

Module Name: Mechanical Design of Food Processing Equipment; FSE: 216

## MATERIALS FOR MACHINE MEMBERS

**Introduction** The knowledge of materials and their properties is of great significance for a design engineer. The machine elements should be made of such a material which has properties suitable for the conditions of operation. In addition to this, a design engineer must be familiar with the effects which the manufacturing processes and heat treatment have on the properties of the materials. In this chapter, we shall discuss the commonly used engineering materials and their properties in Machine Design.

**Classification of Engineering Materials** The engineering materials are mainly classified as:

1. Metals and their alloys, such as iron, steel, copper, aluminium, etc.
2. Non-metals, such as glass, rubber, plastic, etc.

The metals may be further classified as :

*a)* Ferrous metals, and *(b)* Non-ferrous metals.

The *\*ferrous metals* are those which have the iron as their main constituent, such as cast iron, wrought iron and steel.

The *non-ferrous* metals are those which have a metal other than iron as their main constituent, such as copper, aluminium, brass, tin, zinc, etc.

**Selection of Materials for Engineering Purposes** The selection of a proper material, for engineering purposes, is one of the most difficult problem for the designer. The best material is one which serves the desired objective at the minimum cost. The following factors should be considered while selecting the material:

1. Availability of the materials,
2. Suitability of the materials for the working conditions in service, and

### 3. The cost of the materials.

The important properties, which determine the utility of the material, are physical, chemical and mechanical properties.

**Physical Properties of Metals** The physical properties of the metals include luster, colour, size and shape, density, electric and thermal conductivity, and melting point.

**Mechanical Properties of Metals** The mechanical properties of the metals are those which are associated with the ability of the material to resist mechanical forces and load. These mechanical properties of the metal include strength, stiffness, elasticity, plasticity, ductility, brittleness, malleability, toughness, resilience, creep and hardness. We shall now discuss these properties as follows:

**1. Strength.** It is the ability of a material to resist the externally applied forces without breaking or yielding. The internal resistance offered by a part to an externally applied force is called \*stress.

**2. Stiffness.** It is the ability of a material to resist deformation under stress. The modulus of elasticity is the measure of stiffness.

**3. Elasticity.** It is the property of a material to regain its original shape after deformation when the external forces are removed. This property is desirable for materials used in tools and machines. It may be noted that steel is more elastic than rubber.

**4. Plasticity.** It is property of a material which retains the deformation produced under load permanently. This property of the material is necessary for forgings, in stamping images on coins and in ornamental work.

**5. Ductility.** It is the property of a material enabling it to be drawn into wire with the application of a tensile force. A ductile material must be both strong and plastic. The ductility is usually measured by the terms, percentage elongation and percentage reduction in area. The ductile material commonly used in engineering practice (in order of diminishing ductility) are mild steel, copper, aluminium, nickel, zinc, tin and lead.

**6. Brittleness.** It is the property of a material opposite to ductility. It is the property of breaking of a material with little permanent distortion. Brittle materials when subjected to tensile loads, snap off without giving any sensible elongation. Cast iron is a brittle material.

**7. Malleability.** It is a special case of ductility which permits materials to be rolled or hammered into thin sheets. A malleable material should be plastic but it is not essential to be so strong. The malleable materials commonly used in engineering practice (in order of diminishing malleability) are lead, soft steel, wrought iron, copper and aluminium.

**8. Toughness.** It is the property of a material to resist fracture due to high impact loads like hammer blows. The toughness of the material decreases when it is heated. It is measured by the amount of energy that a unit volume of the material has absorbed after being stressed upto the point of fracture. This property is desirable in parts subjected to shock and impact loads.

**9. Machinability.** It is the property of a material which refers to a relative ease with which a material can be cut. The machinability of a material can be measured in a number of ways such as comparing the tool life for cutting different materials or thrust required to remove the material at some given rate or the energy required to remove a unit volume of the material. It may be noted that brass can be easily machined than steel.

**10. Resilience.** It is the property of a material to absorb energy and to resist shock and impact loads. It is measured by the amount of energy absorbed per unit volume within elastic limit. This property is essential for spring materials.

**11. Creep.** When a part is subjected to a constant stress at high temperature for a long period of time, it will undergo a slow and permanent deformation called *creep*. This property is considered in designing internal combustion engines, boilers and turbines.

**12. Fatigue.** When a material is subjected to repeated stresses, it fails at stresses below the yield point stresses. Such type of failure of a material is known as *\*fatigue*. The failure is caused by means of a progressive crack formation which are usually fine and of microscopic size. This property is considered in designing shafts, connecting rods, springs, gears, etc.

