel.

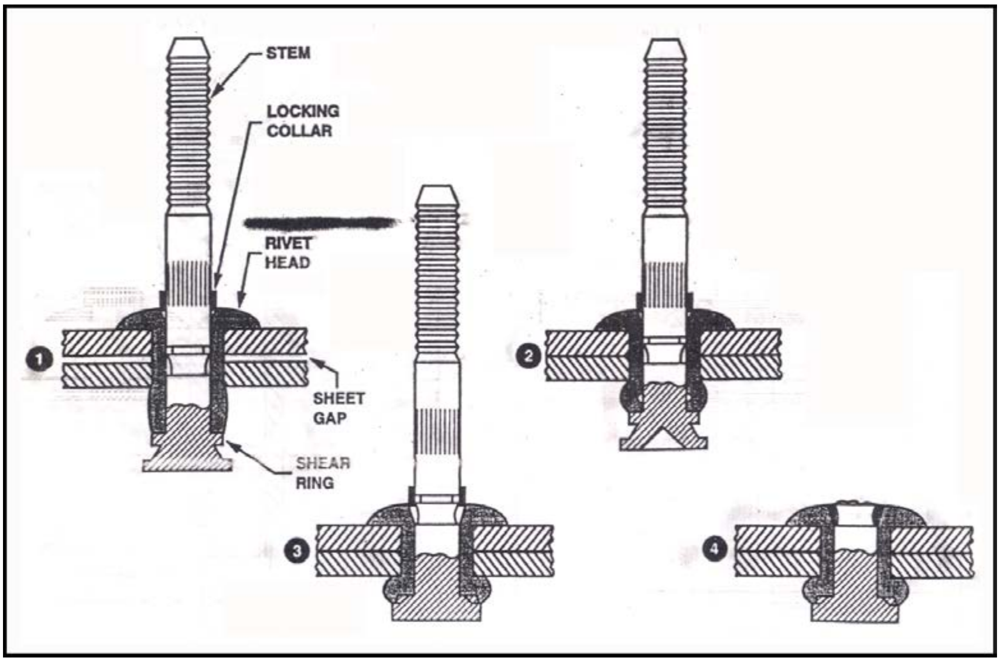


Fig. 21.31, As the stem is pulled into the rivet sleeve, a bulb forms on the rivet's blind side that begins to clamp the two pieces of metal together and fill the hole. (2) - once the pieces are clamped tightly together, the bulb continues to form until the

____.

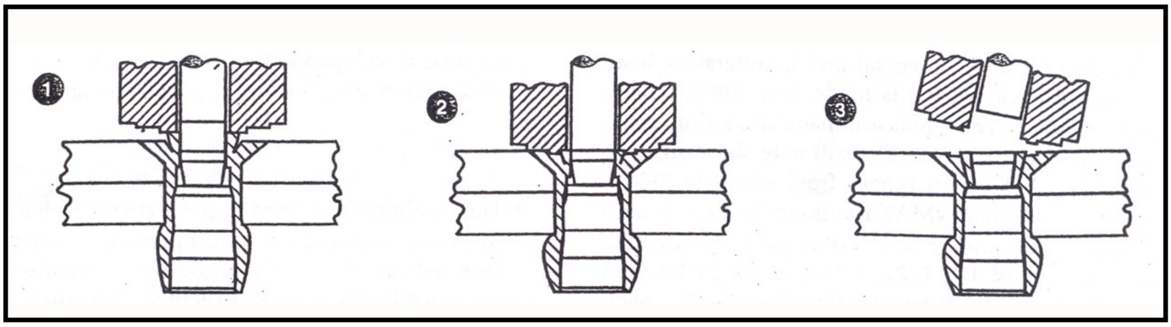


Fig. 21.32, Once an Olympic-Lok rivet is inserted into a prepared hole, the stem is pulled into the sleeve closing any gap between the materials being riveted, filling the hole, and forming a bearing area. (2) - when the stem travel is stopped by the sleeve's internal step, the locking collar shears free and is forced into the locking groove. (3) - continued pulling breaks the stem flush with the rivet head.

When Olympic loks were first introduced, they were advertised as an inexpensive blind fastening system. The price of each rivet is less than the other types of mechanical locking blind rivets, and only three installation tool are required. The installation tools fit both countersunk and universal heads in the same size range.

CHERRYMAX™

The CherryMAX rivet is economical to use and strong enough to replace solid shank rivets, size for size. The economic advantage of the CherryMAX system is that one size puller can be used for the installation of all sizes of CherryMAX rivets. A CherryMAX rivet is composed of five main parts : a pulling stem, a driving anvil, a safe-lock locking collar, a rivet sleeve, and a bulbed blind head. [Figure 21.33]

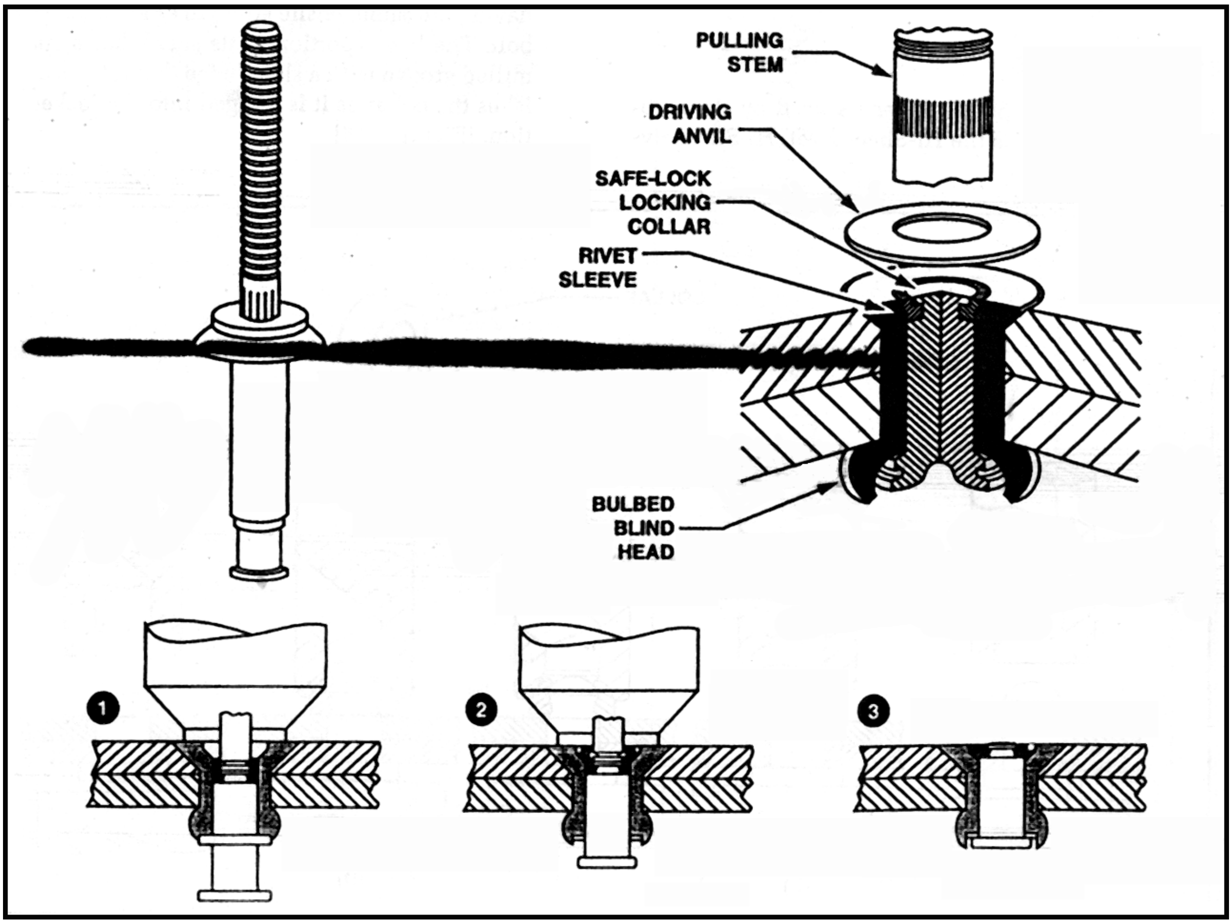


Fig. 21.33, (1) - As the stem pulls into the rivet sleeve it forms a large bulb that seats the rivet head and clamps the two sheets tightly together. (2) - As the blind head is completed, the safe-locking collar moves into the rivet sleeve recess. (3) - as the stem continues to be pulled, the safe-lock collar is formed into the head recess by the driving anvil, locking the stem and sleeve securely together. Further pulling features the stem, providing a flush, burr-free installation.

Available in both universal and countersunk head styles, the rivet sleeve is made from 5056, monel, ad inco 600. The stems are made from alloy steel, CRES, and inco X-750. The ultimate shear strength of CherryMAX rivets ranges from 50KSI to 75KSI. Furthermore, CherryMAX rivets can be used at temperatures from 250°F to 1,400°F. They are available in diameters of 1/8, 5/32, 3/16 and 1/4 inches and are also made with an oversize diameter for each standard diameters listed.

HEAT TREATMENT OF DIFFERENT TYPES OF RIVETS

Rivets which require heat treatment prior to driving should be treated in accordance with the requirements of the relevant specification.

Generally the most satisfactory way of heating rivets is to immerse them in a salt bath, although muffle furnaces of the circulating hot air type are used. The rivets should be placed in wire baskets or perforated containers and immersed in the salts for 15 minutes, then quenched in water at a temperature of not more than 40°C. The time between removal from the bath and quenching must be not more than 10 seconds to achieve satisfactory properties. The temperature of the bath must be 495 ± 5° C (maximum 496°C for 2024 rivets) and if the maximum is exceeded at any time the rivets should be rejected. Rivets which have been heated in a salt bath must be thoroughly washed after quenching to remove all traces of salt.

BS L37 rivets commence to age harden immediately after quenching and should normally be used within 2 hours of treatment (a period of 20 minutes is specified for 2024 rivets). Age hardening can be delayed by storing the rivets at a low temperature immediately after quenching. At a temperature of 0°C to -5°C they will keep satisfactorily for 45 hours and at a temperature of -15°C to 20°C for 150 hours, but must be used within 2 hours of removal from cold storage.

If the treated rivets have not been used within the prescribed time after solution treatment they may be retreated up to a maximum of three times. Further heat treatments would increase the grain size and result in low strength even after ageing.

Precautions must be taken to prevent the accidental use of aged rivets. A satisfactory method of ensuring this is to use the rivets from trays or boxes which are coloured to indicate the periods during which the rivets may be used. Thus a suitable colour code might permit only rivets from green trays to be used during the first two hours of a working day, after which only rivets from blue trays should be used for the next two hours and so on. American 2024 rivets could be controlled in a similar manner but the elapsed time should not exceed 20 minutes.

■■■

INTENTIONALLY BLANK

CHAPTER-22
PIPES AND UNIONS USED IN AIRCRAFTS

GENERAL

The term “aircraft plumbing” refers not only to the hose, tubing, fittings, and connectors used in the aircraft, but also to the processes of forming and installing them.

Occasionally it may be necessary to repair or replace damaged aircraft plumbing lines. Very often the repair cab be made simply by replacing the tubing. However, if replacements are not available, the needed parts may have to be fabricated. Replacement tubing should be of the same size and material as the original line. All tubing is pressure tested prior to initial installation, and is designed to withstand several times the normal operating pressure to which it will be subjected. If a tube bursts or cracks, it is generally the result of excessive vibration, improper installation, or damage caused by collision with an object. All tubing failures should be carefully studied and the cause of the failure determined.

PLUMBING LINES

Aircraft plumbing lines usually are made of metal tubing and fittings or of flexible hose. Metal tubing is widely used in aircraft for fuel, oil, coolant, oxygen, instrument, and hydraulic lines. Flexible hose is generally used with moving parts or where the hose is subject to considerable vibration.

Generally, aluminum alloy or corrosion-resistant steel tubing have replaced copper tubing. The high fatigue factor of copper tubing is the chief reason for its replacement. It becomes hard and brittle from vibration and finally breaks, however it may be restored to its soft annealed state by heating it red hot and quenching it in cold water. Cooling in air will result in a degree of softness but not equal to that obtained with the cold water quench. This annealing process must be accomplished if copper tubing is removed for any reason. Inspection of copper tubing for cracks, hardness, brittleness and general condition should be accomplished at regular intervals to preclude failure. The workability, resistance to corrosion, and lightweight of aluminum alloy are major factors in its adoption for aircraft plumbing.

In some special high-pressure (3,000 p.s.i.) hydraulic installations, corrosion--resistant steel tubing, either annealed or ¼-hard, is used. Corrosion-resistant steel tubing does not have to be annealed for flaring or forming; in fact, the flared section is somewhat strengthened by the cold working and strain hardening during the flaring process. Its higher tensile strength permits the use of tubing with thinner walls; consequently the final installation weight is not much greater than that of the thicker-wall aluminum alloy tubing.

IDENTIFICATIONOFMATERIALS

Before making repairs to any aircraft plumbing, it is important to make accurate identification of plumbing materials. Aluminum alloy or steel tubing cab be identified readily by sight where it is used as the basic plumbing material. However, it is difficult to determine whether a material is carbon steel or stainless steel, or whether it is 1100, 3003, 5052 - 0, or 2024 - T aluminum alloy.

It may be necessary to test samples of the material for hardness by filing or scratching with a scriber. The magnet test is the simplest method for distinguishing between the annealed austenitic and the ferritic stainless steels. The austenitic types are non-magnetic unless heavily cold worked, whereas the straight chromium carbon and low alloy steels are strongly magnetic. Figure 22.1 gives the methods for identifying five common metallic materials by using the magnet and concentrated nitric acid tests.

Material	Magnet test	Nitric acid test
Carbon steel	Strongly magnetic.	Slow chemical action, brown.
18–8	Nonmagnetic.	No action.
Pure nickel	Strongly magnetic.	Slow action, pale green.
Monel	Slightly magnetic.	Rapid action, greenish blue.
Nickel steel	Nonmagnetic.	Rapid action, greenish blue.

Fig. 22.1, Identification of metallic materials

By comparing code markings of the replacement tubing with the original markings on the tubing being replaced, it is possible to identify definitely the material used in the original installation.

The alloy designation is stamped on the surface of large aluminum alloy tubing. On small aluminum alloy tubing, the designation may be stamped on the surface, but more often it is shown by a color code. Bands of the color code, not more than 4 inches in width, are painted at the two ends and approximately midway between the ends of some tubing. When the band consists of two colors, one-half the width is used for each color.

Painted color codes used to identify aluminum alloy tubing are :

Aluminum alloy number	Color of band
1100	White
3003	Green
2014	Gray
2024	Red
5052	Purple
6053	Black
6061	Blue and Yellow
7075	Brown and Yellow

Aluminum alloy tubing, 1100 (½-hard) or 3003 (½-hard), is used for general purpose lines of low or negligible fluid pressures, such as instrument lines and ventilating conduits. The 2024-T and 5052-0 aluminum alloy materials are used in general purpose systems of low and medium pressures, such as hydraulic and pneumatic 1,000 to 1,500 p.s.i. systems and fuel and oil lines. Occasionally, these materials are used in high-pressure (3,000 p.s.i.) systems.

Tubing made from 2024-T and 5052-0 materials will withstand a fairly high pressure before bursting. These materials are easily flared and are soft enough to be formed with hand tools. They must be handled with care to prevent scratches, dents, and nicks.

Corrosion-resistant steel tubing, either annealed or ¼-hard, is used extensively in high-pressure hydraulic systems for the operation of landing gear, flaps, brakes, and the like. External brake lines should always be made of corrosion-resistant steel to minimize damage from rocks thrown by the tires curing takeoff and landing, and from careless ground handling. Although identification markings for steel tubing differ, each usually includes the manufacturer's name or trademark, the SAE number, and the physical condition of the metal.

Metal tubing is sized by outside diameter, which is measured fractionally in sixteenths of an inch. Thus Number 6 tubing is 6/16 (or 3/8 inch) and Number 8 tubing is 8/16 (or ½-inch), etc.

In addition to other classification or means of identification, turbine is manufactured in various wall thicknesses. Thus, it is important when installing tubing to know not only the material and outside diameter, but also the thickness of the wall.

FLEXIBLE HOSE

Flexible hose is used in aircraft plumbing to connect moving parts with stationary parts in locations subject to vibration or where a great amount of flexibility is needed. It can also serve as a connector in metal tubing systems.

Synthetics

Synthetic materials most commonly used in the manufacture of flexible hose are : Buna-N, Neoprene, Butyl and Teflon (trademark of DuPont Corp.). Buna-N is a synthetic rubber compound which has excellent resistance to petroleum products. Do not confuse with Buna-S. Do not use for phosphate ester base hydraulic fluid (Skyrol®). Neoprene is a synthetic rubber compound which has an acetylene base. Its resistance to petroleum products is not as good as Buna-N but has better abrasive resistance. Do not use for phosphate ester base hydraulic fluid (Skydrol®). Butyl is a synthetic rubber compound made from petroleum raw materials. It is an excellent material to use with phosphate ester based hydraulic fluid (Skydrol®). Do not use with petroleum products. Teflon is the Du Pont trade name for tetrafluoroethylene resin. It has a broad operating temperature range (-65°F. to + 450°F.). It is compatible with nearly every substance or agent used. It offers little resistance to flow; sticky viscous materials will not adhere to it. It has less volumetric expansion than rubber and the shelf and service life is practically limitless.

Rubber Hose

Flexible rubber hose consists of a seamless synthetic rubber inner tube covered with layers of cotton braid and wire braid, and an other layer of rubber-impregnated cotton braid. This type of hose is suitable for use in fuel, oil, coolant, and hydraulic systems. The types of hose are normally classified by the amount of pressure they are designed to withstand under normal operating conditions.

1. Low pressure, any pressure below 250 p.s.i. Fabric braid reinforcement.
2. Medium pressure, pressures up to 3,000 p.s.i.
   One wire braid reinforcement.
   Smaller sizes carry pressure up to 1,500 p.s.i.
3. High pressure (all sizes up to 3,000 p.s.i. operating pressures).

Identification markings consisting of lines, letters, and numbers are printed on the hose. (See figure 22.2). These code markings show such information as hose size, manufacturers, date of manufacturer, and pressure and temperature limits. Code markings assist in replacing a hose with one of the same specification or a recommended substitute. Hose suitable for use with phosphate ester base hydraulic fluid will be marked "Skydrol® use". In some instances several types of hose may be suitable for the same use. Therefore, in order to make the correct hose selection, always refer to the maintenance or parts manual for the particular airplane.

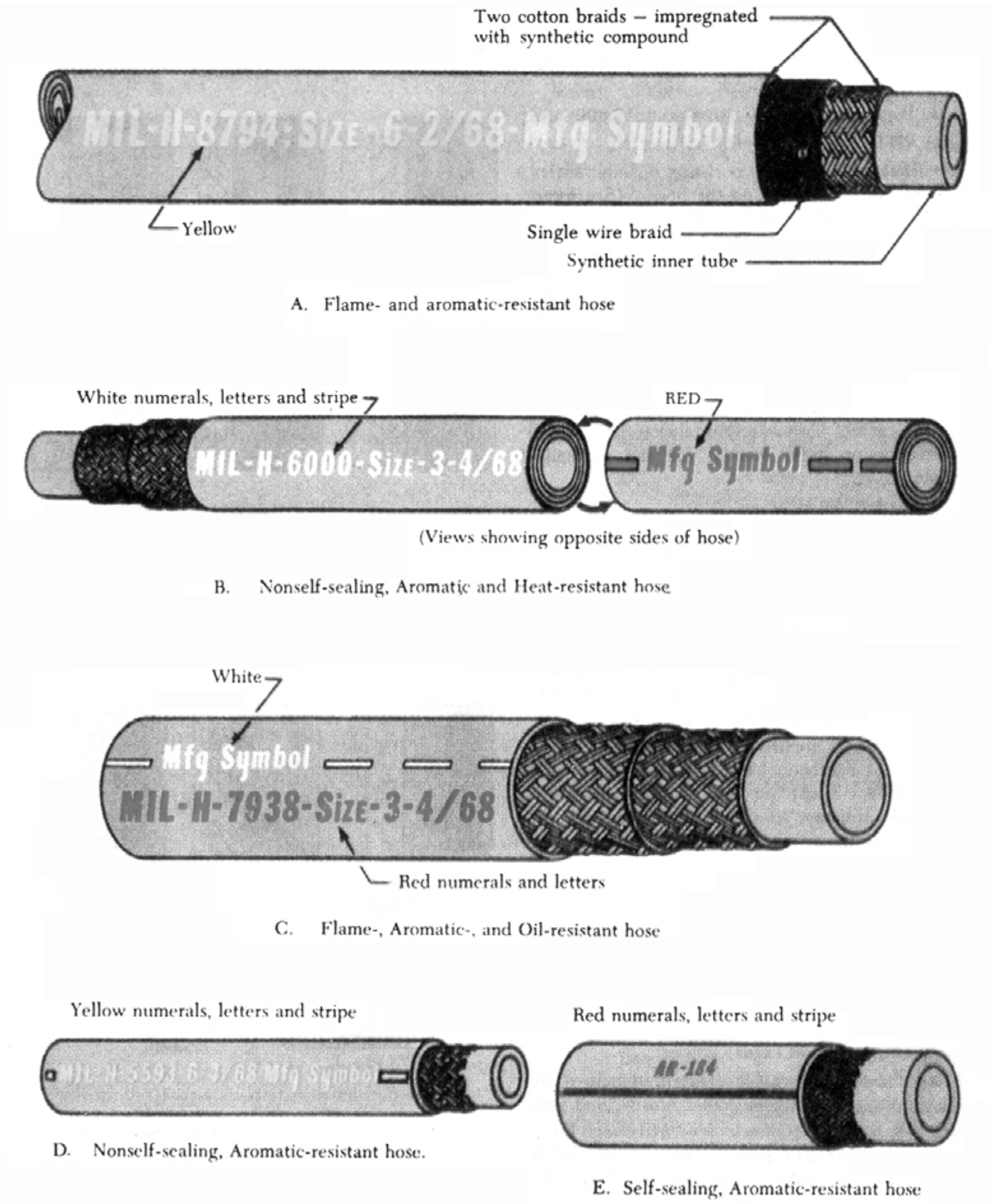


Fig. 22.2, Hose identification markings

Teflon Hose

Teflon hose is a flexible hose designed to meet the requirements of higher operating temperatures and pressures in present aircraft systems. It can generally be used in the same manner as rubber hose. Teflon hose is processed and extruded into tube shape to a desired size. It is covered with stainless steel wire, which is braided over the tube for strength and protection.

Teflon hose is unaffected by any known fuel, petroleum, or synthetic base oils, alcohol, coolants, or solvents commonly used in aircraft. Although it is highly resistant to vibration and fatigue, the principle advantage of this hose is its operating strength.

Size Designation

The size of flexible hose is determined by its inside diameter. Sizes are in one-sixteenth-inch increments and are identical to corresponding sizes or rigid tubing, with which it can be used.

Identification of Fluid Lines

Fluid lines in aircraft are often identified by markers made up of color codes, words, and geometric symbols. These markers identify each line's unction, content, and primary hazard, as well as the direction of fluid flow. Figure 22.3 illustrates the various color codes and symbols used to designate the type of system ad its contents.

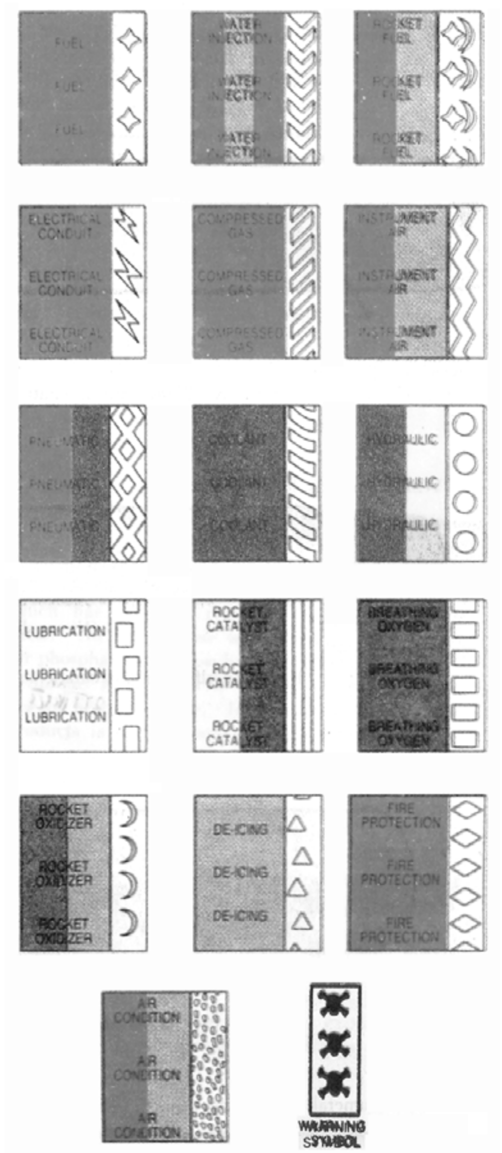


Fig. 22.3, Identification of aircraft fluid lines

In most instances, fluid lines are marked with a 1-inch tape or decals, as shown in Fig. 22.4 (A). On lines 4-inches in diameter (or larger), lines in oil environment, hot lines, and on some cold lines, steel tags may be used in place of tape or decals, as shown in figure 22.4 (B). Paint is used on lines in engine compartments, where there is the possibility of tapes, decals, or tags being drawn into the engine induction system.

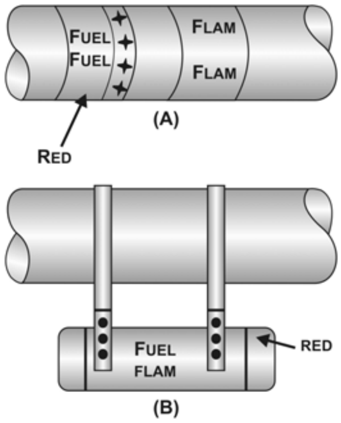


Fig. 22.4, Fluid line identification using : (A tape and decals and (B) metal tags.

In addition to the above-mentioned markings, certain lines may be further identified as to specific function within a system; for example, DRAIN, VENT, PRESSURE, or RETURN.

Lines conveying fuel may be marked FLAM; lines containing toxic materials are marked TOXIC in place of FLAM. Lines containing physically dangerous materials, such as oxygen, nitrogen, or freon, are marked PHDAN.

The aircraft and engine manufacturers are responsible for the original installation of identification markers, but the aviation mechanic is responsible for their replacement when it becomes necessary.

Generally, tapes and decals are placed on both ends of a line and at least once in each compartment through which the line runs. In addition, identification markers are placed immediately adjacent to each valve, regulator, filter, or other accessory within a line. Where paint or tags are used, location requirements are the same as for tapes and decals.

PLUMBING CONNECTORS

Plumbing connectors, of fittings, attach one piece of tubing to another or to system units. There are four types : (1) Flared fitting, (2) Flareless fitting, (3) Bead and clamp, and (4) Swaged. The amount of pressure that the system carries is usually the deciding factor in selecting a connector. The beaded type of joint, which requires a bead and a section of hose and hose clamps, is used only in low - or medium - pressure systems, such as vacuum and coolant systems. The flared, flareless, and swaged types may be used as connectors in all systems, regardless of the pressure.

Flared-Tube fittings

A flared-tube fitting consists of a sleeve and a nut, as shown in figure 22.5. The nut fits over the sleeve and, when tightened, draws the sleeve and tubing flare tightly against a male fitting to form a seal. Tubing used with this type of fitting must be flared before installation.

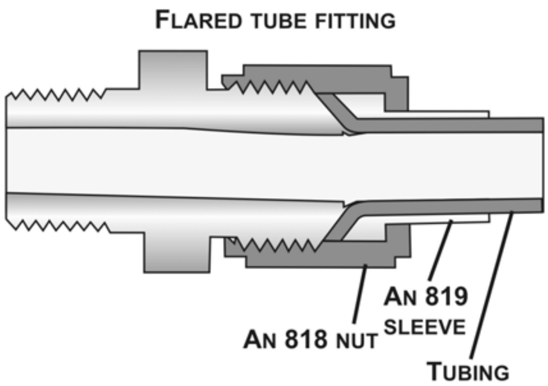


Fig. 22.5, Flared-tube fitting.

The male fitting has a cone-shaped surface with the same angle as the inside of the flare. The sleeve supports the tube so that vibration does not concentrate at the edge of the flare, and distributes the shearing action over a wider area for added strength. Tube flaring and the installation of flared-tube fittings are discussed in detail later in this chapter.

The AC (Air Corps) flared-tube fittings have been replaced by the AN (Army/Navy) standard and MS (Military Standard) fittings. However, since AC fittings are still in use in some of the older aircraft, it is important to be able to identify them. The AN fitting has a shoulder between the end of the threads and the flare cone. (See figure 22.6). The AC fitting does not have this shoulder.

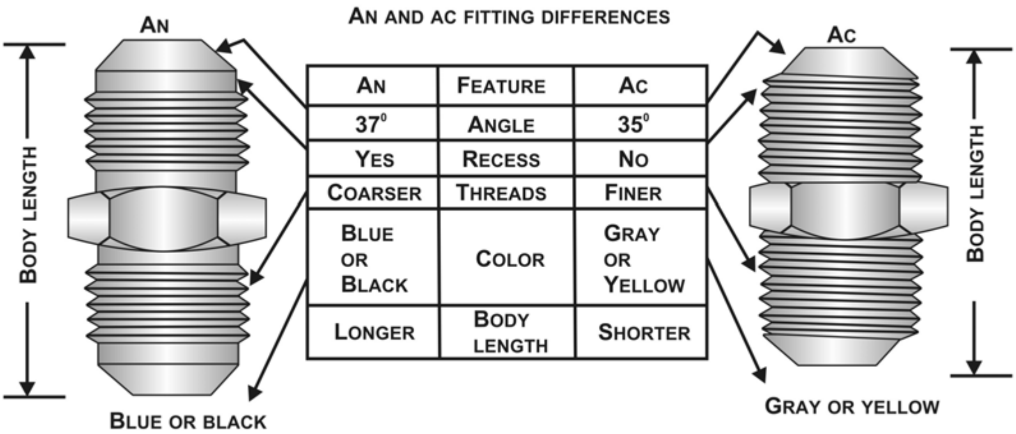


Fig. 22.6, AN and AC fitting differences.

Other differences between the AC and AN fittings include the sleeve design, the AC sleeve being noticeably longer than the AN sleeve of the same size. Although certain flared-tube fittings are interchangeable, the pitch of the threads is different in most cases. Figure 22.7 shows the AN and AC811 fittings that can be safely interchanged. Combinations of end connections, nuts, sleeves, and tube flares are allowed to make up a complete fitting assembly. The use of dissimilar metals should be avoided since their contact will cause corrosion.

Tube Sizes OD	Type End Connection (Male Thread)	Type Nut (Female Thread)	Type Sleeve	Type Tube Flare
All Sizes[1]	AN[1]	AN[1]	AN[1]	AN[1]
All Sizes[2]	811[2]	811[2]	811[2]	811[2]
All Sizes	AN	AN	AN	811
All Sizes	AN	AN	811	811
All Sizes	AN	AN	811	AN
All Sizes	811	811	811	AN
All Sizes	811	811	AN	AN
All Sizes	811	811	AN	811
$\frac{1}{8}$, $\frac{3}{16}$, $\frac{1}{4}$, $\frac{5}{16}$, $1\frac{3}{4}$, 2	AN	811	AN	811
$\frac{1}{8}$, $\frac{3}{16}$, $\frac{1}{4}$, $\frac{5}{16}$, $1\frac{3}{4}$, 2	AN	811	AN	AN
$\frac{1}{8}$, $\frac{3}{16}$, $\frac{1}{4}$, $\frac{5}{16}$, $1\frac{3}{4}$, 2	AN	811	811	AN
$\frac{1}{8}$, $\frac{3}{16}$, $\frac{1}{4}$, $\frac{5}{16}$, $1\frac{3}{4}$, 2	AN	811	811	AN

[1] This is the normal assembly of AN fittings.
[2] This is the normal assembly of AC811 fittings.

Fig. 22.7(a), Interchangeability of AN and AC811 fittings.

When combining AC and AN end connections, nuts, sleeves, or tube flares, if the nut will not move more than two threads by hand, stop and investigate for possible trouble.

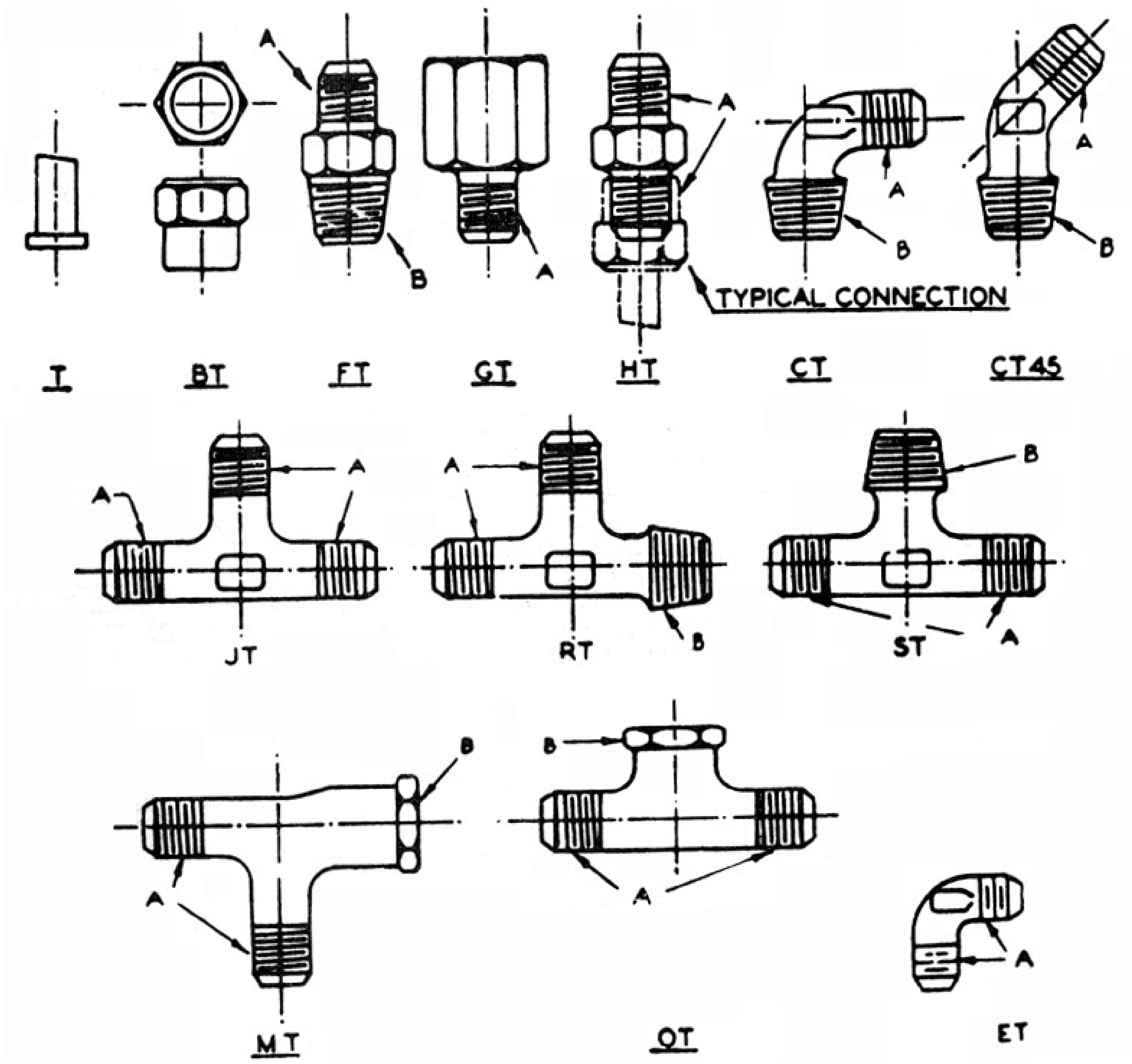


Fig. 22.7 (b), AC811 solderless fittings

The A standard fitting is the most commonly used flared-tubing assembly for attaching the tubing to the various fittings required in aircraft plumbing systems. The AN standard fittings include the AN818 nut and AN819 sleeve. (See figure 22. 8). The AN819 sleeve is used with the AN818 coupling nut. All these fittings have straight threads, but they have different pitch for the various types.

Flared-tube fittings are made of aluminum alloy, steel, or copper base alloys. For identification purposes, all AN steel fittings are colored black, and all AN aluminum alloy fittings are colored blue. The AN 819 aluminum bronze sleeves are cadmium plated and are not colored. The size of these fittings is given in dash numbers, which equal the nominal tube outside diameter (O.D.) in sixteenths of an inch.

Threaded flared-tube fittings have two types of ends, referred to as male and female. The male end of a fitting is externally threaded, whereas the female end of a fitting is internally threaded.

— AN744 to AN932 —

Material:

Aluminum alloy .... (code D)
Steel .... (code, absence of letter)
Brass .... (code B)
Aluminum bronze .... (code Z—for AN819 sleeve)

Size:

The dash number following the AN number indicates the size of the tubing (or hose) for which the fitting is made, in 16ths of an inch. This size measures the O. D. of tubing and the I. D. of hose. Fittings having pipe threads are coded by a dash number, indicating the pipe size in 8ths of an inch. The material code letter, as noted above, fol lows the dash number.

