Engineering Materials

Instructional Objectives

At the end of this lesson, students should know

- Properties and applications of common engineering materials.
- Types and uses of ferrous metals such as cast iron, wrought iron and steel.
- Types and uses of some common non-ferrous metals.
- Types and uses of some non-metals.
- Important mechanical properties of materials.

1.2.1 Introduction

Choice of materials for a machine element depends very much on its properties, cost, availability and such other factors. It is therefore important to have some idea of the common engineering materials and their properties before learning the details of design procedure. This topic is in the domain of material science or metallurgy but some relevant discussions are necessary at this stage.

Common engineering materials are normally classified as metals and non-metals. Metals may conveniently be divided into ferrous and non-ferrous metals. Important ferrous metals for the present purpose are:

(i) cast iron (ii) wrought iron (iii) steel.

Some of the important non-ferrous metals used in engineering design are:

(a) Light metal group such as aluminium and its alloys, magnesium and manganese alloys.

(b) Copper based alloys such as brass (Cu-Zn), bronze (Cu-Sn).

(c) White metal group such as nickel, silver, white bearing metals eg. SnSb7Cu3, Sn60Sb11Pb, zinc etc.

Cast iron, wrought iron and steel will now be discussed under separate headings.

1.2.2 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.

(b) **White cast iron**- In these cast irons carbon is present in the form of iron carbide (Fe_3C) which is hard and brittle. The presence of iron carbide increases hardness and makes it difficult to machine. Consequently these cast irons are abrasion resistant.

(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

Austenitic spheroidal or nodular graphite iron designated, for example, ASGNi20Cr2. These are alloy cast irons and they contain small percentages of silicon, manganese, sulphur, phosphorus etc. They may be produced by adding alloying elements viz. nickel, chromium, molybdenum, copper and manganese in sufficient quantities. These elements give more strength and improved properties. They are used for making automobile parts such as cylinders, pistons, piston rings, brake drums etc.

(f) **Abrasion resistant cast iron**- These are alloy cast iron and the alloying elements render abrasion resistance. A typical designation is ABR33 Ni4 Cr2 which indicates a tensile strength in kg/mm^2 with 4% nickel and 2% chromium.

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 plane 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

Detailed properties of these steels may be found in any standard handbook but in general higher carbon percentage indicates higher strength.

(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.

1.2.3 Specifications

A number of systems for grading steel exist in different countries.

The American system is usually termed as SAE (Society of Automobile Engineers) or AISI (American Iron and Steel Industries) systems. For an example, a steel denoted as SAE 1020 indicates 0.2% carbon and 13% tungsten. In this system the first digit indicates the chief alloying material. Digits 1,2,3,4 and 7 refer to carbon, nickel, nickel/chromium, molybdenum and tungsten respectively. More details may be seen in the standards. The second digit or second and third digits give the percentage of the main alloying element and the last two digits indicate the carbon percentage. This therefore explains that SAE

71360 indicates an alloy steel with 0.6% carbon and the percentage of main alloying material tungsten is 13.

In British system steels are designated by the letters En followed by a number such as 1,2…16, 20 etc. Corresponding constituent elements can be seen from the standards but in general En4 is equivalent to C25 steel, En6 is equivalent to C30 steel and so on.

1.2.4 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.

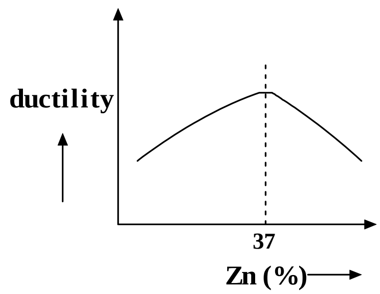
Y-alloy- This is an alloy of 4% Cu, 1.5% Mn, 2% Ni, 6% Si, Mg, Fe and the rest is Al. It gives large strength at high temperature. It is used for aircraft engine parts such as cylinder heads, piston etc.

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.



1.2.4.1F- *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.

1.2.5 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.

1.2.6 Mechanical properties of common engineering materials

The important properties from design point of view are:

(a) **Elasticity**- This is the property of a material to regain its original shape after deformation when the external forces are removed. All materials are plastic to some extent but the degree varies, for example, both mild steel and rubber are elastic materials but steel is more elastic than rubber.

(b) **Plasticity**- This is associated with the permanent deformation of material when the stress level exceeds the yield point. Under plastic conditions materials ideally deform without any increase in stress. A typical stress-strain diagram for an elastic-perfectly plastic material is shown in the figure-1.2.6.1. Mises-Henky criterion gives a good starting point for plasticity analysis. The criterion is given as $(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 = 2\sigma_y^2$, where σ_1, σ_2, σ_3 and σ_y are the three principal stresses at a point for any given loading and the stress at the tensile yield point respectively. A typical example of plastic flow is the indentation test where a spherical ball is pressed in a semi-infinite body where 2a is the indentation diameter. In a simplified model we may write that if $\frac{P}{\pi a^2} > p_m$ plastic flow occurs where, p_m is the flow pressure. This is also shown in figure 1.2.6.1.