**13. Hardness.** It is a very important property of the metals and has a wide variety of meanings. It embraces many different properties such as resistance to wear, scratching, deformation and machinability etc. It also means the ability of a metal to cut another metal. The hardness is usually expressed in numbers which are dependent on the method of making the test. The hardness of a metal may be determined by the following tests:

(a) Brinell hardness test,

(b) Rockwell hardness test,

(c) Vickers hardness (also called Diamond Pyramid) test, and

(d) Shore scleroscope.

**Ferrous materials Cast iron-** It is an alloy of iron, carbon and silicon and it is hard and brittle. Carbon content may be within 1.7% to 3% and carbon may be present as free carbon or iron carbide  $Fe_3C$ . In general the types of cast iron are (a) grey cast iron and (b) white cast iron (c) malleable cast iron (d) spheroidal or nodular cast iron (e) austenitic cast iron (f) abrasion resistant cast iron.

(a) **Grey cast iron-** Carbon here is mainly in the form of graphite. This type of cast iron is inexpensive and has high compressive strength. Graphite is an excellent solid lubricant and this makes it easily machinable but brittle. Some examples of this type of cast iron are FG20, FG35 or FG35Si15. The numbers indicate ultimate tensile strength in MPa and 15 indicates 0.15% silicon.

N.B: It is an ordinary commercial iron having the following compositions : Carbon = 3 to 3.5%; Silicon = 1 to 2.75%; Manganese = 0.40 to 1.0%; Phosphorous = 0.15 to 1% ; Sulphur = 0.02 to 0.15% ; and the remaining is iron.

(c) **Malleable cast iron-** These are white cast irons rendered malleable by annealing. These are tougher than grey cast iron and they can be twisted or bent without fracture. They have excellent machining properties and are inexpensive. Malleable cast iron are used for making parts where forging is expensive such as hubs for wagon wheels, brake supports. Depending on the method of processing they may be designated as black heart BM32, BM30 or white heart WM42, WM35 etc.

(d) **Spheroidal or nodular graphite cast iron-** In these cast irons graphite is present in the form of spheres or nodules. They have high tensile strength and good elongation properties. They are designated as, for example, SG50/7, SG80/2 etc where the first number gives the tensile strength in MPa and the second number indicates percentage elongation.

(e) **Austenitic cast iron-** Depending on the form of graphite present these cast iron can be classified broadly under two headings: Austenitic flake graphite iron designated, for example, AFGNi16Cu7Cr2

**Wrought iron-** This is a very pure iron where the iron content is of the order of 99.5%. It is produced by re-melting pig iron and some small amount of silicon, sulphur, or phosphorus may be present. It is tough, malleable and ductile and can easily be forged or welded. It cannot however take sudden shock. Chains, crane hooks, railway couplings and such other components may be made of this iron.

**Steel-** This is by far the most important engineering material and there is an enormous variety of steel to meet the wide variety of engineering requirements. The present note is an introductory discussion of a vast topic. Steel is basically an alloy of iron and carbon in which the carbon content can be less than 1.7% and carbon is present in the form of iron carbide to impart hardness and strength. Two main categories of steel are (a) Plain carbon steel and (b) alloy steel.

(a) **Plain carbon steel-** The properties of plain carbon steel depend mainly on the carbon percentages and other alloying elements are not usually present in more than 0.5 to 1% such as 0.5% Si or 1% Mn etc. There is a large variety of plain carbon steel and they are designated as C01, C14, C45, C70 and so on where the number indicates the carbon percentage. Following categorization of these steels is sometimes made for convenience:

- Dead mild steel- upto 0.15% C
- Low carbon steel or mild steel- 0.15 to 0.46% C
- Medium carbon steel- 0.45 to 0.8% C.
- High carbon steel- 0.8 to 1.5% C

(b) **Alloy steel-** these are steels in which elements other than carbon are added in sufficient quantities to impart desired properties, such as wear resistance, corrosion resistance, electric or magnetic properties. Chief alloying elements added are usually nickel for strength and toughness, chromium for hardness and strength, tungsten for hardness at elevated temperature, vanadium for tensile strength, manganese for high strength in hot rolled and heat treated condition, silicon for high elastic limit, cobalt for hardness and molybdenum for extra tensile strength. Some examples of alloy steels are 35Ni1Cr60, 30Ni4Cr1, 40Cr1Mo28, 37Mn2. Stainless steel is one such alloy steel that gives good corrosion resistance. One important type of stainless steel is often described as 18/8 steel where chromium and nickel percentages are 18 and 8 respectively. A typical designation of a stainless steel is 15Si2Mn2Cr18Ni8 where carbon percentage is 0.15.