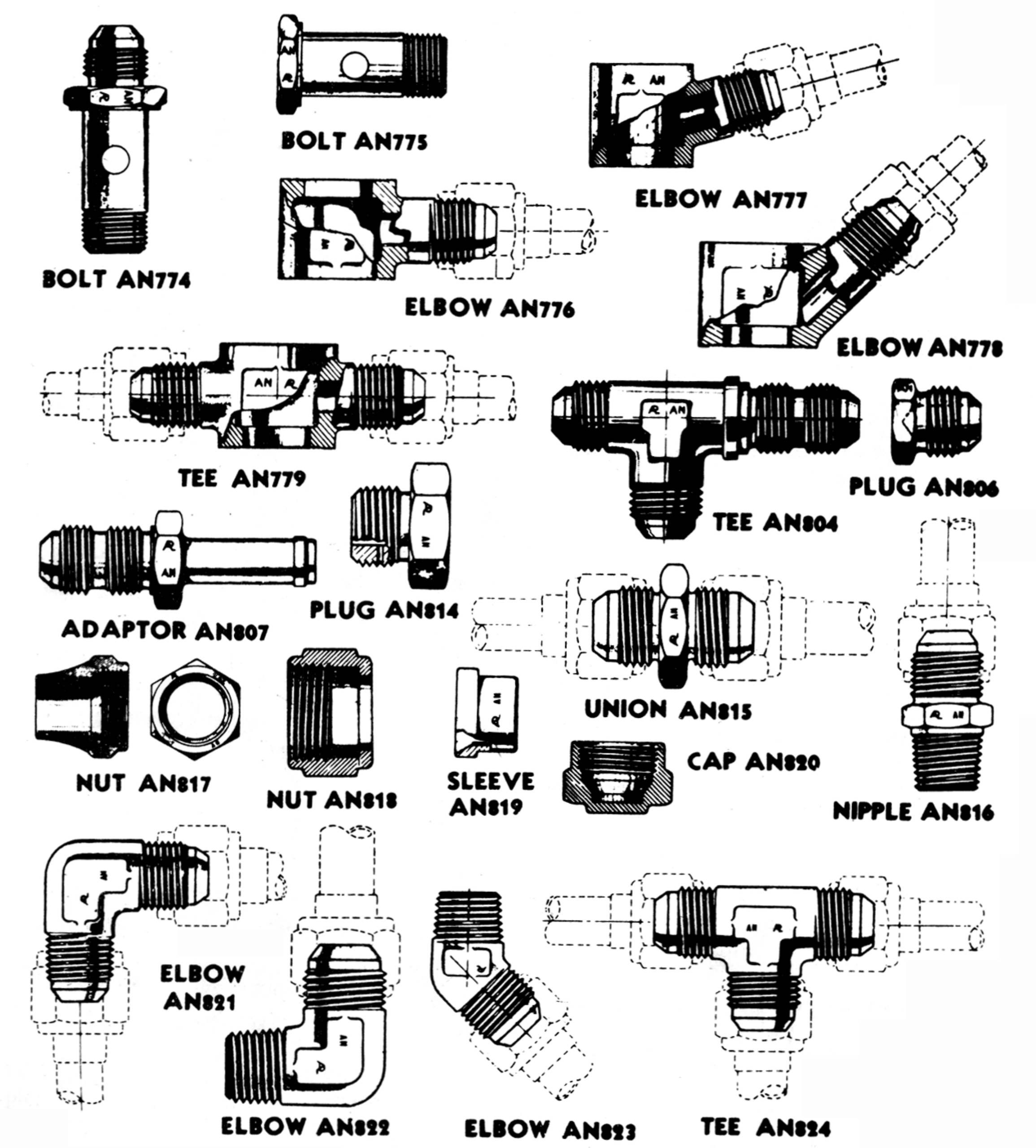


Fig. 22.8, AN plumbing fittings.

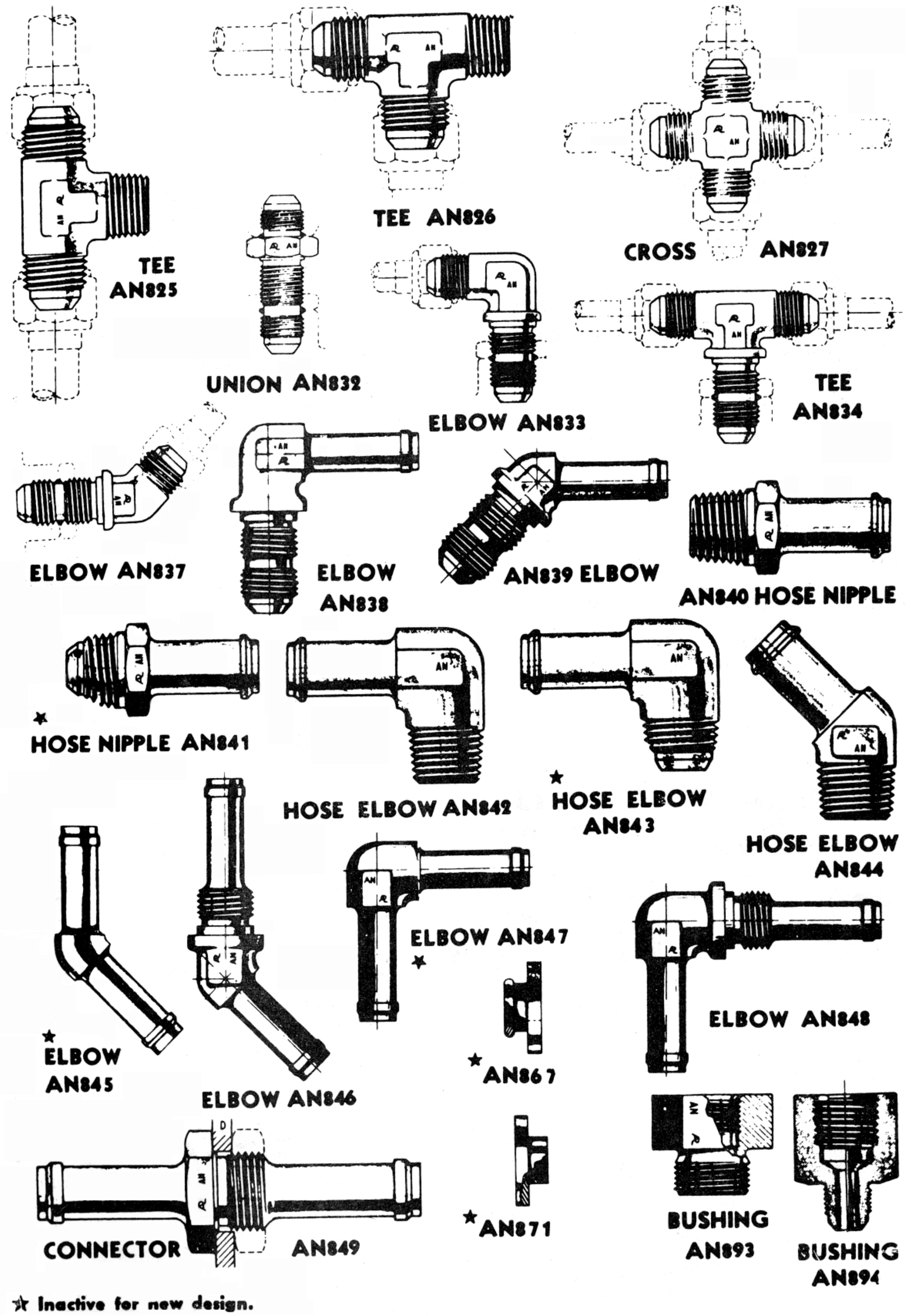


Fig. 22.8, AN plumbing fittings - Continued

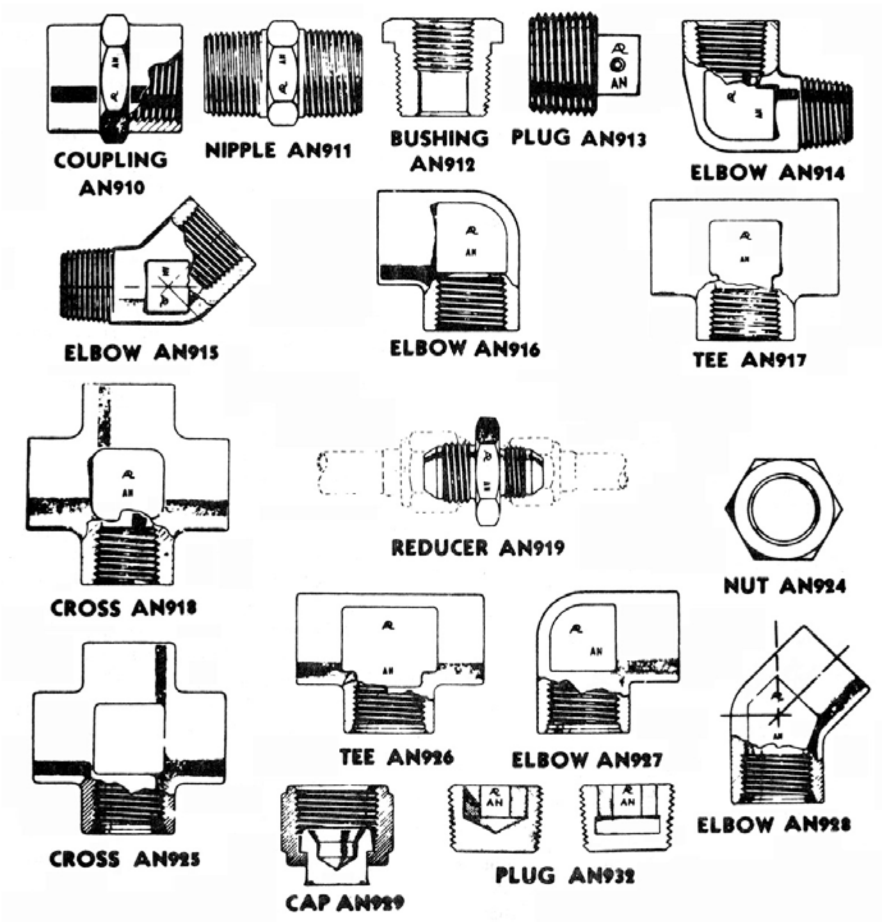


Fig. 22.8, AN plumbing fittings - Continued

Flareless-tube Fittings

The MS (Military Standard) flareless-tube fittings are finding wide application in aircraft plumbing systems. Using this type fitting eliminates all tube flaring, yet provides a safe, strong, dependable tube connection. The fitting consists of three parts : a body, a sleeve, and a nut. The body has a counterbored shoulder, against which the end of the tube rests. (See figure 22.9). The angle of the counterbore causes the cutting edge of the sleeve to cut into the outside of the tube when the two are joined. Installation of flareless-tube fittings is discussed later in this chapter.

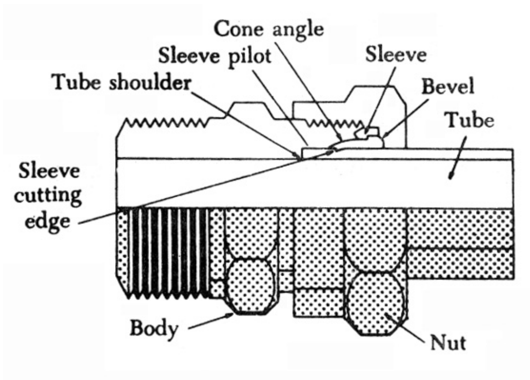


Fig. 22.9, Flareless tube fitting.

Quick-disconnect Couplings

Quick -disconnect couplings of the self-sealing type are used at various points in many fluid systems. The couplings are installed at locations where frequent uncoupling of the lines is required for inspection and maintenance.

Quick-disconnect couplings provide a means of quickly disconnecting a line without loss of fluid or entrance of air into the system. Each coupling assembly consists of two halves, held together by a union nut. Each half contains a valve that is held open when the coupling is connected, allowing fluid to flow through the coupling in either direction. When the coupling is disconnected, a spring in each half closes the valve, preventing the loss of fluid and entrance of air.

The union nut has a quick-lead thread which permits connecting or disconnecting the coupling by turning the nut. The amount the nut must be turned varies with different style couplings. One style requires a quarter turn of the union nut to lock or unlock the coupling while another style requires a full turn.

Some couplings require wrench tightening; others are connected and disconnected by hand. The design of some couplings is such that they must be safetied with safety wire. Others do not require lock wiring, he positive locking being assured by the teeth on the locking spring, which engage ratchet teeth on the union nut when the coupling is fully engaged. The lock spring automatically disengages when the union nut is unscrewed. Because of individual differences, all quick disconnects should be installed according to instructions in the aircraft maintenance manual.

Flexible Connectors

Flexible connectors may be equipped with either swaged fittings or detachable fittings, or they may be used with beads and hose clamps. Those equipped with swaged fittings are ordered by correct length from the manufacturer and ordinarily cannot be assembled by the mechanic. They are swaged and tested at the factory ad are equipped with standard fittings.

The fittings on detachable connectors can be detached and reused if they are not damaged; otherwise new fittings must be used.

The bead and hose clamp connector is often used for connecting oil, coolant, and low-pressure fuel system tubing. The bead, a slightly raised ridge around the tubing or the fitting, gives a good gripping edge that aids in holding the clamp and hose in place. The bead may appear near the end of the metal tubing or on one end of a fitting.

TUBE FORMING PROCESSES

Damaged tubing and fluid lines should be replaced with new parts whenever possible. Sometimes replacement is impractical and repair is necessary. Scratches, abrasions, and minor corrosion on the outside of fluid lines may be considered negligible and can be smoothed out with a burnishing tool or aluminum wool. Limitations on the amount of damage that can be repaired in this manner are discussed later in this chapter under "Repair of Metal Tube Lines. " If a fluid line assembly is to be replaced, the fittings can often be salvaged; then the repair will involved only tube forming and replacement.

Tube forming consists of four processes : (1) Cutting, (2) Bending, (3) Flaring, and (4) Beading. If the tubing is small and of soft material, the assembly can be formed by hand bending during installation. If the tubing is ¼-inch diameter, or larger, hand bending without the aid of tools is impractical.

Tube Cutting

When cutting tubing, it is important to produce a square end, free of burrs. Tubing may be cut with a tube cutter or a hacksaw. The cutter can be used with any soft metal tubing, such as copper, aluminum, or aluminum alloy. Correct use of the tube cutter is shown in figure 22.10.

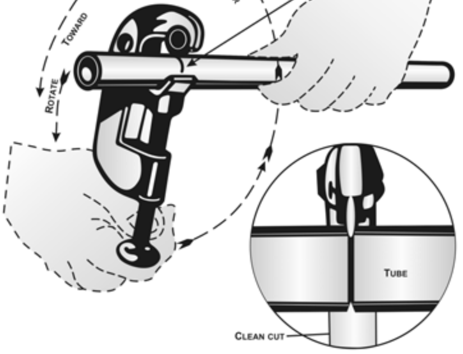


Fig. 22.10, Tube cutting

A new piece of tubing should be cut approximately 10 percent longer than the tube to be replaced to provide for minor variations in bending. Place the tubing in the cutting tool, with the cutting wheel at the point where the cut is to be made. Rotate the cutter around the tubing, applying a light pressure to the cutting wheel by intermittently twisting the thumbscrew. Too much pressure on the cutting wheel at one time could deform the tubing or cause excessive burring. After cutting the tubing, carefully remove any burrs from inside and outside the tube. Use a knife or the burring edge attached to the tube cutter.

When performing the deburring operation use extreme care that the wall thickness of the end of the tubing is not reduced or fractured. Very slight damage of this type can lead to fractured flares of defective flares which will not seal properly. A fine tooth file can be used to file the end square and smooth.

If a tube cutter is not available, or if tubing of hard material is to e cut, use a fine-tooth hacksaw, preferably one having 32 teeth per inch. The use of a saw will decrease the amount of work hardening of the tubing during the cutting operation. After sawing, file the end of the tube square and smooth, removing all burrs.

An easy way to hold small-diameter tubing, when cutting it, is to place the tube in a combination flaring tool and clamp the tool in a vise. Make the cut about one-half inch from the flaring tool. This procedure keeps sawing vibrations to a minimum and prevents damage to the tubing if it is accidentally hit with the hacksaw frame or file handle while cutting. Be sure all flings and cuttings are removed from the tube.

Tube Bending

The objective in tube bending is to obtain a smooth bend without flattening the tube. Tubing under one-fourth inch in diameter usually can be bent without the use of a bending tool. For larger sizes, a hand tube bender similar to that shown in figure 22.11 is usually used.

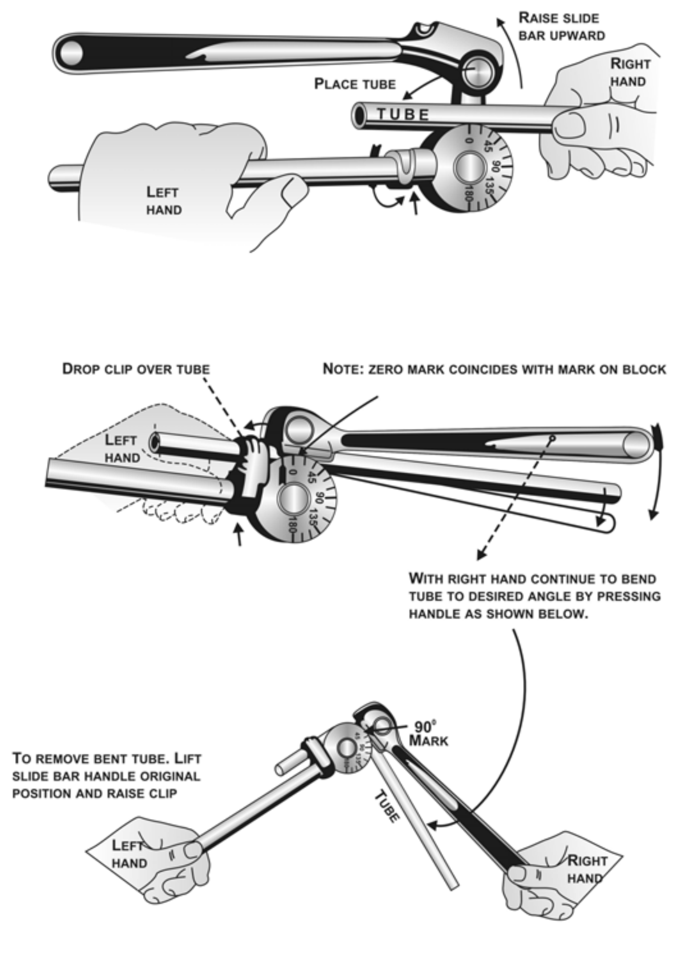


Fig. 22.11, Tube bending

To bend tubing with the hand tube bender, insert the tubing by raising the slide bar handle as far as it will go. Adjust the handle so that the full length of the groove in the slide bar is in contact with the tubing. The zero mark on the radius block and the mark on the slide bar must align. Make the bend by rotating the handle until the desired angle of bend is obtained, as indicated on the radius block.

Bend the tubing carefully to avoid excessive flattening, kinking, or wrinkling. A small amount of flattening in bends is acceptable, but the small amount of flattening in bends is acceptable, but the small diameter of the flattened portion must not be less than 75 percent of the original outside diameter. Tubing with flattened, wrinkled, or irregular bends should not be installed. Wrinkled bends usually result from trying to bend thin-wall tubing without using a tube bender. Examples of correct and incorrect tubing bends are shown in figure 22.12.

Tube bending machines for all types of tubing are generally used in repair stations and large maintenance shops. With such equipment, proper bends can be made on large diameter tubing and on tubing made from hard material. The production tube bender is an example of this type of machine.

The ordinary production tube bender will accommodate tubing ranging from ½-inch to 1½-inch outside diameter. Benders for larger sizes are available, and the principle of their operation is similar to that of the hand tube bender. The radius blocks are so constructed that the radius of bend will vary with the tubing diameter. The radius of bend is usually stamped on the block.

When hand or production tube benders are not available or are not suitable for a particular bending operation, a filler of metallic composition or of dry sand may be used to facilitate bending. When using this method, cut the tube slightly longer than is required. The extra length is for inserting a plug (which may be wooden) in each end.

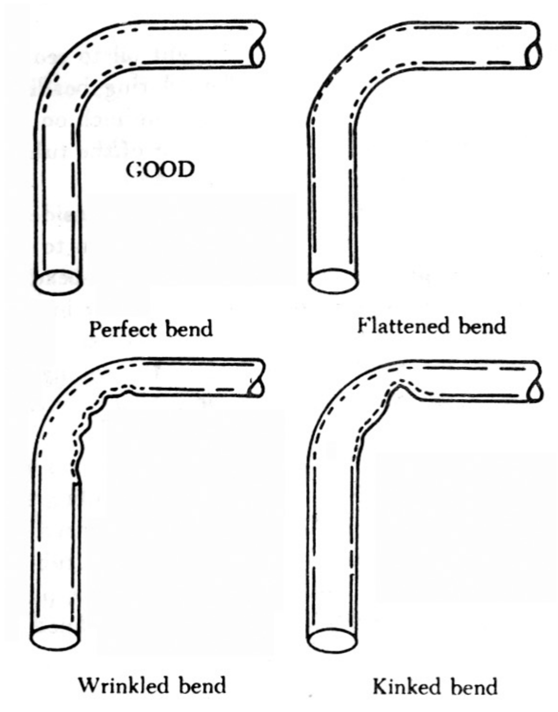


Fig. 22.12, Correct and incorrect tubing bends.

After plugging one end, fill and pack the tube with fine, dry sand and plug tightly. Both plugs must be tight so they will not be forced out when the bend is made. The tube can also be closed by flattening the ends or by soldering metal disks in them. After the ends are closed, bend the tubing over a forming block shaped to the specified radius.

In a modified version of the filler method, a fusible alloy is used instead of sand. In this method, the tube is filled under hot water with a fusible alloy that melts at 160°F. The alloy-filled tubing is then removed from the water, allowed to cool, and bent slowly by hand around a forming block or with a tube bender. After the bend is made, the alloy is again melted under hot water and removed from the tubing.

When using either filler method, make certain that all particles of the filler are removed so that none will be carried into the system in which the tubing is installed. Store the fusible alloy filler where it will be free from dust or dirt. It can be re-melted and re-used as often as desired. Never heat this filler in any other than the prescribed method, as the alloy will stick to the inside of the tubing, making them both unusable.

Tube Flaring

Two kinds of flares are generally used in aircraft plumbing systems, the single flare and the double flare. Flares are frequently subjected to extremely high pressures; therefore, the flare on the tubing must be properly shaped or the connection will leak or fail.

A flare made too small produces a weak joint, which may leak or pull apart; if made too large it interferes with the proper engagement of the screw thread on the fitting and will cause leakage. A crooked flare is the result of the tubing not being cut squarely. If a flare is not made properly, flaws cannot be corrected by applying additional torque when tightening the fitting. The flare and tubing must be free from cracks, dents, nicks, scratches, or any other defects.

The flaring tool used for aircraft tubing has male and female dies ground to produce a flare of 35° to 37°. Under no circumstances is it permissible to use an automotive type flaring tool which produces a flare of 45°.

Single Flare

A hand flaring tool similar to that shown in figure 22.13 is used for flaring tubing. The tool consists of a flaring block or grip die, a yoke, and a flaring pin. The flaring block is a hinged double bar with holes corresponding to various sizes of tubing. These holes are countersunk on one end to form the outside support against which the flare is formed. The yoke is used to center the flaring pin over the end of the tube to be flared.

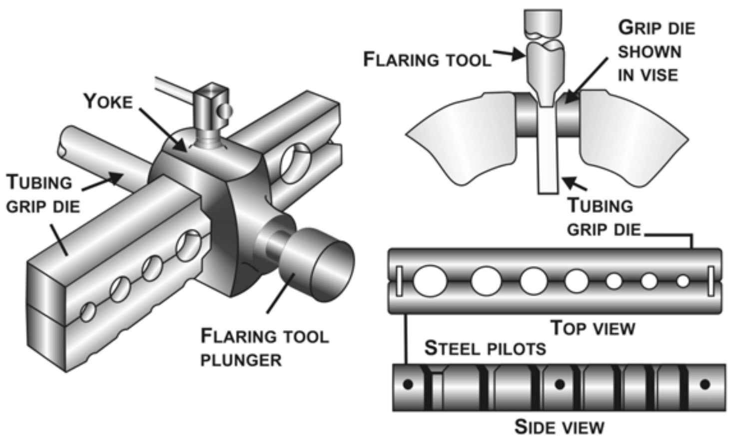


Fig. 22.13, Hand flaring tool (single flare)

To prepare a tube for flaring, cut the tube squarely and remove all burrs. Slip the fitting nut and sleeve on the tube and place the tube in the proper size hole in the flaring tool. Center the plunger or flaring pin over the end of the tube. Then project the end of the tubing slightly from the top of the flaring tool, about the thickness of a dime, and tighten the clamp bar securely to prevent slippage.

Make the flare by striking the plunger several light blows with a lightweight hammer or mallet. Turn the plunger a half turn after each blow and be sure it seats properly before removing the tube from the flaring tool. Check the flare by sliding the sleeve into position over the flare. The outside diameter of the flare should extend approximately one-sixteenth inch beyond the end of the sleeve, but should not be larger than the major outside diameter of the sleeve.

Double Flare

A double flare should be used on 5052-O and 6061-T aluminum alloy tubing for all sizes from 1/8 - to 3/8 - inch outside diameter. This is necessary to prevent cutting off the flare and failure of the tube assembly under operating pressures. Double flaring is not necessary on steel tubing. See figure 5-14 for an illustration of single - and double - flared tubing. The double flare is smoother and more concentric than the single flare a and, therefore, seals better. It is also more resistant to the shearing effect of torque.

To make the double flare, separate the clamp blocks of the double-flaring tool and insert and clamp the tubing with the burred end flush with the top of the clamp. Insert the starting pin into the flaring pin guide and strike the pin sharply with a hammer until the shoulder of the pin stops against the clamp blocks. Remove the starting pin and insert the finishing pin; hammer it until its shoulder rests on the clamp block.

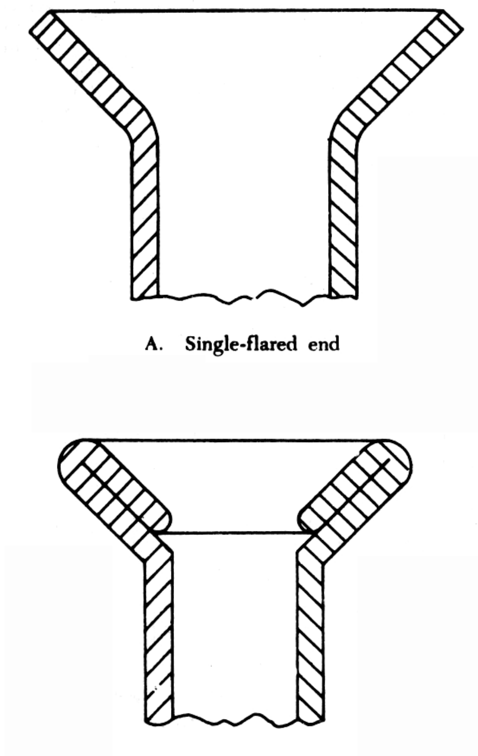
Beading

Tubing may be beaded with a hand-beading tool, with machine-beading rolls, or with grip dies. The method to be used depends on the diameter and wall thickness of the tube and the material from which it was made.

The hand-beading tool is used with tubing having 1/4 - to 1 - inch outside diameter. The bead is formed by using the beader frame with the proper rollers attached. The inside and outside of the tube is lubricated with light oil to reduce the friction between the rollers during beading. The sizes, marked in sixteenths of an inch on the rollers, are for the outside diameter of the tubing that can be beaded with the rollers.

Separate rollers are required for the inside of each tubing size, and care must be taken to use the correct parts when beading. The hand-beading tool works somewhat like the tube cutter in that the roller is screwed down intermittently while rotating the beading tool around the tubing. In addition, a small vise (tube holder) is furnished with the kit.

Other methods and types of beading tools and machines are available, but the hand-beading tool is used most often. As a rule, beading machines are limited to use with large-diameter tubing, over 1 15/16 inch, unless special rollers are supplied. The grip-die method of beading is confined to small tubing.



A. Single-flared end

B. Double-flared end

Fig. 22.14, Cutaway view of single and double flared tube ends.

Flareless-Tube Assemblies

Although the use of flareless-tube fittings eliminates all tube flaring, another operation, referred to as presetting, is necessary prior to installation of a new flareless-tube assembly. Figure 22.15 (steps 1, 2, and 3) illustrates the presetting operation, which is performed as follows :

a. Cut the tube to the correct length, with the ends perfectly square. Deburr the inside and outside of the tube. Slip the nut, then the sleeve, over the tube (step 1).

b. Lubricate the threads of the fitting and nut with hydraulic fluid. Place the fitting in a vise (step 2), and hold the tubing firmly and squarely on the seat in the fitting. (Tube must bottom firmly in the fitting.) Tighten the nut until the cutting edge of the sleeve grips the tube. This point is determined by slowly turning the tube back and forth while tightening the nut. When the tube no longer turns, the nut is ready for final tightening.

c. Final tightening depends upon the tubing. For aluminum alloy tubing up to and including ½-inch outside diameter, tighten the nut from one to one and one-sixth tuns. For steel tubing ad aluminum alloy tubing over ½-inch outside diameter, tighten from one ad one-sixth to one and one-half tuns.

After presetting the sleeve, disconnect the tubing from the fitting ad check the following points (illustrated in step 3) :

a. The tube should extend 3/32 to 1/8 inch beyond the sleeve pilot; otherwise blowoff may occur.

b. The sleeve pilot should contact the tube or have a maximum clearance of 0.005 inch for aluminum alloy tubing or 0.015 inch for steel tubing.

c. A slight collapse of the tube at the sleeve cut is permissible. No movement of the sleeve pilot, except rotation, is permissible.

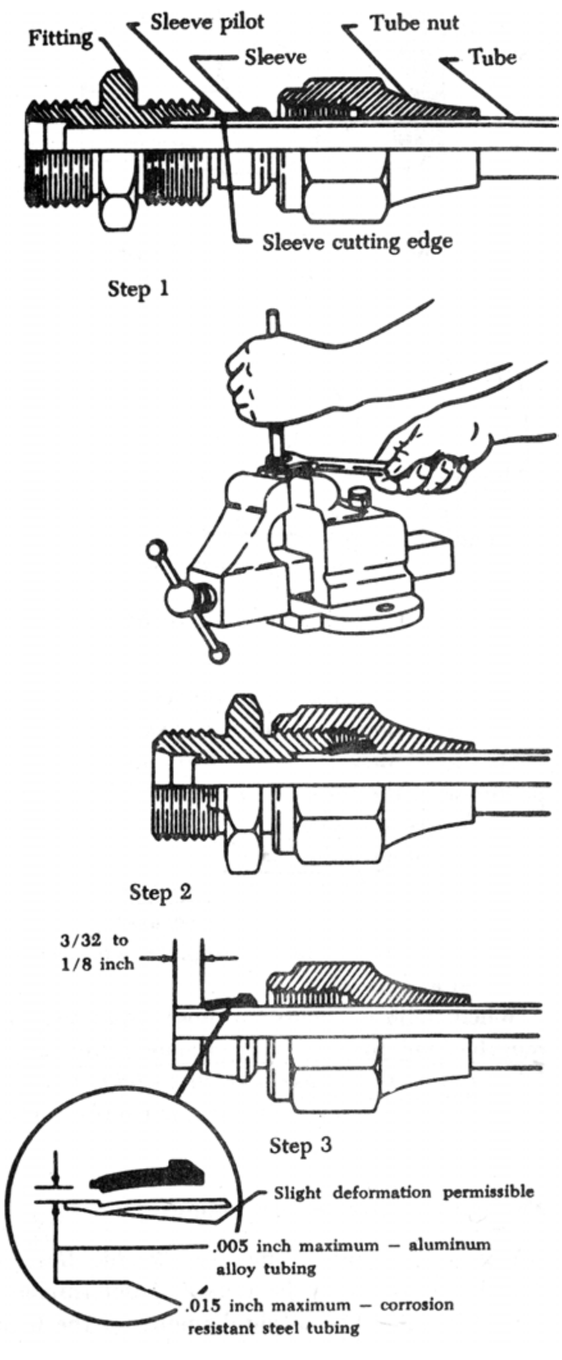


Fig. 22.15, Presetting flareless-tube assembly.

REPAIR OF METAL TUBE LINES

Scratches or nicks no deeper than 10 percent of the wall thickness in aluminum alloy tubing may be repaired, if they are not in the heel of a bend. Replace lines with severe die marks, seams, or splits in the tube. Any crack or deformity in a flare is also unacceptable and is cause for ejection. A dent of less than 20 percent of the tube diameter is not objectionable, unless it is in the heel of a bend. Dents can be removed by drawing a bullet of proper size through the tube by means of a length of cable.

A severely damaged line should be replaced. However, the line can be repaired by cutting out the damaged section and inserting a tube section of the same size and material. Flare both ends of the undamaged and replacement tube sections and make the connection by using standard unions, sleeves, and tube nuts. If the damaged portion is short enough, omit the insert tube and repair by using one union and two sets of connecting fittings.

When repairing a damaged line, be very carefully to remove all chips and burrs. Any ope line that is to be left unattended for some time should be sealed, using metal, wood, rubber, or plastic plugs or caps.

When repairing a low-pressure line using a flexible fluid connection assembly, position the hose clamps carefully in order to prevent overhang of the clamp bands or chafing of the tightening screws on adjacent parts. If chafing can occur, the hose clamps should be repositioned on the hose Figure 22.16 illustrates the design of a flexible fluid connection assembly and gives the maximum allowable angular and dimensional offset.

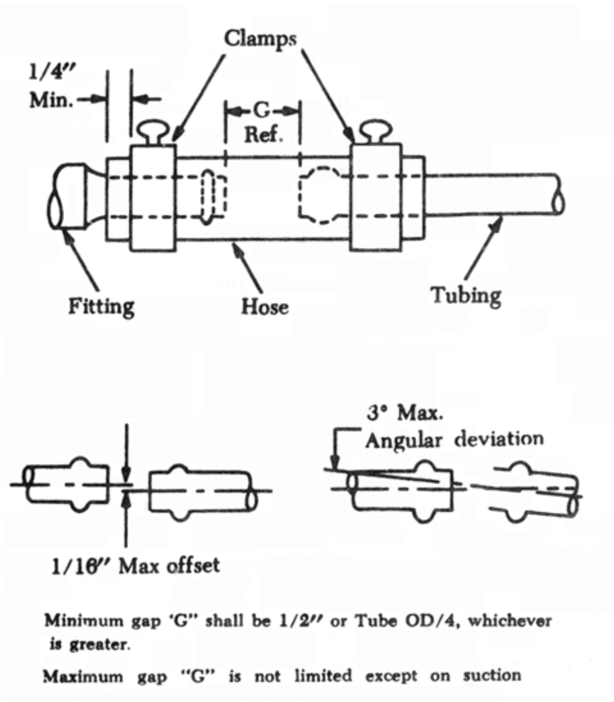


Fig. 22.16, Flexible fluid connection assembly

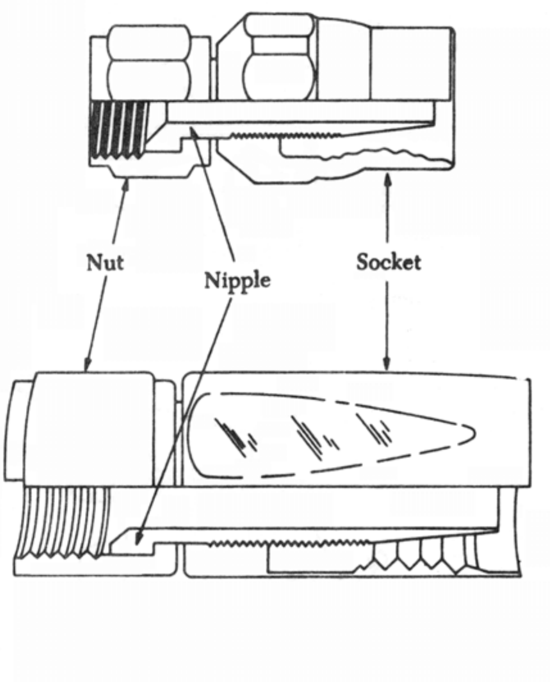


Fig. 22.17, Sleeve-type fittings

Layout of Lines

Remove the damaged or worn assembly, taking care not to further damage or distort it, and use it as a forming template for the new part. If the old length of tubing cannot be used as a pattern, make a wire template, bending the pattern by hand as required for the new assembly. Then bend the tubing to match the wire pattern.

Never select a path that does not require bends in the tubing. A tube cannot be cut or flared accurately enough so that it can be installed without bending and still be free from mechanical strain. Bends are also necessary to permit the tubing to expand or contract under temperature changes and to absorb vibration. If the tube is small (under one-fourth inch) and can be hand formed, casual bends may be made to allow for this. If the tube must be machine formed, definite bends must be made to avoid a straight assembly.

Start all bends a reasonable distance from the fittings, because the sleeves and nuts must be slipped back during the fabrication of flares and during inspections. In all cases the new tube assembly should be so formed prior to installation that it will not be necessary to pull or deflect the assembly into alignment by means of the coupling nuts.

FABRICATION AND REPLACEMENT OF FLEXIBLE HOSE

Hose and hose assemblies should be checked for deterioration at each inspection period. Leakage, separation of the cover or braid from the inner tube, cracks, hardening, lack of flexibility, and excessive "cold flow" are apparent signs of deterioration and reason for replacement. The term "cold flow" describes the deep, permanent impressions in the hose produced by the pressure of hose clamps or supports.

When failure occurs in a flexible hose equipped with swaged end fittings, the entire assembly must be replaced. Obtain a new hose assembly of the correct size and length, complete with factory-installed end fittings.

When failure occurs in hose equipped with reusable end fittings, a replacement line can be fabricated with the use of such tooling as may be necessary to comply with the assembly instructions of the manufacturer.

Assembly of Sleeve-Type Fittings

Sleeve-type end fittings for flexible hose are detachable and may be reused if determined to be serviceable. The inside diameter of the fitting is the same as the inside diameter of the hose to which it is attached. Common sleeve-type fittings are shown in figure 22.17.

To make a hose assembly, select the proper size hose and end fittings. Cut the hose to the correct length using a fine-tooth hacksaw. Place the socket in a vise. Screw the hose into the socket counterclockwise until the hose bottoms on the shoulder of the socket (figure 22.18); then back off one-quarter turn. Lubricate inside of hose and nipple threads liberally. Mark the hose position around the hose at the rear of the socket using a grease pencil or painted line. Insert the nipple into the nut and tighten the nipple and nut on the assembly tool. If an assembly tool is not available, a mating AN815 adapter may e used. Using a wrench on the assembly tool, screw the nipple into the socket and hose. A 1/32 - to 1/16 - inch clearance between the nut and sleeve is required so that the nut will swivel freely when the assembly tool is removed. After assembly, always make sure all foreign matter is removed from inside the hose by blowing out with compressed air.

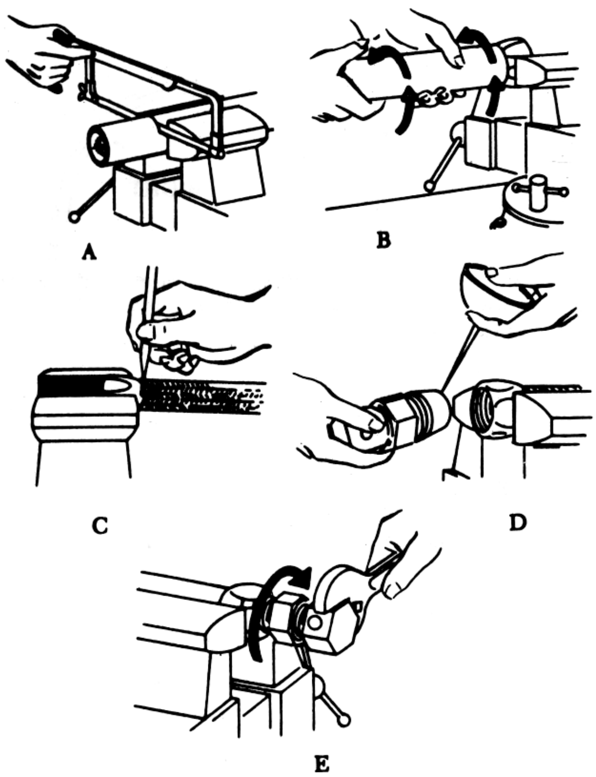


Fig. 22.18, Cutaway view of single and double flared tube ends.

Proof-test After Assembly

All flexible hose must be proof-tested after assembly by plugging or capping one end of the hose and applying pressure to the inside of the hose assembly. The proof-test medium may be a liquid or a gas. For example, hydraulic, fuel, and oil lines are generally tested using hydraulic oil or water, whereas air or instrument lines are tested with dry, oil-free air or nitrogen. When testing with a liquid, all trapped air is bled from the assembly prior to tightening the cap or plug. Hose tests, using a gas, are conducted underwater. In all cases follow the hose manufacturer's instructions for proof-test pressure and fluid to b used when testing a specific hose assembly.

