Unit 5: B. M. E. Part – B: Introduction to engineering materials

Introduction to engineering materials for mechanical construction, composition, mechanical and fabricating characteristics of various types of cast irons, plain carbon and alloy steels, copper, aluminium and their alloys like duralumin, brasses and bronzes, cutting tool materials, super alloys, thermoplastics, thermosets and composite materials

Introduction to engineering materials for mechanical construction:

Material and science

Material means engineering materials, limited to solid materials only. **Science** refers to the branch of applied science which deals with investigation of the relationship existing between the structure of materials and their properties. Materials differ from one another because of the difference in their properties for example gold differs from iron because of its colour, density, and corrosion resistance properties etc. The difference in properties occur due to difference in structure of materials.

All solid materials consists of large number of particles called **molecules** which are bonded together to form the bulk material. Each molecule is composed of tiny particle called **atoms**. Individual property of atoms and their arrangement in the molecule determine the properties and structure of a material.

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 Operating conditions. In addition to this, a design engineer must be familiar with the effects of the manufacturing processes and heat treatment on the properties of the materials. Here we shall discuss the commonly used engineering materials and their properties.

CLASSIFICATION OF ENGINEERING MATERIALS

The factors which form the basis of various systems of classifications of materials in material science and engineering are:

(i) The chemical composition of the material,
(ii) The mode of the occurrence of the material in the nature,
(iii) The refining and the manufacturing process to which the material is subjected prior it acquires the required properties,
The atomic and crystalline structure of material and
(iv) The industrial and technical use of the material.

Common engineering materials that falls within the scope of material science and engineering may be classified into one of the following groups:

(i) Metals (ferrous and non-ferrous) and alloys
(ii) Ceramics
(iii) Organic Polymers
(iv) Composites
(v) Semi-conductors
(vi) Biomaterials
(vii) Advanced Materials

Metallic materials are typically classified according to their use in engineering as under:

(i) ***Pure Metals**:* Generally it is very difficult to obtain pure metal. Usually, they are obtained by refining the ore. Mostly, pure metals are not of any use to the engineers. However, by specialised and very expensive techniques, one can obtain pure metals (purity ~ 99.99%), e.g. aluminium, copper etc.

(ii) ***Alloyed Metals**:* Alloys can be formed by blending two or more metals or at least one being metal. The properties of an alloy can be totally different from its constituent substances, e.g. 18-8 stainless steel, which contains 18% chromium and 8% nickel, in low carbon steel, carbon is less than 0.15% and this is extremely tough, exceedingly ductile and highly resistant to corrosion. We must note that these properties are quite different from the behaviour of original carbon steel.

(iii) ***Ferrous Metals**:* Iron is the principal constituent of these ferrous metals. Ferrous alloys contain significant amount of non-ferrous metals. Ferrous alloys are extremely important for engineering purposes. On the basis of the percentage of carbon and their alloying elements present, these can be classified into following groups:

(a) **Dead Mild Steel:** The percentage of carbon in these materials is upto 0.15%. These are not strong and are very ductile. The production cost of these materials is low.

***(b)Mild Steels**:* The percentage of carbon in these materials range from 0.15% to 0.45%. These are moderately strong and have good weldability. The production cost of these materials is also low.

(b) ***Medium Carbon Steels**:* These contains carbon between 0.45% to 0.6%. The strength of these materials is high but their weldability is comparatively less.

(c) ***High Carbon Steels**:* These contains carbon varying from 0.6% to 1.5%. These materials get hard and tough by heat treatment and their weldability is poor. The steel formed in which carbon content is upto 1.5%, silica upto 0.5%, and manganese upto 1.5% alongwith traces of other elements is called *plain carbon steel*.

(d) ***Cast Iron**:* The carbon content in these substances vary between 2% to 4.5%. The cost of production of these substances is quite low and these are used as ferrous casting alloys.

(iv) ***Non - Ferrous Metals**:* These substances are composed of metals other than iron. However, these may contain iron in small proportion. Out of several non-ferrous metals only seven are available in sufficient quantity reasonably at low cost and used as common engineering metals. These are **aluminium, tin, copper, nickle, zinc and magnesium.** Some other non-ferrous metals, about fourteen in number, are produced in relatively small quantities but these are of vital importance in modern industry. These includes, chromium, mercury, cobalt, tungsten, vanadium, molybdenum, antimony, cadmium, zirconium, beryllium, niobium, titanium, tantalum and manganese.

(v) ***Sintered Metals**:* These materials possess very different properties and structures as compared to the metals from which these substances have been cast. Powder metallurgy technique is used to produce sintered metals. The metals to be sintered are first obtained in powered form and then mixed in right calculated proportions. After mixing properly, they are put in the die of desired shape and then processed with certain pressure. Finally, one gets them sintered in the furnace. We must note that the mixture so produced is not the true alloy but it possesses some of the properties of typical alloys.

(vi) ***Clad Metals**:* A 'sandwich' of two materials is prepared in order to avail the advantage of the properties of both the materials. This technique is termed as *cladding*. Using this technique stainless steel is mostly embedded with a thick layer of mild steel, by rolling the two metals together while they are red hot. This technique will not allow corrosion of one surface. Another example of the use of this technique is cladding of duralium with thin sheets of pure aluminium. The surface layers, i.e. outside layers of aluminium resist corrosion, whereas inner layer of duralumin imparts high strength. This technique is relatively cheap to manufacture.

Selection of Materials for Engineering Purposes

The selection of a proper material, for engineering purposes, is one of the most difficult problem. The best material is one which serve the desired objective at the minimum cost.

One of the most challenging task of an engineer is the proper selection of the material for a particular job/component of a machine or structure. An engineer must be in a position to choose the optimum combination of properties in a material at the lowest possible cost without compromising the quality. The properties and behaviour of a material depends upon the several factors, e.g., composition, crystal structure, conditions during service and the interaction among them. The performance of materials may be found satisfactory within certain limitations or conditions. However, beyond these conditions, the performance of materials may not be found satisfactory. The major factors affecting the selection of materials are:

(i) Component shape
(ii) Dimensional tolerance
(iii) Mechanical properties
(iv) Fabrication requirements
(v) Service requirements
(vi) Cost of the material
(vii) Cost of processing, and
(viii) Availability of the material.

All these major factors have a complex effect on the selection of materials. The shape and size of a component has great effect on the choice of the processing unit which ultimately effects the choice of the material. To make it more clear, we consider an example, let the best possible production method is selected, under given conditions, it is die casting, obviously, now the choice of the material becomes limited, i.e. one can only choose materials with lower melting points, e.g. aluminium, zinc, magnesium and thermoplastics. There are some materials which can be finished to close tolerance while others cannot. Obviously, the required dimensional tolerance for finished components will, influence the choice of materials.

To select a suitable material for specific conditions, all mechanical properties, e.g., hardness, strength, etc. guide us. Method of processing of the material also affects the properties of a component, e.g., forged components can be stronger than the casted components. Different types of working processes may also give different types of fibre structure. However, investment casting can provide precise dimensions at low cost in comparison to machine operations. Service requirements are dimensional stability, strength, toughness, heat resistance, corrosion resistance, fatigue and creep resistance, electrical and thermal conductivity etc. Whereas fabrication requirements are **castability**, i.e., ease in casting a material, **weldability**-ease in welding the material, **machinability**-ease to machine a material, formability-ease to form a material, **hardenability** etc. In most of the cases, the cost of raw material accounts about 50 per-cent of the finished cost. Obviously, the cost of the material is a major factor which influences the choice of the material or process.

Mechanical Properties of Metals

The mechanical properties of the metals are those which are associated with the ability of the materials 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

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.

Note: The ductility of a material is commonly measured by means of percentage elongation and percentage reduction in area in a tensile test.

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 case 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.

Wrought Iron:

It is the purest iron which contains at least 99.5% iron but may contain upto 99.9% iron. The typical composition of a wrought iron is Carbon = 0.020%, Silicon = 0.120%, Sulphur = 0.018%, Phosphorus = 0.020%, Slag = 0.070%, and the remaining is iron.

The wrought iron is produced from pig iron by re-melting it in the puddling furnace of reverberatory type. The molten metal free from impurities is removed from the furnace as a pasty mass of iron and slag. The balls of this pasty mass, each about 45 to 65 kg are formed. These balls are then mechanically worked both to squeeze out the slag and to form it into some commercial shape. The wrought iron is a tough, malleable and ductile material. It cannot stand sudden and excessive shocks. Its ultimate tensile strength is 250 MPa to 500 MPa and the ultimate compressive strength is 300 MPa. It can be easily forged or welded. It is used for chains, crane hooks, railway couplings, water and steam pipes.

Steel:

It is an alloy of iron and carbon, with carbon content up to a maximum of 1.5%. The carbon occurs in the form of iron carbide, because of its ability to increase the hardness and strength of the steel. Other elements *e.g.* silicon, sulphur, phosphorus and manganese are also present to greater or lesser amount to impart certain desired properties to it. Most of the steel produced now-a-days is ***plain carbon steel*** or simply ***carbon steel.*** A carbon steel is defined as a steel which has its properties mainly due to its carbon content and does not contain more than 0.5% of silicon and 1.5% of manganese. The plain carbon steels varying from 0.06% carbon to 1.5% carbon are divided into the following types depending upon the carbon content.