**Non-ferrous metals** Metals containing elements other than iron as their chief constituents are usually referred to as non-ferrous metals. There is a wide variety of non-metals in practice. However, only a few exemplary ones are discussed below:

**Aluminium-** This is the white metal produced from Alumina. In its pure state it is weak and soft but addition of small amounts of Cu, Mn, Si and Magnesium makes it hard and strong. It is also corrosion resistant, low weight and non-toxic.

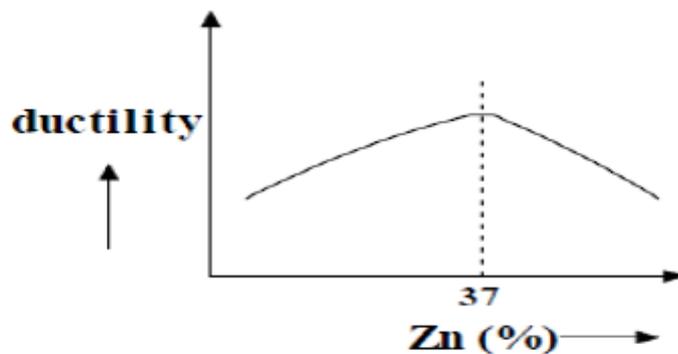
**Duralumin-** This is an alloy of 4% Cu, 0.5% Mn, 0.5% Mg and aluminium. It is widely used in automobile and aircraft components.

**Y-alloy-** This is an alloy of 4% Cu, 1.5% Mn, 2% Ni, 6% Si, Mg, Fe and the rest is Al. It gives large strength at high temperature. It is used for aircraft engine parts such as cylinder heads, piston etc.

**Magnalium-** This is an aluminium alloy with 2 to 10 % magnesium. It also contains 1.75% Cu. Due to its light weight and good strength it is used for aircraft and automobile components.

**Copper alloys** Copper is one of the most widely used non-ferrous metals in industry. It is soft, malleable and ductile and is a good conductor of heat and electricity. The following two important copper alloys are widely used in practice:

**Brass (Cu-Zn alloy)-** It is fundamentally a binary alloy with Zn upto 50% . As Zn percentage increases, ductility increases upto ~37% of Zn beyond which the ductility falls. This is shown in figure-1.2.4.1. Small amount of other elements viz. lead or tin imparts other properties to brass. Lead gives good machining quality and tin imparts strength. Brass is highly corrosion resistant, easily machinable and therefore a good bearing material.



*Figure: Variation of ductility of brass with percentage of zinc.*

**Bronze (Cu-Sn alloy)-**This is mainly a copper-tin alloy where tin percentage may vary between 5 to 25. It provides hardness but tin content also oxidizes resulting in brittleness. Deoxidizers such as Zn may be added. Gun metal is one such alloy where 2% Zn is added as deoxidizing agent and typical compositions are 88% Cu, 10% Sn, 2% Zn. This is suitable for working in cold state. It was originally made for casting guns but used now for boiler fittings, bushes, glands and other such uses.

**Non-metals** Non-metallic materials are also used in engineering practice due to principally their low cost, flexibility and resistance to heat and electricity. Though there are many suitable non-metals, the following are important few from design point of view:

**Timber-** This is a relatively low cost material and a bad conductor of heat and electricity. It has also good elastic and frictional properties and is widely used in foundry patterns and as water lubricated bearings.

**Leather-** This is widely used in engineering for its flexibility and wear resistance. It is widely used for belt drives, washers and such other applications.

**Rubber-** It has high bulk modulus and is used for drive elements, sealing, vibration isolation and similar applications.

**Plastics** These are synthetic materials which can be moulded into desired shapes under pressure with or without application of heat. These are now extensively used in various industrial applications for their corrosion resistance, dimensional stability and relatively low cost. There are two main types of plastics:

(a) **Thermosetting plastics-** Thermosetting plastics are formed under heat and pressure. It initially softens and with increasing heat and pressure, polymerisation takes place. This results in hardening of the material. These plastics cannot be deformed or remoulded again under heat and pressure. Some examples of thermosetting plastics are phenol formaldehyde (Bakelite), phenol-furfural (Durite), epoxy resins, phenolic resins etc.

(b) **Thermoplastics-** Thermoplastics do not become hard with the application of heat and pressure and no chemical change takes place. They remain soft at elevated temperatures until they are hardened by cooling. These can be re-melted and remoulded by application of heat and pressure. Some examples of thermoplastics are cellulose nitrate (celluloid), polythene, polyvinyl acetate, polyvinyl chloride (PVC) etc.