Place the hose assembly in a horizontal position and observe for leakage while maintaining the test pressure. Proof-test pressures should be maintained for at least 30 seconds.

Installation of Flexible Hose Assemblies

Flexible hose must not be twisted on installation, since this reduces the life of the hose considerably and may also loosen the fittings. Twisting of the hose can be determined from the identification stripe running along its length. This stripe should not spiral around the hose.

Flexible hose should be protected from chafing by wrapping it with tape, but only where necessary.

The minimum bend radius fro flexible hose varies according to size and construction of the hose and the pressure under which the hose is to operate. Bends that are too sharp will reduce the bursting pressure of flexible hose considerably below its rated value (figure 22.19).

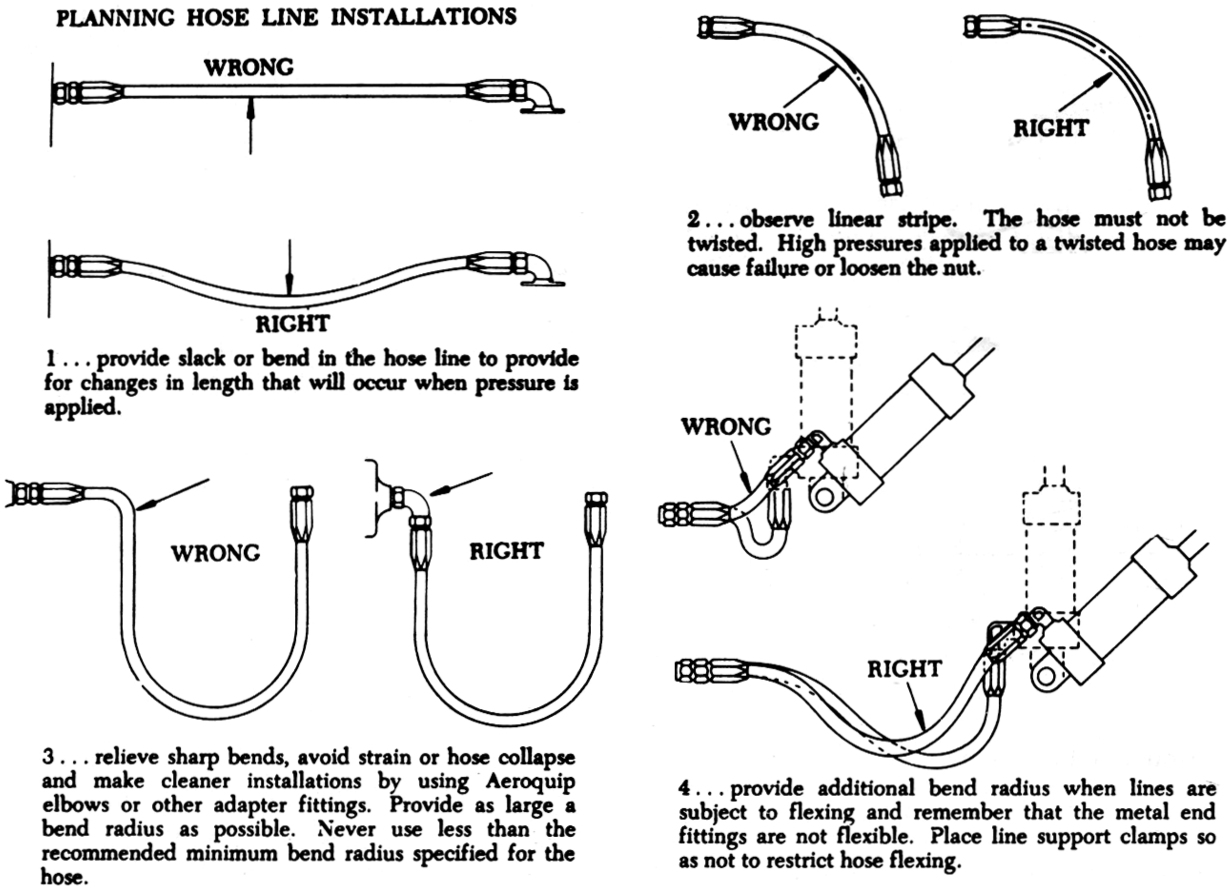


Fig. 22.19, Flexible hose installation

Flexible hose should be installed so that it will be subject to a minimum of flexing during operation. Although hose must be supported at least every 24 inches, closer supports are desirable. A flexible hose must never be stretched tightly between two fittings. From 5 percent to 8 percent of its total length must be allowed for freedom of movement under pressure. When under pressure, flexible hose contracts in length and expands in diameter.

Protect all flexible hose from excessive temperatures, either by locating the lines so they will not be affected or by installing shrouds around them.

INSTALLATION OF RIGID TUBING

Before installing a line assembly in an aircraft, inspect the line carefully. Remove dents and scratches, and be sure all nuts and are snugly mated and securely fitted by proper flaring of the tubing. The line assembly should be clean and free of all foreign matter.

Connection and Torque

Never apply compound to the faces of the fitting or the flare, for it will destroy the metal-to metal contact between the fitting and flare, a contact which is necessary to produce the seal. Be sure that the line assembly is properly aligned before tightening the fittings. Do not pull the installation into place with torque on the nut. Correct and incorrect methods of installing flared-tube assemblies are illustrated in figure 22.20. Proper torque values are given in Figure 22.21. It must e remembered that these torque values are for flared type fittings only. Always tighten fittings to the correct torque value when installing a tube assembly. Overtightening a fitting may badly damage or completely cut off the tube flare, or it may ruin the sleeve or fitting nut. Failure to tighten sufficiently also can be serious, as this condition may allow the line to blow out of the assembly or to leak under system pressure.

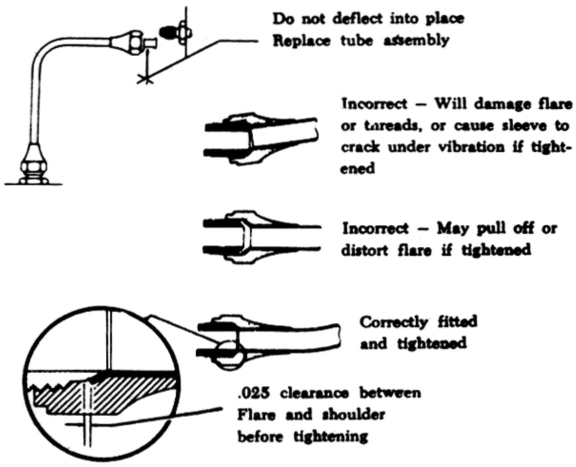


Fig. 22.20, Correct and incorrect methods of tightening flared fittings.

The use of torque wrenches and the prescribed torque values prevents overtightening or undertightening. If a tube fitting assembly is tightened properly, it can be removed and retightened many times before re-flaring is necessary.

Tubing O.D.	Fitting Bolt or Nut Size	Aluminum Alloy Tubing Bolt, Fitting or Nut Torque inch–lbs.	Steel Tubing, Bolt Fitting or Nut Torque inch–lbs.	Hose End Fittings and Hose Assemblies — MS28740 or Equivalent End Fitting: Minimum	Maximum	Minimum bend radii (inches): Alum. alloy 1100-H14 5052-0	Steel
1/8	–2	20 – 30				3/8	
3/16	–3	30 – 40	90 – 100	70	120	7/16	21/32
1/4	–4	40 – 65	135 – 150	100	250	9/16	7/8
5/16	–5	60 – 85	180 – 200	210	420	3/4	1 1/8
3/8	–6	75 – 125	270 – 300	300	480	15/16	1 5/16
1/2	–8	150 – 250	450 – 500	500	850	1 1/4	1 3/4
5/8	–10	200 – 350	650 – 700	700	1150	1 1/2	2 3/16
3/4	–12	300 – 500	900 – 1000			1 3/4	2 5/8
7/8	–14	500 – 600	1000 – 1100				
1	–16	500 – 700	1200 – 1400			3	3 1/2
1–1/4	–20	600 – 900	1200 – 1400			3 3/4	4 3/8
1–1/2	–24	600 – 900	1500 – 1800			5	5 1/4
1–3/4	–28	850 – 1050				7	6 1/8
2	–32	950 – 1150				8	7

Fig. 22.21, Flared fitting data.

Flareless Tube Installation

Tighten the nut by hand until an increase in resistance to turning is encountered. Should it be impossible to run the nut down with the fingers, use a wrench, but be alert for the first signs of bottoming. It is important that the final tightening commence at the point where the nut just begins to bottom.

With a wrench, turn the nut 1/6 turn (one flat on a hex nut). Use a wrench on the connector to prevent it from turning while tightening the nut. After the tube assembly is installed, the system should be pressure tested. Should a connection leak, it is permissible to tighten the nut an additional 1/6 turn (making a total of 1/3 turn). If, after tightening the nut a total of 1/3 turn, leakage still exists, the assembly should be removed and the components of the assembly inspected for scores, cracks, presence of foreign material, or damage from overtightening.

NOTE : Overtightening a flareless-tube nut drives the cutting edge of the sleeve deeply into the tube, causing the tube to be weakened to the point where normal in-flight vibration could cause the tube to shear. After inspection (if no discrepancies are found), reassemble the connections and repeat the pressure test procedures.

CAUTION : Do not in any case tighten the nut beyond 1/3 turn (two flats on the hex nut); this is the maximum the fitting may be tightened without the possibility of permanently damaging the sleeve and nut.

Common faults are :
1. Flare distorted into nut threads.
2. Sleeve cracked.
3. Flare cracked or split.
4. Flare out of round.
5. Inside of flare rough or scratched.
6. Fitting cone rough or scratched.
7. Threads of nut or union dirty, damaged or broken.

Some manufacturers service instructions will specify wrench torque values for flareless tubing installations (e.g. see figure 22.22).

WRENCH TORQUE FOR 304 1/8 H STEEL TUBES

Tube Outside Diameter	Wall Thickness	Wrench Torque Inch–Pounds
3/16	0.016	90 – 110
3/16	0.020	90 – 110
1/4	0.016	110 – 140
1/4	0.020	110 – 140
5/16	0.020	100 – 120
3/8	0.020	170 – 230
3/8	0.028	200 – 250
1/2	0.020	300 – 400
1/2	0.028	400 – 500
1/2	0.035	500 – 600
5/8	0.020	300 – 400
5/8	0.035	600 – 700
5/8	0.042	700 – 850
3/4	0.028	650 – 800
3/4	0.049	800 – 960
1	0.020	800 – 950
1	0.065	1600 – 1750
WRENCH TORQUE FOR 304-1A or 3471A STEEL TUBES		
3/8	0.042	145 – 175
1/2	0.028	300 – 400
1/2	0.049	500 – 600
1	0.035	750 – 900
WRENCH TORQUE FOR 6061-T6 OR T4 TUBES		
1/4	0.035	110 – 140
3/8	0.035	145 – 175
1/2	0.035	270 – 330
1/2	0.049	320 – 380
5/8	0.035	360 – 440
5/8	0.049	425 – 525
3/4	0.035	380 – 470
1	0.035	750 – 900
1 1/4	0.035	900 – 1100

Fig. 22.22, Torque values for flareless fittings.

PLUMBING ASSEMBLY PRECAUTIONS

Make certain that the material in the fittings used is similar to that of the tubing; for example, use steel fittings with steel tubing and aluminum alloy fittings with aluminum alloy tubing. Brass fittings plated with cadmium may be used with aluminum alloy tubing.

Hose clamp tightening, finger-tight-plus turns method		
Initial installation only	Worm screw type clamp 10 threads per inch	Clamps—radial and other type—28 threads per inch
Self sealing hose approximately 15 inch-pounds	Finger-tight-plus 2 complete turns	Finger-tight-plus 2-1/2 complete turns
All other aircraft hose approximately 25 inch-pounds	Finger-tight Plus 1¼ complete turns	Finger-tight Plus 2 complete turns

Retightening of Hose Clamps

If Clamps do not seal at specified tightening, examine hose connections and replace parts as necessary

The above is for initial installation and should not be used for loose clamps

For re-tightening loose hose clamps in service proceed as follows:

1. **Non-self-sealing hose – If the clamp screw cannot be tightened with the fingers do not disturb unless leakage is evident. If leakage is present tighten 1/4 turn.**
2. **Self-sealing hose – If looser than finger-tight, tighten to finger tight and add 1/4 turn.**

Fig. 22.23, Hose clamp tightening.

For corrosion prevention, aluminum alloy lines and fittings are usually anodized. Steel lines and fittings, if not stainless steel, are plated to prevent rusting or corroding. Brass and steel fittings are usually cadmium plate, although some may come plated with nickel, chromium, or tin.

To ensure proper sealing of hose connections and to prevent breaking hose clamps or damaging the hose, follow the hose clamp tightening instructions carefully. When available, use the hose clamp torque-limiting wrench. These wrenches are available in calibrations of 15 and 25 inch-pounds. In the absence of torque-limiting wrenches, the finger-tight-plus-turns method should be followed. Because of the variations in hose clamp design and hose structure, the values given in figure 22.23 are approximate. Therefore, use good judgement when tightening hose clamps by this method. Since hose connections are subject to "cold flow" or a setting process, a followup tightening check should be made for several days after installation.

Support clamps

Support clamps are used to secure the various lines to the airframe or powerplant assemblies. Several types of support clamps are used for this purpose. The rubber-cushioned and plain are the most-commonly used clamps. The rubber-cushioned clamp is used to secure lines subject to vibration; the cushioning prevents chafing of the tubing. The plain clamp is used to secure lines in areas not subject to vibration.

A Teflon-cushioned clamp is used in areas where the deteriorating effect of Skydrol® 500, hydraulic fluid (MIL-0-5606), or fuel is expected. However, because it is less resilient, it does not provide as good a vibration-damping effect as other cushion materials.

Use bonded clamps to secure metal hydraulic, fuel, and oil lines in place. Unbonded clamps should be used only for securing wiring. Remove any paint or anodizing from the portion of the tube at the bonding clamp location. Make certain that clamps are of the correct size. Clamps or supporting clips smaller than the outside diameter of the hose may restrict the flow of fluid through the hose.

Tube OD (in.)	Distance between supports (in.)	
	Aluminum Alloy	Steel
1/8	9½	11½
3/16	12	14
1/4	13½	16
5/16	15	18
3/8	16½	20
1/2	19	23
5/8	22	25½
3/4	24	27½
1	26½	30

Fig. 5.24, Maximum distance between supports for fluid tubing.

All plumbing lines must be secured at specified intervals. The maximum distance between supports for rigid fluid tubing is shown in figure 22.24.

■■■

CHAPTER-23
SPRINGS

INTRODUCTION

A spring is a device, in which the material is arranged in such a way that it can undergo a considerable change, without getting permanently distorted. A spring is used to absorb energy due to resilience, which may be restored as and when required. The quality of a spring is judged from the energy it can absorb e.g., in a watch the spring is wound to absorb strain energy. This energy is released to run the watch, when the spring regains its original shape. A carriage spring is used to absorb shocks. It is thus obvious that a spring, which is capable of absorbing the greatest amount of energy for the given stress is known to be the best one.

STIFFNESS OF A SPRING

The load required to produce a unit deflection in a spring is called spring stiffness or stiffness of a spring.

TYPES OF SPRINGS

We have already discussed that a spring is used for absorbing energy due to resilience. Thus in general, the springs are of the following two types depending upon the type of resilience.

1. Bending spring

A spring, which is subjected to bending only and the resilience is also due to it, is known as bending spring. Laminated springs or leaf springs are also called bending springs.

2. Torsion spring

A spring, which is subjected to torsion or twisting moment only and the resilience is also due to it, is known as torsion spring. Helical springs are also called torsion springs. Some springs are subjected to bending as well as torsion.

FORMS OF SPRINGS

Though there are many forms of springs, which are made by the manufacturers, yet the following types of springs are commonly used in Engineering practice.

1. Carriage springs or leaf springs

These are also called laminated springs and are of two types :
(a) semi-elliptical types (i.e., simply supported at its ends subjected to central load) and
(b) quarter-elliptical (i.e., cantilevery) types.

The carriage springs are widely used in railway wagons, coaches and road vehicles these days. These are used to absorb shocks, which give an unpleasant feeling to the passengers. The energy absorbed by a laminated spring, during a shock, is released immediately without doing any useful work.

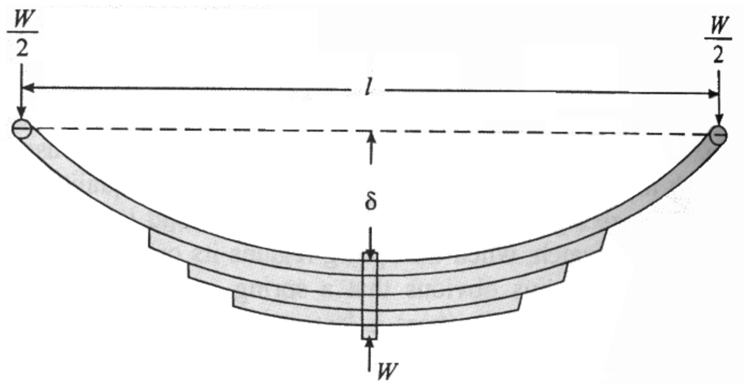


Fig. 23.1, Carriage spring

A laminated spring, in its simplest form consists of a number of parallel strips of a metal having different lengths but same width and placed one over the other in laminations as shown in Fig. 23.1. All the plates are initially bent to the same radius and are free to slide one over the other. When the spring is loaded to the designed load, all the plates become flat and the central defelection disappears. The pupose of this type of arrangement of plates is to make the spring of uniform strength trhoughout. This is achieved by tapering the ends of the laminations. the semi-elliptical type spring rests on the axis of the vehicle and its top plate is pinned at the ends to the chassis of the vehicle.

(b) Quarter-Elliptical Type Leaf Springs

The quarter-elliptical type leaf springs are rarely used, except as certain parts in some machines. Like a carriage spring, a quarter-elliptical type leaf spring consists of a number of parallel strips of a metal having different lengths but same width and placed one over the other in laminations as shown in Fig. 23.2. All the plates are initially bent to the same radius and are free to slide one over the other.

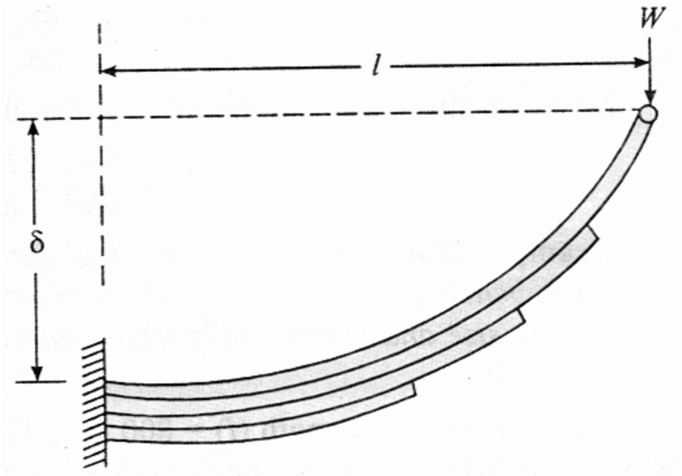


Fig. 23.2, Semi-elliptical leaf spring

2. Helical springs

It is a torsion springs and made up of a wire coiled into a helix. Though there are many types of helical springs, yet the following are important from the subject point of view :

(a) Closely-coiled helical springs and

In a closely coiled helical spring, the spring wire is coiled so close that the each turn is practically a plane at right angles to the axis of the helix and the wire is subjected to torsion. The bending stress is negligible as compared to the torsional stress. A closely-coiled helical spring may be subjected to

(i) axial loading and

(ii) axial twist.

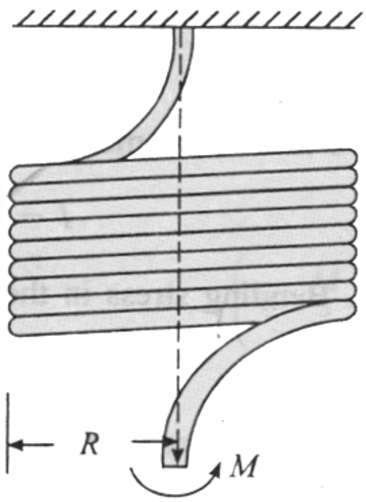


Fig. 23.3, Closely coiled helical spring

(b) Open-coiled helical springs

In an open helical spring, the spring wire is coiled in such a way, that there is large gap between thetwo consecutive turns. As a result of this the spring can take compressive load also.

An open helical spring, like a closed helical spring, may be subjected to
(i) axial loading or
(ii) axial twist.

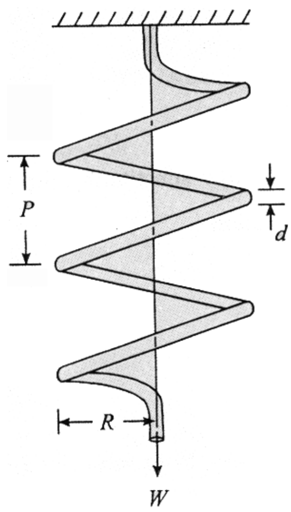


Fig. 23.4, Open coiled helical spring.

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CHAPTER-24
BEARINGS

INTRODUCTION

This chapter gives information on the uses of the various types of ball and roller bearings, and general guidance on installation, maintenance and inspection. Methods of assessing wear are described, but the appropriate aircraft manual should be consulted for the amount of play or clearance permitted, in any installation in which rolling bearings are used.

SHAFT BEARINGS

Bearing play an important role in power transmission and their fitting and maintenance must, therefore, be given a careful consideration. A proper bearing should always be selected for a particular use. During use, excessive pressure must be avoided as the same is likely to squeeze out the oil, causing abrasion of the metals in contact and a sudden rise in temperature. The various metals generally used to form bearing surfaces are cast iron, steel, bronze and babbitt metal. Out of these, cast iron should be used only for light pressures and speeds. All the bearings should have a continuous lubrication, ring lubrication being the most common method for the same. A particular precaution should always be taken that no dirt or other foreign material enters between the shaft and the bearing, otherwise it will cause abrasion and reduce the life of the bearing.

PURPOSE & USES

Bearings provide support to different shafts and spindles during power transmission. In group drive system, they support the main driving shaft and the countershafts and the machine spindles of the driven shafts of the machinery. In individual drive system also they provide support to countershafts and machine spindles. In the former case, rails, hangers and brackets are used to support the bearings at proper locations. The choice of a hanger or a bracket will depend upon the position of the shaft to be supported. If the main driving shaft is located away from the vertical wall of the workshop, horizontal rails can be grouted in the walls and the bearings mounted over them to support the running shaft. If the main shaft is to run close to the roof, hangers can be suspended from the roof at suitable locations and bearings supported in them. In this system, the countershafts are generally mounted close to the walls and are usually supported in bearings mounted in the brackets grouted in the walls. In individual drive also, countershafts and machine spindles are required to be supported in suitable bearings. So, this can be taken as master rule that whenever and wherever shafts and spindles are used for power transmission, bearings are essentially required to support them and enable them to run true.

TYPES OF PLAIN BEARINGS

The common plain shaft bearings are mainly classified into the following three groups :

BALL BEARINGS

These bearings may be divided into four main groups, namely radial, angular contact, thrust and instrument precision bearings.

Radial Bearings

This is the most common type of rolling bearing and is found in all forms of transmission assemblies such as shafts, gears and control-rod end fittings. The bearings are manufactured with the balls in either single or double rows, rigid for normal applications, or self-aligning for positions where accurate alignment cannot be maintained. Such bearings may also be provided with metal shields or synthetic rubber seals to prevent the ingress of foreign matter and retain the lubricant, and with a cir clip groove or flange for retention purposes. The balls are often retained in a cage, but in some case filling slots in the inner and outer rings permit individual insertion of the balls, thus allowing a larger number of balls to be used and giving the bearing a greater radial load capacity; however, axial loads are limited due to the presence of the raceway interruptions.

Angular Contact Bearings

These bearings are capable of accepting radial loads, and axial loads in one direction. The outer ring is recessed on one side to allow the ball and cage assembly to be fitted, thus enabling more balls to be used and the cage to be in one piece. The axial loading capacity of an angular contact bearing depends to a large extent on the contact angle. To achieve the contact angle large radial internal clearances are usually employed; the standards of clearance specified for radial bearings do not normally apply.

i. In applications where axial loads will always be in one direction, a single angular contact bearing may be used, but where axial loads vary in direction an opposed pair of bearings is often used, and adjusted to maintain the required axial clearance.

ii. A particular type of angular contact bearing, known as a duplex bearing, is fitted with a split inner or outer ring, and is designed to take axial loads in either direction. The balls make contact with two separate raceways in each ring, and one essential condition of operation is that the bearing should never run unloaded. The bearings are not adjustable, and radial loads should always be lighter than axial loads. This is a most efficient form of thrust bearing and is not speed limited as is the washer type described below.

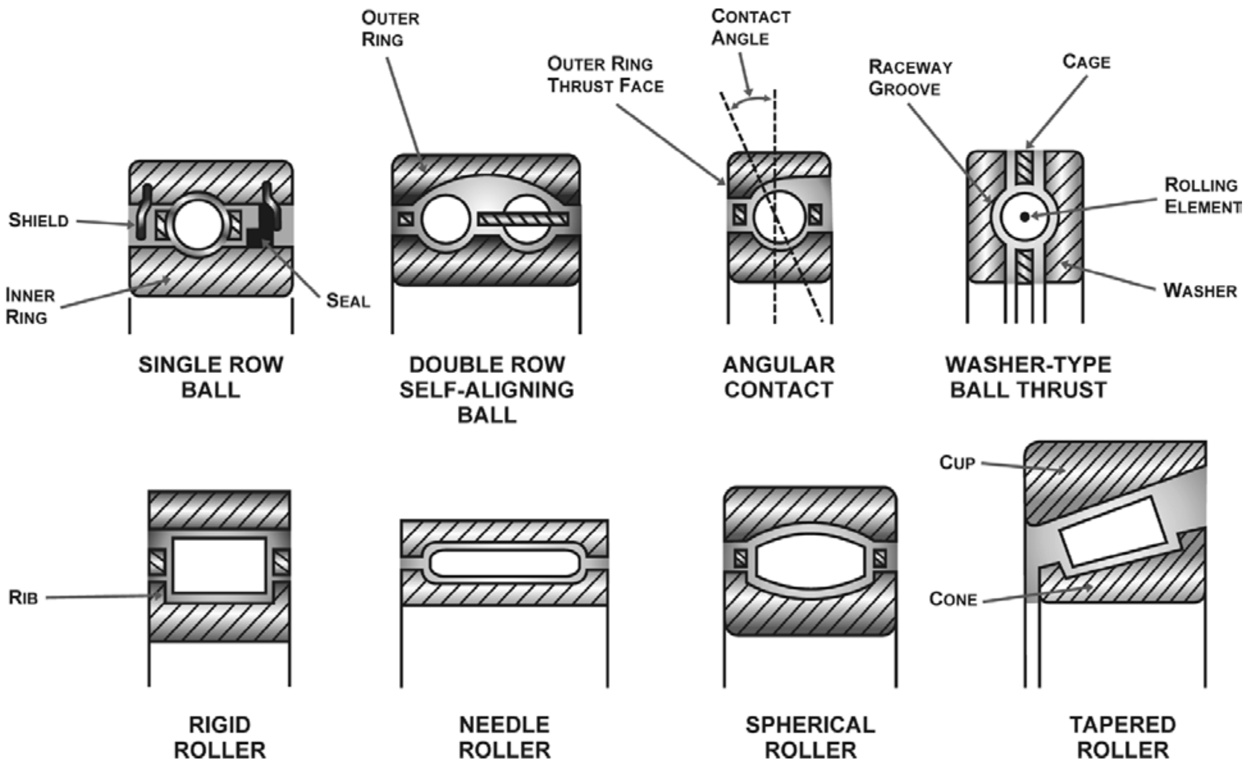


Fig.24.1, Examples of Ball and Roller Bearings

Thrust Bearings
Thrust bearings are designed for axial loading only, and are normally used in conjunction with a roller bearing or radial ball bearing. The balls are retained in a cage and run between washers having either flat or grooved raceways. Centrifugal loading on the balls has an adverse effect on the bearings and they are, therefore, most suitable for carrying heavy loads at low speeds.

Instrument Precision Bearings
These bearings are used mainly in instrument and communication equipment, and care manufactured to a high degree of accuracy and finish. They are generally of the radial bearing type without filling slots, although other types are obtainable. Tolerances quoted in BS 3469 for instrument precision bearings are closer than those quoted in BS 292 for standard ball and roller bearings, and only three classes of radial internal clearance are specified. BS 3469 also contains details of test procedures for instrument precision bearings.

NOTE
Neither BS 3469 nor BS 292 quotes tolerances for axial clearance.

ROLLER BEARINGS
Bearings are broadly classified by the type of rolling element used in their construction. Ball bearings employ steel balls which rotate in grooved raceways, whilst roller bearings utilise cylindrical, tapered or spherical rollers, running in suitably shaped raceways. Both types of bearings are designed for operation under continuous rotary or oscillatory conditions, but, whilst ball bearings and tapered roller bearings accept both radial and axial loads, other types of roller bearings accept mainly radial loads. The following paragraphs amplify the uses of the various types of bearings, and examples are shown in Figure 24.1.

Caged bearing are in general use for engine applications and in equipment with rotational speeds in excess of approximately 100 rev/min. Most other bearings on an aircraft are intended for oscillating or slow rotation conditions and do not have a cage; they are generally shielded or sealed and pre-packed with grease, but some have re lubrication facilities.

Roller bearings may be divided into three main groups, according to whether they have cylindrical, spherical or tapered rollers.

NOTE

"Brinelling" is indentation of the surface of a material, resembling the indentations formed during a Brinell hardness test.

Tapered Roller Bearings

These bearings are designed so that the axes of the rollers form an angle with the shaft axis. They are capable of accepting simultaneous radial loads and axial loads in one direction, the proportions of the loads determining the taper angle. Tapered roller bearings are often mounted back to back in pairs, and adjusted against each other to obtain a working clearance. Because the axial load on the rollers results in rubbing contact on the cone rib, careful lubrication is essential, particularly at high speeds.

Spherical Roller Bearings

A spherical roller bearing may have one or two rows of rollers which run in a spherical raceway in the outer ring, thus enabling the bearing to accept a minor degree of misalignment between opposite bearings. The bearing is capable of withstanding heavy radial loads, and moderate axial loads from either direction.

JOURNAL BEARINGS

These are the simplest of all the bearings. In its simplest form, called the Simple or Solid bearing, it is a solid block carrying a central hole to accommodate the shaft journal. That portion of the shaft which remains inside the bearing is called journal. This bearing, shown in Fig. 24.2, bears the load of the shaft in a direction normal to the axis of the shaft, as shown. A countersunk hole at the top is provided for lubrication purpose. This bearing is, however, hardly used these days.

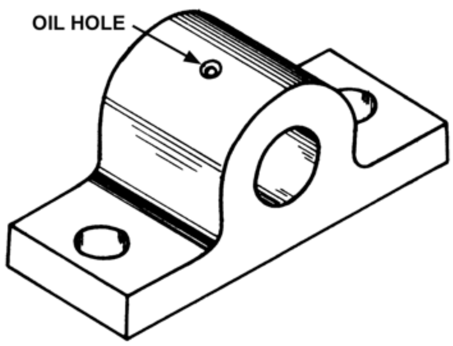


Fig. 24.2, A simple or solid journal bearing.

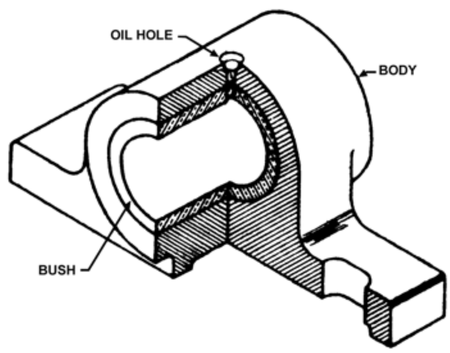


Fig. 24.3, A bushed bearing.

An improved variety of this type of bearing, known as Bushed Bearing, is shown in Fig. 24.3. It carries a brass or gun metal bush and, as usual, a lubrication hole at the top. The main advantage of using the bush is that it can be replaced by another bush when it is worn out. Thus, the same bearing block can continue to be used by replacing the worn out bushes.

A highly improved variety of bushed bearing, which suits best for supporting large sized shafts running at higher loads and higher speeds, is a Plummer Block or Pedastal Bearing, shown at Fig. 24.4. It, however, needs a careful and proper lubrication for its efficient performance. As shown, it mainly consists of a cast iron pedastal, as the main supporting member, bushes iron pedastal, as the main supporting member, bushes made of a gun metal or bronze in two halves, a cast iron-cap and mild steel bolts and nuts to complete the assembly. The bushes are also known as brasses or steps. Provision is always made to prevent rotation of brasses. The following main advantages are associated with the use of this bearing :

a. Removal and replacement of brasses is easy, because they are made in two halves.
b. Placement and removal of the shaft is easy, because only the cap is to be removed for the purpose.
c. At site adjustment for wear in brasses is possible by simply tightening the cap.
d. Chances of axial movement of brasses are eliminated by providing flanges or collars on either end.
e. Changes of rotation of brasses are eliminated by proper design, such as providing sungs, providing flats on the outer surface etc.

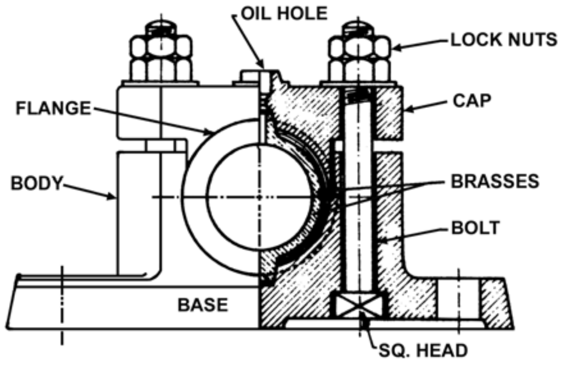


Fig. 24.4, A plummer block or pedastal bearing.

ROD END BEARING

A rod end brearing, also known as a heim joint or rose joint is a mechanical articulating jont. Such joints are used on the ends of control rods, steering links, tie rods, or anywhere a precision articulating joint is required. A ball swivel with an opening through which a bolt or other attaching hardware may pass is pressed into a circular casing with a threaded shaft attached. The threaded portion may be either male or female.

CONICAL BEARING

It may be cylinders or truncated cones. Only radial loads (i.e., loads perpendicular to the axis of rotation) can be carried when the rollers are cylindrical, but with conical rollers both radial and thrust, or axial, loads.

TRUNCATED PIVOT BEARING OR FOOTSTEP BEARING

It is also known as Pivot Bearing and is used to support a vertical shaft. As shown in Fig. 24.5, it consists of a supporting casting or body with a sole, a gun metal bush or liner with a collar at its top and a gun metal disc or pad. A snug is provided at the bottom of the pad to prevent its rotation. The four holes in the sole enable fastening of the bearing by means of bolts and nuts to a suitable supporting base. A neck is provided in the bush below the collar to prevent its rotation. The top inside surface of the bush is made slightly larger than the shaft to provide clearance for lubrication. If the gunmetal bush or disc is worn out during use it can be replaced by a new one instead of replacing the complete bearing. The pressure in this bearing is exerted by the shaft in a vertical direction i.e. parallel to its axis.

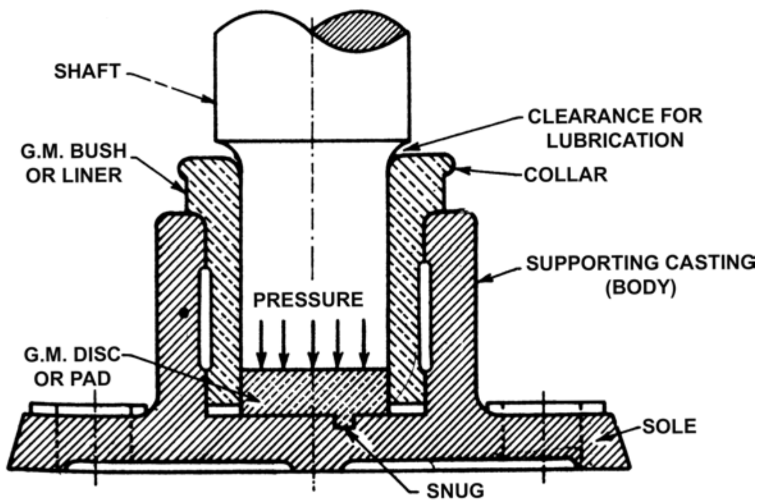


Fig. 24.5, A footstep or pivot bearing.

COLLARED BEARING OR THRUST BEARING

These bearings are used to support those shafts which exert end thrust, i.e., the pressure is parallel to the axis of the shaft in a horizontal direction. Obviously, the support pressure also acts parallel to the shaft. Examples of use of such bearings can be seen in different types of turbines, propeller shafts and metal working machinery, etc. In pivot bearing also the bearing pressure acts parallel to the axis of the shaft, but in that case the shaft is supported at its end and does not pass through the bearing. In case of the thrust bearing, the shaft passes through and extends beyond the bearing.

The shaft, according to requirement, may carry one or more collars. These collars rest against the bearing surfaces. When the shaft carries only one collar the thrust bearing is known as a single collar thrust bearing or simply a collar bearing, and when it carries more than one collars the bearing is called a multicollar thrust bearing or simply a Thrust bearing. These two types of bearings with their main features are shown schematically in Figs. 24.6 and 24.7 respectively. Construction details of these can, however, be obtained from some good book on machine drawing and design, if needed.

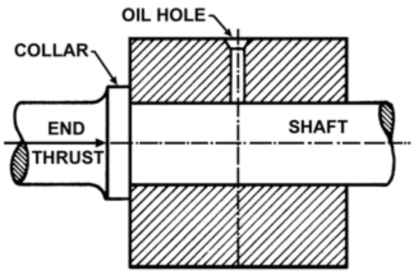


Fig. 24.6, A collar bearing.

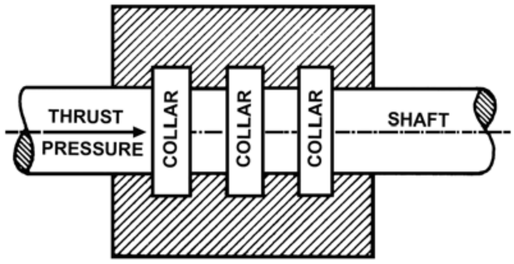


Fig. 24.7, A thrust bearing.

Common features of plain bearings

The term 'Plain bearings' encompasses all the types of bearings discussed above. The following features are common in all these bearings :

a. The shaft journal rotates in a housing (solid bearing), a bush or liner.
b. There is always a sliding friction between the shaft and the bush or liner.
c. The starting friction in these bearings is high.
d. As compared to other types of bearings, say ball or roller, the frictional losses are more.
e. For easy adjustment, most of the plain bearings are made in two parts - a body and the cap.
f. Adequate clearance is always provided between the shaft journal and bearing surface so as to accommodate the lubricant.
g. Although they do not possess a high degree of precision, these bearings are very rigid and strong. They are, therefore, widely used where strength and rigidity are prime considerations.
h. These bearings are simple in construction and manufacturing and are cheap.
i. For efficient operation and longer life, all these bearings require very regular and effective lubrication.