1. Dead mild steel — up to 0.15% carbon
2. Low carbon or mild steel — 0.15% to 0.45% carbon
3. Medium carbon steel — 0.45% to 0.6% carbon
4. High carbon steel — 0.6% to 1.5% carbon

According to Indian standard [IS 1762 (Part-I)–1974], a new system of designating the steel is recommended. According to this standard, steels are designated on the following two Basis:

(*a*) On the basis of mechanical properties, and
(*b*) On the basis of chemical composition.

Steels Designated on the Basis of Mechanical Properties

These steels are carbon and low alloy steels where the main criterion in the selection and inspection of steel is the tensile strength or yield stress. According to Indian standard IS: 1570 (Part–I)- 1978 (Reaffirmed 1993), these steels are designated by a symbol 'Fe' or 'Fe E' depending on whether the steel has been specified on the basis of minimum tensile strength or yield strength, followed by the figure indicating the minimum tensile strength or yield stress in N/mm^2.

For example 'Fe 290' means a steel having minimum tensile strength of 290 N/mm^2 and 'Fe E 220' means a steel having yield strength of 220 N/mm^2.

Notes:

1. The steels from grades Fe 290 to Fe 490 are general structural steels and are available in the form of bars, sections, tubes, plates, sheets and strips.
2. The steels of grades Fe 540 and Fe 620 are medium tensile structural steels.
3. The steels of grades Fe 690, Fe 770 and Fe 870 are high tensile steels.

Table: Indian standard designation of steel according to IS : 1570 (Part I)-1978 (Reaffirmed 1993).

Indian standard designation	*Tensile strength (Minimum) N/mm²*	*Yield stress (Minimum) N/mm²*	*Minimum percentage elongation*	*Uses as per IS : 1871 (Part I)—1987 (Reaffirmed 1993)*
Fe 290 Fe E 220	290 290	170 220	27 27	It is used for plain drawn or enamelled parts, tubes for oil well casing, steam, water and air passage, cycle, motor cycle and automobile tubes, rivet bars and wire.
Fe 310 Fe E 230 Fe 330 Fe E 250	310 310 330 330	180 230 200 250	26 26 26 26	These steels are used for locomotive carriages and car structures, screw stock and other general engineering purposes.
Fe 360 Fe E 270	360 360	220 270	25 25	It is used for chemical pressure vessels and other general engineering purposes.
Fe 410 Fe E 310	410 410	250 310	23 23	It is used for bridges and building construction, railway rolling stock, screw spikes, oil well casing, tube piles, and other general engineering purposes.
Fe 490 Fe E 370	490 490	290 370	21 21	It is used for mines, forgings for marine engines, sheet piling and machine parts.
Fe 540 Fe E 400	540 540	320 400	20 20	It is used for locomotive, carriage, wagon and tramway axles, arches for mines, bolts, seamless and welded tubes.
Fe 620 Fe E 460	620 620	380 460	15 15	It is used for tramway axles and seamless tubes.
Fe 690 Fe E 520	690 690	410 520	12 12	It is used for locomotive, carriage and wagon wheels and tyres, arches for mines, seamless oil well casing and drill tubes, and machine parts for heavy loading.
Fe 770 Fe E 580	770 770	460 580	10 10	It is used for locomotive, carriage and wagon wheels and tyres, and machine parts for heavy loading.
Fe 870 Fe E 650	870 870	520 650	8 8	It is used for locomotive, carriage and wagon wheels and tyres.

Steels Designated on the Basis of Chemical Composition

According to Indian standard, IS: 1570 (Part II/Sec I)-1979 (Reaffirmed 1991), the carbon steel is designated in the following order :

(*a*) Figure indicating 100 times the average percentage of carbon content,

(*b*) Letter 'C', and

c) Figure indicating 10 times the average percentage of manganese content. The figure after multiplying shall be rounded off to the nearest integer.

For example 20C8 means a carbon steel containing 0.15 to 0.25 per cent (0.2 per cent on an average) carbon and 0.60 to 0.90 per cent (0.75 per cent rounded off to 0.8 per cent on an average) manganese.

Table 2 Indian standard designation of carbon steel according to IS : 1570 (Part II/Sec 1) – 1979 (Reaffirmed 1991).

Indian standard designation	*Composition in percentages*		*Uses as per IS : 1871 (Part II)–1987 (Reaffirmed 1993)*
	Carbon (C)	*Manganese (Mn)*	
4C2	0.08 Max.	0.40 Max.	It is a dead soft steel generally used in electrical industry.
5C4 7C4 10C4	0.10 Max. 0.12 Max. 0.15 Max.	0.50 Max. 0.50 Max. 0.30 – 0.60	These steels are used where cold formability is the primary requirement. In the rimming quality, they are used as sheet, strip, rod and wire especially where excellent surface finish or good drawing qualities are required, such as automobile body, and fender stock, hoods, lamps, oil pans and a multiple of deep drawn and formed products. They are also used for cold heading wire and rivets and low carbon wire products. The killed steel is used for forging and heat treating applications.
10C4 14C6	0.15 Max. 0.10 – 0.18	0.30 – 0.60 0.40 – 0.70	The case hardening steels are used for making camshafts, cams, light duty gears, worms, gudgeon pins, spindles, pawls, ratchets, chain wheels, tappets, etc.
15C4	0.20 Max.	0.30 – 0.60	It is used for lightly stressed parts. The material, although easily machinable, is not designed specifically for rapid cutting, but is suitable where cold web, such as bending and riveting may be necessary.

Effect of Impurities on Steel

The following are the effects of impurities like silicon, sulphur, manganese and phosphorus on steel.

1. ***Silicon*.** The amount of silicon in the finished steel usually ranges from 0.05 to 0.30%. Silicon is added in low carbon steels to prevent them from becoming porous. It removes the gases and oxides, prevent blow holes and thereby makes the steel tougher and harder.
2. ***Sulphur*.** It occurs in steel either as iron sulphide or manganese sulphide. Iron sulphide because of its low melting point produces red shortness, whereas manganese sulphide does not effect so much. Therefore, manganese sulphide is less objectionable in steel than iron sulphide.
3. ***Manganese*.** It serves as a valuable deoxidising and purifying agent in steel. Manganese also combines with sulphur and thereby decreases the harmful effect of this element remaining in the steel. When used in ordinary low carbon steels, manganese makes the metal ductile and of good bending qualities. In high speed steels, it is used to toughen the metal and to increase its critical temperature.
4. ***Phosphorus*.** It makes the steel brittle. It also produces cold shortness in steel. In low carbon steels, it raises the yield point and improves the resistance to atmospheric corrosion. Sum of carbon and phosphorus usually does not exceed 0.25%.

Designation of Free Cutting Steels

The free cutting steels contain sulphur and phosphorus. These steels have higher sulphur content than other carbon steels. In general, the carbon content of such steels vary from 0.1 to 0.45 per cent and sulphur from 0.08 to 0.3 per cent. These steels are used where rapid machining is the prime requirement. It may be noted that the presence of sulphur and phosphorus causes long chips in machining to be easily broken and thus prevent clogging of machines. Now a days, lead is used from 0.05 to 0.2 per cent instead of sulphur, because lead also greatly improves the machinability of steel without the loss of toughness.

According to Indian standard, IS : 1570 (Part III)-1979 (Reaffirmed 1993), carbon and carbon manganese free cutting steels are designated in the following order :

1. Figure indicating 100 times the average percentage of carbon, Letter 'C',
3. Figure indicating 10 times the average percentage of manganese, and
4. Symbol 'S' followed by the figure indicating the 100 times the average content of sulphur. If instead of sulphur, lead (Pb) is added to make the steel free cutting, then symbol 'Pb' may be used.

Alloy Steel

An alloy steel may be defined as a steel in which elements other than carbon are added in sufficient amount to produce an improvement in properties. The alloying is done for specific purposes to increase wearing resistance, corrosion resistance and to improve electrical and magnetic properties, which cannot be obtained in plain carbon steels. The chief alloying elements used in steel are nickel, chromium, molybdenum, cobalt, vanadium, manganese, silicon and tungsten. Each of these elements confer certain qualities upon the steel to which it is added. These elements may be used separately or in combination to produce the desired characteristic in steel.

Following are the effects of alloying elements on steel:

1. ***Nickel***. It increases the strength and toughness of the steel. These steels contain 2 to 5% nickel and from 0.1 to 0.5% carbon. In this range, nickel contributes great strength and hardness with high elastic limit, good ductility and good resistance to corrosion. **An alloy containing 25% nickel possesses maximum toughness and offers the greatest resistance to rusting, corrosion and burning at high temperature.** It has proved to be of advantage in the manufacture of boiler tubes, valves for use with superheated steam, valves for I.C. engines and spark plugs for petrol engines. A nickel steel alloy containing 36% of nickel is known as ***invar***. It has nearly zero coefficient of expansion. So it is in great demand for measuring instruments and standards of lengths for everyday use.