***1.2.6.1F**- Stress-strain diagram of an elastic-perfectly plastic material and the plastic indentation.*

(c) **Hardness**- Property of the material that enables it to resist permanent deformation, penetration, indentation etc. Size of indentations by various types of indenters are the measure of hardness e.g. Brinnel hardness test, Rockwell hardness test, Vickers hardness (diamond pyramid) test. These tests give hardness numbers which are related to yield pressure (MPa).

(d) **Ductility**- This is the property of the material that enables it to be drawn out or elongated to an appreciable extent before rupture occurs. The percentage elongation or percentage reduction in area before rupture of a test specimen is the measure of ductility. Normally if percentage elongation exceeds 15% the material is ductile and if it is less than 5% the material is brittle. Lead, copper, aluminium, mild steel are typical ductile materials.

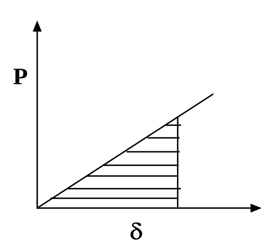
(e) **Malleability**- It is a special case of ductility where it can be rolled into thin sheets but it is not necessary to be so strong. Lead, soft steel, wrought iron, copper and aluminium are some materials in order of diminishing malleability.

(f) **Brittleness**- This is opposite to ductility. Brittle materials show little deformation before fracture and failure occur suddenly without any warning. Normally if the elongation is less than 5% the material is considered to be brittle. E.g. cast iron, glass, ceramics are typical brittle materials.

(g) **Resilience**- This is the property of the material that enables it to resist shock and impact by storing energy. The measure of resilience is the strain energy absorbed per unit volume. For a rod of length L subjected to tensile load P, a linear load-deflection plot is shown in figure-1.2.6.2.

Strain energy (energy stored) $= \frac{1}{2}P\delta L = \frac{1}{2}\frac{P}{A}\frac{\delta L}{L}AL = \frac{1}{2}\sigma\varepsilon V$

Strain energy/unit volume $= \frac{1}{2}\sigma\varepsilon$



***1.2.6.2F**- A linear load-deflection plot.*

(h) **Toughness**- This is the property which enables a material to be twisted, bent or stretched under impact load or high stress before rupture. It may be considered to be the ability of the material to absorb energy in the plastic zone. The measure of toughness is the amount of energy absorbed after being stressed upto the point of fracture.

(i) **Creep**- When a member is subjected to a constant load over a long period of time it undergoes a slow permanent deformation and this is termed as "creep". This is dependent on temperature. Usually at elevated temperatures creep is high.

1.2.7Questions with Answers

Q.1: Classify common engineering materials.

A.1: Common engineering materials can be broadly classified into metals and non-metals. Metals include ferrous and non-ferrous metal and the non-metals include timber, leather, rubber and a large variety of polymers. Among the ferrous metals different varieties of cast iron, wrought iron and alloy steels are extensively used in industry. There are also a large variety of timber, leather and polymers that are used in industry.

Q.2: What are the advantages of malleable cast iron over white or grey cast iron?

A.2: Malleable cast iron are tougher than grey or white cast iron and can be twisted or bent without fracture. They also have excellent machining properties and are relatively inexpensive.

Q.3: A standard alloy steel used for making engineering components is 20Cr18 Ni2. State
the composition of the steel.

A.3: The composition of the steel is 0.2% carbon, 18% chromium and 2% nickel.

Q.4: How are plain carbon steel designated?

A.4 Properties of plain carbon steel depend mainly on the carbon percentage and they are designated as C01, C45, C70 where carbon percentage is represented in terms of the digits, for example C01 steel contains 0.01% carbon.

Q.5: Name two important copper alloys and give their typical compositions.

A.5: Two most important copper alloys are bronze and brass. Bronze is a Cu-Sn alloy with the typical composition of 88% Cu, 10% Sn and 2% Zn. Brass is a Cu-Zn alloy with the typical composition of red brass of 85% Cu , 15% Zn.

Q.6: List at least five important non-metals commonly used in machine design.

A.6: Some important non-metals for industrial uses are:

Timber, leather, rubber, bakelite, nylon, polythene, polytetraflutoethylene (PTFE).

Q.7: State atleast 5 important mechanical properties of materials to be considered in machine design.

A.7: Some important properties of materials to be considered in design are:

Elastic limit, yield and ultimate strength, hardness and toughness.

Q.8: Define resilience and discuss its implication in the choice of materials in machine design.

A.8: Resilience is defined as the property of a material that enables it to resist shock and impact. The property is important in choosing materials for machine parts subjected to shock loading, such as, fasteners, springs etc.

1.2.8 Summary of this Lesson

In this lesson the properties and uses of different types of metals and non-metals, generally used in machine design, are discussed. Primarily ferrous and non-ferrous metals and some non-metals are discussed. Mechanical properties of some common engineering materials are also discussed briefly.

1.2.8 Reference for Module-1

1) Design of machine elements by M.F.Spotts, Prentice hall of India, 1991.
2) Machine design-an integrated approach by Robert L. Norton, Pearson Education Ltd.
3) A textbook of machine design by P.C.Sharma and D.K.Agarwal, S.K.Kataria and sons, 1998.
4) A text book of machine design by R. S. Khurmi and J.K.Gupta, S.Chand and company ltd., 1997.