CYLINDRICAL ROLLER BEARINGS

These bearings are capable of carrying greater radial loads than ball bearings of similar external dimensions, due to the greater contact area of the rolling elements. Bearings with ribs on both rings will also carry light, intermittent, axial loads.

i. The type of cylindrical roller bearing most commonly used is that in which the diameter and length of the rollers are equal, and standard sizes within this type are listed in BS 292. Bearings having rollers of a length greater than their diameter are also used for special applications.
ii. A different kind of bearing in this category is the needle roller bearing, in which the length of the rollers is several times greater than their diameter. These bearings are designed for pure radial loads and are often used in locations where the movement is oscillatory rather than rotary, such as universal couplings and control-rod ends. Needle bearing are particularly useful in locations where space is limited, and are often supplied as a cage and roller assembly, the shaft of the components acting as the inner ring. The dimensions and surface finish of the shaft must be closely controlled to the standards specified by the bearing manufacturer. These bearings are particularly susceptible to the effects of misalignment and lack of lubricant, and may also be subject to brinelling, due to the lack of rotational movement.

RADIAL INTERNAL CLEARANCE

Radial ball bearings and cylindrical roller bearings are manufactured with various amounts of radial internal clearance. Standard bearings are available in four grades of fit, namely Group 2, Normal Group, Group 3 and Group 4, while instrument precision bearings are supplied in the first three groups only. Bearings are usually marked in some way to indicate the class of fit, a system of dots, circles or letters often being used. It is important that replacement bearings are of the same standard.

Group2 bearings have the smallest radial internal clearance and are normally used in precision work where minimum axial and radial movement is required. These bearings should not be used where operating conditions, such as high temperatures, could reduce internal clearances, and are not suitable for use as thrust bearings or for high speed.

Normal Group bearings are used for most general applications where only one ring is an interference fit and where no appreciable transfer of heat to the bearing is likely to occur.

Group3 bearings have a greater radial internal clearance than Normal Group bearings and are used where both rings are an interference fit, or where one ring is an interference fit and some transfer of heat must be accepted. They are also used for high speeds and where axial loading predominates.

Group 4 bearings have the largest radial internal clearance; they are used where both rings are an interference fit, and the transfer or heat reduces internal clearances.

LUBRICATION

Adequate lubrication is essential for all types of rolling bearings. The purposes of the lubricant are to lubricate the areas of rubbing contact, e.g. between the rolling elements and the cage, to protect the bearing from corrosion, and to dissipate heat. For low rotational speeds, or for oscillating functions such as are found in a number of airframe applications, grease is a suitable lubricant; at higher rotational speeds grease would generate excessive temperatures because of churning, and oil is more suitable. Because of the variety of uses to which rolling bearings are put, and the varying requirements of different locations, it is important that only those lubricants recommended in the approved Maintenance Manual should be used.

External bearings on aircraft are often of the pre-packed, shielded or sealed types, and are usually packed with antifreeze grease because of the low temperatures encountered; theses bearings cannot normally be re-packed with grease, and when un serviceable, must be rejected. Wheel bearings are normally tapered roller bearings, and should be re-packed with the correct grease when refitting the wheel.

Bearings fitted in engines and gearboxes are generally lubricated by oil spray, splash, mist, drip feed, or controlled level oil bath, and loss of lubricant is prevented by the use of oil retaining devices such as labyrinth seals, felt or rubber washers, and oil throwers.

INSTALLATION OF BEARINGS

The majority of bearing failures are caused by faulty installation, unsatisfactory lubrication, or inadequate protection against the entry of liquids, dirt or grit. To obtain the maximum life from a bearing, therefore, great care must be exercised during installation and maintenance, and strict cleanliness must be maintained at all times.

Where bearings carry axial loads only, the rings need only be a push fit in the housing or on the shaft, as appropriate, but bearings which carry radial loads must be installed with an interference fit between the revolving ring and its housing or shaft, otherwise creep or spin may take place and result in damage to both components. In instances where light alloy housing are used, the bearing may appear to be a loose fit during installation owing to the need to control bearing fit in the housing at the low temperatures experienced at high altitude.

Before installation, a bearing should be checked to ensue that it is free from damage and corrosion, and that it rotates freely. In some cases bearings are packed with storage grease, which is unsuitable for service use and must be removed by washing in a suitable solvent as specified below in topic clearance bearings. All open bearings should be lubricated with the specified oil or grease before installation.

Bearings must be assembled the right way round, i.e. as specified in the appropriate drawing or manual, and should be seated squarely against the shoulders on shafts or housing so that raceway are at right angles to the shaft axis. Damage to the shoulders stress on the bearing and promote rapid wear. It is important, therefore, to ensure that there is no damage likely to prevent correct seating of the bearing rings, and that all mating surfaces are scrupulously clean.

NOTE

Some bearings are supplied as matched pairs, and it is important that they are mounted correctly.

Bearings may often be installed using finger pressure only, but where one ring is an interference fit (usually the rotating inner spring), an assembly tool or press should be used; in some instances it may also be necessary to freeze the shaft or heat the bearing in hot oil, depending on the degree of interference specified. If these tools are not available, the use of a soft steel or brass tube drift may be permitted in some instances; any force necessary must be applied only to the ring concerned, since force applied to the companion ring may result in damage to the rolling elements, or brinelling of the raceways.

NOTE

If a drift is used, the tube must be a close fit over the shaft and must not transmit force to the ring ribs. Light taps from a hammer should be distributed evenly round the top of the drift, to prevent misalignment. On no account should a copper drift be used, as work-hardening could result in chips of copper entering the bearing.

Retaining devices are used to prevent axial movements of the inner and outer rings of a bearing. Stationary outer rings are normally held in place by circlips or retaining plates, and shims are often used in conjunction with the latter to adjust the clearances in thrust or location bearings. All bearings capable of clearance adjustment must be adjusted to the correct clearance or preload specified in the relevant Maintenance or Overhaul Manual, otherwise damage or excessive wear may result. Rotating inner rings are usually firmly held by means of a washer and nut on the shaft and, although the thread may be handed to prevent loosening during operation, care should be taken to ensure that the nut is securely locked to the shaft.

NOTE
In the case of rod end bearings, the out races may be retained in their housing by indentations at the entry faces of the housing, or by use of an epoxy sealer.

On completing of assembly , the bearing housing should, where applicable, be lightly packed with grease to provide, an adequate reserve of lubricant, and oil-lubricated bearing should be lightly lubricated with the appropriate oil. Excessive greasing should be avoided, however, since grease is expelled from the bearing as soon as it begins to rotate, and , if insufficient space is left, churning and overheating may occur, causing the grease to run out and the bearing to fail; as a rough guide, the bearing should be approximately one third full.

MAINTENANCE OF BEARINGS

Ball and roller bearings if properly lubricated and installed, have a long life and require little attention. Bearings failures may have serious results, however, and aircraft Maintenance Manuals and approved Maintenance Schedules included inspections and, where applicable, lubrication for all types of rolling bearings.

Lubrication

Most bearings used in airframe applications are shielded or sealed to prevent the entry of dirt or fluids which could adversely affect bearing life; these bearings cannot normally be regreased, and must be replaced if it is evident that the lubricant has been washed out, or otherwise lost through failure of the seals or bearing wear. Grease nipples are provided for some open bearings so that the grease may be replenished at specified intervals, or when grease is lost through the use of solvents, paint strippers, detergents or de-icing fluid. Nipples should be wiped clean before applying the grease gun, to prevent the entry of dirt into the bearing. Grease forced into the bearing will displace the old grease, and any surplus exuding from the bearing should be wiped off with a clean lint-free cloth.

INSPECTION

Ball and roller bearings are deliberately selected by aircraft and component designers, for use in installation where play or lost motion are unacceptable; wear or corrosion, once started, progress rapidly, and bearings showing evidence of these faults should be discarded. Frequent removal of bearings from shafts or housings may result in damage to either the bearing rings or mating surfaces, and for this reason a routine inspection of a bearing is normally carried out in situ; wheel bearings, however ,are normally inspected when the wheel is removed. If doubt exists as to the serviceability of a bearing, it should be removed, cleaned and inspected .

It may not often be possible to examine the rolling elements and raceways while a bearing is in position, but is usually possible to examine the rings externally for overheating, damage and corrosion, and to examine the cage for loose rivets and damage, after removing surplus grease with a clean lint-free cloth. In all cases a bearing should be checked for wear as follows :-

i. Actuate the moving parts slowly to check for smoothness of operation. Roughness may result from grit in the bearing or surface damage to the rolling elements or raceways, caused by corrosion or excessive wear.
ii. Check for wear by moving the inner race or shaft in both axial and radial directions. The amount of clearance will depend to a large extent on the initial grade of fit of the bearing, but some wear will be acceptable with all classes of fit and may only be considered as unsatisfactory if it leads to excessive backlash in controls, or vibration during operation.
iii. Check shielded bearings to ensure that there is no rubbing contact between the stationary and rotating components. Contact between the shield and inner ring is evidence of excessive wear in the bearing and could lead to contamination of the lubricant by particles of metal rubbed off the shield.

With some bearings, creep or spinning of the races may occur and lead to damage to the shaft or outer ring housing. Where housing end covers or shaft nuts can be removed, these faults may be recognised by polishing of the ring faces.

The internal condition of a bearing may sometimes be revealed by an examination of the lubricant exuding from the bearing. Metal particles reflect light, and give a rough feeling when the lubricant is rubbed into the palm of the hand.

A problem frequently encountered with airframe bearings is moisture contamination, which may result in freezing in a inability to operate a control in low temperature conditions. Every precaution should be taken to prevent the entry to liquids into bearings, and re lubrication of open bearings is often specified after washing. During inspection ,particular attention should be given to rust stains, which may be a good indication of the presence of moisture.

The condition of landing wheel bearings on small aircraft, on which wheels are changed at infrequent intervals, may be checked by rocking and spinning the wheel. This check would normally be impractical and unnecessary on larger aircraft, since the wheels are changed more frequently in order to replace worn tyres.

REMOVAL OF BEARINGS

Many roller bearings are made in two parts, which can be separated for cleaning and inspection without removing he outer ring from its housing or the inner ring from its shaft; all that is necessary is partial dismantling of the associated components to allow the bearing to be inspected and rotated. When it is necessary to remove separated rings or completed bearings, care is necessary to ensure that they are light hammer blows transmitted through the medium of a soft tubular drift may prove effective. Any force necessary should be applied to the ring concerned, since force applied to the companion ring may result in damage to the raceways and rolling elements. Force should not be applied to the ribs of a roller bearing as this may result in fracture or damaged, which would necessitate the rejection of the bearing.

NOTE

Bearings are selectively assembled to match rolling elements very closely for size, and ensure correct internal clearances. When disassembly between partly dismantled bearings, and are reassemble in their original configuration.

CLEANING BEARINGS

Bearings to be cleaned for further examination should first be wiped free of all grease adhering to the surfaces; dry compressed air will assist in dislodging it form the cage and rolling elements, but the bearing should not be allowed to rotate.

The bearings should then be soaked or swilled in white spirit to remove any remaining grease or dirt. It is permissible to oscillate or turn the races slowly to ensure that all foreign matter has been removed, but the bearing should not be spun in this condition, otherwise the working surfaces may become damaged due to the lack of lubrication.
If a bearing cannot be completely cleaned by the above method, a forced jet of white spirit may be used to advantage. The jet may be obtained by fitting a pump to the washing tank, but an efficient filter must be provided.

Jet cleaning can be considerably assisted if the bearing is mounted on a tapered mandrel so that the inner ring will remain stationary, whilst allowing the outer ring to revolve slowly as a result of the fluid from the jet passing through the bearing.

After cleaning, the bearing should be dried with clean, warm, dry compressed air, taking care to permit only very slow rotation, and lightly lubricated with oil to prevent corrosion. The bearing should be slowly rotated during oiling to ensure that all surfaces are covered.

INSPECTION AFTER REMOVAL

After removal and cleaning, bearings should be inspected for corrosion, pitting, fracture, chip, discoloration and excessive internal clearances. With self-aligning bearings or bearings having detachable rings, the condition of the rolling elements and raceways can be seen by swivelling the outer ring through 90 or by separating the outer ring, as appropriate. With bearings having non-detachable rings, the raceways and balls or rollers are sometimes accessible for visual examination, but if not, the raceways and balls or rollers are sometimes accessible for visual examination, but if not, their condition may be judged by holding the inner ring and oscillating the outer ring. Provided their is no foreign matter inside the bearing, any roughness will indicate internal damage.

Slight corrosion on the outer surface of the rings is usually acceptable, provided that it does not prevent proper fit of the rings in housings or on shafts. Staining on the raceways or rolling elements may be acceptable on non-critical bearings, but deep pitting or scaling of the surface would not be acceptable on any types of bearings. Fracture, chips or damage to the rings, balls, rollers or cage, would necessitate rejecting the bearing.

If the rings show signs of creep or spinning, the outside and inside diameters of the bearing should be checked with a micrometer and plug gauge respectively. The shaft and housing should also be inspected for damage and wear, to ensure that a proper fit will be obtained when the bearing is replaced.

The running smoothness of a bearing may be determined by mounting it on a shaft which is mechanically rotated at 500 to 1000 rev\min. With the shaft running and the bearing oiled, the outer ring should be held, and the smoothness and resistance should be determined by applying alternate axial and radial loads in either direction. The outer ring must be square to the shaft, or a false impression of roughness may result.

Excessive wear in a bearing will result in large internal clearances, and a badly worn bearing will normally have been rejected following the initial inspection in situ. Axial clearance in a bearing is seldom quoted since it depends on the internal design of the particular bearing, but, where necessary, a rough guide to the radial internal clearance indicator, the average radial movement obtained at various angular positions of the outer ring. It is important that the outer ring is moved in the same plane as the inner ring, or an incorrect reading will result.

PROTECTION AGAINST CORROSION

Bearings which have been found satisfactory and are to be reused immediately, should be lubricated with oil or grease as appropriate, and reinstalled; bearings which are to be stored should be dipped in rust preventive oil, wrapped in grease proof paper and suitably boxed and labelled. Bearings should be stored horizontally, in a clean, dry atmosphere, and it is recommended that, after one year in storage, the bearings should be inspected for corrosion and re-protected.

■■■

CHAPTER-25
GEARS, GEAR TRAINS AND BEARINGS

DETAILED KNOWLEDGE OF GEARS, GEAR MATERIALS, CLASSIFICATIONS

A gear is an important machine element which is used for transmission of power or motion or both from one shaft to the other. It is normally a round blank carrying projections or teeth along its periphery which enable a positive drive. Gears are vastly employed to from mechanisms for transmission of power from one part to the other in a machine and to effect change in speed or torque or both of one part with respect to the other. Many factors, such as the relative position of the two shafts, the load or power they are expected to transmit, space limitation, running conditions, speeds to be employed and similar other factors.

Gear making is a highly specialised job and so is their design. In this chapter we will confine our discussions to the former part, i.e., Gear making only and for the latter one, i.e., 'Gear design' some standard textbook on the subject may be consulted. A specific point to note here is that all gear cutting machines are single purpose machines as they can be used only for gear cutting. Even more specialised are those machines which cut only one type of gears. Milling machine, however, is a multipurpose machine which, in addition to gear cutting, performs many other operations but it is not suitable for mass production of gears. Its use is, therefore, confined to tool room work only where only a few gears are required to be cut or general repair work is carried out.

DEVELOPMENTAL BACKGROUND

The friction wheels are supposed to be the forerunners of the modern toothed wheels or gears. The friction wheels were simple round discs mounted at the ends of two shafts. The power transmission from one shaft to the other was due to the friction between the mating surfaces of the two wheels. That is why the name 'Friction wheels' was given to these wheels.

The principle of operation of two types of such wheels is shown in Fig. 25.1. The two mating wheels are pressed against each other and the amount of power transmission depends upon the friction between the mating surfaces of the two wheels. Inserts of some compressible material were normally used to increase the friction between the two wheels and, hence, their transmission efficiency. However, in modern practice, since the development of the toothed wheels, the use of friction gears is very rare except in case of very light items in which the torque is very low, such as in the table drive of record players.

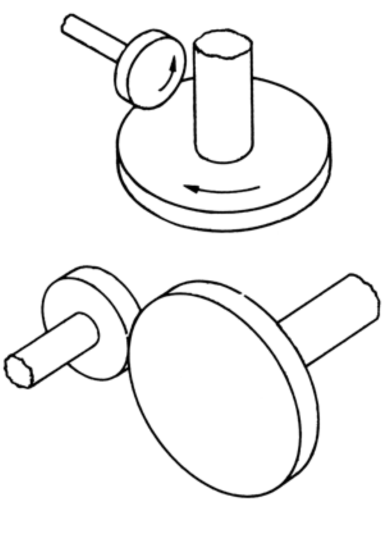


Fig. 25.1, Examples of two types of friction wheels.

DIFFERENT TYPES OF GEAR

(a) Spur Gears

They are the simplest of all the gears and are easiest in production. The teeth cut along the periphery are parallel to the axis of the gear. They are used to transmit power or motion between parallel shafts. Out of the two mating gears, the smaller is known as a pinion and larger one a wheel. (Fig. 25.2)

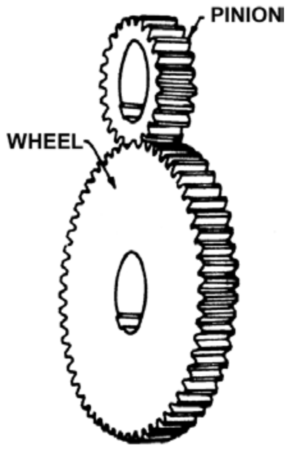


Fig. 25.2, Spur gears.

(b) Helical Gears

These gears are more expensive and difficult in production than the former. The teeth along the periphery are at the angle to the axis of the gear. Each of these teeth forms a part of a helix or spiral. These gears are stronger and quicker than the spur gears because more number of teeth are in mesh at the same time and the engagement of teeth is gradual. With the result they provide a much smoother operation than the former and are preferred where very high speeds are employed. They may be used for transmission of power between both parallel as well as non-parallel shafts. These shafts may be coplaner or lie in different planes. The main disadvantages with these gears is that during the operation they develop an end thrust and for neutralising the same we have to employ a thrust bearing. Alternatively the single helical gears can be replaced by double helical gears, called herring bone gears.

(c) Spiral Gears

Skew or Spiral gearing illustrated in Fig. 25.3 is used to connect non-parallel, non-intersecting shafts. The pitch surfaces are cylindrical and the teeth have point contact. These gears are, therefore, suitable only for transmitting small power. The center distance for a pair of spiral gears is the shortest distance between the two shafts making any angle between them.

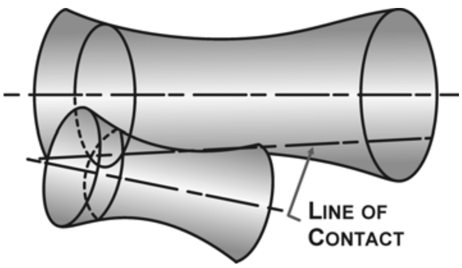


Fig. 25.3, Spiral Gear

(d) Rack & Pinion

A rack can be best described as a gear of infinite radius. It works in conjunction with a small gear, called pinion. The combination provides a means to convert the reciprocating motion into rotary motion and vice versa.

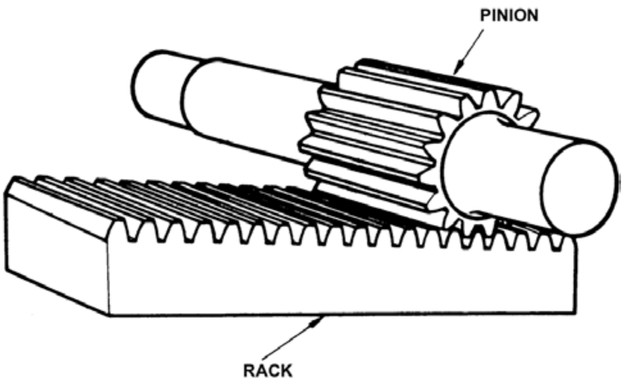


Fig. 25.4, Rack and pinion.

(e) Worm & worm wheel

A worm is more or less similar to a screw having single or multiple start threads which form the teeth of the worm. This worm drives the worm gear to enable transmission of power. The drive is non-reversible, i.e., the worm is always the driver and the worm gear the driven, or in other words we can say that worm gear cannot drive the worm. This is so due to small helix of worm gear teeth. So, for a non-reversible type gear drive this combination is an automatic choice. Another specific use of this combination is in speed reduction. By using a worm gear having many teeth considerable speed reduction can be effected which is not possible through other gearing systems within a limited space. The axes of worm gear are non-intersecting and at right angles. (Fig. 25.5).

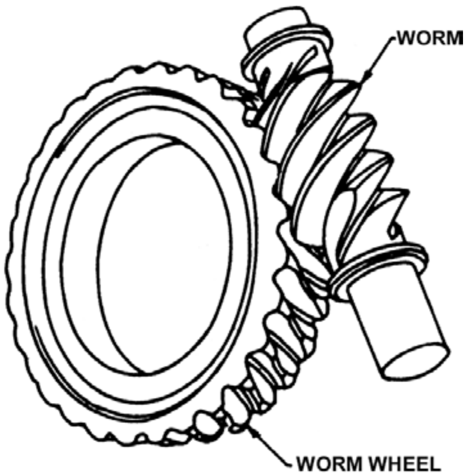


Fig. 25.5, Worm and worm gear (or worm wheel)

(f) Bevel Gears

They are used to connect shafts at any desired angle to one another, but not parallel. The most common angle between the connected shafts is normally 90°. The shafts may lie in the same plane or different planes. If power transmission is the only object the two mating gears may have same numbers or teeth, but if some speed reduction is also desired the number of teeth in the two will differ. The toothed body of bevel gear is actually a frustum of a cone. The straight bevel gear carries straight teeth which, if extended, will meet at a common point called apex. Apex also forms the point of intersection of the axes of the connected shafts. If the gear carries spiral teeth it is known as spiral bevel gear. Mitre gears is the name given to a pair of mating bevel gears in which each will have the same number of teeth and their axes will intersect at right angles to each other. Crown gear is the term used to denote a bevel gear which is cut on a plane surface instead of the usual conical one.

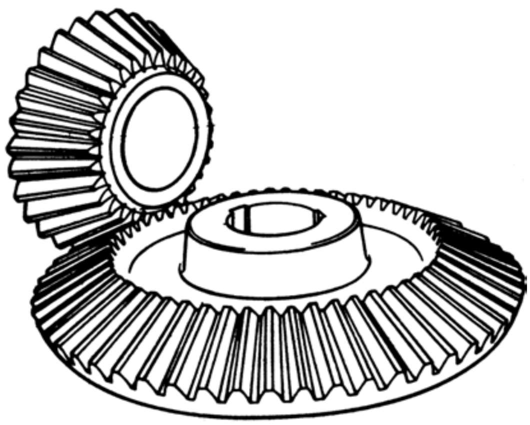


Fig. 25.6, Bevel gears (Straight Teeth)

(g) Reverted Gear Train (Reduction Gearing)

When the axes of the first gear (i.e. first driver) and the last gear (i.e. last driven or follower) are co-axial, then the gear train is known as reverted gear train as shown in Fig. 25.7.

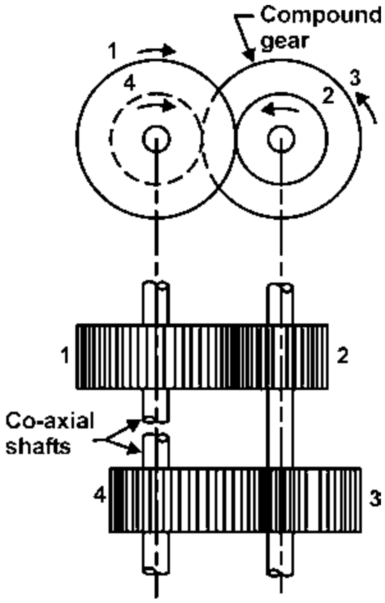


Fig. 25.7, Reverted gear train.

We see that gear 1 (i.e. first driver) drives the gear 2 (i.e. first driven or follower) in the opposite direction. Since the gears 2 and 3 are mounted on the same shaft, therefore they form a compound gear and the gear 3 will rotate in the same direction as that of gear 2. The gear 3 (which is now the second driver) drives the gear 4 (i.e. the last driven or follower) in the same direction as that of gear 1. Thus we see that in a reverted gear train, the motion of the first gear and the last gear is like.

Let T_1 = Number of teeth on gear 1,
r_1 = Pitch circle radius of gear 1, and
N_1 = Speed of gear 1 in r.p.m.

Similarly,

T_2, T_3, T_4 = Number of teeth on respective gears,
r_2, r_3, r_4 = Pitch circle radii of respective gears, and
N_2, N_3, N_4 = Speed of respective gears in r.p.m.

Since the distance between the centres of the shafts of gears 1 and 2 as well as gears 3 and 4 is same, therefore

$$r_1 + r_2 = r_3 + r_4 \quad \text{(i)}$$

Also, the circular pitch or module of all the gears is assumed to be same, therefore number of teeth on each gear is directly proportional to its circumference or radius.

$$\therefore \quad T_1 + T_2 = T_3 + T_4 \quad \text{(ii)}$$

and

$$\text{Speed ratio} = \frac{\text{Product of number of teeth on drivens}}{\text{Product of number of teeth on drivers}}$$

or

$$\frac{N_1}{N_4} = \frac{T_2 \times T_4}{T_1 \times T_3} \quad \text{(iii)}$$

From equations (i), (ii) and (iii), we can determine the number of teeth on each gear for the given centre distance, speed ratio and module only when the number of teeth on one gear is chosen arbitrarily.

The reverted gear trains are used tin automotive transmissions, lathe back gears, industrial speed reducers, and in clocks (where the minute and hour hand shafts are co-axial)

(h) Simple Gear Trains (Driver / Driven Gear)

When the distance between the two shafts is small, the two gears 1 and 2 are made to mesh with each other to transmit motion from one shaft to the other, as shown in Fig. 25.8 (a). Since the gear 1 drives the gear 2, therefore gear 1 is called the driver and the gear 2 is called the driven or follower. It may be noted that the motion of the driven gear is opposite to the motion of driving gear.

Driver Gear

In a gear system, the gear that receives energy from the driving mechanism. A driver gear transmit power to a machine driven gear to perform work.

Driven Gear

In a gear system, the gear that receives motion from the driver gear on a machine. Driven gears often turn tools or components.

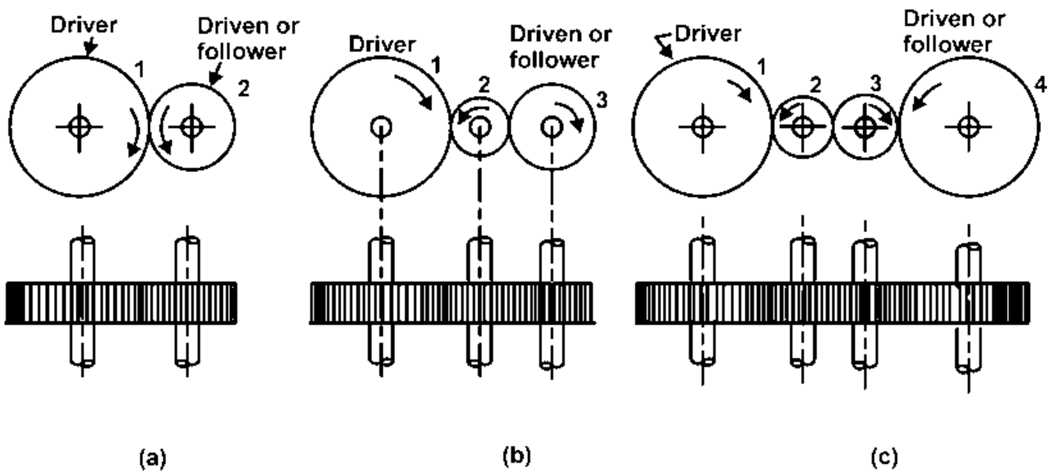


Fig. 25.8, Simple gear train.

Let N_1 = Speed of gear 1 (or driver) in r.p.m.,

N_2 = Speed of gear 2 (or driven or follower) in r.p.m.,

T_1 = Number of teeth on gear 1, and

T_2 = Number of teeth on gear 2.

Since the speed ratio (or velocity ratio) of gear train is the ratio of the speed of the driver to the speed of the driven or follower and ratio of speeds of any pair of gears in mesh is the inverse of their number of teeth, therefore

$$\text{Speed ratio} = \frac{N_1}{N_2} = \frac{T_2}{T_1}$$

It may be noted that ratio of the speed of the driven or follower to the speed of the driver is known as train value of the gear train. Mathematically

$$\text{Train value} = \frac{N_2}{N_1} = \frac{T_1}{T_2}$$

From above, we see that the train value is the reciprocal of speed ratio.

Compound Gear Train

When there are more than one gear on a shaft, as shown in Fig. 25.9, it is called a compound train of gear.

We have seen earlier that the idle gears, in a simple train of gears do not effect the speed ratio of the system. But these gears are useful in bridging over the space between the driver and the driven.

But whenever the distance between the driver and the driven or follower has to be bridged over by intermediate gears and at the same time a great (or much less) speed ratio is required, then the advantage of intermediate gears is intensified by providing compound gears on intermediate shafts. In this case, each intermediate shaft has two gears rigidly fixed to it so that they may have the same speed. One of these two gears meshes with the driver and the other with the driven or follower attached to the next shaft as shown in Fig. 25.9.

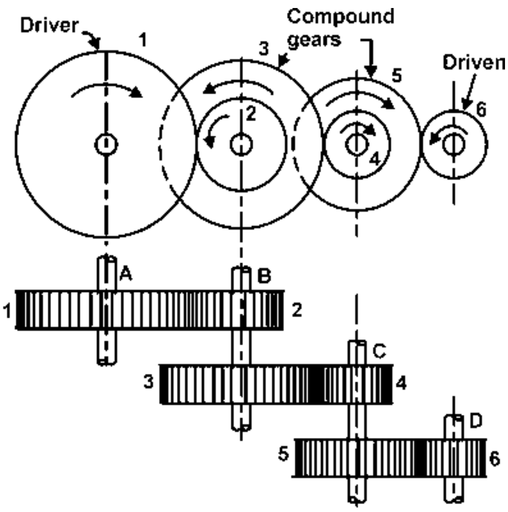


Fig. 25.9, Compound gear train.

In a compound train of gears, as shown in Fig. 25.9, the gear 1 is the driving gear mounted on shaft a, gears 2 and 3 are compound gears which are mounted on shaft B. The gears 4 and 5 are also compound gears which are mounted on shaft C and the gear 6 is the driven gear mounted on shaft D.

(i) Epicyclic Gear Train

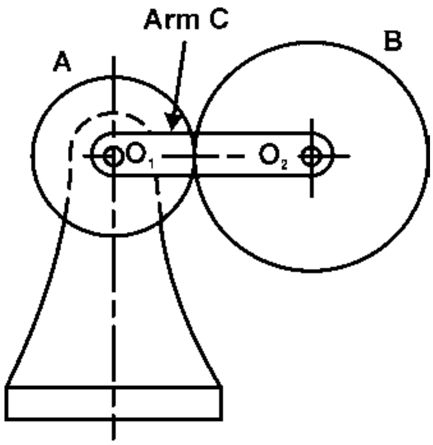


Fig. 25.10, Epicyclic gear train.

We have already discussed that in an epicyclic gear train, the axes of the shafts, over which the gears are mounted, may move relative to a fixed axis. A simple epicyclic gear train is shown in Fig. 25.10, where a gear a and the arm C have a common axis at O_1 about which they can rotate. The gear B meshes with gear A and has its axis on the arm at O_2, about which the gear B can rotate. If the arm is fixed, the gear train is simple and gear A can drive gear B or vice versa, but if gear A is fixed and the arm is rotated about the axis of gear A (i.e. O_1), then the gear B is forced to rotate upon and around gear A. Such a motion is called epicyclic and the gear trains arranged in such a manner that one or more of their members move upon an around another member are known as epicyclic gear trains (epi. means upon and cyclic means around). The epicyclic gear trains may be simple or compound.

The epicyclic gear trains are useful for transmitting high velocity ratios with gears of moderate size in a comparatively lesser space. The epicyclic gear trains are used in the back gear of lathe, differential gears of the automobiles, hoists, pulley blocks, wrist watches etc.

ON THE BASIS OF LINEAR VELOCITY

I. Low Velocity Gears

The gears having velocity less than 3 m/s are termed as low velocity gears.

II. Medium Velocity Gears

Gears having velocity between 3 and 15 m/s are known as medium velocity gears.

III. High Velocity Gears

The velocity of gears is more than 15 m/s, then these are called high speed gears.

UNDERSTANDING TERMS

TERMINOLOGY OF GEARS

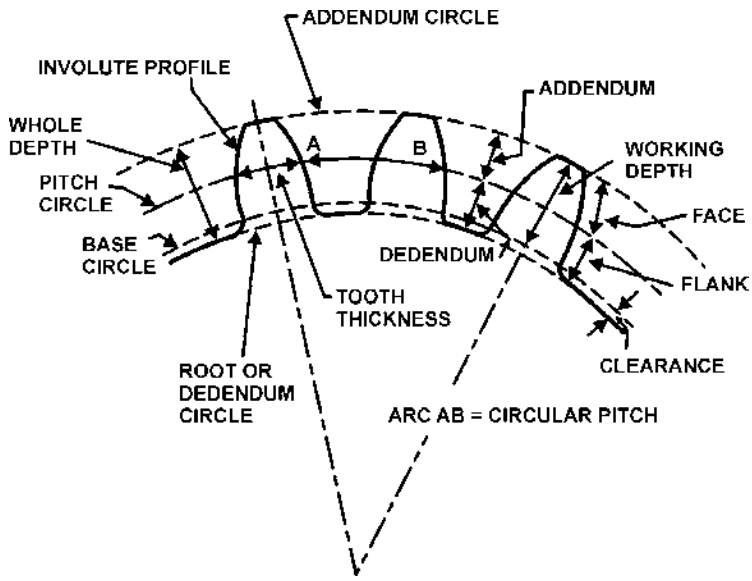


Fig.25.11, Terms used in gears.

Addendum circle

The circle which limits the tops of the gear teeth and represents its maximum diameter is called Addendum circle.

Addendum

It is the radial distance between the addendum circle and pitch circle.

Pitch circle

The circle on which fall the centres of the pitch cylinders, on which the tooth profiles are formed, is called pitch circle.

Dedendum

It is the radial distance between the pitch circle and the root circle.

Clearance

The distance between the top of a tooth of one gear and the bottom of the corresponding space of the mating gear is known as clearance.

Basic circle

It occurs only in involute gears and is that circle from which the involute curve of the tooth profile is generated.

Pressure angle

The angle made by the line of action with the common tangent to the pitch circle is called pressure angle. Its value is 14° or 20° for involute gears.

Face

The portion of tooth lying between the addendum 'circle and pitch circle is called face.

Flank

Portion of the tooth lying between the pitch circle and dedendum circle is called flank.

Thickness

Width of the tooth measured along the pitch circle is called the tooth thickness.

Backlash

The difference between actual tooth thickness and the width of space, with which it meshes, is known as backlash.

Circular pitch (p)

It is the distance between corresponding points of adjacent teeth measured along the pitch circle.

Diametral pitch (P)

It is a number that represents the number of teeth on the gear per unit of diameter of the pitch circle.

i.e., $P = \frac{N}{d}$

where, N = number of teeth in the gear
and d = diameter of pitch circle.

Module (M)

It can be described as the metric standard for pitch. It is the linear distance in mm that each tooth of the gear would occupy if the gear teeth were spaced along the pitch diameter.

Important ratios

Let, d = pitch circle dia
R = pitch circle radius
P = diametral pitch
p = circular pitch
M = module
N = No. of teeth in gear
Add. = Addendum
Ded. = Dedendum

Then, $P = \frac{\text{N (No. of teeth in gear)}}{\text{d (dia. of pitch circle)}}$

or, $d = \frac{N}{P}$ (i)

Also, $M = \frac{d}{N} = \frac{1}{P}$ (ii)

or, $d = M \times N$

Now, $\pi d = N \times P$

$\therefore$ $d = \frac{N.P}{\pi}$ (iii)

Equating (i) and (iii)

$$\frac{N}{P} = \frac{N.p}{\pi}$$

or $p = \frac{\pi.N}{P.N} = \frac{\pi}{P}$ (iv)

Again, $p = \frac{N}{d}$ or $d = \frac{N}{P}$ (v)

and, $M = \frac{\text{pitch circle dia.}}{\text{no. of teeth}} = \frac{d}{N}$ or $d = MN$ (vi)

Equating (v) and (vi), we get :

$$MN = \frac{N}{p}$$

or, $$M = \frac{N}{N.P} = \frac{1}{p} \qquad \text{(vii)}$$

Standard modules

The Indian Standards Institution has recommended the following modules (in mm) in order of preference.

First choice

1, 1.25, 1.5, 2, 2.5, 3, 4, 5, 6, 8, 10, 12, 16, 20.

Second choice

1.125, 1.375, 1.75, 2.25, 2.75, 3.5, 4.5, 5.5, 7.9, 11, 14, 18.

Third choice

3.25, 3.75, 6.5.

TEETH, CYCLOIDAL & INVOLUTE

Cycloidal Teeth

A cycloid is the curve traced by a point on the circumference of a circle which rolls without slipping on a fixed straight line. When a circle rolls without slipping on the outside of a fixed circle, the curve traced by a point on the circumference of a circle is known as epi-cycloid. On the other hand, if a circle rolls without slipping on the inside of a fixed circle, then the curve traced by a point on the circumference of a circle is called hypo-cycloid.

In Fig. 25.12 (a), the fixed line or pitch line of a rack is shown. When the circle C rolls without slipping above the pitch line in the direction as indicated in Fig. 25.12 (a), then the point P on the circle traces epi-cycloid PA. This represents the face of the cycloidal tooth profile. When the circle D rolls without slipping below the pitch line, then the point P on the circle D traces hypo-cycloid PB, which represents the flank of the cycloidal tooth. The profile BPA is one side of the cycloidal rack tooth. Similarly, the two curves P'A' and P'B' forming the opposite side of the tooth profile are traced by the point P' when the circles C and D roll in the opposite directions.

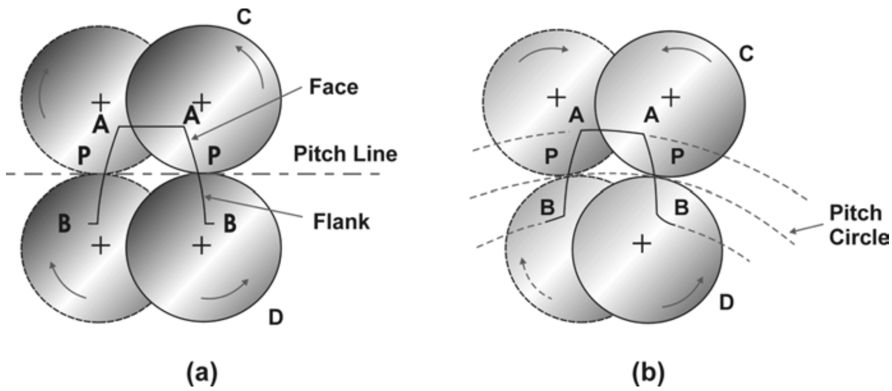


Fig. 25.12, Construction of cycloidal teeth of a gear.