2. ***Chromium.*** It is used in steels as an alloying element to combine hardness with high strength and high elastic limit. It also imparts corrosion-resisting properties to steel. The most common chrome steels contains from 0.5 to 2% chromium and 0.1 to 1.5% carbon. The chrome steel is used for balls, rollers and races for bearings. **A *nickel chrome steel* containing 3.25% nickel, 1.5% chromium and 0.25% carbon is much used for armour plates. Chrome nickel steel is extensively used for motor car crankshafts, axles and gears requiring great strength and hardness.**

3. ***Tungsten.*** It prohibits grain growth, increases the depth of hardening of quenched steel and confers the property of remaining hard even when heated to red colour. It is usually used in conjunction with other elements. Steel containing 3 to 18% tungsten and 0.2 to 1.5% carbon is used for cutting tools. The principal uses of tungsten steels are for cutting tools, dies, valves, taps and permanent magnet

4. ***Vanadium.*** It aids in obtaining a fine grain structure in tool steel. The addition of a very small amount of vanadium (less than 0.2%) produces a marked increase in tensile strength and elastic limit in low and medium carbon steels without a loss of ductility. The ***chrome-vanadium steel*** containing about 0.5 to 1.5% chromium, 0.15 to 0.3% vanadium and 0.13 to 1.1% carbon have extremely good tensile strength, elastic limit, endurance limit and ductility. These steels are frequently used for parts such as springs, shafts, gears, pins and many drop forged parts.
5. ***Manganese.*** It improves the strength of the steel in both the hot rolled and heat treated condition. The manganese alloy steels containing over 1.5% manganese with a carbon range of 0.40 to 0.55% are used extensively in gears, axles, shafts and other parts where high strength combined with fair ductility is required. The principal uses of manganese steel is in machinery parts subjected to severe wear. These steels are all cast and ground to finish.
6. ***Silicon.*** The silicon steels behave like nickel steels. These steels have a high elastic limit as compared to ordinary carbon steel. Silicon steels containing from 1 to 2% silicon and 0.1 to 0.4% carbon and other alloying elements are used for electrical machinery, valves in I.C. engines, springs and corrosion resisting materials.
7. ***Cobalt.*** It gives red hardness by retention of hard carbides at high temperatures. It tends to decarburise steel during heat-treatment. It increases hardness and strength and also residual magnetism and coercive magnetic force in steel for magnets.
8. ***Molybdenum.*** A very small quantity (0.15 to 0.30%) of molybdenum is generally used with chromium and manganese (0.5 to 0.8%) to make molybdenum steel. These steels possess extra tensile strength and are used for air-plane fuselage and automobile parts. It can replace tungsten in high speed steels

Indian Standard Designation of Low and Medium Alloy Steels

According to Indian standard, IS: 1762 (Part I)-1974 (Reaffirmed 1993), low and medium alloy steels shall be designated in the following order:

1. Figure indicating 100 times the average percentage carbon.

2. Chemical symbol for alloying elements each followed by the figure for its average Percentage content multiplied by a factor as given below:

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

For example 40 Cr 4 Mo 2 means alloy steel having average 0.4% carbon, 1% chromium and 0.25% molybdenum.

Notes: 1. The figure after multiplying shall be rounded off to the nearest integer.
2. Symbol 'Mn' for manganese shall be included in case manganese content is equal to or greater than 1 per cent.
3. The chemical symbols and their figures shall be listed in the designation in the order of decreasing content

Stainless Steel

It is defined as that steel which when correctly heat treated and finished, resists oxidation and corrosive attack from most corrosive media. The different types of stainless steels are discussed below:

1. ***Martensitic stainless steel*.** The chromium steels containing 12 to 14 per cent chromium and 0.12 to 0.35 per cent carbon are the first stainless steels developed. Since these steels possess martensitic structure, therefore, they are called ***martensitic stainless steels*.** These steels are magnetic and may be hardened by suitable heat treatment and the hardness obtainable depends upon the carbon content.

With increasing carbon, it is possible by hardening and tempering to obtain tensile strength in the range of 600 to 900 N/mm2, combined with reasonable toughness and ductility. In this condition, these steels find many useful general applications where mild corrosion resistance is required.
These steels may be used where the corrosion conditions are not too severe, such as for hydraulic, steam and oil pumps, valves and other engineering components.

2. ***Ferritic stainless steel*.** The steels containing greater amount of chromium (from 16 to 18 per cent) and about 0.12 per cent carbon are called ***ferritic stainless steels*.** These steels have better corrosion resistant property than martensitic stainless steels. But, such steels have little capacity for hardening by heat treatment. However, in the softened condition, they possess good ductility and are mainly used as sheet or strip for cold forming and pressing operations for purposes where moderate corrosion resistance is required.

Note: When nickel from 1.5 to 2.5 per cent is added to 16 to 18 per cent chromium steel, it not only makes more resistant to corrosion than martensitic steel but also makes it hardenable by heat treatment. Such a steel has good resistance to electrolytic corrosion when in contact with non-ferrous metals and graphite packing. Thus it is widely used for pump shafts, spindles and valves as well as for many other fittings where a good combination of mechanical and corrosion properties are required.

3. ***Austenitic stainless steel*.** The steel containing high content of both chromium and nickel are called ***austenitic stainless steels*.** There are many variations in chemical composition of these steels, but the most widely used steel contain 18 per cent chromium and 8 per cent nickel with carbon content as low as possible. Such a steel is **commonly known as *18/8 steel*.** These steels cannot be hardened by quenching, in fact they are softened by rapid cooling from about 1000°C. They are nonmagnetic and possess greatest resistance to corrosion and good mechanical properties at elevated temperature.

They can be easily welded, but after welding, it is susceptible to corrosive attack in an area adjacent to the weld. This susceptibility to corrosion (called inter crystalline corrosion or weld decay) may be removed by softening after welding by heating to about 1100°C and cooling rapidly. These steels are used in the manufacture of pump shafts, rail road car frames and sheathing, screws, nuts and bolts and small springs. Since 18/8 steel provide excellent resistance to attack by many chemicals.

Note: When increased corrosion resistance properties are required, for some purposes, then molybdenum from 2 to 3 per cent may be added.

Heat Resisting Steels

The steels which can resist creep and oxidation at high temperatures and retain sufficient strength are called ***heat resisting steels***. A number of heat resisting steels have been developed as discussed below:

1. ***Low alloy steels.*** These steels contain 0.5 per cent molybdenum. The main application of these steels are for superheater tubes and pipes in steam plants, where service temperatures are in the range of 400°C to 500°C.
2. ***Valve steels.*** The chromium-silicon steels such as ***silchrome*** (0.4% C, 8% Cr, 3.5% Si) and ***Volmax*** (0.5% C, 8% Cr, 3.5% Si, 0.5% Mo) are used for automobile valves. They possess good resistance to scaling at dull red heat, although their strength at elevated temperatures is relatively low. For aeroplane engines and marine diesel engine valves, 13/13/3 nickel-chromium-tungsten valve steel is usually used.
3. ***Plain chromium steel.*** The plain chromium steel consists of
   (*a*) Martensitic chromium steel with 12–13% Cr, and
   (*b*) Ferritic chromium steels with 18–30% Cr.
   These steels are very good for oxidation resistance at high temperatures as compared to their strength which is not high at such conditions. The maximum operating temperature for martensitic steels is about 750°C, whereas for ferritic steels it is about 1000 – 1150°C.
4. ***Austenitic chromium-nickel steels.*** These steels have good mechanical properties at high temperatures with good scaling resistance. These alloys contain a minimum of 18 per cent chromium and 8 per cent nickel stabilised with titanium or niobium. Other carbide forming elements such as molybdenum or tungsten may also be added in order to improve creep strength. Such alloys are suitable for use upto 1100°C and are used for gas turbine discs and blades.

Indian Standard Designation of High Alloy Steels (Stainless Steel and Heat Resisting Steel): According to Indian standard, IS : 1762 (Part I)-1974 (Reaffirmed 1993), the high alloy steels (*i.e.* stainless steel and heat resisting steel) are designated in the following order:

1. Letter 'X'.
2. Figure indicating 100 times the percentage of carbon content.
3. Chemical symbol for alloying elements each followed by a figure for its average percentage content rounded off to the nearest integer.
4. Chemical symbol to indicate specially added element to allow the desired properties.

For example, X 10 Cr 18 Ni 9 means alloy steel with average carbon 0.10 per cent, chromium 18 per cent and nickel 9 per cent.

High Speed Tool Steels:

These steels are used for cutting metals at a much higher cutting speed than ordinary carbon tool steels. The carbon steel cutting tools do not retain their sharp cutting edges under heavier loads and higher speeds. This is due to the fact that at high speeds, sufficient heat may be developed during the cutting operation and causes the temperature of the cutting edge of the tool to reach a red heat. This temperature would soften the carbon tool steel and thus the tool will not work efficiently for a longer period. The high speed steels have the valuable property of retaining their hardness even when heated to red heat. Most of the high speed steels contain tungsten as the chief alloying element, but other elements like cobalt, chromium, vanadium, etc. may be present in some proportion. Following are the different types of high speed steels:

1. ***18-4-1 High speed steel*.** This steel, on an average, contains 18 per cent tungsten, 4 per cent chromium and 1 per cent vanadium. It is considered to be one of the best of all purpose tool steels. It is widely used for drills, lathe, planer and shaper tools, milling cutters, reamers, broaches, threading dies, punches, etc.