In the similar way, the cycloidal teeth of a gear may be constructed as shown in Fig. 25.12 (b). The circle C is rolled without slipping on the outside of the pitch circle and the point P on the circle C traces epi-cycloid PA, which represents the face of the cycloidal tooth. The circle D is rolled on the inside of pitch circle and the point P on the circle D traces hypo-cycloid PB, which represents the flank of the tooth profile. The profile BPA is one side of the cycloidal tooth. The opposite side of the tooth is traced as explained above.

The construction of the two mating cycloidal teeth is shown in Fig. 25.13. A point on the circle D will trace the flank of the tooth T_1 when circle D rolls without slipping on the inside of pitch circle of wheel 1 and face of tooth T_2 when the circle D rolls without slipping on the outside of pitch circle of wheel 2. Similarly, a point on the circle C will trace the face of tooth T_1 and flank of tooth T_2. The rolling circles C and D may have unequal diameters, but if several wheels are to be interchangeable, they must have rolling circles of equal diameters.

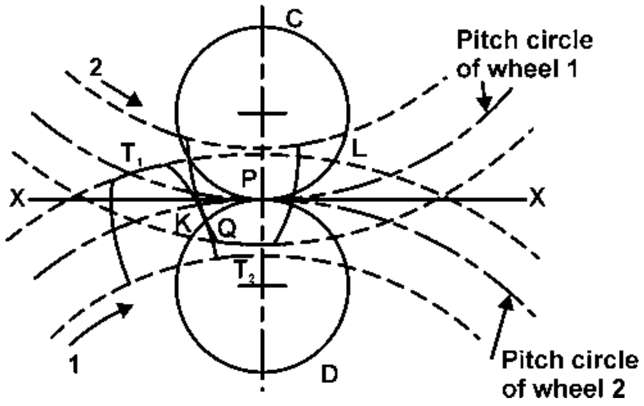


Fig. 25.13, Construction of two mating cycloidal teeth.

A little consideration will show, that the common normal XX at the point of contact between two cyclidal teeth always passes through the pitch point, which is the fundamental condition for a constant velocity ratio.

Involute Teeth

An involute of a circle is a plane curve generated by a point on a tangent, which rolls on the circle without slipping or by a point on a taut string which in unwrapped from a reel as shown in Fig. 25.14. In connection with toothed wheels, the circle is known as base circle. The involute is traced as follows :

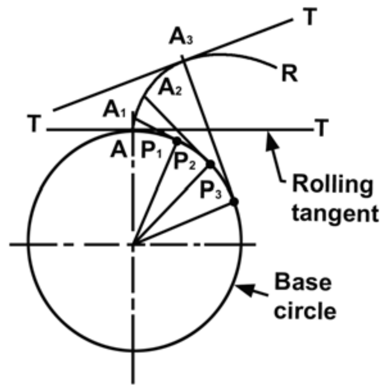


Fig. 25.14, Construction of involute.

Let A be the starting point of the involute. The base circle is divided into equal number of parts e.g. AP_1, P_1P_2, P_2P_3 etc. The tangents at P_1, P_2, P_3 etc. are drawn and the length P_1A_1, P_2A_2, P_3A_3 equal to the arcs AP_1, AP_2 and AP_3 are set off. Joining the points A, A_1, A_2, A_3 etc, we obtain the involute curve AR. A little consideration will show, that at any instant A_3, the tangent A_3T to the involute is perpendicular to P_3A_3 and P_3A_3 is the normal to the involute. In other words normal at any point of an involute is a tangent to the circle.

Now, let O_1 and O_2 be the fixed centres of the two base circles as shown in Fig. 25.15 (a). Let the corresponding involutes AB and A_1B_1 be in contact at point Q. MQ and NQ are normals to the involutes at Q and are tangents to base circles. Since the normal of an involute at a given point is the tangent drawn from that point to the base circle, therefore the common normal MN at Q is also the common tangent to the two base circles. We see that the common normal MN intersects the line of centres O_1O_2 at the fixed point P (called pitch point). Therefore the involute teeth satisfy the fundamental condition of constant velocity ratio.

From similar Triangles O_2NP and O_1MP,

$$\frac{O_1M}{O_2N} = \frac{O_1P}{O_2P} = \frac{\omega_2}{\omega_1}$$

which determines the ratio of the radii of the two base circles. The radii of the base circles is given by

$$O_1M = O_1P\cos\phi, \text{ and } O_2N = O_2P\cos\phi$$

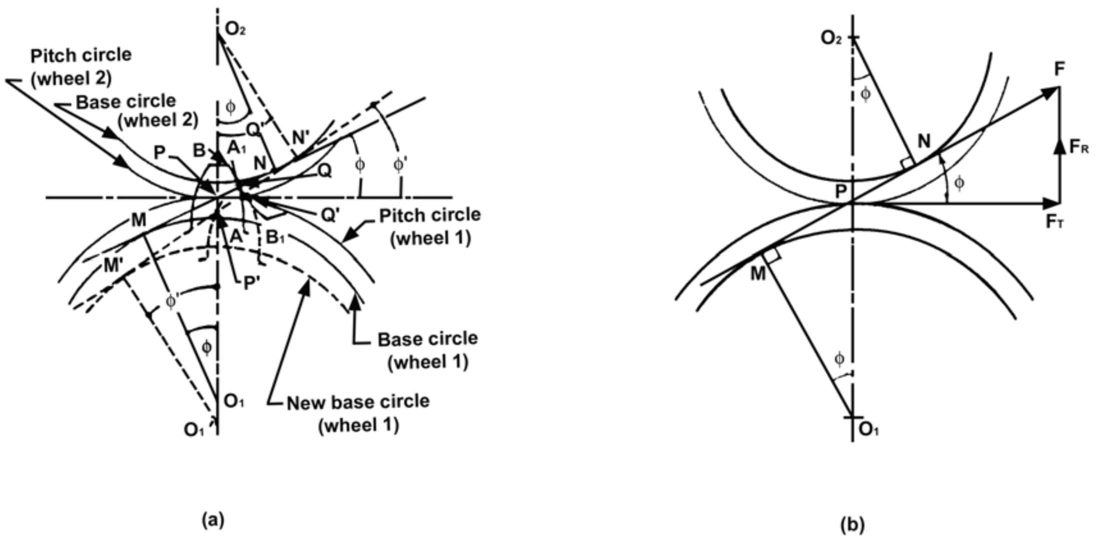


Fig. 25.15, Involute teeth

Also the centre distance between the base circles,

$$O_1O_2 = O_1P + O_2P = \frac{O_1M}{\cos\phi} + \frac{O_2N}{\cos\phi} = \frac{O_1M + O_2N}{\cos\phi}$$

where ϕ is the pressure angle or the angle of obliquity. It is the angle which the common normal to the base circles (i.e. MN) makes with the common tangent to the pitch circles.

When the power is being transmitted, the maximum tooth pressure (neglecting friction at the teeth) is exerted along the common normal through the pitch point. This force may be resolved into tangential and radial or normal components. These components acts along and at right angles to the common tangent to the pitch circles.

If F is the maximum tooth pressure as shown in Fig. 25.15 (b), then

Tangential force, $F_T = F\cos\phi$

and radial or normal force, $F_R = F\sin\phi$

$\therefore$ Torque exerted on the gear shaft

$= F_T \times r$, where r is the pitch circle radius of the gear.

Note

The tangential force provides the driving torque and the radial or normal force produces radial deflection of the rim and bending of the shafts.

INTERFERENCE

Fig. 25.16 shows a pinion with centre O_1, in mesh with wheel or gear with centre O_2. MN is the common tangent to the base circles and KL is the path of contact between the two mating teeth.

A little consideration will show, that if the radius of the addendum circle of pinion is increased to O_1N, the point of contact L will move from L to N. When this radius is further increased, the point of contact L will be on the inside of base circle of wheel and not on the involute profile of tooth on wheel. The tip of tooth on the pinion will then undercut the tooth on the wheel. This effect is known as interference, and occurs when the teeth are being cut. In brief, the phenomenon when the tip of tooth undercuts the root on its mating gear is known as interference.

Similarly, if the radius of the addendum circle of the wheel increases beyond O_2M, then the tip of tooth on wheel will cause interference with the tooth on pinion. The points M and N are called interference points. Obviously, interference may be avoided if the path of contact does not extend beyond interference points. The limiting value of the radius of the addendum circle of the pinion is O_1N and of the wheel is O_2M.

From the above discussion, we conclude that the interference may only be avoided, if the point of contact between the two teeth is always on the involute profiles of both the teeth. In other words, interference may only be prevented, if the addendum circles of the two mating gears cut the common tangent to the base circles between the points of tangency.

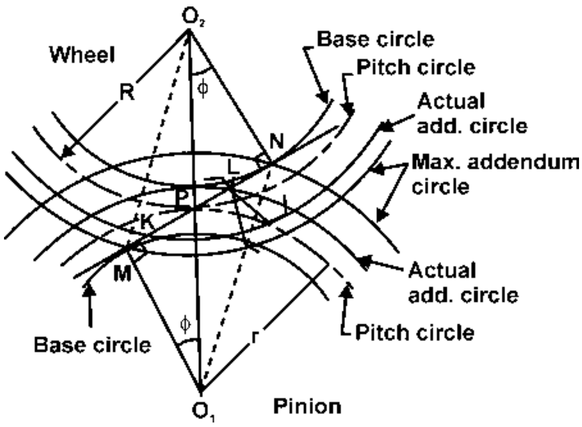


Fig. 25.16, Interference in involute gears.

TYPE OF GEAR TRAINS

Design of Spur Gears

Sometimes, the spur gear (i.e. driver and driven) are to be designed for the given velocity ratio and distance between the centres of their shafts.

Let x = Distance between the centres of two shafts,

N_1 = Speed of the driver,

T_1 = Number of teeth on the driver,

d_1 = Pitch circle diameter of the driver,

N_2, T_2 and d_2 = Corresponding values for the driven or follower, and

pc = Circular pitch

We know that the distance between the centres of two shafts,

$$x = \frac{d_1 + d_2}{2} \quad \text{(i)}$$

and speed ratio or velocity ratio,

$$\frac{N_1}{N_2} = \frac{d_2}{d_1} = \frac{T_2}{T_1} \quad \text{(ii)}$$

From the above equations, we can conveniently find out the values of d1 and d2 (or T_1 and T_2) and the circular pitch (p_c). The values of T_1 and T_2, as obtained above, may or may not be whole numbers. But in a gear since the number of its teeth is always a whole number, therefore a slight alterations must be made in the values of x, d_1 and d_2, so that the number of teeth in the two gears may be a complete number.

Idler Gear

A gear situated between a driving gear and a driven gear to transfer motion, without any change of direction or of gear ratio.

An idler-wheel drive is a system used to transmit the rotation of the main shaft of a motor to another rotating device. For example the platter of a record-reproducing turntable or the crankshaft-to-camshaft gear train of an automobile.

An idler gear is a gear wheel that is inserted between two or more other gear wheels.

The purpose of an idler gear can be two-fold. Firstly, the idler gear will change the direction of rotation of the output shaft. Secondly, an idler gear can assist to reduce the size of the input/output gears whilst maintaining the spacing of the shafts.

Meshing of Gear

A gear is a rotating machine part having cut teeth, or cogs, which mesh with another toothed part in order to transmit torque. Two or more gears working in tandem are called a transmission and can produce a mechanical advantage through a gear ratio and thus may be considered a simple machine. Geared devices can change the speed, magnitude, and direction of a power source. The most common situation is for a gear to mesh with another gear, however a gear can also mesh a non-rotating toothed part, called a rack, thereby producing translation instead of rotation.

The gears in a transmission are analogous to the wheels in a pulley. An advantage of gears is that the teeth of a gear prevent slipping.

When two gears of unequal number of teeth are combined a mechanical advantage is produced, with both the rotational speeds and the torques of the two gears differing in a simple relationship.

In transmissions which offer multiple gear ratios, such as bicycles and cars, the term gear , as in first gear, refers to a gear ratio rather than an actual physical gear. The term is used to describe similar devices even when gear ratio is continuous rather than discrete, or when the device does not actually contain any gears, as in a continuously variable transmission.

The earliest known reference to gears was circa 50 A.D. by Hero of Alexandria, but they can be traced back to the Greek mechanics of the Alexandrian school in the 3rd century BC and were greatly developed by Greek polymath Archimedes (287-212 BC).

Gear Ratio

The gear ratio is the relationship between the numbers of teeth on two gears that are meshed or two sprockets connected with a common roller chain, or the circumferences of two pulleys connected with drive belt.

General Description

In the picture to the right, the smaller gear (known as the pinion) has 13 teeth, while the second, larger gear (known as the idler gear) has 21 teeth. The gear ratio is therefore 21/13, 1.62/1, or

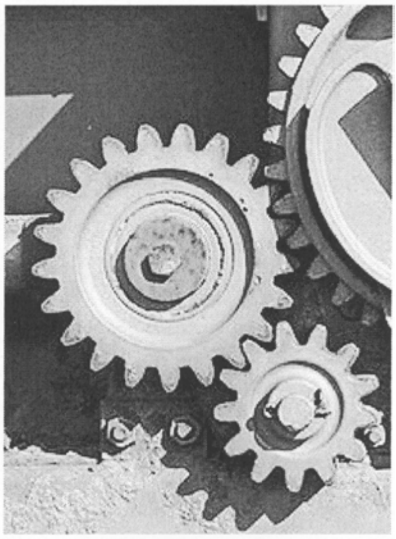


Fig. 25.17, Gear Ratio

Gear Ratio (GR) = (Number of teeth on Gear or driven) / Number of teeth on Pinion or driver).

The ratio means that the pinion gear must make 1.62 revolutions to turn the idler gear 1 revolution. It also means that for every one revolution of the pinion, the idler gear has made 1/1.62, or 0.62, revolutions. In practical terms, the idler gear turns more slowly.

Suppose the largest gear in the picture has 42 teeth, the gear ratio between the second and third gear is thus 42/21, or 2 : 1, and hence the total gear ratio is $1.62 \times 2 = 3.23$. For every 3.23 revolutions of the smallest gear, the largest gear turns one revolution, or for every one revolution of the smallest gear, the largest gear turns 0.31 (1/3.23) revolution, a total reduction of about 1:3.23 (Gear Reduction Ratio (GRR) = 1/Gear Ratio (GR)).

Since the intermediate (idler) gear contacts directly both the smaller and the larger gear it can be removed from the calculation, also giving a ratio of 42/13 = 3.23

■ ■ ■

CHAPTER-26
BELTS AND DRIVES

INTRODUCTION

The belts or ropes are used to transmit power from one shaft to another by means of pulleys which rotate at the same speed or at different speeds. The amount of power transmitted depends upon the following factors :

1. The velocity of the belt.
2. The tension under which the belt is placed on the pulleys.
3. The arc of contact between the belt and the smaller pulley.
4. The conditions under which the belt is used.

TYPES OF BELTS

Though there are many types of belts used these days, yet the following are important from the subject point of view:

1. Flat Belt

The flat belt as shown in fig. 26.1 (a), is mostly used in the factories and workshops, where a moderate amount of power is to be transmitted, from one pulley to another when the two pulleys are not more than 8 metres apart.

2. V-belt

The V-belt as shown in Fig. 26.1 (b), is mostly used in the factories and workshops, where a great amount of power is to be transmitted, from one pulley to another, when the two pulleys are very near to each other.

3. Circular belt or rope

The circular belt rope as shown in Fig 26.1 (c) is mostly used in the factories and workshops, where a great amount of power is to be transmitted, from one pulley to another, when the two pulleys are more than 8 metres apart.

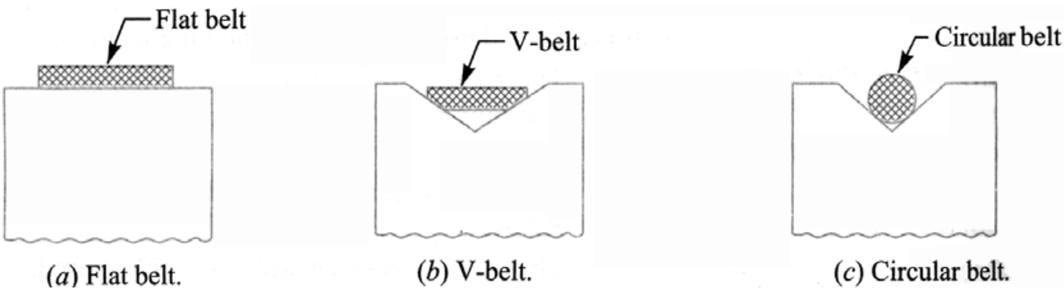


Fig. 26.1, Types of belts

If a huge amount of power is to be transmitted, then a single belt may not be sufficient. In such a case, wide pulleys (for V-belts or circular belts) with a number of grooves are used. Then a belt in each groove is provided to transmit the required amount of power from one pulley to another.

MATERIAL USED FOR BELTS

The material used for belts and ropes must be strong, flexible, and durable. It must have a high coefficient of friction. The belts, according to the material used, are classified as follows :

1. Leather Belts

The most important material for flat belt is leather. The best leather belts are made from 1.2 metres to 1.5 metres long strips cut from either side of the back bone of the top grade steer hides. The hair side of the leather is smoother and harder than the flesh side, but the flesh side is stronger. The fibres on the hair side are perpendicular to the surface, while those on the flesh side are interwoven and parallel to the surface. Therefore for these reasons the hair side of a belt should being contact with the pulley surface as shown in Fig. 26.2. This gives a more intimate contact between belt and pulley and places the greatest tensile strength of the belt section on the outside, where the tension is maximum as the belt passes over the pulley.

The leather may be either oak-tanned or mineral salt-tanned e.g. chrome-tanned. In order to increase the thickness of belt, the strips are cemented together. The belts are specified according to the number of layers e.g. single, double or triple ply and according to the thickness of hides used e.g. light medium or heavy.

The leather belts must be periodically cleaned and dressed or treated with a compound or dressing containing neats foot or other suitable oils so that the belt will remain soft and flexible.

Fig. 26.2, Leather Belts

2. Cotton or fabric belts

Most of the fabric belts are made by folding canvass or cotton duck to three or more layers (depending upon the thickness desired) and stitching together. These belts are woven also into a strip of the desired width and thickness. They are impregnated with some filler like linseed oil in order to make the belt water-proof and to prevent injury to the fibres. The cotton belts are cheaper and suitable in warm climates, in damp atmospheres and in exposed positions. Since the cotton belts require little attention, therefore these belts are mostly used in farm machinery, belt conveyor etc.

3. Rubber belt

The rubber belts are made of layers of fabric impregnated with rubber composition and have a thin layer of rubber on the faces. These belts are very flexible but are quickly destroyed if allowed to come into contact with heat, oil or grease. One of the principle advantage of these belts is that they amy be easily made endless. These belts are found suitable for saw mills, paper mills where they are exposed to moisture.

4. Balata belts

These belts are similar to rubber belts except that balata gum is used in place of rubber. These belts are acid proof and water proof and it is not effected by animal oils or alkalies. The balata belts should not be at temperatures above 40°C because at this temperature the balata begins to soften and becomes sticky. The strength of balata belts is 25 per cent higher than rubber belts.

PULLEYS

The pulleys are used to transmit power form one shaft to another by means of flat belts, V-belts or ropes. Since the velocity ratio is the inverse ratio of the diameters of driving and driven pulleys, therefore the pulley diameters should be carefully selected in order to have a desired velocity ratio. The pulleys must be in perfect alignment in order to allow the belt to travel in a line normal to the pulley faces.

The pulleys may be made of cast steel or pressed steel, wood and paper. The cast materials should have good friction wear characteristics. The pulleys made of pressed steel are lighter than cast pulleys, but in many cases they have lower friction and may produce excessive wear.

TYPES OF PULLEYS FOR FLAT BELTS

Following are the various types of pulleys for flat belts :

1. Cast Iron Pulleys
2. Steel Pulleys,
3. Wooden Pulleys,
4. Paper Pulleys and
5. Fast and loose pulleys.

We shall now discuss, the above mentioned pulleys in the following pages

1. Cast Iron Pulleys

The pulleys are generally made of cast iron, because of their low cast. The rim is held in place by web from the central boss or by arms or spokes. The arms may be straight or curved as shown in Fig. 26.3 (a) and (b) and the cross-section is usually elliptical.

When a cast pulley contracts in the mould, the arms are in a state of stress and very liable to break. The curved arms tend to yield rather than to break. The arms are near the hub.

The cast iron pulleys are generally made with rounded rims. This slight convexity is known as crowning tends to keep the belt in centre on a pulley rim while in motion. The crowning may be 9 mm for 300 mm width of pulley face.

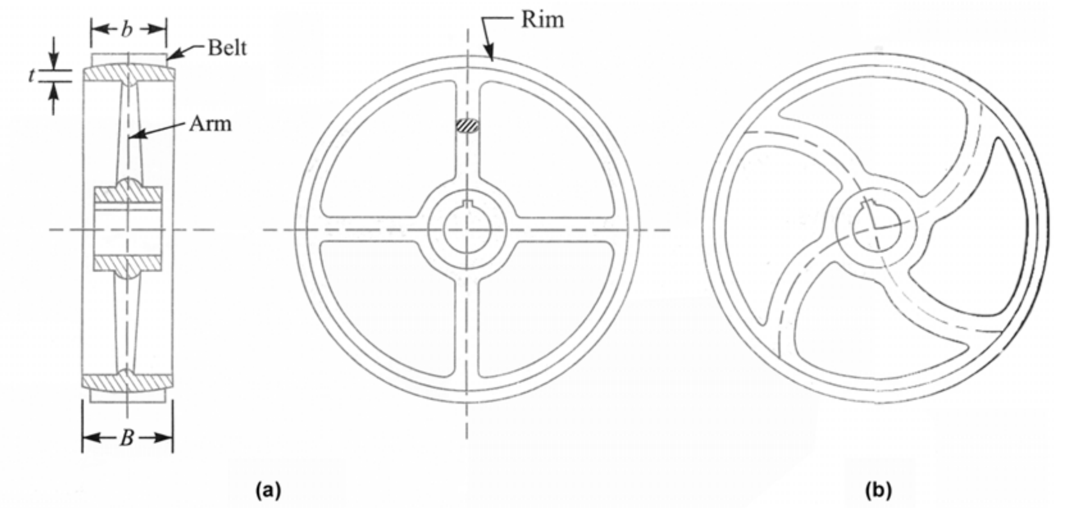


Fig. 26.3, Solid Cast iron pulleys.

The cast iron pulleys may be solid as shown in Fig. 26.3 or split type as shown in Fig. 26.4. When it is necessary to mount a pulley on a shaft which already carrying pulleys etc. or have its ends swelled, it is easier to use a split-pulley. There is a clearance between the faces and the two halves are readily tightened upon the shafts by the bolts as shown in Fig. 26.4. A sunk key is used for heavy drives.

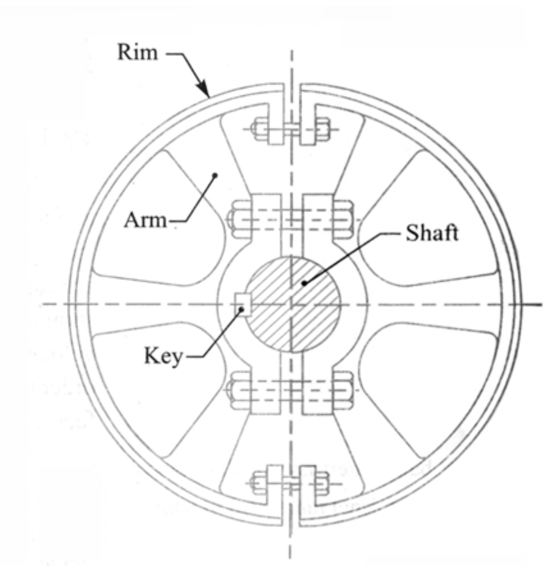


Fig. 26.4, Split cast iron pulley.

2. Steel Pulleys

Steel pulleys are made from pressed steel sheets and have great strength and durability. These pulleys are lighter in weight (about 40 to 60% less) than cast iron pulleys of the same capacity and are designed to run at high speeds. They present a coefficient of friction with leather belting which is atleast equal to that obtained by cast iron pulleys.

Steel pulleys are generally made in two halves which are bolted together. The clamping action of the hub holds the pulley to its shaft, thus no key is required except for most severe service. Steel pulleys are generally equipped with interchangeable bushings to permit their use with shafts of different sizes The following table shows the number of spokes and their sizes according to Indian Standard, IS : 1691 - 1980 (Reaffirmed 1990).

Other proportions for the Steel pulleys are :

$$\text{Length of hub} = \frac{\text{Width of face}}{2}$$

The length of hub should not be less than 100 mm for 19 mm diameter spokes and 138 mm for 22mm diameter of spokes.

Table 26.1. Standard number of spokes and their sizes according to IS : 1691 - 1980 (Reaffirmed 1990)

Diameter of pulley (mm)	*No. of spokes*	*Diameter of spokes (mm)*
280 – 500	6	19
560 – 710	8	19
800 – 1000	10	22
1120	12	22
1250	14	22
1400	16	22
1600	18	22
1800	18	22

Thickness or rim = 5 mm for all sizes.

A single row of spokes is used for pulleys having width upto 300 mm and double row of spokes for widths above 300 mm.

3. Wooden Pulleys

Wooden pulleys are light and possesses higher coefficient of friction than cast iron or steel pulleys. These pulleys have 2/3 rd of the weight of cast iron pulleys of similar size. They are generally made from selected maple which is laid in segments and glued together under heavy pressure. They are kept from absorbing moisture by protective coatings of shellac or varnish so that warping may not occur. These pulleys are made both solid or split with cast iron hubs with keyways or have adjustable bushings which prevents relative rotation between them and the shaft by the frictional resistance set up. These pulleys are used for motor drives in which the contact arc between the pulley face and belt is restricted.

4. Paper Pulleys

Paper pulleys are made from compressed paper fibre an are formed with a metal in the centre. These pulleys are usually used for belt transmission from electric motors, when the centre to centre shaft distance us small.

5. Fast and Loose Pulleys

A fast and loose pulley, as shown in Fig. 26.5, used on shafts enables machine to be started or stopped at will. A fast pulley is keyed to the machine shaft while the loose pulley runs freely. The belt runs over the fast pulley to transmit power by the machine and it is shifted to the loose pulley when the machine is not required to transmit power. By this way, stopping of one machine does not interfere with the other machines which run by the same line shaft.

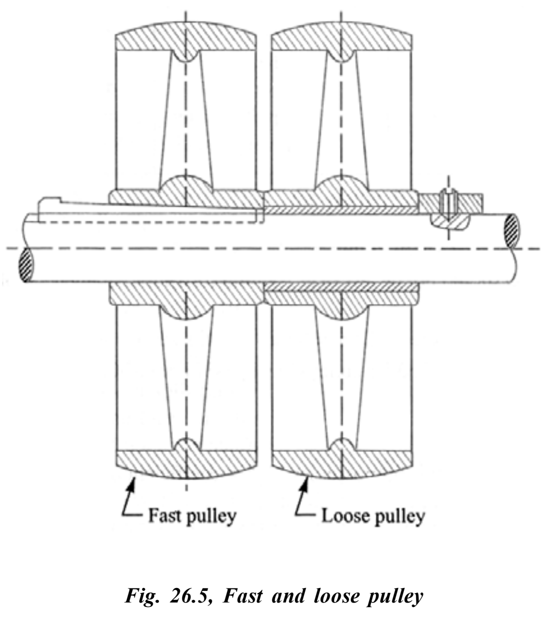


Fig. 26.5, Fast and loose pulley

CHAIN AND SPROCKET

We have learnt in previous paragraphs that on belt and rope drives slipping may occur. In order to avoid slipping, steel chains are used. The chains are made up of number of rigid links which are hinged together by pin joints in order to provide the necessary flexibility for wrapping round the driving and driven wheels. These wheels have projecting teeth of special profile and fit into the corresponding recesses in the links of the chain as shown in Fig. 26.6. The toothed wheels are known as Sprocket wheels or simply sprockets. The sprockets and the chain are thus constrained to move together without slipping and ensures perfect velocity ratio.

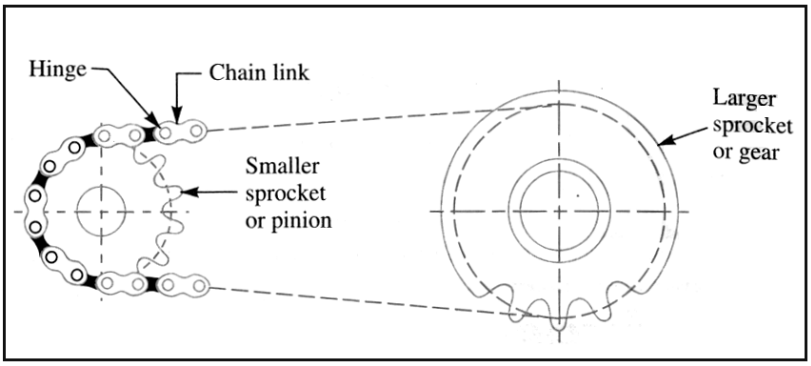


Fig. 26.6, Sprockets and chain

The chains are mostly used to transmit motion and power from one shaft to another, when the centre distance between their shafts is short such as in bicycles, motor cycles, agricultural machinery, conveyors, rolling mills, road rollers etc. The chains may also be used for long centre distance of upto 8 metres. The chains are used for velocities up to 25 m/s and for power upto 110 kW. in some cases, higher power transmission is also possible.

ADVANTAGES AND DISADVANTAGES OF CHAIN DRIVE OVER BELT OR ROPE DRIVE

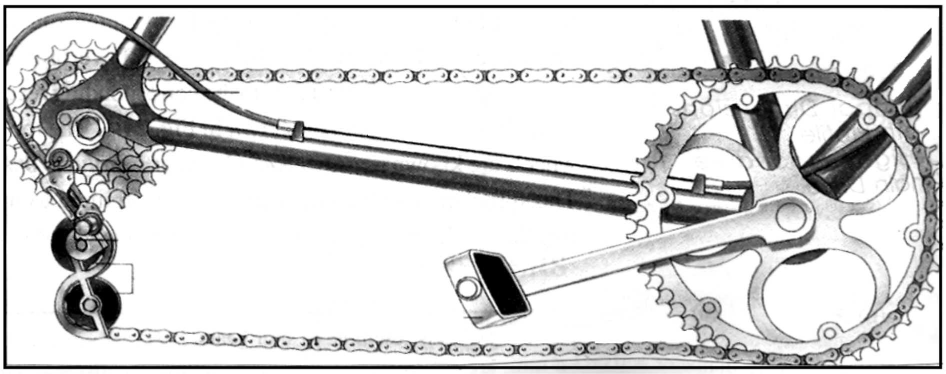
Following are the advantages and disadvantages of chain drive over belt or rope drive :

Advantages

1. As no slip takes place during chain drive, hence perfect velocity ratio is obtained.
2. Since the chains are made of metal, therefor they occupy less space in width than a belt or rope drive.
3. It may be used for both long as well as short distances.
4. It gives a high transmission efficiency (upto 98 percent).
5. It gives less load on the shafts.
6. It has the ability to transmit motion to several shafts by one chain only.
7. It transmits more power than belts.
8. It permits high speed ratio of 8 to 10 in one step.
9. It can be operated under adverse temperature and atmospheric conditions.

Disadvantages

1. The production cost of chains is relatively high.
2. The chain drive needs accurate mounting and careful maintenance, particularly lubrication and slack adjustment.
3. The chain drive has velocity fluctuations especially when unduly stretched.



Sports bicycle gear and chain drive mechanism

CLASSIFICATION OF CHAINS

The chains, on the basis of their use, are classified into the following three groups:

1. Hoisting and hauling (or crane) chains,

These chains are used for hoisting and hauling purposes and operate at a maximum velocity of 25 m/s. The hoisting and hauling chains are of the following two types:

(a) Chain with oval links

The links of this type of chain are of oval shape, as shown in Fig. 26.7 (a). The joint of each link is welded. The sprockets which are used for this type of chain have receptacles to receive the links. Such type of chains are used only at low speeds such as in chain hoists and in anchors for marine works.

(*a*) Chain with oval links. (*b*) Chain with square links.

Fig. 26.7, Hoisting and hauling chains

(b) Chain with square links

The links of this type of chain are of square shape, as shown in Fig. 26.7(b). Such type of chains are used in hoists, cranes, dredges. The manufacturing cost of this type of chain is less than that of chain with oval links, but in these chains, the kinking occurs easily on overloading.

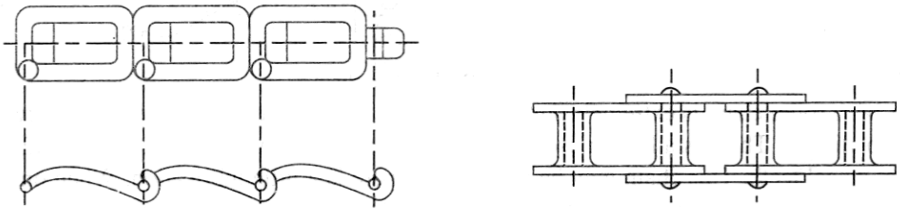
2. Conveyor (or tractive) chains,

These chains are used for elevating and conveying the materials continuously at a speed upto 2 m/s. The conveyor chains are of the following two types :

(a) Detachable or hook joint type chain, as shown in Fig. 26.8 (a), and

(b) Closed joint type chain, as shown in Fig. 26.8 (b)

The conveyor chains are usually made of malleable cast iron. These chains do not have smooth running qualities. The conveyor chains run at slow speeds of about 0.8 to 3 m/s.



(*a*) Detachable or hook joint type chain. (*b*) Closed joint type chain.

Fig. 26.8, Conveyor Chains

3. Power transmitting (or driving) chains.

These chains are used for transmission of power, when the distance between the centres of shafts is short. These chains have provision for efficient lubrication. The power transmitting chains are of the following three types.

(a) Block or Bush chain

A block or bush chain is shown in Fig. 26.9. This type of chain was used in the early stages of development in the power transmission.

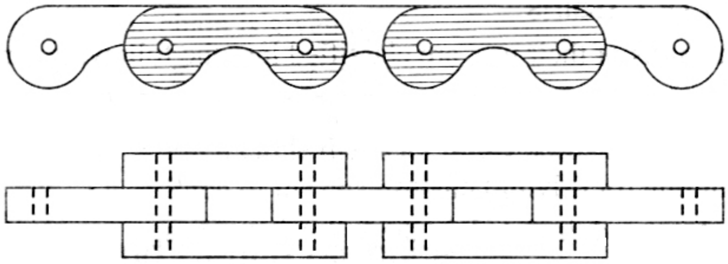


Fig. 26.9, Block or bush chain

It produces noise when approaching or leaving the teeth of the sprocket because of rubbing between the teeth and the links. Such type of chains are used to some extent as conveyor chain at small speed.

(b) Bush roller chain

A bush roller chain as shown in Fig. 26.10 consists of outer plates or pin link plates, inner plates or roller link plates, pins, bushes and rollers. A pin passes through the bush which is secured in the holes of the roller between the two sides of the chain. The rollers are free to rotate on the bush which protect the sprocket wheel teeth against wear. The pins, bushes and rollers are made of alloy steel.

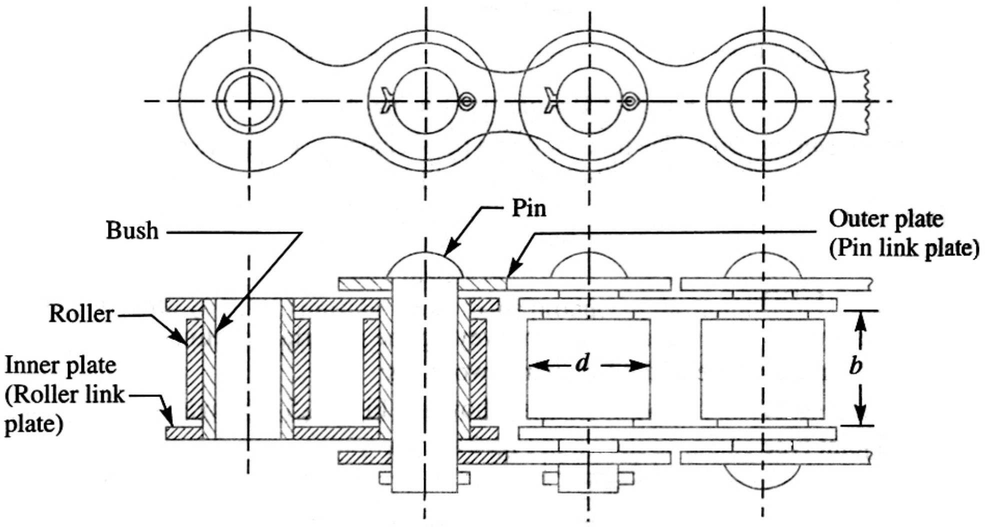


Fig. 26.10, Bush roller chain

A bush roller chain is extremely strong and simple in construction. It gives good service under severe conditions. There is a little noise with this chain which is due to impact of the rollers on the sprocket wheel teeth. This chain may be used where there is a little lubrication. When one of these chains elongates slightly due to wear and stretching of the parts, then the extended chain is of greater pitch than the pitch of the sprocket wheel teeth. The rollers then fit unequally into the cavities of the wheel. The result is that the total load falls on one teeth or on a few teeth. The stretching of the parts increase wear of the surfaces of the roller and of the sprocket wheel teeth.

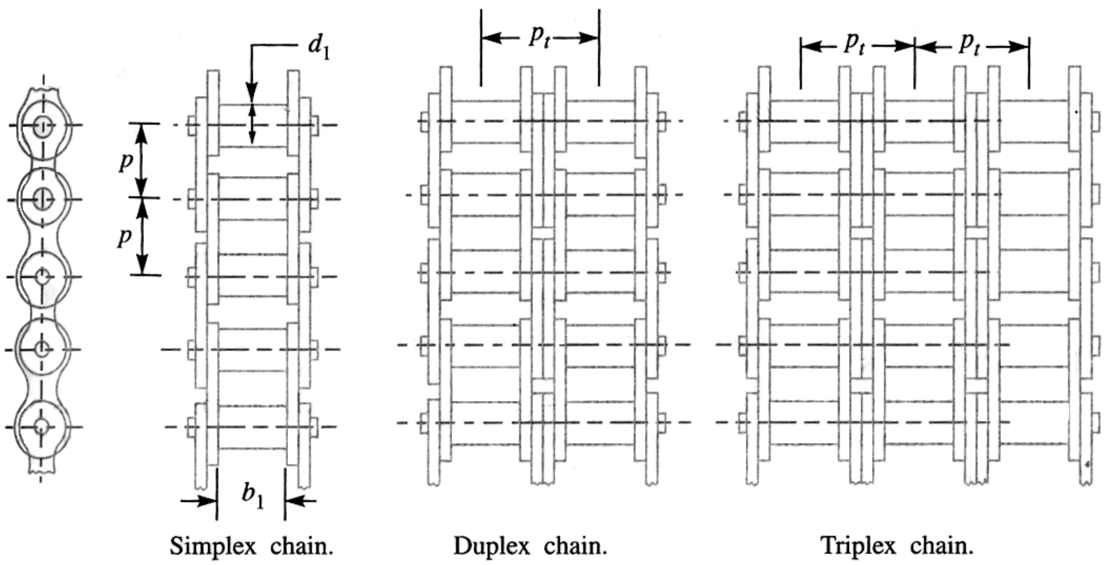


Fig. 26.11, Types of roller chain.

The roller chains are standardised and manufactured on the basis of pitch. These chains are available in single-row or multi-row roller chains such as simple, duplex or triplex strands, as shown in Fig. 26.11.

(c) Silent Chain

A silent chain (also known as inverted tooth chain) is shown in Fig. 26.12.

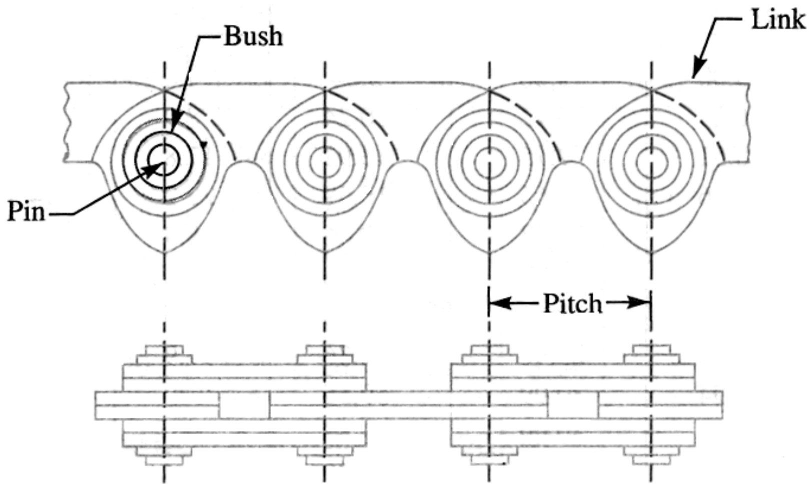


Fig. 26.12, Silent Chain

It is designed to eliminate the evil effects caused by stretching and to produced noiseless running. When the chain stretches and the pitch of the chain increases, the links ride on the teeth of the sprocket wheel at a slightly increased radius. This automatically corrects the small change in the pitch. There is not relative sliding between the teeth of the inverted tooth chain and the sprocket wheel teeth. When properly lubricated, this chain gives durable service and runs very smoothly and quietly.

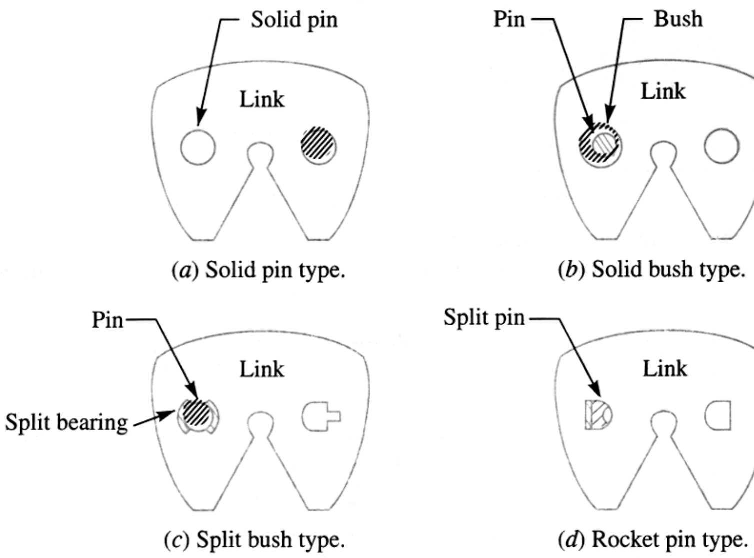


Fig. 26.13, Silent chain joints.

The various types of joints used in a silent chain are shown in Fig. 26.13.

■■■

CHAPTER-27
CONTROL CABLES

INTRODUCTION
Cables are the most widely used linkage in primary flight control systems. Cable-type linkage is also used in engine controls, emergency extension systems for the landing gear, and various other systems throughout the aircraft.

Cable-type linkage has several advantages over the other types. It is strong and light in weight, and its flexibility makes it easy to route through the aircraft. An aircraft cable has a high mechanical efficiency and can be set up without backlash, which is very important for precise control.

Cable linkage also has some disadvantages. Tension must be adjusted frequently due to stretching and temperature changes.

Aircraft control cables are fabricated from carbon steel or stainless steel.

DIFFERENT TYPES OF CONTROL CABLES AND CABLE CONSTRUCTION
The basic component of a cable is a wire. The diameter of the wire determines the total diameter of the cable. A number of wires are preformed into a helical or spiral shape and then formed into a strand. These preformed strands are laid around a straight center strand to form a cable.

Cable designations are based on the number of strands and the number of wires in each strand. The most common aircraft cables are the 7 × 7, and 7 × 19.

The 7 × 7 cable consists of seven strands of seven wires each. Six of these strands are laid around the center strand (See figure 27.1). This is a cable of medium flexibility and is used for trim tab controls, engine controls, and indicator controls.

The 7 × 19 cable is made up of seven strands of 19 wires each. Six of these strands are laid around the center strand (see figure 27.1). This cable is extra flexible and is used in primary control systems and in other places where operation over pulleys is frequent.

Aircraft control cables vary in diameter, ranging from 1/16 to 3/8 inch. The diameter is measured as shown in figure 27.1.

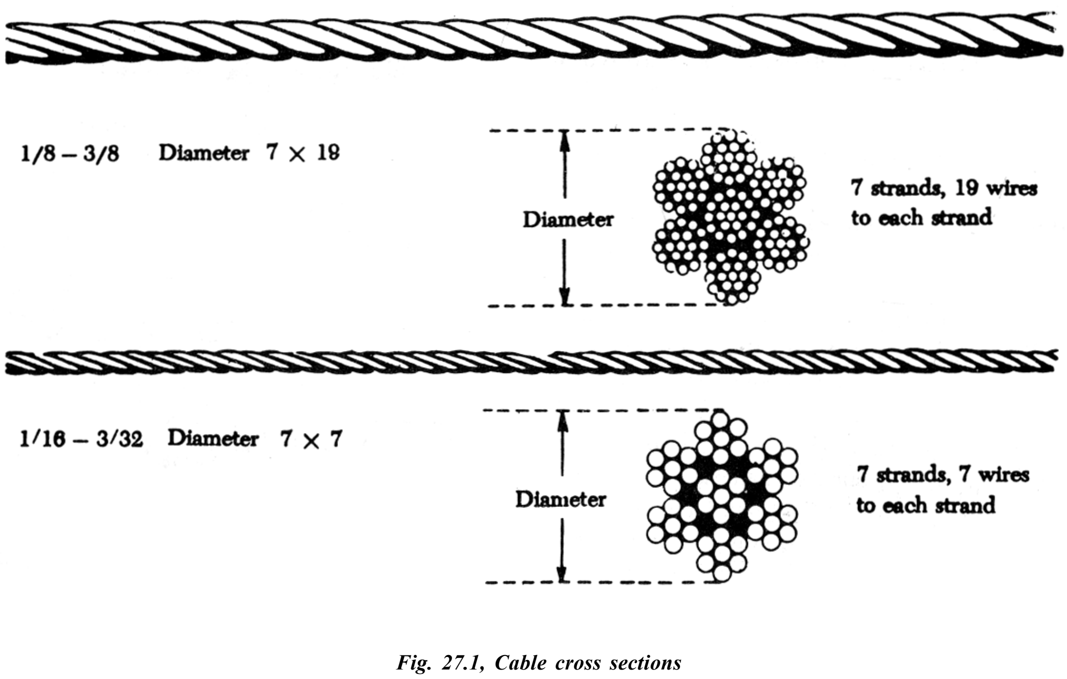


Fig. 27.1, Cable cross sections

Cable fittings (AN663, AN668)

Cables may be equipped with several different types of fittings such as terminals, thimbles, bushings, and shackles.

Terminal fittings are generally of the swaged type. They are available in the threaded end, form end, eye end, single-shank ball end, and double-shank ball end. The threaded end, fork end, and eye end terminals are used to connect the cable to a turnbuckle, bellcrank or other linkage in the system. The ball-end terminals are used for attaching cables to quadrants and special connections where space is limited. Figure 27.2 illustrates the various types of terminal fittings.

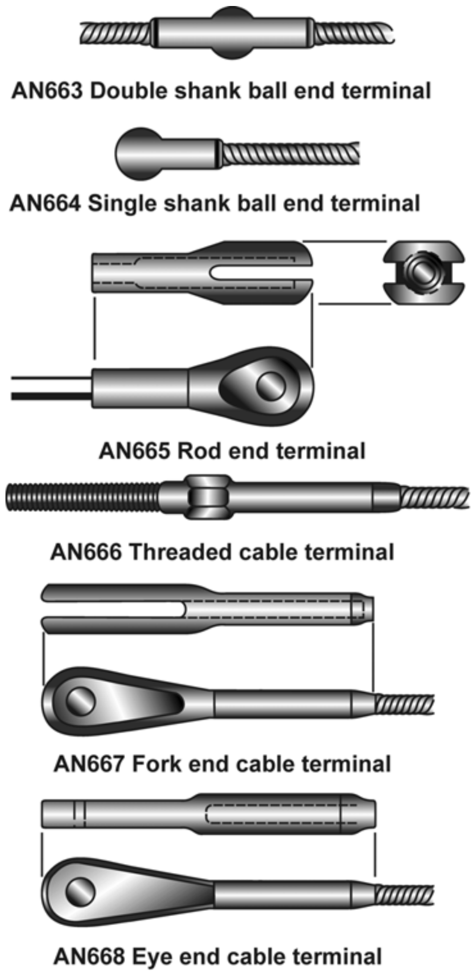


Fig. 27.2, Types of terminal fittings.

The thimble, bushing, and shackle fittings may be used in place of some types of terminal fittings when facilities and supplies are limited and immediate replacement of the cable is necessary.

Turnbuckles and Compensation Device

A turnbuckle assembly is a mechanical screw device consisting of two threaded terminals and a threaded barrel. Figure 27.3 illustrates a typical turnbuckle assembly.

Turnbuckles are fitted in the cable assembly for the purpose of making minor adjustments in cable length and for adjusting cable tension. One of the terminals has right-hand threads and the other has left-hand threads. The barrel has matching right - and left - hand internal threads. The end of the barrel with the left-hand threads can usually be identified by a groove or knurl around that end of the barrel.

When installing a turnbuckle in a control system, it is necessary to screw both of the terminals an equal number of turns into the barrel. It is also essential that all turnbuckle terminals be screwed into the barrel until not more than three threads are exposed on either side of the turnbuckle barrel.

After a turnbuckle is properly adjusted it must be safetied.

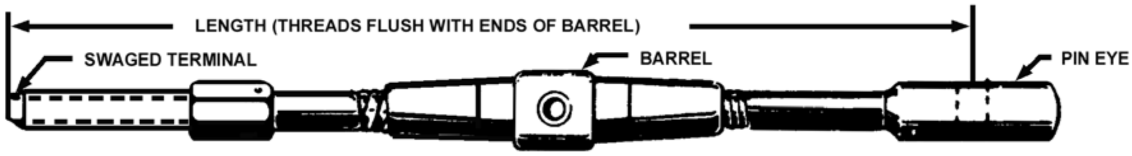


Fig. 27.3, Typical turnbuckle assembly.

PUSH-PULL TUBE LINKAGE

Push-pull tubes are used as linkage in various types of mechanically operated systems. This type linkage eliminates the problem of varying tension and permits the transfer of either compression or tension stress through a single tube.

A push-pull tube assembly consists of a hollow aluminum alloy or steel tube with an adjustable end fitting and a checknut at either end. (See figure 27.4). The checknuts secure the end fittings after the tube assembly has been adjusted to its correct length. Push-pull tubes are generally made in short lengths to prevent vibration and bending under compression loads.

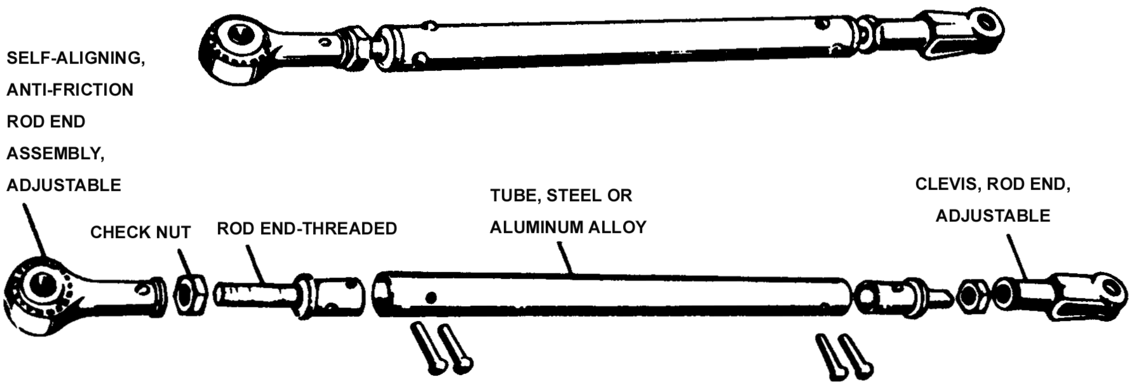


Fig. 27.4, Push-pull tube assembly.

PULLYS AND CABLE SYSTEM COMPONENTS

TURNBUCKLES

The turnbuckle is a device used in cable control systems to adjust cable tension. The turnbuckle barrel is threaded with left-hand threads inside one end and right-hand threads inside the other. When adjusting cable tension, the cable terminals are screwed into either end of the barrel and equal distance by turn turning the barrel. After a turnbuckle is adjusted, it must be safe tied.

CABLE CONNECTORS

In addition to turnbuckles, cable connectors are used in some systems. These connectors enable a cable length to be quickly connected or disconnected from a system. Fig.27.5, illustrates one type of cable connector in use. This type is connected or disconnected by compressing the spring.

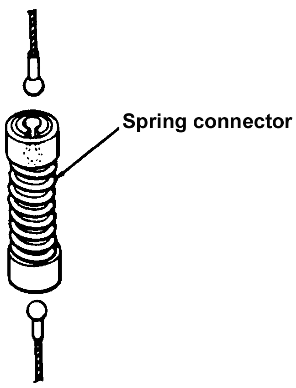


Fig.27.5. Cable connector.

HYDRAULICALLY OPERATED CONTROL SYSTEMS

As the airspeed of late model aircraft increased, actuation of controls in flight became more difficult. It soon became apparent that the pilot needed assistance to overcome the airflow resistance to control movement. Spring tabs which were operated by the conventional control system were moved so that the airflow over them actually moved the primary control system were moved so that the airflow over them actually moved the primary control surface. This was sufficient for the aircraft operating in the lowest of the high speed ranges (250-300 mph).

For high speeds a power assist (hydraulic) control system was designed. Conventional cable or push pull rod systems are installed and are tied into a power transmission quadrant. With the system activated, the pilot effort is used to open valves thereby directing hydraulic fluid to actuators, which are connected to the control surfaces by control rods. The actuators move the control surface to the desired flight condition. Reversing the input effort moves the control surface in the opposite direction.

MANUAL CONTROL

The control system from the cockpit is connected by a rod across the power transmission quadrant to the control actuating system. During manual operation, the pilot's effort is transmitted from the control wheel through this direct linkage to the control surface. Those aircraft which do not have the manual reversion system may have as many as three sources of hydraulic power primary block-up and auxiliary. Any or all of the primary controls may be operated by these systems.

Gust lock

A cam on the control quadrant shaft engages a spring-loaded roller for the purpose of centring and neutralizing the controls with hydraulic system off (aircraft parked). Pressure is trapped in the actuators and since the controls are neutralized by the cam and roller, no movement of the control surfaces is permitted.

Cable guides

Cable guides consist primarily of fairleads, pressure seals, and pulleys.

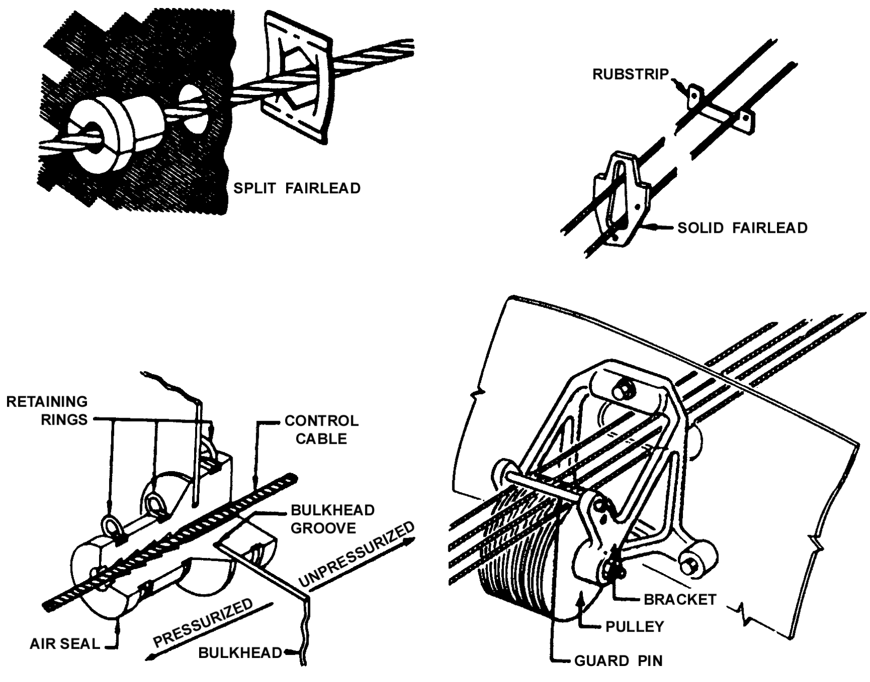


Fig. 27.6.Cable guides.

A fairlead (Fig.27.6) may be made from the nonmetallic material, such as phenolic or a metallic material such a soft aluminium. The fairlead completely encircles the cable where it passes through holes in bulkheads or other metal parts. Fairleads are used to guide cables in a straight line through or between structural member of the aircraft. Fairleads should never deflect the alignment of a cable more than 3mm from a straight line.

Pressure seals are installed where cables (or rods) move through pressure bulkheads. The seal grips tightly enough to prevent excess air pressure loss not enough to hinder movement of the cable. Pressure seals should be inspected at regular intervals to determine that the retaining rings are in place. If a retaining ring comes off, it may slide along the cable and cause jamming of a pulley.

Pulleys are used to guide cables and also to change the direction of cable movement. Pulley bearings are sealed, and need no lubrication other than the lubrication done at the factory. Brackets fastened to the structure of the aircraft support the pulleys. Cables passing over pulleys are kept in place by guards. The guards are close-fitting to prevent jamming or to prevent the cables from slipping off when they slacken due to temperature variations.

Mechanical linkages

Various mechanical linkages connect the cockpit controls to control cables and surface controls. These devices either transmit motion or change the direction of motion of the control system. The linkage consists primarily of control (push pull) rods, torque tubes, quadrants, sectors, bell cranks and cable drums.

Control rods are used as links in flight control system to give a push-pull motion. They may be adjusted at one or both ends. View A of Figure 27.7 shows the parts of a control rod. Notice that it consists of a tube having threaded rod end, or rod ends. An adjustable anti friction rod end, or rod end clevis, permits attachment of the tube to flight control system parts. The checknut, when tightened, prevents the rod end or clevis from loosening.

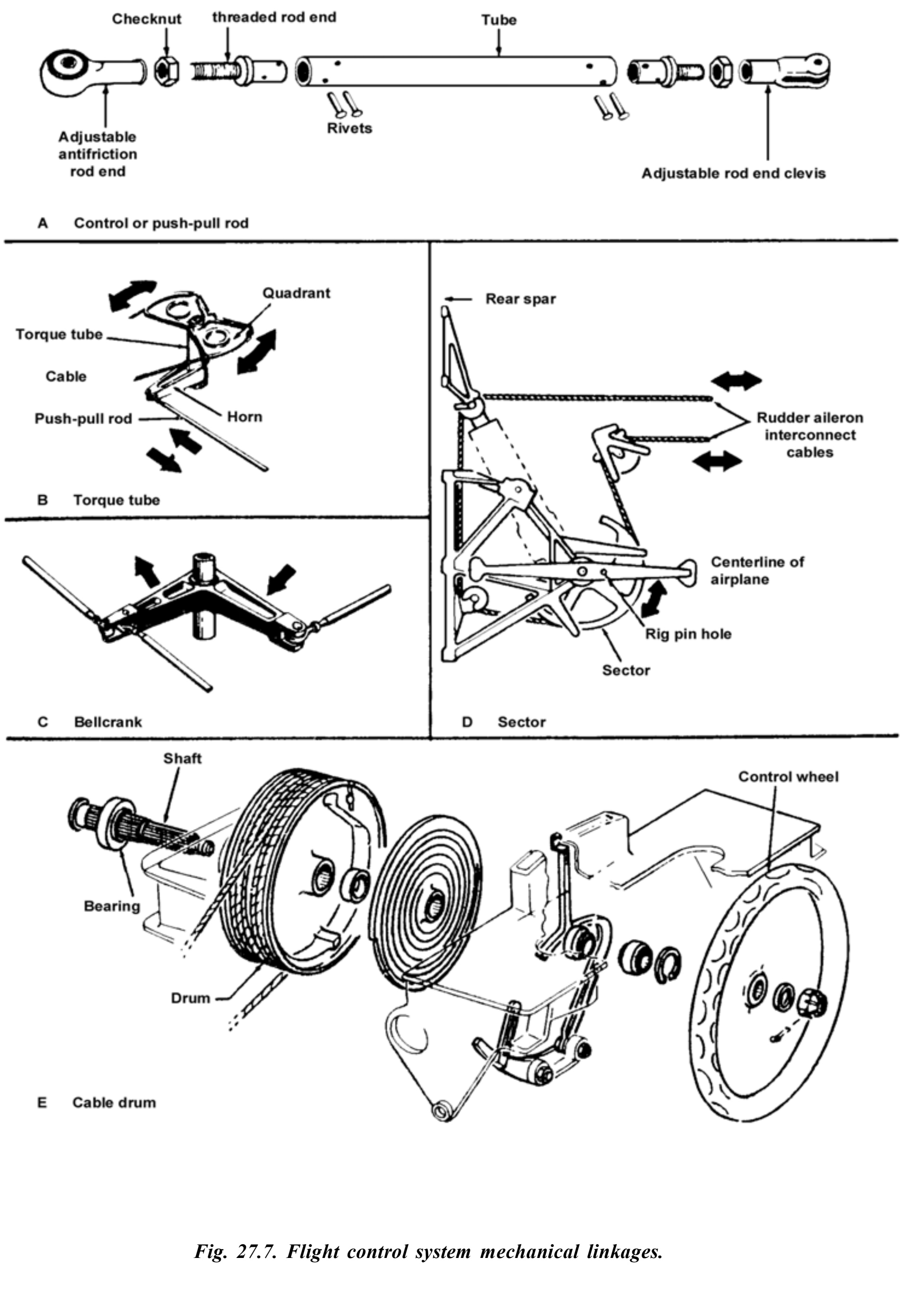


Fig. 27.7. Flight control system mechanical linkages.

Control rods should be perfectly straight, unless designed to be otherwise, when they are installed. The bell crank to which they are attached should be checked for freedom of movement before and after attaching the control rods. The assembly as a whole should be checked for correct alignment. When the rod is fitted with self-aligning bearings free rotational movement of the rods must be obtained in all positions.

It is possible for control rods fitted with bearings to become disconnected because of failure of the peening that retains the ball races in the rod end. This can be avoided by installing the control rods so that the flange of the rod end is interpreted between the ball race and the anchored end of the attaching pin or bolt as shown in Fig. 27.8.

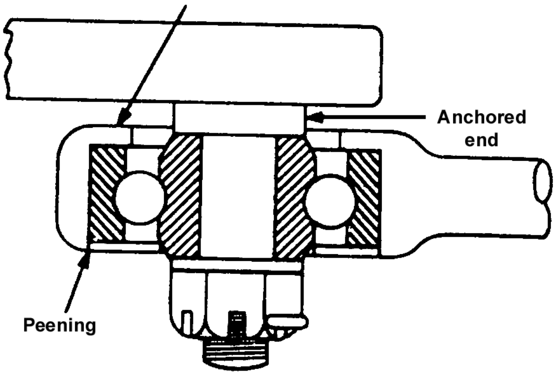


Fig.27.8. Rod end flange interposed between the bearing race and the end of the attaching bolt.

Another alternative is to place a washer, having larger diameter than the hole in the flange, under the retaining nut on the end of the attaching pin or bolt.

Torque tubes

Where an angular or twisting motion is needed in control system, a torque is installed. Fig.27.7 'c' and 'd' illustrate a bell crank and a sector. View B of Figure shows how a torque is used to transmit motion in opposite directions.

Quadrants, bell cranks, sectors, and drums change direction of motion and transmit motion to parts such as control rods, cables and torque tubes. The quardrant shown in (Fig.27.7 'b') is typical of flight control system linkages used by various manufacturers. Fig.27.7 'c' and 'd' illustrate a bellcrank and a sector. View E illustrates a cable drum. Cable drums are used primarily in trim tab system. As the trim tab control wheel is moved clockwise or counter clockwise, the cable drum winds or unwinds to actuate the trim tab cables.

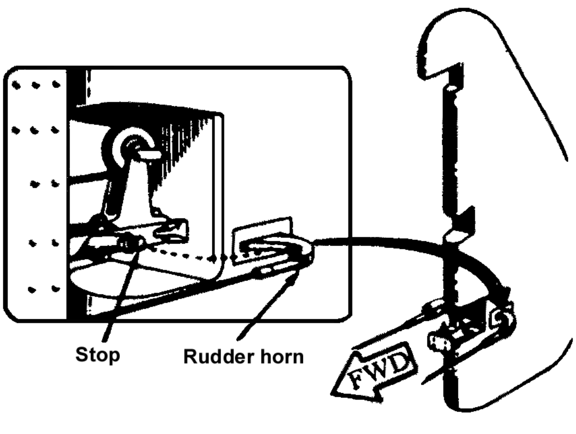


Fig.27.9. Adjustable rudder stops.

Stops

Adjustable and non-adjustable stops (whichever the case requires are used to limit the throw-range or travel movement of the ailerons, elevator, and rudder. Usually there are two sets of stops for each of the three main control surfaces, one set being located at the control surface, wither in the snubber cylinders or as structural stops (Fig.27.9), and the other at the cockpit control. Either of these may serve as the actual limit stop. However, those situated at the control surface usually perform this function. The other stops do not normally contact each other, but are adjusted to a definite clearance when the control surface is at the full extent of its travel. These work as override stops to prevent stretching of cables and damage to the control system during violent maneuvers. When rigging control system, refer to the applicable maintenance manual for the sequence of steps for adjusting these stops to limit the control surface travel.

Control surface snubbers and locking devices

Various types of device are in use to lock the control surfaces when the aircraft is parked or moved. Locking devices prevent damage to the control surfaces and their linkage from gusts and high-velocity winds. Common devices that are in use are the internal locking brake (sector brake) spring loaded plunger, and external control surface locks.

Internal locking devices

The internal locking device is used to secure the ailerons rudder, and elevator in their neutral positions. The locking device is usually operated through a cable system by a spring loaded plunger (pin) that engages a hole in the control surface mechanical linkage to lock the surface. A spring connected to the pin forces it back to the unlock position when the cockpit control lever is placed in the "unlock" position. An over-centre toggle linkage is used on some other type aircraft to lock the control surface.

Control surface locking systems are usually so designed that the throttles cannot be advanced until the control surface are unlocked. This prevents taking off with the control surface in the locked position.

A typical control lock for small aircraft consists of a metal tube that is installed to lock the control wheel and rudder pedals to an attachment in the cockpit. Such a system is illustrated in Fig. 27.10.

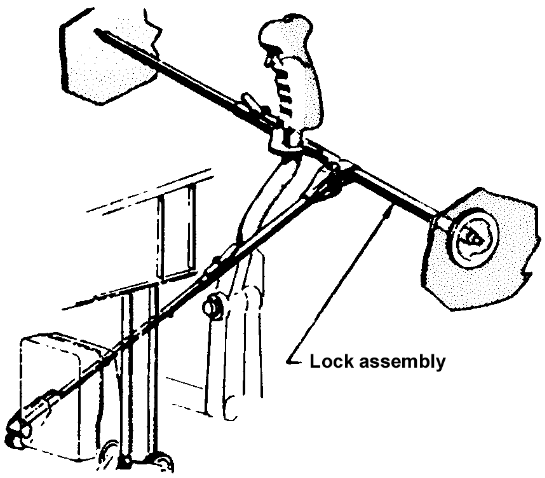


Fig.27.10. Typical control lock assembly for small aircraft.

Control surface snubbers

Hydraulic booster units are used on some aircraft to move the control surfaces. The surfaces are usually protected from wind gusts by snubbers incorporate in to the booster unit. On some aircraft an auxiliary snubber cylinder is connected directly to the surface to provide protect in. The snubbers hydraulically check or cushion control surface movement when the aircraft is parked. This prevents wind gusts from slamming the control surfaces into their stops and possibly causing damage.

External control surface locks.

External control locks are in the form of channelled wood blocks. The channelled wood block slide into the openings between the ends of the movable surfaces and the aircraft structure. This locks the surfaces neutral. When not in use, these locks are stowed within the aircraft.

BOWDEN CABLES

A Bowden cable is a type of flexible cable used to transmit mechanical force or energy by the movement of an inner cable (most commonly of steel or stainless steel) relative to a hollow outer cable housing. The housing is generally of composite construction, consisting of helical steel wire, often lined with plastic, and with aplastic outer sheath.

Fig.27.11, Bowden Cable

The linear movement of the inner cable is generally used to transmit a pulling force, although for very light applications over shorter distances (such as the remote shutter release cables on mechanical film cameras) a push may also be used. Usually provision is made for adjusting the cable tension using an inline hollow bolt (often called a "barrel adjuster"), which lengthens or shortens the cable housing relative to a fixed anchor point. Lengthening the housing (turning the barrel adjuster out) tightens the cable; shortening the housing (turning the barrel adjuster in) loosens the cable.

CABLE ASSEMBLY (AIRCRAFT FLEXIBLE CONTROL SYSTEM)

The convention cable assembly consists of flexible cable, terminals (end fittings) for attaching to other, and turn buckles.

At each regular inspection period, cables should be inspected for broken wires by passing a cloth along their length and observing points where the cloth snags. To thoroughly inspect the cable, move the surface control to its extreme travel limits. This will reveal the cable in pulley, fair lead, and drum areas. If the surface of the cable is corroded, relieve cable tension. Then carefully force the cable open by reverse twisting, and visually inspect the interior for corrosion. Corrosion on the interior strands of the cable indicates failure of the cable and requires replacement of the cable. If there is no internal corrosion, remove external corrosion with a coarse weave rag or fibber brush. Never use metallic wools or solvents to clean flexible cable. Metallic wools embed dissimilar metal particles, which cause further corrosion. Solvents remove the internal cable lubricant, which also results in further corrosion. After thoroughly cleaning the flexible cable, apply corrosion-preventive compound. This compound preserves and lubricates the cable.

Breakage of wires occur most of frequently where cables pass over pulleys and through fairleads. Typical breakage points are shown in Figure 27.12. Control cables and wires should be replaced if worn, distorted, corroded, or otherwise damaged.

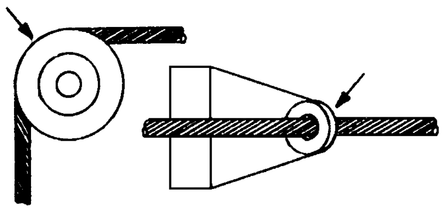


Fig. 27.12. Typical brekage point.

Lockclad cable is used on some large aircraft for all long, straight runs. It consists of the conventional flexible steel cable with aluminium tubing swaged to it to lock the cable inside the tubing. Lockclad cable construction has certain advantages. Changes in tension due to temperature are less than with conventional cable. Furthermore, the amount of stretch at a given load is less than with conventional cable.

Lockclad cables should be replaced when the covering is worn through, exposing worn wire strands; is broken; or shows worns spots which cause the cable to bump when passing over fairlead rollers.

■■■

CHAPTER-28
ELECTRICAL CABLES CONTROL CONNECTORS

TYPES OF WIRES AND CABLES

Wires and cables are designed and manufactured for duties under specific environmental conditions and are selected on this basis. This ensures functioning of distribution and consumer systems, and also helps to minimize risk for fire and structural damage in the event of failure of any kind. Table 28.1 gives details of some commonly used general service wires and cables of U.K. manufacture, while typical constructional features are illustrated in (Fig 28.1).

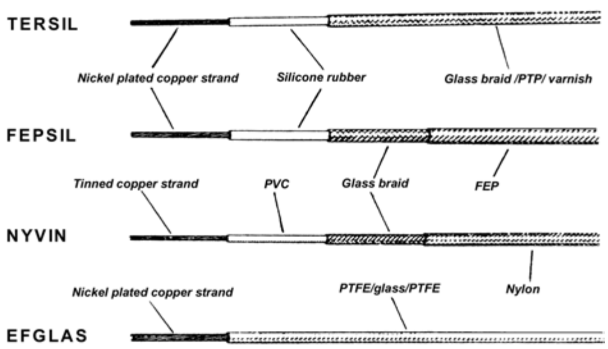


Fig. 28.1. Constructional features of some typical cables.

The names adopted for the various types are derived from contractions of the names of the various insulating materials used. For example, "NYVIN" is derived from "NYlon" and from poly VINyl-chloride (P.V.C.); and "TERSIL" is derived from polyesTER and SILicone. Cables may also be further classified by prefixes and suffixes relating to the number of cores and any additional protective covering. For example, "TRINYVIN" would denote a cable made up of three single Nyvin cables, and if suffixed by "METSGEATH" the name would further denote that the cable is enclosed in a metal braided sheath.

It will be noted from the Table that only two metals are used for conductors, i.e. copper (which may also be tinned, nickel-plated or silver-plated depending on cable application) and aluminium. Copper has a very low specific resistance and is adopted for all but cables of large cross-sectional areas. An aluminium conductor having the same resistance as a copper conductor, has only two-thirds of the weight but twice the cross-sectional area of the copper conductor. This has an advantage where low-resistance short-term circuits are concerned; for example, in power supply circuits of engine starter motor systems.

The insulation materials used for wires and cables must conform to a number of rigid requirements such as, toughness and flexibility over a fairly wide temperature range, resistance to fuels, lubricants and hydraulic fluids, ease of stripping for terminating, non-flammability and minimum weight. These requirements, which are set out in standard specifications, are met by the materials listed in Table 28.1 and in the selection of the correct cable for a specific duty and environmental condition.

To ensure proper identification of cables, standard specification also require that cable manufacturers comply with a code and mark outer protective coverings accordingly. Such a coding scheme usually signifies, in sequence, the type of cable, country of origin ("G" for U.K. manufacturers) manufacturer's code letter, year of manufacture also by a letter, and its wire gauge size, thus, NYVIN G-AN 22. A colour code scheme is also adopted particularly as a means of tracing the individual cores of multicore cables to and from their respective terminal points. In such cases it is usual for the insulation of each core to be produced in a different colour and in accordance with the appropriate specification. Another method of coding, and one used for cables in three-phase circuits of some types of aircraft, is the weaving of a coloured trace into the outer covering of each core; thus red-(phase A); yellow - (phase B); blue - (phase C). The code may also be applied to certain single-core cables by using a coloured outer covering.

ROUTING OF WIRES AND CABLES

As noted earlier in this chapter, the quantity of wires and cables required for a distribution system depends on the size and complexity of the systems. However, regardless of quantity, it is important that wires and cables be routed through an aircraft in a manner which, is safe, avoids interference with the reception and transmission of signals by such equipment as radio and compass systems, and which also permits a systematic approach to their identification, installation and removal, and to circuit testing. Various methods, dependent also on size and complexity, are adopted but in general, they may be grouped under three principal headings : (i) open loom, (ii) ducted loom, and (iii) conduit.

Open Loom

In this method, wires or cables to be routed to and from consumer equipment in the specific zones of the aircraft, are grouped parallel to each other in a bundle and bound together with waxed cording or p.v.c. strapping. A loom is supported at intervals throughout its run usually by means of clips secured at relevant parts of the aircraft structure. An application of the method to an aircraft junction box is shown in (Fig. 28.2).

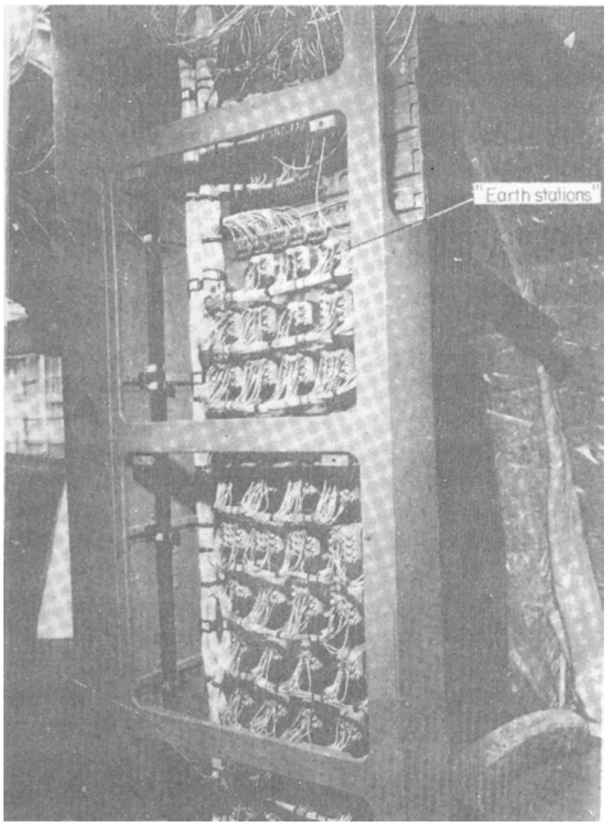


Fig. 28.2. Open looms.

The composition of a cable loom is dictated by such factors as (i) overall diameter, (ii) temperature conditions, i.e. temperature rise in cables when operating at their maximum current-carrying capacity in varying ambient temperature conditions, (iii) type of current, i.e. whether alternating, direct, heavy-duty or light-duty, (iv) interference resulting from inductive or magnetic effects, (v) type of circuit with which cables are associated; this applies particularly to circuits in the essential category, the cables of which must be safe-guarded against damage in the event of short circuits developing in adjoining cables.

Magnetic fields exist around cables carrying direct current and where these cables must interconnect equipment in the vicinity of a compass magnetic detector element, it is necessary for the fields to be cancelled out. This is achieved by routing the positive and earth-return cables together and connecting the earth-return cable at an earthing point located at a specific safe distance from the magnetic detector element of a compass system.