2. ***Molybdenum high speed steel*.** This steel, on an average, contains 6 per cent tungsten, 6 per cent molybdenum, 4 per cent chromium and 2 per cent vanadium. It has excellent toughness and cutting ability. The molybdenum high speed steels are better and cheaper than other types of steels. It is particularly used for drilling and tapping operations.

3. ***Super high speed steel*.** This steel is also called ***cobalt high speed steel*** because cobalt is added from 2 to 15 per cent, in order to increase the cutting efficiency especially at high temperatures.

This steel, on an average, contains 20 per cent tungsten, 4 per cent chromium, 2 per cent vanadium and 12 per cent cobalt. Since the cost of this steel is more, therefore, it is principally used for heavy cutting operations which impose high pressure and temperatures on the tool.

Indian Standard Designation of High Speed Tool Steel

According to Indian standard, IS: 1762 (Part I)-1974 (Reaffirmed 1993), the high speed tool steel is designated in the following order :

1. Letter ‘XT’.

2. Figure indicating 100 times the percentage of carbon content.

3. Chemical symbol for alloying elements each followed by the figure for its average percentage content rounded off to the nearest integer, and

4. Chemical symbol to indicate specially added element to attain the desired properties.

For example, XT 75 W 18 Cr 4 V 1 means a tool steel with average carbon content 0.75 per cent, tungsten 18 per cent, chromium 4 per cent and vanadium 1 per cent

Spring Steels

The most suitable material for springs are those which can store up the maximum amount of Work or energy in a given weight or volume of spring material, without permanent deformation. These steels should have a high elastic limit as well as high deflection value. The spring steel, for aircraft and automobile purposes should possess maximum strength against fatigue effects and shocks. The steels most commonly used for making springs are as follows:

1. ***High carbon steels*.** These steels contain 0.6 to 1.1 per cent carbon, 0.2 to 0.5 percent silicon and 0.6 to 1 per cent manganese. These steels are heated to 780 – 850°C according to the composition and quenched in oil or water. It is then tempered at 200 – 500°C to suit the particular application. These steels are used for laminated springs for locomotives, carriages, wagons, and for heavy road vehicles. The higher carbon content oil hardening steels are used for volute, spiral and conical springs and for certain types of petrol engine inlet valve springs.
2. ***Chrome-vanadium steels*.** These are high quality spring steels and contain 0.45 to 0.55 per cent carbon, 0.9 to 1.2 per cent chromium, 0.15 to 0.20 per cent vanadium, 0.3 to 0.5 per cent silicon and 0.5 to 0.8 per cent manganese. These steels have high elastic limit, resistance to fatigue and impact stresses. Moreover, these steels can be machined without difficulty and can be given a smooth surface free from tool marks. These are hardened by oil quenching at 850 – 870°C and tempered at 470 – 510°C for vehicle and other spring purposes. These steels are used for motor car laminated and coil springs for suspension purposes, automobile and aircraft engine valve springs.
3. ***Silicon-manganese steels*.** These steels contain 1.8 to 2.0 per cent silicon, 0.5 to 0.6 per cent carbon and 0.8 to 1 per cent manganese. These steels have high fatigue strength, resistance and toughness. These are hardened by quenching in oil at 850 – 900°C and tempered at 475 – 525°C. These are the usual standard quality modern spring materials and are much used for many engineering purposes.

Heat Treatment of Steels

The term heat treatment may be defined as an operation or a combination of operations, involving the heating and cooling of a metal or an alloy in the solid state for the purpose of obtaining certain desirable conditions or properties without change in chemical composition. The aim of heat treatment is to achieve one or more of the following objects :

1. To increase the hardness of metals.
2. To relieve the stresses set up in the material after hot or cold working.
3. To improve machinability.
4. To soften the metal.
5. To modify the structure of the material to improve its electrical and magnetic properties.
6. To change the grain size.
7. To increase the qualities of a metal to provide better resistance to heat, corrosion and wear.

Cast Iron

The cast iron is obtained by re-melting pig iron with coke and limestone in a furnace known as cupola. It is primarily an alloy of iron and carbon. The carbon contents in cast iron varies from 1.7 per cent to 4.5 per cent. It also contains small amounts of silicon, manganese, phosphorous and sulphur. The carbon in a cast iron is present in either of the following two forms:

1. Free carbon or graphite, and
2. Combined carbon or cementite.

Since the cast iron is a brittle material, therefore, it cannot be used in those parts of machines which are subjected to shocks. The properties of cast iron which make it a valuable material for engineering purposes are its low cost, good casting characteristics, high compressive strength, wear resistance and excellent machinability. The compressive strength of cast iron is much greater than the tensile strength. Following are the values of ultimate strength of cast iron:

Tensile strength = 100 to 200 MPa, Compressive strength = 400 to 1000 MPa
Shear strength = 120 MPa

Types of Cast Iron

The various types of cast iron in use are discussed as follows:

1. *Grey cast iron*. 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.

The grey colour is due to the fact that the carbon is present in the form of free graphite. It has a low tensile strength, high compressive strength and no ductility. It can be easily machined. A very good property of grey cast iron is that the free graphite in its structure acts as a lubricant. Due to this reason, it is very suitable for those parts where sliding action is desired. The grey iron castings are widely used for machine tool bodies, automotive cylinder blocks, heads, housings, fly-wheels, pipes and pipe fittings and agricultural implements.

According to Indian standard specifications (IS: 210 – 1993), the grey cast iron is designated by the alphabets 'FG' followed by a figure indicating the minimum tensile strength in MPa or N/mm^2.

For example: 'FG 150' means grey cast iron with 150 M. Pa. or N/mm^2 as minimum tensile strength. The seven recommended grades of grey cast iron with their tensile strength and Brinell hardness number (B.H.N) are given in the following table

Table: Grey Iron castings, as per IS : 210 - 1993

IS Designation	Tensile Strength (MPa or N/mm^2)	Brinell Hardness number (B H N)
FG 150	150	130 to 180
FG 200	200	160 to 220
FG 220	220	180 to 220
FG 260	260	180 to 230
FG 300	300	180 to 230
FG 350	350	207 to 241
FG 400	400	207 to 270

2. ***White cast iron*****.** The white cast iron shows a white fracture and has the following approximate compositions:

Carbon = 1.75 to 2.3%; Silicon = 0.85 to 1.2% ; Manganese = less than 0.4%; Phosphorus = less than 0.2%; Sulphur = less than 0.12%, and the remaining is iron.

The white colour is due to fact that it has no graphite and whole of the carbon is in the form of carbide (known as cementite) which is the hardest constituent of iron. The white cast iron has a high tensile strength and a low compressive strength. Since it is hard, therefore, it cannot be machined with ordinary cutting tools but requires grinding as shaping process. The white cast iron may be produced by casting against metal chills or by regulating analysis. The chills are used when a hard, wear resisting surface is desired for such products as for car wheels, rolls for crushing grains and jaw crusher plates.

3. ***Chilled cast iron*****.** It is a white cast iron produced by quick cooling of molten iron. The quick cooling is generally called chilling and the cast iron so produced is called chilled cast iron. All castings are chilled at their outer skin by contact of the molten iron with the cool sand in the mould. But on most castings, this hardness penetrates to a very small depth (less than 1 mm). Sometimes, a casting is chilled intentionally and sometimes chilled becomes accidently to a considerable depth. The intentional chilling is carried out by putting inserts of iron or steel (chills) into the mould. When the molten metal comes into contact with the chill, its heat is readily conducted away and the hard surface is formed. Chills are used on any faces of a casting which are required to be hard to withstand wear and friction.

4. ***Mottled cast iron*****.** It is a product in between grey and white cast iron in composition, colour and general properties. It is obtained in castings where certain wearing surfaces have been chilled.

5. ***Malleable cast iron*****.** The malleable iron is a cast iron-carbon alloy which solidifies in the as-cast condition in a graphite free structure, *i.e*. total carbon content is present in its combined form as cementite (Fe_3C). It is ductile and may be bent without breaking or fracturing the section. The tensile strength of the malleable cast iron is usually higher than that of grey cast iron and has excellent machining qualities. It is used for machine parts for which the steel forgings would be too expensive and in which the metal should have a fair degree of accuracy, *e.g*. hubs of wagon wheels, small fittings for railway rolling stock, brake supports, parts of agricultural machinery, pipe fittings, door hinges, locks etc.

Alloy Cast Iron

The cast iron contain small percentages of other constituents like silicon, manganese, sulphur and phosphorus. These cast irons may be called as **plain cast irons.** The alloy cast iron is produced by adding alloying elements like nickel, chromium, molybdenum, copper and manganese in sufficient quantities. These alloying elements give more strength and result in improvement of properties. The alloy cast iron has special properties like increased strength, high wear resistance, corrosion resistance or heat resistance. The alloy cast irons are extensively used for gears, automobile parts like cylinders, pistons, piston rings, crank cases, crankshafts, camshafts, sprockets, wheels, pulleys, brake drums and shoes, parts of crushing and grinding machinery etc.

Effect of Impurities on Cast Iron

As the cast iron contains small percentages of silicon, sulphur, manganese and phosphorous. The effect of these impurities on the cast iron are as follows:

1. ***Silicon*.** It may be present in cast iron upto 4%. It provides the formation of free graphite which makes the iron soft and easily machineable. It also produces sound castings free from blow-holes, because of its high affinity for oxygen.

2. ***Sulphur*.** It makes the cast iron hard and brittle. Since too much sulphur gives unsound casting, therefore, it should be kept well below 0.1% for most foundry purposes.

3. ***Manganese*.** It makes the cast iron white and hard. It is often kept below 0.75%. It helps to exert a controlling influence over the harmful effect of sulphur.

4. ***Phosphorus*.** It aids fusibility and fluidity in cast iron, but induces brittleness. It is rarely allowed to exceed 1%. Phosphoric irons are useful for casting of intricate design and for many light engineering castings when cheapness is essential.

Non-ferrous Metals

The non-ferrous metals are those which contain a metal other than iron as their chief constituent. The non-ferrous metals are usually employed in industry due to the following characteristics:

1. Ease of fabrication (casting, rolling, forging, welding and machining),
2. Resistance to corrosion,
3. Good Electrical and thermal conductivity, and
4. Light Weight.

The various non-ferrous metals used in engineering practice are aluminium, copper, lead, tin, zinc, nickel, etc. and their alloys.

Non-ferrous metals and their alloys are discussed in detail, in the following pages.

Aluminium

It is white metal produced by electrical processes from its oxide (alumina), which is prepared from a clayey mineral called ***bauxite*.** It is a light metal having specific gravity 2.7 and melting point 658°C. The tensile strength of the metal varies from 90 MPa to 150 MPa. In its pure state, the metal would be weak and soft for most purposes, but when mixed with small amounts of other alloys, it becomes hard and rigid. So, it may be blanked, formed, drawn, turned, cast, forged and die cast. Its good electrical conductivity is an important property and is widely used for overhead cables. The high resistance to corrosion and its non-toxicity makes it a useful metal for cooking utensils under ordinary condition and thin foils are used for wrapping food items. It is extensively used in aircraft and automobile components where saving of weight is an advantage.

Aluminium Alloys

The aluminium may be alloyed with one or more other elements like copper, magnesium, manganese, silicon and nickel. The addition of small quantities of alloying elements converts the soft and weak metal into hard and strong metal, while still retaining its light weight. The main aluminium alloys are:

1. ***Duralumin.*** It is an important and interesting wrought alloy. Its composition is as follows:
Copper = 3.5 – 4.5%; Manganese = 0.4 – 0.7%;
Magnesium = 0.4 – 0.7%, and the remainder is aluminium.

This alloy possesses maximum tensile strength (upto 400 MPa) after heat treatment and age hardening. After working, if the metal is allowed to age for 3 or 4 days, it will be hardened. This phenomenon is known as ***age hardening.*** It is widely used in wrought conditions for forging, stamping, bars, sheets, tubes and rivets. It can be worked in hot condition at a temperature of 500°C. However, after forging and annealing, it can also be cold worked. Due to its high strength and light weight, this alloy is used in automobile and aircraft components. It is also used in manufacturing connecting rods, bars, rivets, pulleys, etc.

2. ***Y-alloy.*** It is also called copper-aluminium alloy. The addition of copper to pure aluminium increases its strength and machinability. The composition of this alloy is: Copper = 3.5 – 4.5%; Manganese = 1.2 – 1.7%; Nickel = 1.8 – 2.3%; Silicon, Magnesium, Iron = 0.6% each; and the remainder is aluminium. This alloy is heat treated and age hardened like duralumin. The ageing process is carried out at room temperature for about five days. It is mainly used for cast purposes, but it can also be used for forged components like duralumin. Since *Y*-alloy has better strength (than duralumin) at high temperature, therefore, it is much used in aircraft engines for cylinder heads and pistons.

3. ***Magnalium.*** It is made by melting the aluminium with 2 to 10% magnesium in a vacuum and then cooling it in a vacuum or under a pressure of 100 to 200 atmospheres. It also contains about 1.75% copper. Due to its light weight and good mechanical properties, it is mainly used for aircraft and automobile components.

4. ***Hindalium.*** It is an alloy of aluminium and magnesium with a small quantity of chromium. It is the trade name of aluminium alloy produced by Hindustan Aluminium Corporation Ltd, Renukoot (U.P.). It is produced as a rolled product in 16 gauge, mainly for anodized utensil manufacture.

Copper

It is one of the most widely used non-ferrous metals in industry. It is a soft, malleable and ductile material with a reddish-brown appearance. Its specific gravity is 8.9 and melting point is 1083°C. The tensile strength varies from 150 MPa to 400 MPa under different conditions. It is a good conductor of electricity. It is largely used in making electric cables and wires for electric machinery and appliances, in electrotyping and electroplating, in making coins and household utensils.

It may be cast, forged, rolled and drawn into wires. It is non-corrosive under ordinary conditions and resists weather very effectively. Copper in the form of tubes is used widely in mechanical engineering. It is also used for making ammunitions. It is used for making useful alloys with tin, zinc, nickel and aluminium.

Copper Alloys

The copper alloys are broadly classified into the following two groups:

1. *Copper-zinc alloys* (*Brass*). The most widely used copper-zinc alloy is brass. There are various types of brasses, depending upon the proportions of copper and zinc. This is fundamentally a binary alloy of copper with zinc each 50%. By adding small quantities of other

Elements, the properties of brass may be greatly changed. For example, the addition of lead (1 to 2%) improves the machining quality of brass. It has a greater strength than that of copper, but have a lower thermal and electrical conductivity. Brasses are very resistant to atmospheric corrosion and can be easily soldered. They can be easily fabricated by processes like spinning and can also be electroplated with metals like nickel and chromium. The following table shows the composition of various types of brasses according to Indian standards.

Table : Composition and uses of brasses:

Indian standard designation	*Composition in percentages*	*Uses*
Cartridge brass	Copper = 70 Zinc = 30	It is a cold working brass used for cold rolled sheets, wire drawing, deep drawing, pressing and tube manufacture.
Yellow brass (Muntz metal)	Copper = 60 Zinc = 40	It is suitable for hot working by rolling, extrusion and stamping.
Leaded brass	Copper = 62.5 Zinc = 36 Lead = 1.5	
Admiralty brass	Copper = 70 Zinc = 29 Tin = 1	These are used for plates, tubes, etc.
Naval brass	Copper = 59 Zinc = 40 Tin = 1	It is used for marine castings.
Nickel brass (German silver or Nickel silver)	Copper = 60 – 45 Zinc = 35 – 20 Nickel = 5 – 35	It is used for valves, plumbing fittings, automobile fitting, type writer parts and musical instruments.

2. *Copper-tin alloys* (*Bronze*). The alloys of copper and tin are usually termed as bronzes. The Useful range of composition is 75 to 95% copper and 5 to 25% tin. The metal is comparatively hard, resists surface wear and can be shaped or rolled into wires, rods and sheets very easily. In corrosion resistant properties, bronzes are superior to brasses. Some of the common types of bronzes are as follows:

(*a*) ***Phosphor bronze*.** When bronze contains phosphorus, it is called phosphor bronze. Phosphorus increases the strength, ductility and soundness of castings. The tensile strength of this alloy when cast varies from 215 MPa to 280 MPa but increases upto 2300 MPa when rolled or drawn. This alloy possesses good wearing qualities and high elasticity. The metal is resistant to salt water corrosion. The composition of the metal varies according to whether it is to be forged, wrought or made into castings. A common type of phosphor bronze has the following composition according to Indian standards :

Copper = 87–90%, Tin = 9–10%, and Phosphorus = 0.1–3%.

It is used for bearings, worm wheels, gears, nuts for machine lead screws, pump parts, linings and for many other purposes. It is also suitable for making springs.

(**b**) ***Silicon bronze*.** It contains 96% copper, 3% silicon and 1% manganese or zinc. It has good general corrosion resistance combined with higher strength. It can be cast, rolled, stamped, forged and pressed either hot or cold and it can be welded by all the usual methods. It is widely used for boilers, tanks, stoves or where high strength and good corrosion resistance is required.

(***c***) ***Beryllium bronze*.** It is a copper base alloy containing about 97.75% copper and 2.25% beryllium. It has high yield point, high fatigue limit and excellent cold and hot corrosion resistance. It is particularly suitable material for springs, heavy duty electrical switches, cams and bushings. Since the wear resistance of beryllium copper is five times that of phosphor bronze, therefore, it may be used as a bearing metal in place of phosphor bronze. It has a film forming and a soft lubricating property, which makes it more suitable as a bearing metal.

(***d***) ***Manganese bronze*.** It is an alloy of copper, zinc and little percentage of manganese. The usual composition of this bronze is as follows:
Copper = 60%, Zinc = 35%, and Manganese = 5%
This metal is highly resistant to corrosion. It is harder and stronger than phosphor bronze. It is generally used for bushes, plungers, feed pumps, rods etc. Worm gears are frequently made from this bronze.

(***e***) ***Aluminium bronze*.** It is an alloy of copper and aluminium. The aluminium bronze with 6–8% aluminium has valuable cold working properties. The maximum tensile strength of this alloy is 450 MPa with 11% of aluminium. They are most suitable for making components exposed to severe corrosion conditions. When iron is added to these bronzes, the mechanical properties are improved by refining the grain size and improving the ductility. Aluminium bronzes are widely used for making gears, propellers, condenser bolts, pump components, tubes, air pumps, slide valves and bushings, etc. Cams and rollers are also made from this alloy. The 6% aluminium alloy has a fine gold colour which is used for imitation jewellery and decorative purposes.