Ducted Loom

This method is basically the same as that of the open loom except that the bundles are supported in ducts which are routed through the aircraft and secured to the aircraft structure (see Fig. 28.3). Ducts may be of aluminium alloy, resinimprenated asbestos or moulded fibre-glass-reinforced plastic. In some applications of this method, a main duct containing several channels may be used, each channel supporting a cable loom corresponding to a specific consumer system. For identification purposes, each loom is bound with appropriately coloured waxed cording.

TABLE 28.1

Type	Specification		Materials			
	British B.S.G.	American MIL-W-	Conductor	Insulation & Covering	Ambient temperature range	Application
NYVIN	177	5086 A (Type 2)	Tinned Copper or Aluminium	P.V.C. Compound Glass braid Nylon	-75°C to + 65°C	General services wiring except where ambient temperatures are high and/or extended.
PREN			Tinned Copper or Aluminium	Glass braid polychloroprene Compound	-75°C to + 50°C	Properties of flexibility are required.
TERSIL	189	8777 B (ASG)	Nicke-plated Copper; or Aluminium	Silicone Rubber Polyester tapes Glass braid Polyester fiber Varnish	-75°C to + 150°C	
EFGLAS	192	7129 B	Nickel-plated Copper	Glass braid P.T.F.E. +	-75°C to + 220°C	In high operating temperatures and in areas where resistance to aircraft fluids necessary. Also where severe flexing under low-temperature conditions is encountered e.g., landing m,gear shock strut switch circuits.
UNIFIRE - "F"			Nickel-plated Copper	Glass braid P.T.F.E. Asbestos felt impregnated with silicone varnish	Up to 240°C	In circuits required to function during or after a fire.
NYVINMETSHEATH			Tinned Copper or Aluminium	As for NYVIN plus an overall tinned-copper braid overlaid with polyester tape, nylon braid and lacquer	-75°C to + 65°C	In areas where screening required
FEPSIL	206		Nickel-plated Copper	Silicone Rubber Glass braid and Varnish F.E.P.	-75°C to + 190°C	

Conduits are generally used for conveying cables in areas where there is the possibility of exposure to oil, hydraulic or other fluids. Depending on the particular application, conduits may take the form of either plastic, flexible metal or rigid metal sheaths. In cases where shielding against signal interference is necessary the appropriate cables are conveyed by metal conduits in contact with metal structural members to ensure good bonding.

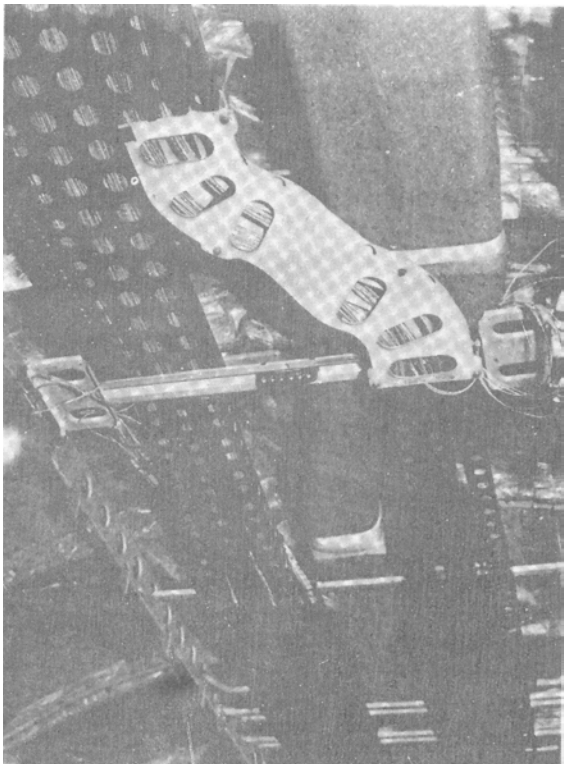


Fig. 28.3. Ducted looms.

Cable Seals

In pressurized cabin aircraft it is essential for many cables to pass through pressure bulkheads without a "break" in them and without causing leakage of cabin air. This is accomplished by sealing the necessary apertures with either pressure bungs or pressure-proof plugs and sockets. An example of a pressure bung assembly is shown in (Fig. 28.4). It consists of a housing, perforated synthetic rubber bung, antifriction washer and knurled clamping nuts; the housing is flanged and threaded, having a tapered bore to accept the bung. The holes in the bung vary in size to accommodate cables of various diameters, each hole being sealed by a thin covering of synthetic rubber at the smaller diameter end of the bung. The covering is pierced by a special tool when loading the bung with cables.

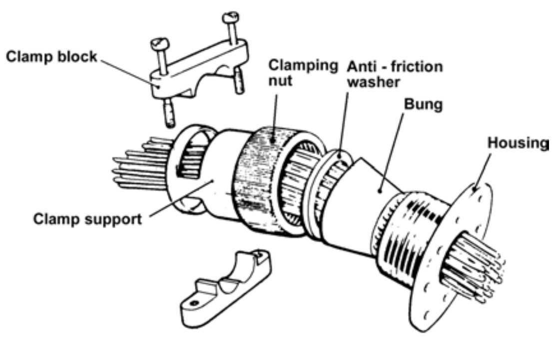


Fig. 28.4. Pressure bung assembly.

The cables are a tight fit in the holes of the bung which, when fully loaded and forced into the housing by the clamping nut, is compressed tightly into the housing and around the cables. The anti-friction washer prevents damage to the face of the bung when the clamping nut is turned. On assembly, holes not occupied by cables are plunged with plastic plugs.

In instances where cable "breaks" are required at a pressure bulkhead, the cables at each side of the bulkhead are terminated by specially-sealed plug or socket assemblies of a type similar to those shown in (Fig. 28.5).

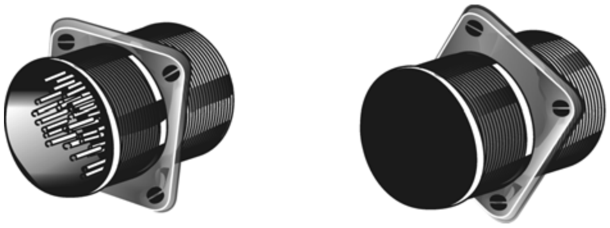


Fig. 28.5. Fixed through-type (bulkhead).

WIRES AND CABLES CONSTRUCTION

Wires and cables constitute the framework of power distribution systems conducting power in its various forms and controlled quantities, between sections contained within consumer equipment (known as "equipment" wires and cables), and also between equipment located in the relevant areas of an aircraft (known as "airframe" wires and cables). The differences between a wire and a cable relate principally to their constructional features (and indirectly to their applications also) and may be understood from the following broad definitions.

A wire is single solid rod or filament of drawn metal enclosed in a suitable insulating material and outer protective covering. Although the term properly refers to the metal conductor, it is generally understood to include the insulation and covering. Specific applications of single wires are to be found in consumer equipment; for example, between the supply connections and the brush gear of a motor, and also between the various components which together make up the stages of an electronic amplifier.

A cable is usually made up of a conductor composed of a group of single solid wires stranded together to provide greater flexibility, and enclosed by insulating material and outer protective covering. A cable may be either of the single core type, i.e., with cores stranded together as a single conductor, or of the multicore type having a number of single core cables in a common outer protective covering.

Having highlighted the above definitions, it is interesting to note that with the present lack of international standardization of terminology, they may not be used in the same context. For example, in the U.S. and some other countries, the term "wire" is used as an all embracing one.

In connection with power distribution systems in their various forms, such terms as "wiring systems", "wiring of components", "circuit wiring" are commonly used. These are of a general nature and apply equally to systems incorporating either wires, cables or both.

CABLE CHARACTERISTICS

Table 28.2 Characteristics of copper and aluminum

Characteristic	**Copper**	**Aluminum**
Tensile strength (lb./in.^{2})...........	55,000	25,000
Tensile strength for same conductivity (lb.)..................	55,000	40,000
Weight for same conductivity (lb.)..	100	48
Cross section for same conductivity (C.M.)..................	100	160
Specific resistance (Ω /mil ft.)...	10.6	17

SPECIAL PURPOSE CABLES

For certain of electrical systems, cables are required to perform a more specialized function than that of the cables already referred to. Some examples of what are generally termed, special purpose cables, are described in the following paragraphs.

Ignition Cables (H.T. Cable)

These cables are used for the transmission of high tension voltages in both piston engine and turbine engine ignition systems, and are of the single-core stranded type suitably insulated, and screened by metal braided sheathing to prevent interference. The number of cables required for a system corresponds to that of the sparking plugs or igniter plugs as appropriate, and they are generally made up into a complete ignition cable harness. Depending on the type of engine installation, the cables may be enclosed in a metal conduit, which also forms part of a harness, or they may be routed openly. Cables are connected to the relevant system components by special end fitting comprising either small springs or contact caps secured to the cable conductor, insulation, and a threaded coupling assembly.

Thermocouple Cables

These cables are used for the connection of cylinder head temperature indicators and turbine engine exhaust gas temperature indicators to their respective thermocouple sensing elements. The conducting materials are normally the same as those selected for the sensing element combinations , namely, iron and constantan or copper and constantan for cylinder head thermocouples, chromel (an alloy of chromium and nickel) and alumel (an alloy of aluminium and nickel) for exhaust gas thermocouples.

In the case of cylinder head temperature indicating systems only one thermocouple sensing element is used and the cables between it and a firewall connector are normally asbestos covered. For exhaust gas temperature measurement a number of thermocouples are required to be radially disposed in the gas stream, and it is the usual practice therefore, to arrange the cables in the form of a harness tailored to suit a specific engine installation. The insulating material of the harness cables is either silicone rubber or P.T.F.E. impregnated fibre glass. The cables terminate at an engine or firewall junction box from which cables extend to the indicator. The insulating material of extension cables is normally of the polyvinyl type, since they are subject to lower ambient temperatures than the engine harness. In some applications extension cables are encased in silicone paste within metalbraided flexible conduit.

Co-axial Cables

Co-axial cables contain two or more separate conductors. The innermost conductor may be of the solid, or stranded copper wire type, and may be plain, tinned, silver-plated or even gold-plated in some applications, depending on the degree of conductivity required. The remaining conductors are in the form of tubes, usually of fine wire braid. The insulation is usually of polyethylene or Teflon. Outer coverings or jackets serve to weatherproof the cables and protect them from fluid, mechanical and electrical damage. The materials used for the covering are manufactured to suit operations under varying environmental conditions.

Co-axial cables have several main advantages. First, they are shielded against electrostatic and magnetic fields; an electrostatic field does not extend beyond the outer conductor and the fields due to current flow in inner and outer conductors cancel each other.

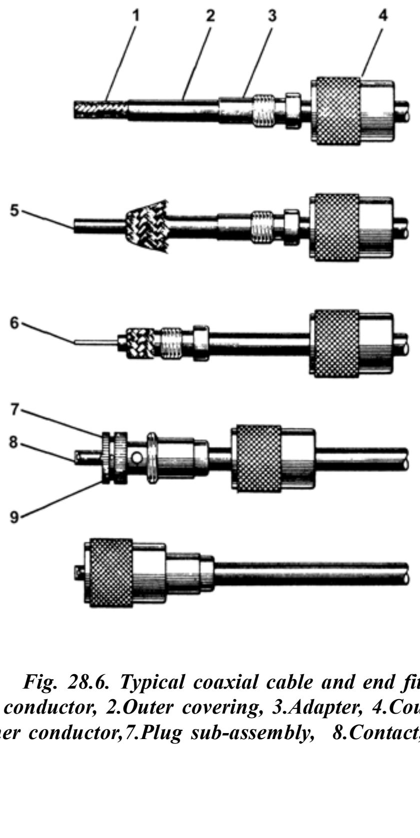


Fig. 28.6. Typical coaxial cable and end fitting,
1.Outer braid conductor, 2.Outer covering, 3.Adapter, 4.Coupling ring, 5.Insulation, 6.Inner conductor,7.Plug sub-assembly, 8.Contact, 9.Solder holes

Secondly, since co-axial cables do not radiate, then likewise they will not pick up any energy, or be influenced by other strong fields. The installations in which coaxial cables are most commonly employed are radio, for the connection of antennae, and capacitance type fuel quantity in indicating systems for the interconnection of tank units and amplifiers. The construction of a typical coaxial cable and also the sequence adopted for attaching the end fitting are shown in (Fig. 28.6). The outer covering is cut back to expose the braided outer conductor (step "A") which is then fanned out and folded back over the adapter (step "B" and "C"). At the same time, the insulation is cut back to expose the inner conductor. The next step (D) is to screw the sub-assembly to the adapter thereby clamping the outer conductor firmly between the two components. Although not applicable to all cables the outer conductor may also be soldered to the sub-assembly through solder holes. The assembly is completed by soldering a contact on to the inner conductor may also be soldered to the sub-assembly through solder holes. The assembly is completed by soldering a contact on to the inner conductor and screwing the coupling ring on to the sub-assembly.

CONNECTING TERMINAL LUGS TO TERMINAL BLOCKS

Terminal lugs should be installed on terminal blocks in such a manner that they are locked against movement in the direction of loosening (Fig. 28.7).

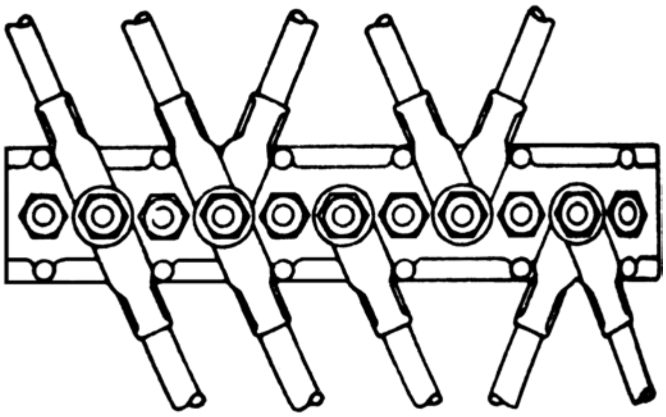


Fig. 28.7. Connecting terminals to terminal block.

Terminal blocks are normally supplied with studs secured in place by a plain washer, an external tooth lockwasher, and a nut. In connecting terminals, a recommended practice is to place-copper terminal lugs directly on top of the nut, followed with a plain washer and elastic stop nut, or with a plain washer, split steel lockwasher, and plain nut.

Aluminum terminal lugs should be placed over a plated brass plain washer, followed with another plated brass plain washer, split steel lockwasher, and plain nut or elastic stop nut. The plated brass washer should have diameter equal to the tongue width of the aluminum terminal lug. Consult the manufacturer's instructions for recommended dimensions of these plated brass washers. Do not place any washer in the current path between two aluminum terminal lugs or between two copper terminal lugs. Also, do not place a lockwasher directly against the tongue or pad of the aluminum terminal.

To join a copper terminal lug to an aluminum terminal lug, place a plated brass plain washer over the nut which holds the stud in place; follow with the aluminum terminal lug, a plated brass plain washer, the copper terminal lug, plain washer, split steel lockwasher and plain nut or self-locking, all metal nut. As a general rule use a torque wrench to tighten nuts to ensure sufficient contact pressure. Manufacturer's instructions provide installation torques for all types of terminals.

CRIMPING TOOLS

Hand, portable power, and stationary power tools are available for crimping terminal lugs. These tools crimp the barrel of the terminal lug to the conductor and simultaneously crimp the insulation grip to the wire insulation.

Hand crimping tools all have a self-locking ratchet that prevents opening the tool until the crimp is complete. Some hand crimping tools are equipped with a nest of various size inserts to fit different size terminal lugs. Others are used on one terminal lug size only. All types of hand crimping tools are checked by gages for proper adjustment of crimping jaws.

Fig. 28.8 shows a terminal lug inserted into a hand tool. The following general guidelines outline the crimping procedure:

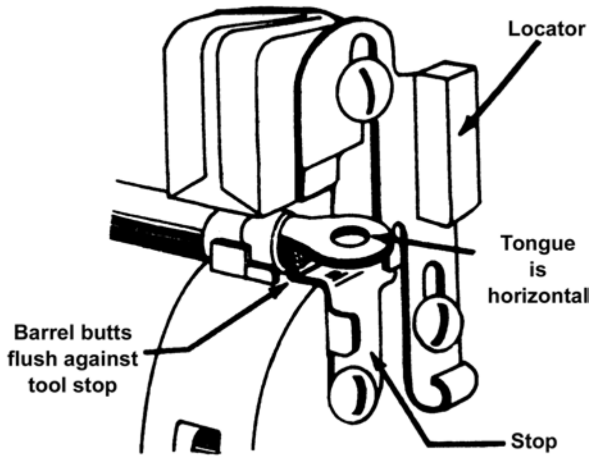


Fig. 28.8. Inserting terminal lug into hand tool.

1. Strip the wire insulation to proper length.
2. Insert the terminal lug, tongue first, into the hand tool barrel crimping jaws until the terminal lug barrel butts flush against the tool stop.
3. Insert the stripped wire into the terminal lug barrel until the wire insulation butts flush against the end of the barrel.
4. Squeeze the tool handles until the ratchet releases.
5. Remove the completed assembly and examine it for proper crimp.

Some types of uninsulated terminal lugs are insulated after assembly to a wire by means of pieces of transparent flexible tubing called "sleeves." The sleeve provides electrical and mechanical protection at the connection. When the size of the sleeving used is such that it will tightly over the terminal lug, the sleeving need not be tied; otherwise, it should be tied with lacing cord (Fig. 28.9).

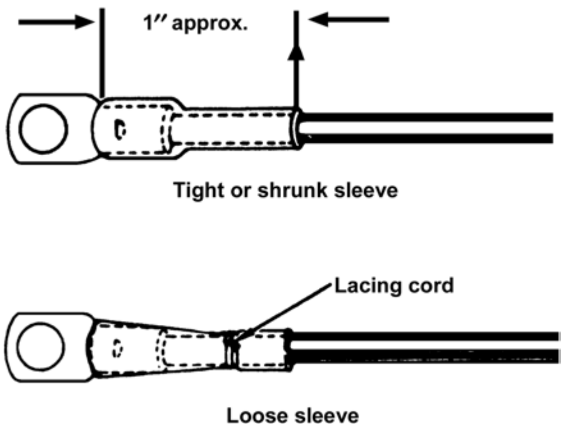


Fig. 28.9. Insulating sleeves.

Aluminum Wire Terminals

Aluminium wire is being used increasingly in aircraft systems because of its weight advantage over copper. However, bending aluminium will cause "work hardening" of the metal, making it brittle. This results in failure or breakage of strands much sooner than in a similar case with copper wire. Aluminum also forms a high-resistant oxide film immediately upon exposure to air. To compensate for these disadvantages, it is important to use the most reliable installation procedures.

Only aluminum terminal lugs are used to terminate aluminum wires. They are generally available in three types: (1) Straight, (2) right-angle, and (3) flag. All aluminum terminals incorporate an inspection hole (Fig. 28.9) which permits checking the depth of wire insertion. The barrel of aluminum terminal lugs is filled with a petrolatumzinc dust compound. This compound removes the oxide film from the aluminum by a grinding process during the crimping operation. The compound will also minimize latter oxidation of the completed connection by excluding moisture and air. The compound is retained inside the terminal lug barrel by a plastic or foil seal at the end of the barrel.

Splicing Copper Wires Using Preinsulated Wires

Preinsulated permanent copper splices join small wires of sizes 22 through 10. Each splice size can be used for more than one wire size. Splices are usually color-coded in the same manner as preinsulated, small copper terminal lugs. Some splices are insulated with white plastic. Splices are also used to reduce wire sizes as shown in (Fig. 28.10).

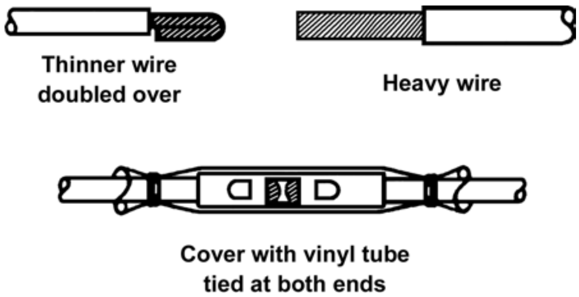


Fig. 28.10. Reducing wire size with a permanent splice.

Crimping tools are used to accomplish this type of splice. The crimping procedures are the same as those sued for terminal lugs, except that the crimping operation must be done twice, one for each end of the splice.

Emergency Splicing Repairs

Broken wires can be repaired by means of crimped splices, by using terminal lugs from which the tongue has been cut off, or by soldering together and potting broken strands. These repairs are applicable to copper strands. These repairs are applicable to copper wire. Damaged aluminum wire must not be temporarily spliced. These repairs are for temporary emergency use only and should be replaced as soon as possible with permanent repairs. Since some manufacturers prohibit splicing, the applicable manufacturer's instructions should always be consulted.

Splicing with Solder and Potting Compound

When neither a permanent splice nor a terminal lug is available, a broken wire can be repaired as follows (see Fig. 28.11):

1. Install a piece of plastic sleeving about 3 in. long, and of the proper diameter to fit loosely over the insulation, on one piece of the broken wire.

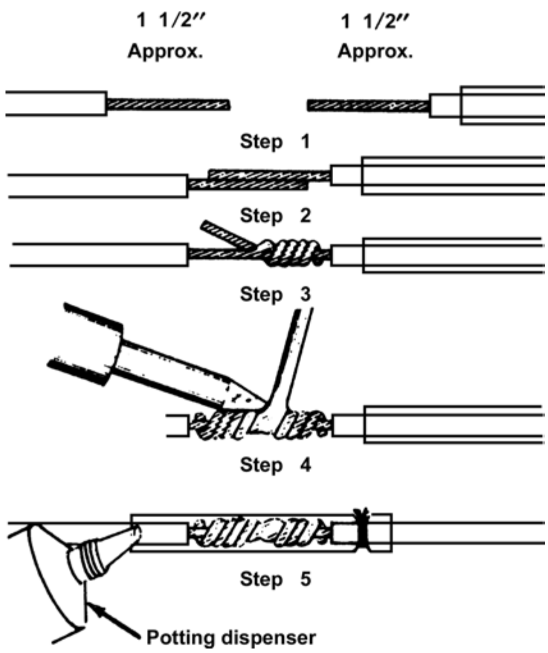


Fig. 28.11. Repairing broken wire by soldering and potting.

2. Strip approximately 1-1/2 in. from each broken end of the wire.
3. Lay the stripped ends side by side and twist one wire around the other with approximately four turns.
4. Twist the free end of the second wire around the first wire with approximately four turns. Solder the wire turns together, using 60/40 tin-lead resin-core solder.

5. When solder is cool, draw the sleeve over the soldered wires and tie at one end. If potting compound is available, fill the sleeve with potting material and tied securely.
6. Allow the potting compound to set without touching for 4 hrs. Full cure and electrical characteristics are achieved in 24 hrs.

CONNECTORS

Connectors (plugs and receptacles) facilitate maintenance when frequent disconnection is required. Since the cable is soldered to the connector inserts, the joints should be individually installed and the cable bundle firmly supported to avoid damage by vibration. Connectors have been particularly vulnerable to corrosion in the past, due to condensation within the shell. Special connectors with waterproof features have been developed which may replace nonwaterproof plugs in areas where moisture causes a problem. A connector of the same basic type and design should be used when replacing a connector. Connectors that are susceptible to corrosion difficulties may be treated with a chemically inert waterproof jelly. When replacing connector assemblies, the socket-type insert should be used on the half which is "live" or "hot" after the connector is disconnected to prevent unintentional grounding.

Types of Connectors

Connectors are identified by AN numbers and are divided into classes with the manufacturer's variations in each class. The manufacturer's variations are differences in appearance and in the method of meeting a specification. Some commonly used connectors are shown in (Fig. 28.12). There are five basic classes of AN connectors used in most aircraft. Each class of connector has slightly different construction characteristics. Classes A, B, C, and D are made of aluminum, and class K is made of steel.

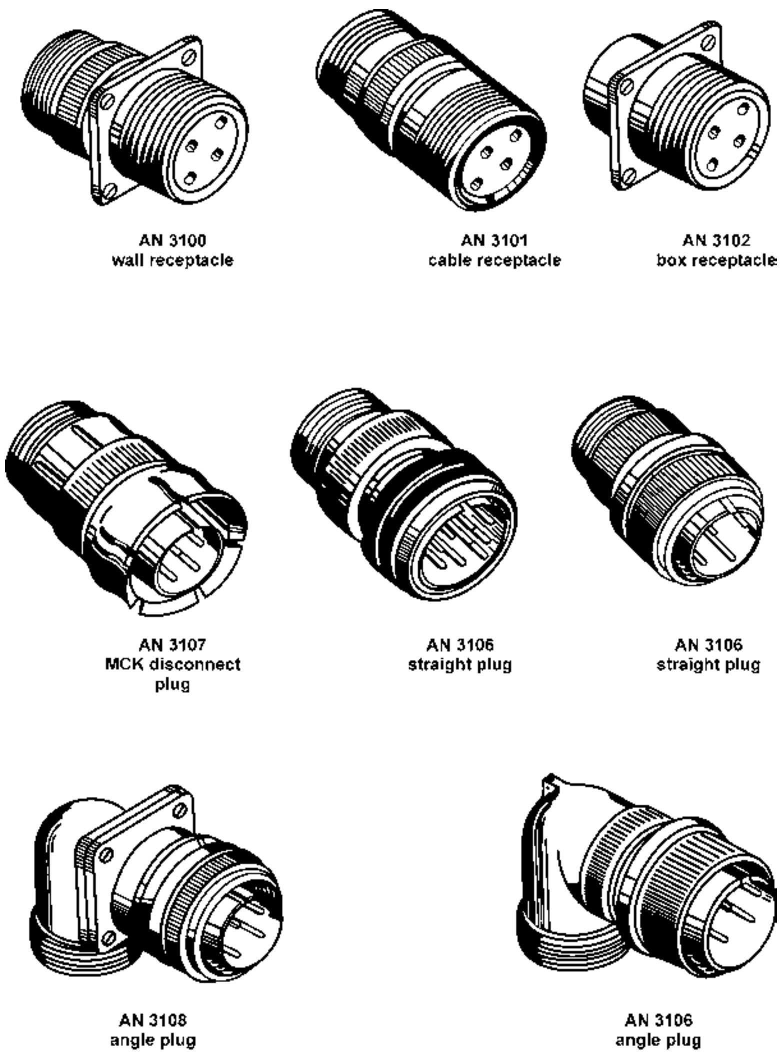


Fig. 28.12. AN connectors.

1. Class A-- Solid, one-piece back shell general-purpose connector.
2. Class B-- Connector back shell separates into two parts lengthwise. Used primarily where it is important that the soldered connectors are readily accessible. The back shell is held together by a threaded ring or by screws.
3. Class C--A pressurized connector with inserts that are not removable. Similar to a class A connector in appearance, but the inside sealing arrangement is sometimes different. It is used on walls or bulkheads of pressurized equipment.
4. Class D-- Moisture and vibration-resistant connector which has a sealing grommet in the back shell. Wires are threaded through tight-fitting holes in the grommet, thus sealing against moisture.
5. Class K--A fireproof connector used in areas where it is vital that the electric current is not interrupted, even though the connector may be exposed to continuous open flame. Wires are crimped to the pin or socket contacts and the shells are made of steel. This class of connector is normally longer than other connectors.

CURRENT AND VOLTAGE RATING

Factor Affecting Selection of Conductor Material

Although silver is the best conductor, its cost limits its use to special circuits where a substance with high conductivity is needed.

The two most generally used conductors are copper and aluminum. Each has characteristics that make its use advantageous under certain circumstances; also, each has certain disadvantages.

Copper has a higher conductivity; it is more ductile (can be drawn out), has relatively high tensile strength, and can be easily soldered. It is more expensive and heavier than aluminum.

Current-carrying capacity of wire (in amperes)

Size	Rubber or Thermoplastic	Thermoplastic asbestos, var-cam, or	Impregnated asbestos	Asbestos weatherproof	Slow-burning or asbestos var-cam
0000	300	385	475	510	370
000	260	330	410	430	320
00	225	285	355	370	275
0	195	245	305	325	235
1	165	210	265	280	205
2	140	180	225	240	175
3	120	155	195	210	150
4	105	135	170	180	130
6	80	100	125	135	100
8	55	70	90	100	70
10	40	55	70	75	55
12	25	40	50	55	40
14	20	30	40	45	30

Although aluminum has only about 60% of the conductivity of copper, it is used extensively. Its lightness makes possible long spans, and its relatively large diameter for a given conductivity reduces corona, the discharge of electricity from the wire when it has a high potential. The discharge is greater when smaller diameter wire is used. Some bus bars are made of aluminum instead of copper, where there is a greater radiating surface for the same conductance.

Voltage Drop in Aircraft Wire and Cable

It is recommended that the voltage drop in the main power cables from the aircraft generation source or the battery to the bus should not exceed 2% of the regulated voltage when the generator is carrying rated current or the battery is being discharged at a 5-minute rate. Table 28.3 shows the recommended maximum voltage drop in the load circuits between the bus and the utilization equipment.

Table 28.3 Recommended maximum voltage drop in load circuits

Nominal System Voltage	Allowable Voltage Drop	
	Continuous Operation	Intermittent Operation
14	0.5	1
28	1	2
115	4	8
200	7	14

The resistance of the current return path through the aircraft structure is always considered negligible. However, this is based on the assumption that adequate bonding of the structure or a special electric current return path has been provided which is capable of carrying the required electric current with a negligible voltage drop. A resistance measurement of 0.005 ohms from ground point of the generator or battery to ground terminal of any electrical device is considered satisfactory. Another satisfactory method of determining circuit resistance is to check the voltage drop across the circuit. If the voltage drop does not exceed the limit established by the aircraft or product manufacturer, the resistance value for the circuit is considered satisfactory. When using the voltage drop method of checking a circuit, the input voltage must be maintained at a constant value.

The chart in (Fig. 28.13) applies to copper conductors carrying direct current. Curve 1, 2. and 3 are plotted to show the maximum ampere rating for the specified conductor under the specified conditions shown. To select the correct size of conductor, two major requirements must be met. First, the size must be sufficient to prevent an excessive voltage drop while carrying the required current over the required distance. Secondly, the size must be sufficient to prevent overheating of the cable while carrying the required current. The charts in (Figures 28.13 and 28.14) can simplify these determination. To use this chart to select the proper size of conductor, the following must be known :

1. The conductor length in feet.
2. The number of amperes of current to be carried.
3. The amount of voltage drop permitted.
4. Whether the current to be carried will be intermittent or continuous, and if continuous, whether it is a single conductor in free air, in a conduit, or in a bundle.

Assume that it is desired to install a 50-foot conductor from the aircraft bus to the equipment in a 28-volt system. For this length, a 1-volt drop is permissible for contiuous operation. By referring to the chart in (Fig. 28.14) the maximum number of feet a conductor may be run carrying a specified current with a 1-volt drop can be determined. In this example the number 50 is selected.

Assuming the current required by the equipment is 20 amperes, the line indicating the value of 20 amperes should be selected from the diagonal lines. Follow this diagonal line downward until it intersects the horizontal line number 50. From this point, drop straight down to the bottom of the chart to find that a conductor between size No. 8 and 10 is required to prevent a greater drop than 1 volt. Since the indicated value is between two numbers, the larger size, No. 8, should be selected. This is the smallest size which should be used to avoid an excessive voltage drop.

To determine that the conductor size is sufficient to preclude overheating, disregard both the numbers along the left side of the chart and the horizontal lines. Assume that the conductor is to be a single wire in free air carrying continuous current. Place a pointer at the top of the table on the diagonal line numbered 20 amperes. Follow this line until the pointer intersects the diagonal line marked "curve 2". Drop the pointer straight down to the bottom of the chart. This point is between numbers 16 and 18. The larger size, No.16, should be selected. This is the smallest-size conductor acceptable for carrying 20-ampere current in a single wire in free air without overheating.

If the installation is for equipment having only an intermittent (Max, 2 min.) requirement for power, the chart in (Fig. 28.13) is used in the same manner.

DIMENSIONS

For most conductors, the amount of resistance varies directly with the conductor's length. That is, as length increases for a given conductor, its resistance increases.

On the other hand, the resistance of a conductor varies inversely with its cross-sectional area. In other words, as a conductor's cross-sectional area increases, resistance decreases. Aircraft wire is measured by the**American Wire Gage (AWG)** system, with the larger numbers representing the smaller wires. The smallest size wire normally used in aircraft is 22-gauge wire, which has a diameter of about 0.025 inch. However, conductors carrying large amounts of current are typically of the 0000, or four aught size, and have a diameter of about 0.52 inch.

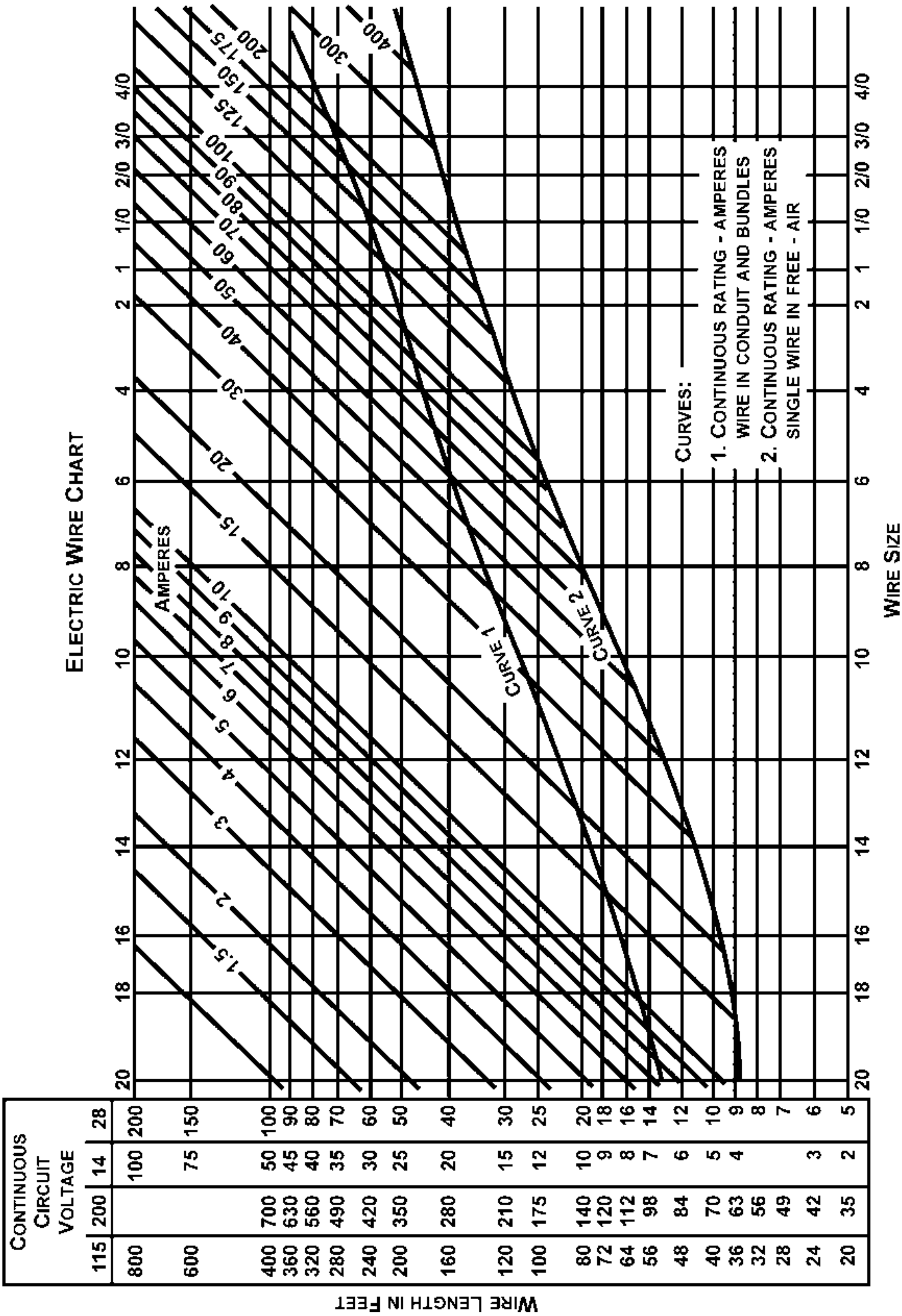


Fig. 28.13. Conductor chart, continuous rating. (Applicable to copper conductors)

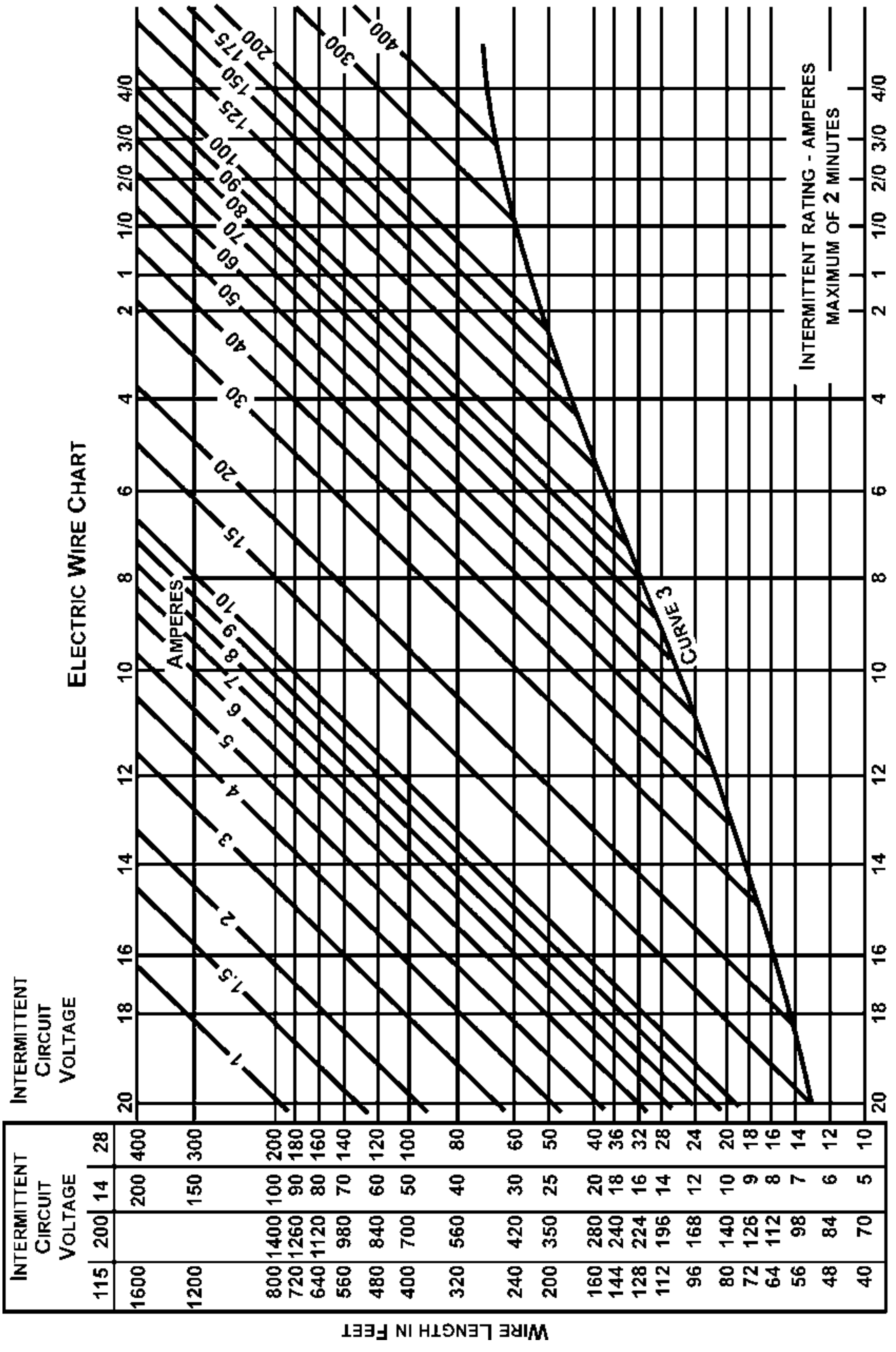


Fig. 28.14. Conductor chart, intermittent rating. (Applicable to copper conductors)

A **circular mil** is the standard measurement of a round conductor's cross-sectional area. One mil is equivalent to .001 inches. Thus, a wire that has a diameter of .125 is expressed as 125 mils. To find the cross-sectional area of a conductor in circular mils, square the conductor's diameter. For example, if a round wire has a diameter of 3/8 inch. or 375 mils, its circular area is 1,40,625 circular mils (375×345=1,40,625).