Gun Metal:

It is an alloy of copper, tin and zinc. It usually contains 88% copper, 10% tin and 2% zinc. This metal is also known as ***Admiralty gun metal*.** The zinc is added to clean the metal and to increase its fluidity. It is not suitable for being worked in the cold state but may be forged when at about 600°C. The metal is very strong and resistant to corrosion by water and atmosphere. Originally, it was made for casting guns. It is extensively used for casting boiler fittings, bushes, bearings, glands, etc.

Lead:

It is a bluish grey metal having specific gravity 11.36 and melting point 326°C. It is so soft that it can be cut with a knife. It has no tenacity. It is extensively used for making solders, as a lining for acid tanks, cisterns, water pipes, and as coating for electrical cables. The lead base alloys are employed where a cheap and corrosion resistant material is required. An alloy containing 83% lead, 15% antimony, 1.5% tin and 0.5% copper is used for large bearings subjected to light service.

Tin:

It is brightly shining white metal. It is soft, malleable and ductile. It can be rolled into very thin sheets. It is used for making important alloys, fine solder, as a protective coating for iron and steel sheets and for making tin foil used as moisture proof packing. A tin base alloy containing 88% tin, 8% antimony and 4% copper is called ***babbit metal*.** It is a soft material with a low coefficient of friction and has little strength. It is the most common bearing metal used with cast iron boxes where the bearings are subjected to high pressure and load.

Note : Those alloys in which lead and tin are predominating are designated as ***white metal bearing alloys*.** This alloy is used for lining bearings subjected to high speeds like the bearings of aero-engines.

Bearing Metals:

The following are the widely used bearing metals:

1. Copper-base alloys, **2.** Lead-base alloys,
3. Tin-base alloys, and **4.** Cadmium-base alloys

The **copper base alloys** are the most important bearing alloys. These alloys are harder and Stronger than the white metals (lead base and tin base alloys) and are used for bearings subjected to heavy pressures. These include brasses and bronzes, the **lead base** and **tin base alloys.** The **cadmium base alloys** contain 95% cadmium and 5% silver. It is used for medium loaded bearings subjected to high temperature.
The selection of a particular type of bearing metal depends upon the conditions under which it is to be used. It involves factors relating to bearing pressures, rubbing speeds, temperatures, lubrication, etc. A bearing material should have:

1. low coefficient of friction.
2. good wearing qualities.
3. ability to withstand bearing pressures.
4. ability to operate satisfactorily with suitable lubrication.
5. a sufficient high melting point.
6. high thermal conductivity.
7. good casting qualities.
8. minimum shrinkage after casting.
9. non-corrosive properties.
10. be economical in cost.

Zinc Base Alloys:

The most of the die castings are produced from zinc base alloys. These alloys can be casted easily with a good finish at fairly low temperatures. They have also considerable strength and are low in cost. The usual alloying elements for zinc are aluminium, copper and magnesium and they are all held in close limits.
The composition of two standard die casting zinc alloys are as follows:

1. Aluminium 4.1%, copper 0.1%, magnesium 0.04% and the remainder is zinc.
2. Aluminium 4.1%, copper 1%, magnesium 0.04% and the remainder is zinc.

Aluminium improves the mechanical properties and also reduces the tendency of zinc to dissolve iron. Copper increases the tensile strength, hardness and ductility. Magnesium has the beneficial effect of making the castings permanently stable. These alloys are widely used in the automotive industry and for other high production markets such as washing machines, oil burners, refrigerators, radios, photographs, television, business machines, etc.

Nickel Base Alloys:

The nickel base alloys are widely used in engineering industry on account of their high mechanical strength properties, corrosion resistance, etc. The most important nickel base alloys are discussed below:

1. ***Monel metal.*** It is an important alloy of nickel and copper. It contains 68% nickel, 29% copper and 3% other constituents like iron, manganese, silicon and carbon. Its specific gravity is 8.87 and melting point 1360°C. It has a tensile strength from 390 MPa to 460 MPa. It resembles nickel in appearance and is strong, ductile and tough. It is superior to brass and bronze in corrosion resisting properties. It is used for making propellers, pump fittings, condenser tubes, steam turbine blades, sea water exposed parts, tanks and chemical and food handling plants.

2. ***Inconel.*** It consists of 80% nickel, 14% chromium, and 6% iron. Its specific gravity is 8.55 and melting point 1395°C. This alloy has excellent mechanical properties at ordinary and elevated temperatures. It can be cast, rolled and cold drawn. It is used for making springs which have to withstand high temperatures and are exposed to corrosive action. It is also used for exhaust manifolds of aircraft engines.

3. ***Nichrome.*** It consists of 65% nickel, 15% chromium and 20% iron. It has high heat and oxidation resistance. It is used in making electrical resistance wire for electric furnaces and heating elements.

4. ***Nimonic.*** It consists of 80% nickel and 20% chromium. It has high strength and ability to operate under intermittent heating and cooling conditions. It is widely used in gas turbine engine

Non-metallic Materials

The non-metallic materials are used in engineering practice due to their low density, low cost, flexibility, resistant to heat and electricity. The following non-metallic materials are important as per engineering applications are concerned.

1. ***Plastics.*** The plastics are synthetic materials which are moulded into shape under pressure with or without the application of heat. These can also be cast, rolled, extruded, laminated and machined. Following are the two types of plastics :
   (*a*) Thermosetting plastics, and
   (*b*) Thermoplastic.

   T***hermosetting plastics*** are those which are formed into shape under heat and pressure, undergo chemical changes of condensation and polymerization resulting in a permanently hard product. The thermosetting materials undergo a chemical change when moulded and cannot be re-softened by heating to reshape them. But as additional heat and pressure is applied, it becomes hard by a chemical change known as phenol formal dehyden (Bakelite), phenol-furfural (Durite), urea formaldehyde (Plaskon), etc. The mould temperature for the thermosetting are usually considerably higher than for the thermoplastics, and the finished product is capable of withstanding much higher temperatures without deformation. Thermosetting plastics have heat resisting properties due to cross – linked structure of three dimensional molecules. They are widely used for telephone receivers, radio and T, V, cabinets, switch boards, electrical outlets, etc

T***hermoplastic those*** *plastics which undergo no chemical change during moulding and do not become hard with the application of heat and pressure are termed as thermoplastics. They remain soft at elevated temperatures until they are hardened by cooling. Thermo plastics* do not become hard with the application of heat and pressure and no chemical change occurs. These can be re-melted repeatedly by successive application of heat. Some of the common thermoplastics are cellulose nitrate (Celluloid), polythene, polyvinyl acetate, polyvinylchloride (P.V.C.), etc.

The plastics are extremely resistant to corrosion and have a high dimensional stability. They are mostly used in the manufacture of aeroplane and automobile parts. They are also used for making safety glasses, laminated gears, pulleys, self-lubricating bearing, etc. due to their resilience and strength.

2. ***Rubber*****.** It is one of the most important natural plastics. It resists abrasion, heat, strong alkalis and fairly strong acids. Soft rubber is used for electrical insulations. It is also used for power transmission belting, being applied to woven cotton or cotton cords as a base. The hard rubber is used for piping and as lining for pickling tanks.

3. ***Leather*****.** It is very flexible and can withstand considerable wear under suitable conditions. It is extensively used for power transmission belting and as a packing or as washers.

4. ***Ferrodo*****.** It is a trade name given to asbestos lined with lead oxide. It is generally used as a friction lining for clutches and brakes.

Composite Materials:

A composite is considered to be any multiphase material that exhibits a significant proportion of the properties of both constituent phases such that a better combination of properties is realized. This is termed as the *principle of combined action*. According to this principle, better combinations are fashioned by the judicious combination of two or more distinct materials.

A composite is a multiphase material that is artificially made, as to one that occurs naturally. In addition, the constituent phases in a composite must be chemically dissimilar and separated by a distinct interface. This is why most metallic alloys and many ceramics do not fit this definition because their multiple phases are formed as a consequence of natural phenomena.

All composites generally have one thing in common: a *matrix* or *binder* combined with a reinforcing material. Obviously, a composite consists of a matrix material, dispersed within which is a dispersion of one or more phases of another material. If the fibres are directionally oriented and continuous, the material is termed an *advanced composite*.

Examples of Composites:

Reinforced concrete is a good example of composite material. When concrete is reinforced with steel bars, the concrete becomes the matrix, which surrounds the reinforcing fibre, the rebar.

Another example is **reinforced fibre glass** products such as **fishing rods. Glass fibres are set in a thermosetting resin matrix. This produces a strong, lightweight, flexible fishing rod.**

Other fibres are produced from **aramid (Kevlar and Nomex), boron, carbon, graphite, and ultrahigh-molecular-weight polyethylene (spectra).** The **matrix** for these materials is typically a thermosetting epoxy resin. **These materials provide some exceptional increase in mechanical properties, sometimes three to six times greater than steel.**

Another example of a composite material is **pearlitic steels**. The microstructure of this material consists of alternating layers of α - ferrite and cementite. The ferrite phase is soft and ductile, whereas cementite is hard and very brittle. The combined mechanical characteristics of this composite, i.e. pearlite (reasonably high ductility and strength) are superior to those of either of the constituent phases.

Other common varieties of composites include combinations: fibre-resin, fibre-ceramic, carbon-metal, metal concrete, metal resin and wood plastic. **Most of the contemporary advanced composites use glass, kevlar (an aramid), or one of the various types of graphite fibres**.

Fibre composites form an important subset of this class of engineering materials. Obviously, a composite is a multiphase material that is artificially made, as to one that occurs naturally. In addition, the constituent phases in a composite must be chemically dissimilar and separated by a distinct interface. This is why most metallic alloys and many ceramics do not fit this definition because their multiple phases are formed as a consequence of natural phenomena.

Reasons for making composites:

The incorporation of fibres into brittle ceramics produces a composite of enhanced toughness. **Fillers,** such as the presence of aggregate in concrete, reduce the overall cost of the product, and additionally improve the compressive strength.

The second phase may furthermore be a gas, as in the manufacture of foamed products of low density.

On the basis of strength and stiffness alone fiber reinforced composite materials may not be superior to metals of comparable strength, but when the specific modulus (i.e. modulus per unit weight) and specific strength are considered, then their use implies that the weight of components can be reduced. This is an important factor in all forms of transport, where reductions of weight result in greater energy savings.

In order to produce a new generation of extraordinary materials, scientists and engineers while designing composite materials, have ingeniously combined various metals, ceramics, and polymers.

One can **classify composite** materials as per simple scheme shown in Fig. 1. There are three main divisions: particle reinforced, fibre - reinforced, and structural composites. We note that there exist at least two subdivisions for each main division.

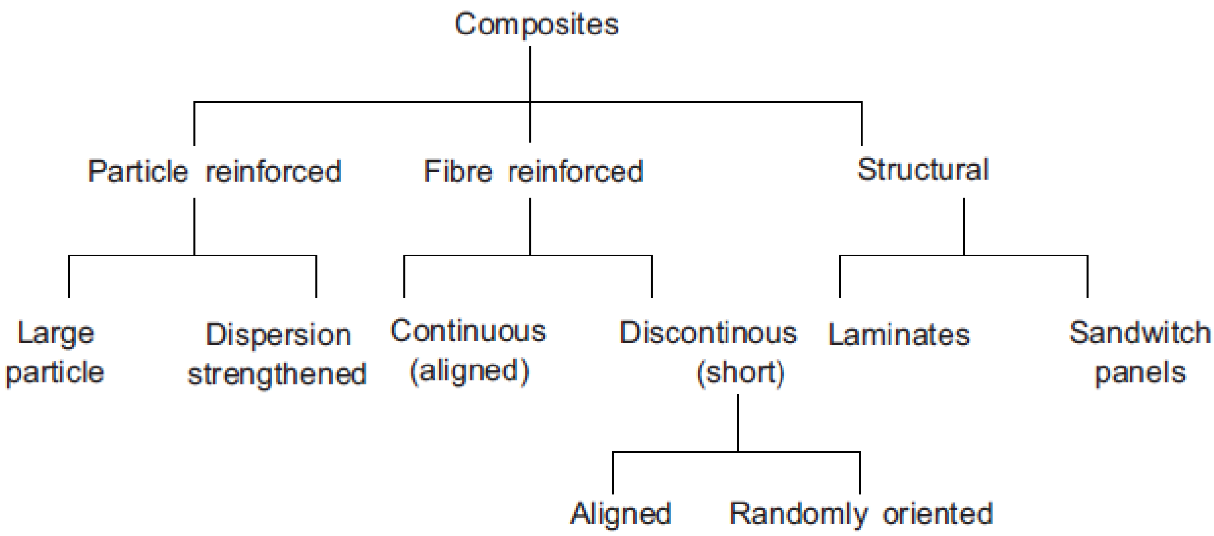

Fig. 1 A simple classification schemes for the various composite types

Examples of these three groups include:

Concrete, a mixture of cement and aggregate, which is a particulate composite;

Fibre glass, a mixture of glass fibres imbedded in a resin matrix, which is a fibre composite; and plywood, alternating layers of laminate veneers, which is a laminate composite.

GENERAL CHARACTERISTICS

(i) Composite materials are superior to all other known structural materials in specific strength and stiffness, high temperature strength, fatigue strength and other properties. The desired combination of properties can be tailored in advance and realized in the manufacture of a particular material.

(ii) Composite materials are complex materials whose components differ strongly from each other in the properties, are mutually insoluble or only slightly soluble and divided by distinct boundaries.

(iii) The principle of manufacture of composites has been borrowed from nature. Trunks and stems of plants and bones of man and animals are examples of natural composites. In wood, cellulose fibres are bonded by plastic lignin, in bones, thin and strong fibres of phosphates are bonded by plastic collagen.

(iv) The properties of composites mainly depend on the **physico-mechanical properties** of their components and the strength of bonds between them. A characteristic feature of composite materials is that the merits of their components are fully utilized. Composite materials may acquire certain valuable properties not found in the components.

(v) The **base, or matrix,** of composites may consist of metals or alloys (metallic composites), polymers, carbon and ceramic materials (non metallic composites).

(vi) The **matrix is essentially the binding and shaping component in composites**. Its properties determine to a large extent the process conditions for the manufacture of composite materials and the important operating characteristics, e.g., working temperature, fatigue strength, resistance to environmental effects, density, and specific strength.

(vii) Composites with combined matrix may be called ***multi-matrix***, or ***multi-layer*** **composites** (Fig. 2(a)). Multi-matrix composites can be characterized by a wider spectrum of useful properties.
For example, use of **titanium as an addition to aluminium may increase the strength of a composite material in directions transverse to fibres**. Aluminium layers in a matrix diminish the density of composite material.

(viii) **Fillers**, i.e., other components are uniformly distributed in a matrix. These plays the major part in strengthening of composites and thus they are called ***strengtheners***. **Fillers** should possess high values of strength, hardness and elastic modulus. These characteristics should be substantially higher than those of the matrix. With an increase of the elastic modulus and ultimate strength of a filler, the corresponding properties of a composite material also increase, but do not reach the value of the filler. **Fillers are alternatively called reinforcing components.** This is a broader term than '**strengthener**', it does not specify the particular strengthening role of filler which may used for improving other properties of a composite. The properties of a composite material can also depend on the shape (geometry), dimensions, concentration and distribution of filler (reinforcement pattern). **As regards their shape, fillers are divided into three main groups**

(i) **zero-dimensional *(ii)* one dimensional, and *(iii)* two dimensional.**

By the reinforcement pattern, composite materials are divided into three groups: with uniaxial, biaxial, and triaxial reinforcement.

(ix) Fillers of different shape may be used for obtaining a wider complex of properties or enhancing a particular property of a composite material. For example, the strength of bond between one-dimensional filler elements (glass or carbon fibres) and a

polymer matrix can be increased by introducing a zero-dimensional filler (particles of asbestos, silicon carbide, etc.).

The same purpose can be achieved by reinforcing a composite material with fillers of the same shape, but different composition.

For example, the modulus of elasticity of composite materials with a polymer matrix reinforced by glass fibres can be increased by additional reinforcement with boron fibres.

Composite materials containing two-or more different fillers are termed ***complex-reinforced composites***. (Fig. 2b).

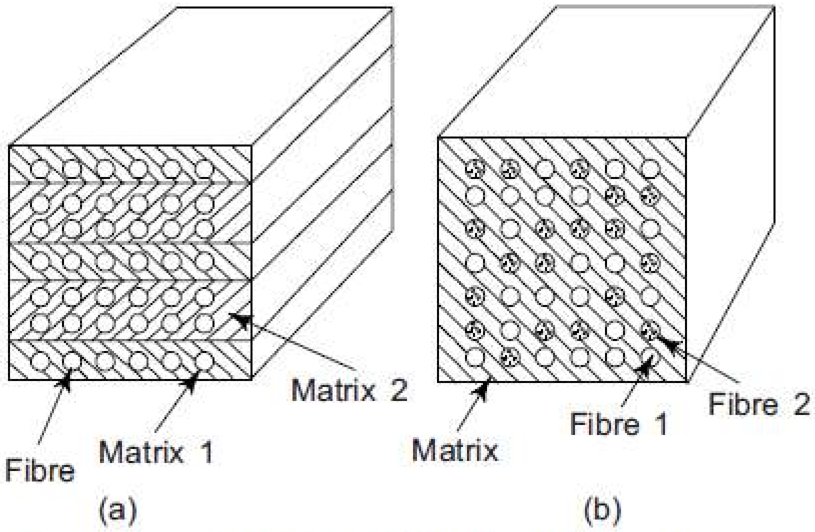

Fig. 2 Schemes of (a) multi-matrx and (b) polyfibre composite materials

PARTICLE-REINFORCED COMPOSITES

These can be further classified under two subgroups:

(i) *large particle* and

(ii) *dispersion- strengthened composites*.