The **square mil** is the unit of measure for square or rectangular conductors such as bus bars. To determine the cross-sectional area of a conductor in square mils, multiply the conductor's length by its width. For example, the cross-sectional area of a strip of copper that is 400 mils thick and 500 mils wide is 2,00,000 square mils.

It should be noted that one circular mil is .7854 of one square mil. Therefore, to convert a circular mil area to a square mil area, multiply the area in circular mils by .7854 mil. Conversely, to convert a square mil area to a circular area, divide the area in square mils by .7854 (Fig. 28.15).

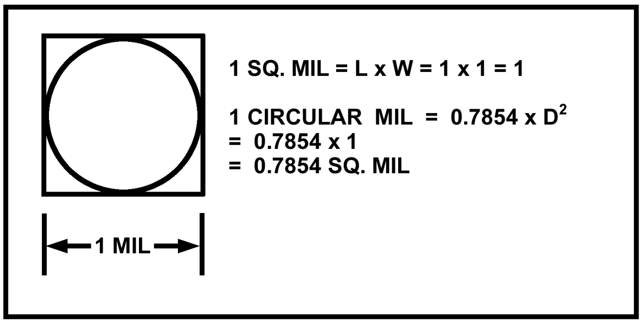


Fig. 28.15. The area of a round conductor is measured in circular mils.

Coding Schemes

As an aid to the correlation of the details illustrated in any particular diagram with the actual physical conditions, i.e. where items are located, sizes of cables used, etc., aircraft manufacturers also adopt an identification coding scheme apart from those adopted by cable manufacturers. Such a scheme may either be to the manufacturer's own specification, or to one devised as a standard coding scheme. In order to illustrate the principle of schemes generally, some example applications of one of the more widely adopted coding standards will be described .

In this scheme, deviced by the Air Transport Association of America under Specification No. 100, the coding for cable installations consists of a six-position combination of letters and numbers which is quoted on all relevant wiring diagrams and routing charts and is imprinted on the outer covering of cables. In cases where the code cannot be affixed to a cable it is printed on non-metallic sleeves placed over the ends of the cable.

The code is printed at specified intervals along the length of a cable by feeding it through a special printing machine. The following example serves to illustrate the significance of each position of the code:

1 P 1 A 22 N

Position 1. The number in this position is called the unit number and is only used where components have identical circuits, e.g., the components of a twin generator system. In this case number 1 refers to the cables interconnecting the components of the first system. The number is omitted from cables used singly.

Position 2. In this position, a letter is used to indicate the function of the circuit i.e., it designates the circuit or system with which the cable is connected. Each system has its own letter. When the circuit is part of radar, radio, special electronic equipment, a second letter is used to further define the circuit.

Position 3. The number in this position is that of the cable and is used to differentiate between cables which do not have a common terminal in the same circuit. In this respect, contacts of switches, relays, etc. are not classified as common terminals. Beginning with the lowest number and progressing in numerical order as far as is practicable, a different number is given to each cable.

Position 4. The letter used in this position, signifies the segments of cable (i.e., that portion of cable between two terminals or connections) and differentiates between segments in a particular circuit when the same cable number is used throughout. When practicable, segments are lettered in alphabetical sequence (excluding the letter "I" and "O") the letter "A" identifying the first segment of each cable, beginning at the power source. A different letter is use for each of the cable segments having a common terminal or connection.

Position 5. In this position, the number used indicates the cable size and corresponds to the American Wire Gauge (AWG) range of sizes. This does not apply to coaxial cables for which the number is omitted, or to thermocouple cables for which a dash (-) is used as a substitute.

Position 6. In this position, a letter indicates whether a cable is used as a connection to a neutral or earth point, an a.c. phase cable, or as a thermocouple cable, the letter "V" indicates a supply cable in a single-phase circuit, while in three-phase circuit, while in three-phase circuits the cables are identified by the letters "A", "B" and "C". Thermocouple cables are identified by letters which indicate the type of conductor material, thus: AL (Alumel); CH (Chromel); CU (Copper); CN (Constantan).

The practical application of the coding scheme may be understood from (Fig. 28.16) which shows the wiring of a very simple temperature sensing switch and warning lamp system.

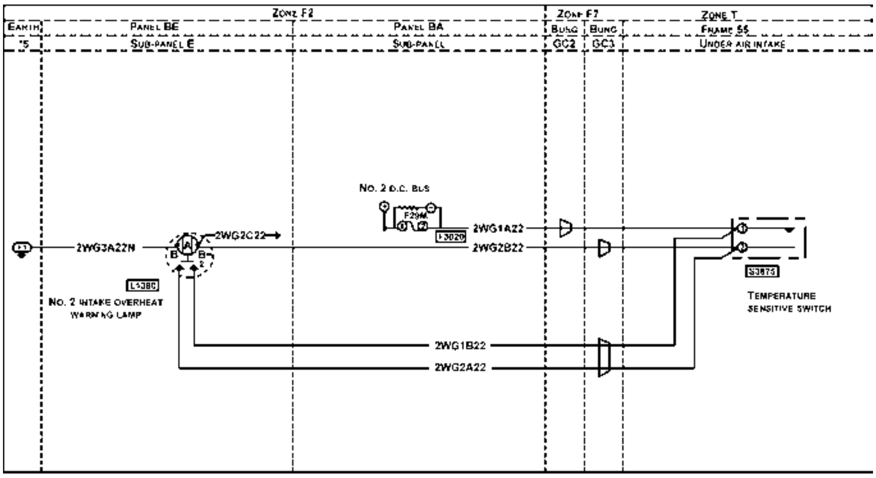


Fig. 28.16. Routing chart.

The system is related to the No.2 engine air intake, its circuit function is designated by the letters "WG", and it uses cables of wire size 22 throughout. Starting from the power source i.e., from the No. 2 d.c. busbar, the first cable is run from the fuse connection 2, through a pressure bung to terminal 1 of the switch; thus, the code for this cable is 2 WG 1 A 22. Terminal 1 also serves as a common power supply connection to the contact 2 of the press-to-test facility in the warning lamp; therefore, the interconnecting cable which also passes through a press-to-test facility in the warning lamp; therefore, the interconnecting cable which also passes through a pressure bung, is a second segment cable and as the cables are the second pair in the circuit and respectively first and second segments, their code numbers are 2 WG 2 A 22 and 2 WG 2 B 22. The cable shown going away from the B+ terminal of the lamp, is a third segment connecting a supply to a lamp in a centralized warning system and so accordingly carries the code 2 WG 2 C 22. The circuit is completed via cable number 3 and since it connects to earth it carries the full six-position code; thus, 2 WG 2 A 22 N.

The coding schemes adopted for items of electrical equipment, control panels, connector groups, junction boxes, etc. are related to physical locations within the aircraft and for this purpose aircraft are divided into electrical zones. A reference letter and number are allocated to each zone and also to equipment, connectors, panels etc., so that they can be identified within the zones. The reference letters and numbers are given in the appropriate wiring diagrams and are correlated to the diagrammatic representations of all items. In the aircraft itself, references are marked on or near the related items.

Electrical Wiring Installation

The following recommended procedures for installing aircraft electrical wiring are typical of those used on most types of aircraft. For purposes of this discussion, the following definitions are applicable :

1. Open wiring-- any wire, wire group, or wire bundle not enclosed in conduit.
2. Wire group-- two or more wires going to the same location, tied together to retain identity of the group.
3. Wire bundle-- two or more wire groups tied together because they are going in the same direction at the point where the tie is located.
4. Electrically protected wiring-- wires which include (in the circuit) protections against overloading, such as fuses, circuit breakers, or other limiting devices.
5. Electrically unprotected wiring-- wires (generally from generators to main bus distribution points) which do not have protection, such as fuses, circuit breakers, or other current-limiting devices.

INSTALLATION OF CONNECTORS/COUPLING

The following procedures outline one recommended method of assembling connectors to receptacles :

1. Locate the proper position of the plug in relation to the receptacle by aligning the key of one part with the groove or keyway of the other part.
2. Start the plug into the receptacle with a slight forward pressure and engage the thread of coupling ring and receptacle.
3. Alternately push in the plug and tighten the coupling ring until the plug is completely seated.
4. Use connector pliers to tighten coupling rings one-sixteenth to one-eighth of a turn beyond finger tight if space around the connector is too small to obtain a good finger grip.
5. Never use force to mate connectors to receptacles. Do not hammer a plug into its receptacle, and never use a torque wrench or pliers to lock coupling rings.

A connector is generally disassembled from a receptacle in the following manner :

1. Use connector pliers to loosen coupling rings which are too tight to be loosened by hand.
2. Alternately pull on the plug body and unscrew the coupling ring until the connector is separated.
3. Protect disconnected plugs and receptacles with caps or plastic bags to keep debris from entering and causing faults.
4. Do not use excessive force, and do not pull on attached wires.

"POTTING"

This is a technique usually applied to plugs and sockets which are to be employed in situations where there is the possibility of water or other liquids passing through the cable entry. It eliminates elaborate cable ferrules, gland nuts, etc., by providing a simple plastic shroud with sufficient height to cover the terminations, and filling the cavity with a special compound which though semi-fluid in its initial condition, rapidly hardens into a rubbery state to form a fairly efficient seal. In addition to sealing it provides reinforcement for the cable connections.

The potting compound consists of a basic material and an alkaline or acid base material (known as an "accelerator") which are thoroughly mixed in the correct proportion to give the desired consistency and hardness of the compound. Once mixed, the compound is injected into a special mould and allowed to set. When the mould is removed, the resilient hemispherically-shaped insulation extends well into the plug or socket, bonding itself to the back of the insulant around the contact and conductor joints and partly out along the conductor insulation.

CONNECTOR IDENTIFICATION

Code letters and numbers are marked on the coupling ring shell to identify a connector. This code (Fig. 28.17) provides all the information necessary to obtain the correct replacement for a defective or damaged part.

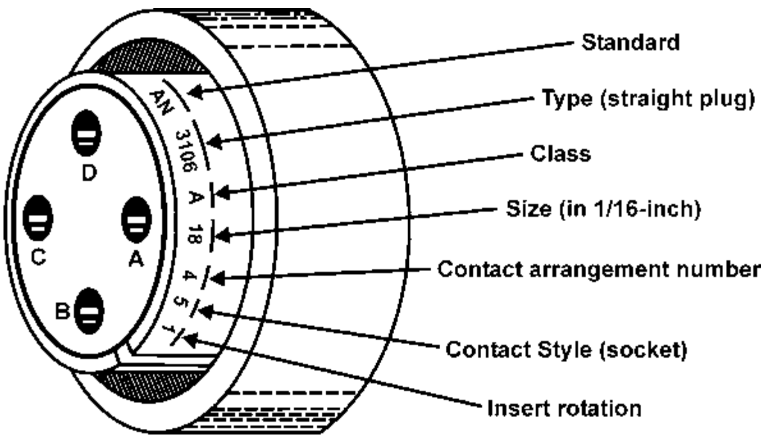


Fig. 28.17. AN connector marking.

Many special-purpose connectors have been designed for use in aircraft applications. These include subminiature and rectangular shell connectors, and connectors with short body shells, or of split-shell construction.

■■■

CHAPTER-29
SWAGING

HANDLING OF CABLE

Cable may be permanently damaged, or its working life may be considerably curtailed, by careless handling and unwinding. Care is necessary to prevent the cable from forming itself into a loop, which, if pulled tight, could produce a kink. A kink is shown by the core strand leaving the centre of the rope, and lying between the outer strands or protruding in the form of a small loop.

Cable should always be stored on suitably designed reels. The diameter of the reel barrel should be at least forty times the cable diameter. British Standards stipulate that reels should be made from a wood which will not corrode the cable, and that interior surfaces should be lined with an inert waterproof material. Precautions should also be taken to protect the cable from grit and moisture, and from damage in transit.

To remove cable from reel, a spindle should be placed through the centre of the reel, and supported in a suitable stand. Cable may then be removed by pulling the free end in line with the reel, allowing the reel to rotate. Cable should not be unwound by paying off loose coils, or by pulling the cable away from a stationary reel laid on its side.

When a long length of cable has been cut from a reel, and it is necessary to coil the cut piece, the coil diameter should be at least 50 times the cable diameter, with a minimum diameter of 150 mm (6 in). Care must be taken to prevent dust, grit and moisture, from coming into contact with the coiled cable.

The ends of stored cable are whipped to prevent fraying, and, if a length has been cut from the reel, the remaining free end should be whipped.

When a coil is being unwound, the coil should be rotated so that the cable is paid out in a straight line.

Cutting Cable

Cable should always be cut using mechanical methods. Cable cutters or heavy duty pliers should normally be used, but alternatively, the cable may be laid on an anvil and cut with a sharp chisel and hammer blows. Cable should not be cut by flame. If a non-preformed cable is being cut, it should be whipped with waxed cord on both sides of the cut, prior to being cut. With a preformed cable it will normally only be necessary to bind the cable temporarily with masking tape.

SWAGING

Swaging is an operation in which a metallic end fitting is secured to the end of a cable by plastic deformation of the hollow shank of the end fitting. The end of the cable is inserted into the hollow shank of the fitting, and the shank is then squeezed in a swaging machine, so that it grips the cable. This is the most satisfactory method of attaching an end fitting to a cable, and it can be expected to provided a cable assembly at least as strong as the cable itself. Most transport aircraft, and a large number of light aircraft, use control cables manufactured in this way.

Manufacturers of cable assemblies normally swage with rotary machines. In these machines the shank of the end fitting is placed between suitable dies, and is subjected to a series of forming blow, which reduce the shank diameter, and lock the fitting to the cable

Swaging may also be carried out on a portable swaging machine, which squeezes the shank of the end fitting between dies. The use of a portable swaging machine is discussed below.

A range of swaged end fittings is covered by BS specifications, but some older types of aircraft may be fitted with cable assemblies containing components employing with SBAC AS specification which are now obsolete. When it is necessary to make up control cables for these aircraft, approval may be granted for the use of equivalent BS parts, but the complete cable control run may have to be changed.

BS specifications provide a range of fittings which prevent incorrect assembly of control cables. Turn barrels and tension rods are designed to connect to screwed end and tapped end swaged fittings respectively. For each size of cable two alternative sizes of end fittings are available, and each size is provided with either a left or right hand thread. Swaged fittings can thus be arranged to ensure that a control run cannot be incorrectly assembled.

Swaging procedure

The procedure outlined below is applicable when a machine of the type illustrated in Fig. 29.1 is used. Where use of a different type of machine is authorised, the procedure is similar, except for the setting and operation of the machine, which in all cases should be in accordance with the manufacturer's instructions.

a. Ensure that the new cable is the correct size, by using a suitable gauge, or by measuring the diameter.

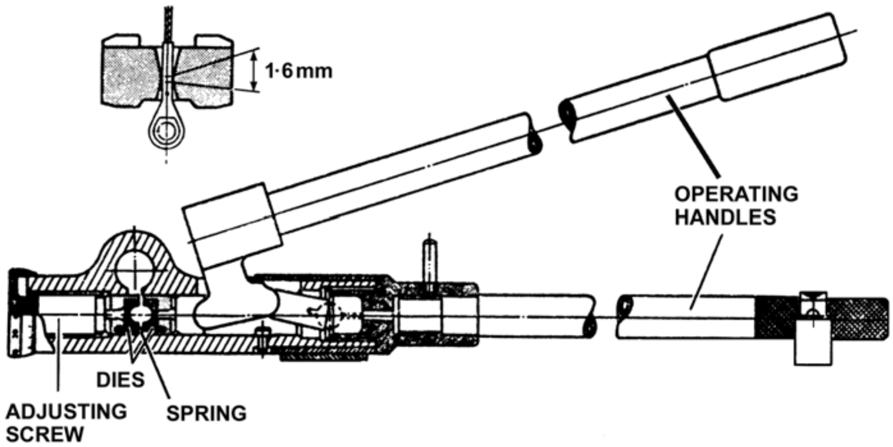


Fig. 29.1, Portable Swaging Machine

b. Cut the cable to the length specified on the drawing, and ensure that the ends are clean and square.

Note

Swaging elongates the end fitting, and an allowance for this must be made when cutting the cable. The allowance to be made should be stated on the appropriate drawing or specification.

c. Select the appropriate end fitting, and clean it by immersing it in solvent; then shake, and wipes dry.

d. Assemble the end fitting to drawing requirements. With drilled-through fittings, the cable end must pass the inspection hole, but be clear of the locking wire hole. For fittings with a blind hole, the cable must bottom in the hole. Bottoming may be checked by marking the cable with paint, at a distance from the end equal to the depth of the hole, and by ensuring that the paint mark reaches the fitting when the cable is inserted. When the cable and the fitting are correctly assembled, they should both be lightly lubricated.

e. Fit the dies for the particular end fitting in the swaging machine, open the handles of the machine, and unscrew the adjuster until the end fitting can be placed in the dies. With the end fitting centred in the die recess, close the handles fully, and screw in the adjuster until the dies grip the fitting. Open the handles, and tighten the adjuster by the amount of squeeze required for the particular end fitting; normally this should be approximately 0.18 mm (0.007 in).

f. Place the fitting in the position shown in the small sketch in Fig. 29.1, so as to swage to within approximately 1.2 mm (0.050 in) from the inspection hole. Check that the cable is in the correct position [see (d)], and operate the handles to squeeze the fitting.

g. Release the handles and rotate the fitting through approximately 50°. Repeat the squeezing and rotating until the fitting has been moved one full turn.

h. Withdraw the end fitting from the dies 1.6 mm (1\16 in) and repeat the cycle of squeezing and turning.

j. Continue operation until the whole shank is swaged. Check the diameter of the shank, and if it has not been reduced to the size required by the appropriate drawing or specification, reset the adjusting screw and repeat the swaging operation.

k. When the shank of the end fitting has been reduced to the correct diameter, remove and inspect the fitting

l. Fit the identification device as prescribed in the drawing, and mark it with the cable part number in the prescribed manner (in some cases the part number may be etched directly onto the end fitting). The identification may be in the form of a wired-on tag, or a cylindrical sleeve lightly swaged onto the shank of the end fitting.

m. Assemble any fittings, such as cable stops, on the cable, and swage on the opposite end fitting.

n. Dip the end fittings in lanolin, to prevent corrosion resulting from damaged plating, and to exclude moisture.

Portable swaging machine

Although unserviceable cables are usually replaced by cables which have been manufactured, pre-stretched and proof loaded in accordance with an approved drawing, and which have been supplied by the aircraft manufacturer, occasions may arise when such a cable is not available, and it is necessary appropriate drawings or instructions are available, end fittings may be swaged onto a cable using a hand-operated machine such as the one illustrated in Fig. 29.1.

Note

The proficiency of a person engaged in the manufacture of locally made cable assemblies, should be established by trial swagings on test cables, which should be tested to the satisfaction of the supervising inspector. The effectiveness of subsequent swaging operations should be checked periodically, by selecting a representative sample, and subjecting it to a tensile test to destruction.

A portable swaging machine is supplied with sets of dies for swaging various types of fittings to cable appropriate size, and with gauges for checking shank diameter after swaging. It is normally mounted on a widen block, and should be used on a low bench so that adequate pressure can be applied to the lever. An adjusting screw in the head of the machine alters the amount of squeeze applied, and a graduated scale permits accurate setting.

Inspection of swaged fitting

On completion of the swaging operations, the following inspection should be carried out.

a. Check that the correct combination of cable and fittings has been used .
b. Re-check the diameter of the swaged shank, using a GO-NOT GO gauge or a micrometer. If the diameter of the fitting is too small, it has been over-swaged, and the cable and the fitting must be rejected. Excessive work hardening of the fitting will cause it to crack, and may also damage the cable.
c. Check, by means of the inspection hole or paint mark, that the cable is correctly engaged in the end fitting
d. Check that the swaging operation has not disturbed the lay of the cable, where the cable enters the end fitting.
e. Ensure that the shank is smooth, parallel, and in line with the head of the fitting, and that the swaged shank length is correct.
f. Proof load the completed cable assembly in accordance with the appropriate drawing .
g. Inspect the fittings for cracks using a lens of 10 × magnification, or carry out a crack detection test, using magnetic or dye processes, as appropriate.
h. Check that the cable assembly is the correct length), and ensure that any required identification marking, including evidence of proof loading, has been carried out, and that any specified protective treatment has been applied.

Note

The first swaged fitting in a production batch is usually sectioned after proof loading, so that the interior surface can be examined for cracks. If this check is satisfactory, the settings on the swaging machine should be noted, and used for completion of the batch.

SWAGED SPLICES

A number of proprietary methods are used to secure cable in the from of a loop, which may then be attach the cable to a terminal fitting or turn buckle. The 'Talurit' swaged splice is approved for use on some British aircraft control cables, and is also widely used on ground equipment. The process provides a cable assembly 90% of the breaking strength of the cable. It may only be used to replace cables employing the same type of splice, or hand splices, and must not be used where swaged end fittings were used previously.

A typical 'Talurit' splice is illustrated in Fig. 29.2, to make this type of splice, the end of the cable is threaded through a ferrule of the appropriate size, looped, and passed back through the ferrule. A thimble is fitted in the loop, and the ferrule is squeezed between swages (dies) in a hand-operated or power-operated press. The metal of the ferrule is extruded between the two paralleled lengths of cable, and around the cable strands, and firmly locks the cable without disturbing its lay.

Ferrules are made in a variety of shapes, sizes and materials. Aluminium alloy ferrules are used with galvanised or tinned carbon steel cable, and copper ferrules are used with corrosion resisting steel cable.

When making a splice, the proper ferrule should be selected by the code numbers indicated on the appropriate drawing, and the associated swages should be fitted to the press. The loop and thimble should be adjusted after the swages have closed sufficiently to grip the ferrule; the cable must grip the thimble firmly, and the dimensions indicated in Fig. 29.2, must be obtained before swaging commences.

The press should be operated until the faces of the swages are touching, then the pressure should be released. Continuing to apply pressure after the faces have met, may cause damage to the press and swages. Only one pressing operation is normally required, but some long ferrules are designed for swaging in two separate operations, the swages in these cases being half the length of the ferrule.

After swaging , surplus metal is visible as a flash along each side of the ferrule, and may be removed with a file. If no flash has been formed, the sizes of the ferrule and swages should be re-checked, and it should be ascertained that the press is operating correctly.

The inspection of the finished splice consists of ensuring that the ferrule is correctly formed and not cracked, and of carrying out a proof test. In some instances a dimensional check is also specified, but, since the swages meet during the pressing operation, little variation in diameter will normally be obtained.

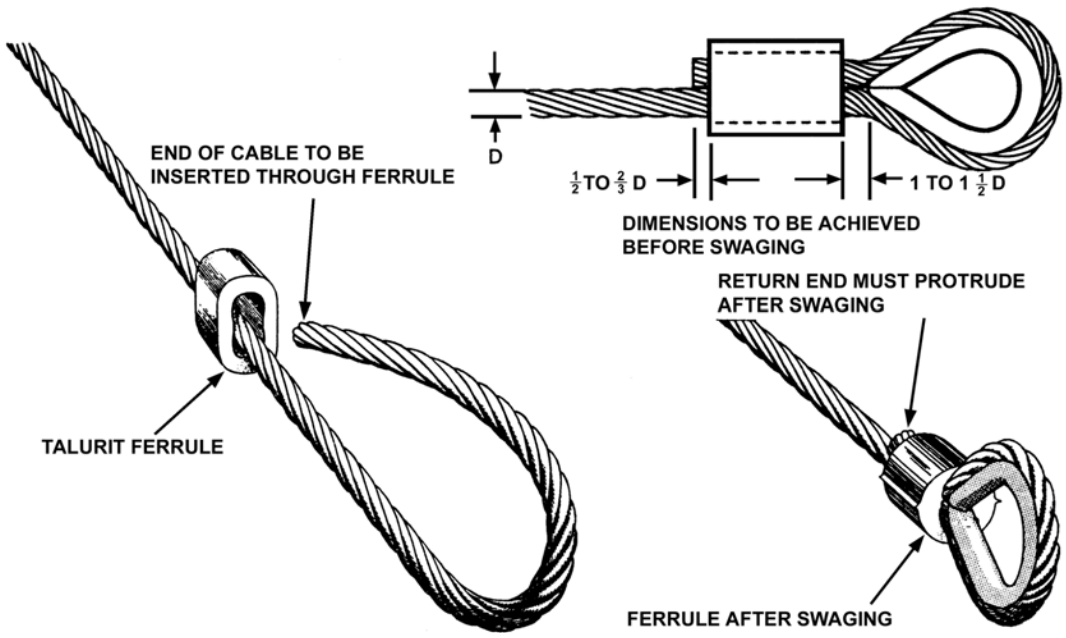


Fig. 29.2, 'Talurit' Swaged Splice

Manual Splicing

Although manual splicing may be permitted for some particular applications, it is seldom used on modern aircraft. It is less strong than either the swaged fitting or the swaged splice, and considerable experience is required in order to consistently obtain splices of adequate strength by this method. Persons engaged on splicing should be given an initial competency test, and representative samples of their work should be selected periodically, for tensile tests. Splices on cable manufactured to BS W9 OR W11, should not fail at less than 80% of the breaking strength of the cable. There are several methods of splicing, the procedure in each case varying in detail. A recommended method is given in the following paragraph, but other methods may be used, provided that the resulting splice is no less strong.

Splicing Procedure

The cable is normally spliced around a brass or steel thimble. The identification tag and, where applicable, the turn buckle eye-end, should be placed on the thimble, and the centre of the thimble bound to the cable. These cable should be whipped with waxed thread on either side of the thimble, as shown in Fig. 29.4.

Note

When cutting the cables to length , approximately 23 cm (9 in) should be allowed for each splice on cables up to 3.2 mm (1\8 in) diameter, and 30 cm (12 in) should be allowed for each splice in cable between 4.0 mm (5\32 in) and 6.4 mm (1\4 in) diameter.

The method of whipping with a waxed thread is illustrated in Fig. 29.3. A loop is formed in the thread (sketch A), and binding commenced from the open end of the loop towards the closed end (sketch B). When a sufficient length has been whipped, end 'b' of the thread is passed through the loop, and secured under the whipping by pulling end 'a' (sketch C); the loose ends are then cut off.

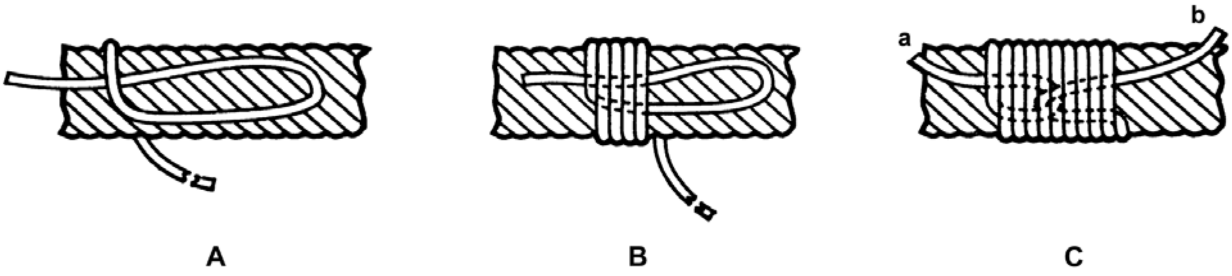


Fig. 29.3, Method of Whipping

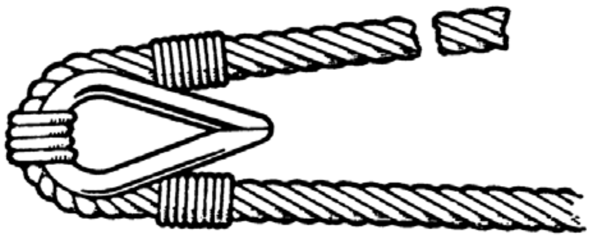


Fig. 29.4, Whipping of Cable

It is essential that the cable and thimble are securely held in a vice, using cable clamps or specially prepared vice blocks, and bound with a Fig. of eight binding as illustrated in Fig. 29.5. No attempt should be made to splice a cable without fully effective clamping devices.

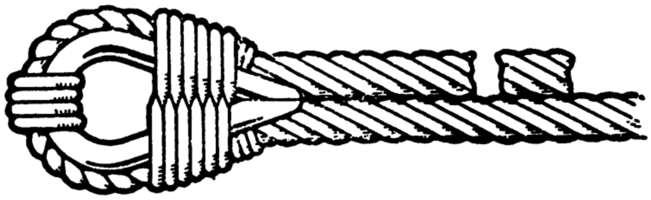


Fig. 29.5, Figure-of-Eight Binding

The strands at the end of the cable should be separated, and whipped or soldered to prevent unlaying of single wires. The cable is then ready for splicing.

Note

For descriptive purposes, the six outer strands of the free end of the cable will, in paragraphs below, be called the 'free strands', and will be numbered 1 to 6, while outer strands of the main cable will be lettered 'a' to `f', as shown in Fig. 29.6 & 29.7.

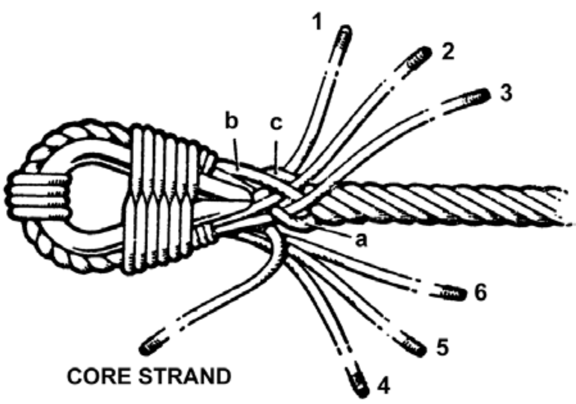


Fig. 29.6, First Round of Tucks (Front)

The core strand should be positioned so that there are three free stands on either side, and it should be bent back slightly. The first round of tucks should be completed as follows-3 under a, 1 under b and c, 2 under b (see Fig. 29.6); turn over and tuck 4 under f, 5 under e, and 6 under d (see Fig. 29.7). All free strands should be pulled tight, and then bent back to lock them in position. Care should be taken to avoid disturbing the lay of the cable by excessive pulling.

The core strand should be taken forward and temporarily secured to the main cable with thread, then pulled under a suitable free strand into the centre of the splice. The six free strands should then, in turn, be tucked over a strand and under a strand, e.g. 3 over b and under c, 1 over d and under e. On completing the second round of tucks, the free strands should be pulled tight, and locked back as before.

The third round of tucks should be completed in a similar manner to the second, taking care to bury the core strand in the centre of the splice.

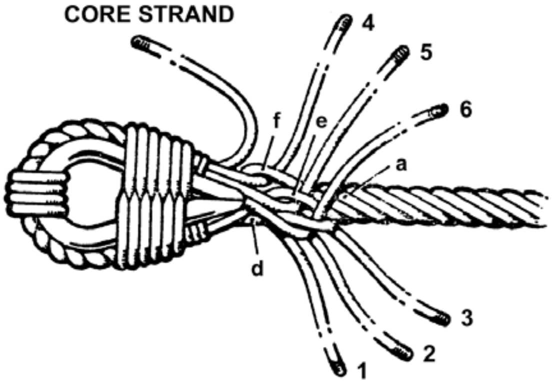


Fig. 29.7, First Round of Tucks (Reverse)

The last full round of tucks, i.e. the fourth, should be the same as the second and third rounds.

The half round of tucks for finishing the splice should be completed by tucking alternate free strands over one, and under two main cable strands. To finish and shape the splice, it should be beaten with a hardwood or rawhide mallet on a hardwood block, while the cable is held taut. The splice should be rotated against the direction of tucking during the beating process. Excessive hammering must be avoided. Free strands should be cut flush with the splice, and the last one and a half tucks should be whipped with waxed cord. The central binding and figure-of-eight lashing should be removed.

If both ends of the cable are to be spliced, the cable length should be checked before commencing the second splice, so that the completed cable will be of the required length.

Inspection of Splices

The splice should be inspected for symmetry and appearance. The wires should be close together, and no light should show between the strands or wires. A typical splice is shown in Fig. 29.8

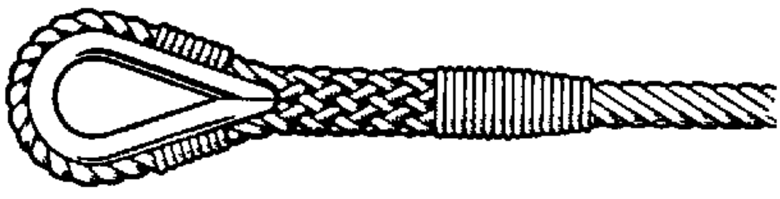


Fig. 29.8, Typical Spliced Joint

The resistance of the splice to bending should be checked. A bad splice will not be resistant to bending, and, when it is bent, the strands and wires will slacken.

The tightness of the thimble in the loop should be checked. The lay of the strands in the cable should be maintained as far as the splice permits, as disturbance in the lay of the cable adjacent to the splice may result in considerable weakening of the cable. The completed cable must be proof loaded.

Proof loading

All cables must be proof loaded after swaging or splicing, by subjecting the cable to a specified load. The purpose of proof loading is both to ensure that the end fittings are satisfactorily installed, and to pre-stretch the cable, i.e. to bed-in the strands and wires. British practice is to load the cable to 50% of its declared minimum breaking strength, and American practice is to load the cable to 60% of its declared minimum breaking strength. If no specific instructions are included in the drawing, then loading of the cable should be carried out in accordance with whichever of these practises is appropriate.

If end fittings have been fitted or splices have been made on pre-stretched cable, no appreciable elongation will result from proof loading. If the cable was not pre stretched, it may be expected to elongate slightly, and this should have been taken into consideration on the appropriate drawing.

A test rig suitable for proof loading cables is illustrated in Fig. 29.9, but other similar methods would be acceptable. These cable should be contained within a trough or other protective structure, to safeguard the operator in the event of failure of the cable. Adaptors should be used to attach the cable end fittings to the test rig, and these should be at least as strong as the cable. Particular care should be taken not to damage the thimbles on spliced cables; packing or bushes should be used to spread the load.

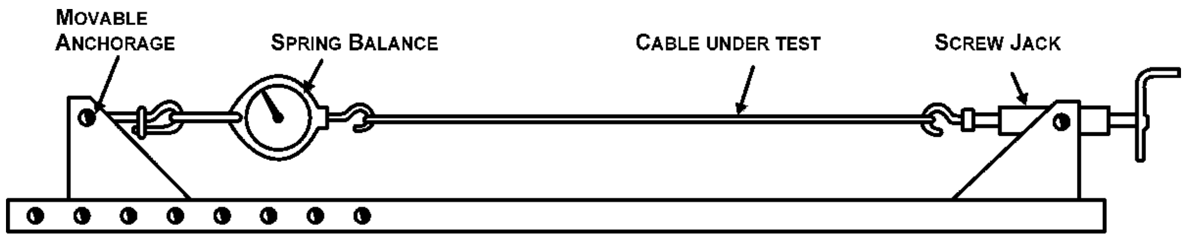


Fig. 29.9, Test Rig for Proof Loading

Before proof loading a cable with swaged end fittings, the cable should be painted with a quick-drying paint at its point of entry into the fittings, and allowed to dry. Cracking of the dried paint during proof loading will indicate slipping of the cable resulting from an unsatisfactory joint.

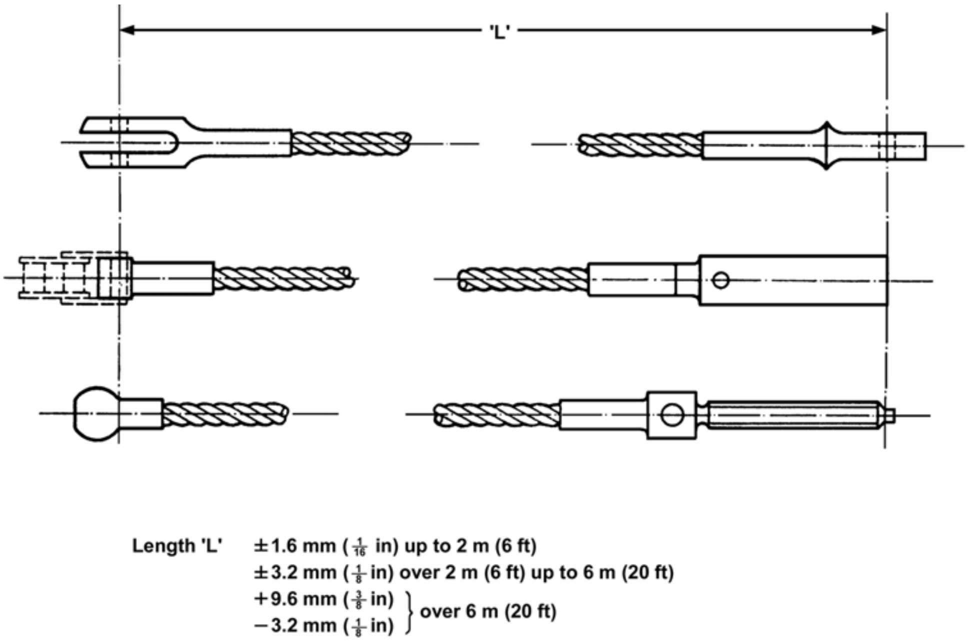


Fig. 29.10, Length of Assemblies

The test should consist of slowly applying the specified load, maintaining this load for a minimum specified period (normally 30 seconds for swaged fittings, but up to 3 minutes for splices), then releasing it, and carefully examining the cable for signs of pulling out of the end fittings, or stretching of the splice.

The end fittings should be checked for cracks using an electromagnetic method or, if the fitting is of stainless steel, a penetrant dye process (for details of these process read N.D.T.).

The length of the completed cable assembly should be measured after proof loading. Prior to measurement cables longer than 120 cm (4 ft) should be tensioned with a load of approximately 550 N (112 1bf), or 2% of the breaking load of the cable, whichever is the least. Fig. 29.10 shows the datum points and tolerances for the measurement of cables fitted with swaged end fittings to British Standards. Cables with different types of end fittings, or loops, should be measured according to the appropriate drawings or specifications.

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