The distinction between these is based upon reinforcement or strengthening mechanism. The term 'large' indicate that particle-matrix interactions cannot be treated on the atomic or molecular level; rather continuum mechanics is used. The particulate phase for most of these composites is harder and stiffer than the matrix. In the vicinity of each particle, these reinforcing particles tend to restrain movement of the matrix phase. Obviously, the matrix transfers some of the applied stress to the particles, which bear a fraction of the load. We may note that the degree of reinforcement or improvement of mechanical behaviour depends on strong bonding at the matrix particle interface. Particles for dispersion-strengthened composites are normally much smaller (diameter between 0.01 and 0.1 mm). Particle-matrix interactions occur on the atomic or molecular level and lead to strengthening. The matrix bears the major portion of an applied load, where as the small dispersed particle hinder or impede the motion of dislocations. Obviously, plastic deformation is restricted such that yield and tensile strengths, as well as hardness improve.

FIBRE-REINFORCES COMPOSITES

These are strong fibre imbedded in a softer matrix to produce products with high strength-to-weight ratios. The matrix material transmits the load to fibres, which absorb the stress. Under an applied stress, fibre matrix bond ceases at the fibre ends, yielding a matrix deformation pattern. In order to have effective strengthening and stiffening of the composite material, some critical fibre length is essential. This critical length *lc* is dependent on the fibre diameter *d* and its ultimate (or tensile) strength σ_f, and on the fibre-matrix bond strength. The strength of these composites comes from the bonding between the reinforcement fibres and the matrix. The length-to-diameter, or *aspect*, ratio of the fibres used as reinforcement influences the properties of the composite. The higher the aspect ratio, the stronger the composite. Therefore, long, continuous fibres are better than short ones for composite construction. However, continuous fibres are more difficult to produce and place in the matrix. Shorter fibres are easier to place in the matrix but offer poor reinforcement. The greater the number of fibres, the stronger the composite. This holds true upto about 80% of the volume of the composite, where the matrix can no longer completely surround the fibres.

Fibres for which $l >> lc$ (normally $l > 15\ lc$) are called *continuous*, whereas fibres which have lengths shorter than this are termed *discontinuous*. The matrix deforms around the discontinuous fibre having length less than *lc*, such that there is virtually no stress transference and little reinforcement by the fibre. In order to affect a significant improvement in strength of the composite, the fibres must be continuous.

The arrangement or *orientation* of the fibres relative to each other, the fibre *concentration,* and *distribution* all have a significant influence on the strength and other properties of fibre-reinforced composites. There are two possible extremes with respect to orientation:

(i) a parallel alignment of the longitudinal axis of the fibres in the single direction, and

(ii) a totally random alignment. Continuous fibres are normally aligned as shown in Fig. 4(a), discontinuous fibres may be aligned shown in Fig. 4(b) and randomly oriented, as or partially oriented as shown in Fig. 4(c). One can realize overall better composite properties when fibre distribution is uniform.

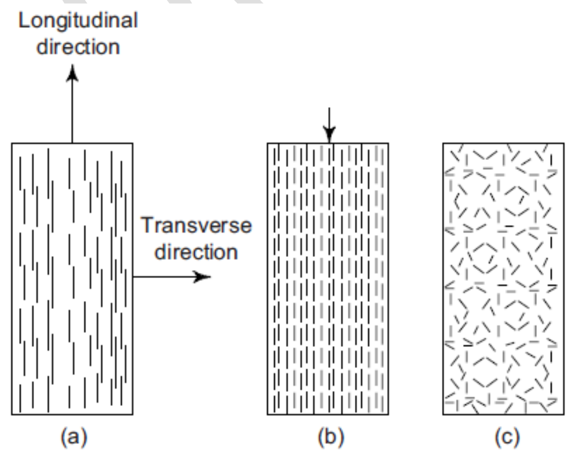

Fig. 4 Representation of (a) continuous and aligned, (b) discontinuous and aligned, and (c) discontinuous and randomly oriented fibre-reinforced composites

Laminar Composites

When multidirectional stresses are imposed within a single plane, aligned layers that are fastened together one on top of another at different orientations are frequently utilized.

These are called ***laminar composites***. These are generally designed to provide high strength and low cost at a lighter weight. A familiar laminar composite is plywood, where the veneers are joined by **adhesives, typically phenolic or amine resins**. The individual odd number of piles are staked so that the grain in each layer runs perpendicular to that of the layers above and below it (Fig. 6). This technique offers plywood that is strong and yet cheaper. Some safety glass is a laminated structure, where an adhesive such as **polyvinyl butyral** is used between two outer layers of glass to keep the glass from flying when broken. Formica is another common laminate used for countertops. Laminates require two or more layers be bonded together. Laminations may also be constructed using fabric material such as cotton, paper, or woven glass fibres embedded in a plastic matrix. Obviously, a laminar composite has relatively high strength in a number of directions in the two-dimensional plane; however, the strength in any given direction is, of course, lower than it would be if all the fibres were oriented in that direction. Modern ski is one example of a relatively **complex *laminated structure.*** Applications involving totally multidirectional applied stresses generally use discontinuous fibres, which are randomly oriented in the matrix material. We may note that the reinforcement efficiency is found only 1/5th that of an aligned composite in the longitudinal direction; however, the mechanical characteristics are isotropic. For a particular composite, consideration of orientation and fibre length will depend on the level and nature of the applied stress as well as fabrication cost. Short-fibre composites (both aligned and randomly oriented) production rates are rapid, and intricate shapes can be formed that are not possible with continuous fibre reinforcement. Moreover, fabrication costs are considerably lower than for continuous and aligned.

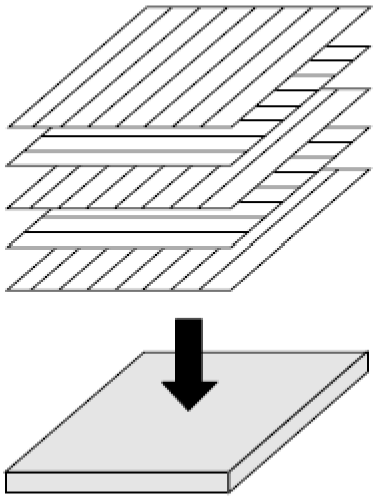

Fig. 6 Laminar composite. The stacking of successive oriented, fibre-reinforced layers

Sandwich Structures

These have thin layers of facing materials over a low density material, or combcore, such as a polymer foam or expanded metal structure. A familiar sandwich-structured composite is corrugated cardboard. The corrugated paper core is covered by two faces of thin paper. In structures of this type, the facing material serves to fix the inner core in place. The core provides the strength. Typical face materials include aluminium alloys, fibre-reinforced plastics, titanium, steel and plywood. Structurally, the core serves two purposes:

(i) it separates the faces and resists deformations perpendicular to face plane, and

(ii) it provides a certain degree of sheer rigidity along planes that are perpendicular
to the faces. Foamed polymers, synthetic rubbers, inorganic cements, balsa wood, etc. materials and structures are used for cores. Core has lower stiffness and lower strength.

Another popular core consists of a '***honeycomb***' structure, which finds wide use in industries such as the aircraft industry, where higher strength and lower weight are important factors. The honeycomb structure consists of thin foils that have been formed into interlocking hexagonal cells, with axis oriented perpendicular to the face panels. The material used may be similar to the face material. These structures are light weight, stiff, and strong and can be filled to provide sound and vibration damping. The honeycomb structure is shown in Fig. 7.

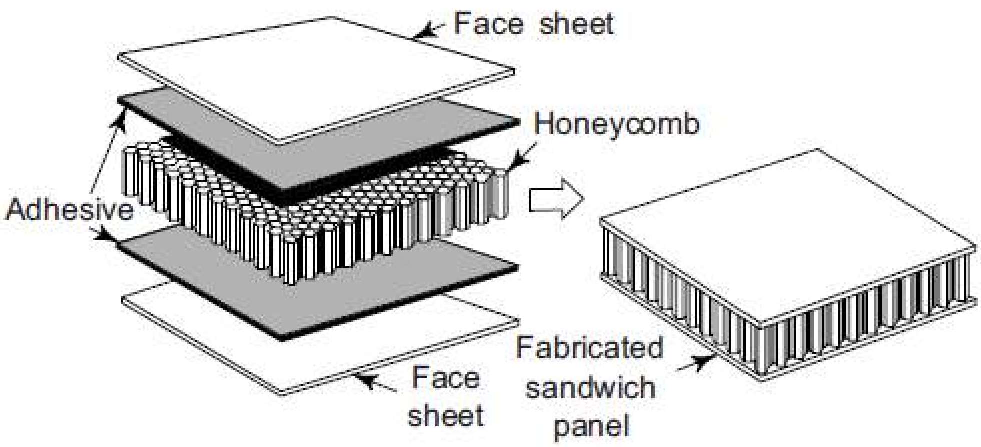

Fig. 7 Honeycomb structure

Continuous and Aligned Fibre Composites Mechanical behaviour of this type of composite depend on:
(i) Stress-strain behaviours of fibre and matrix phases,
(ii) The phase volume fractions, and
(iii) The direction in which the stress or load is applied.

Moreover, the properties of a composite having its fibres aligned are highly anisotropic, i.e., dependent on the direction in which they are measured.

Reinforced Concrete:
One can increase the strength of portland cement concrete by additional reinforcement. **One can achieve this by means of steel rods, wires, bars (rebar), or mesh, which are embedded into the fresh and uncured concrete.** Obviously, the reinforcement renders the hardened structure capable of **supporting greater tensile, compressive and shear stresses.** Considerable reinforcement is maintained even when cracks develop in the concrete. **The coefficient of thermal expansion for steel is nearly the same as that of concrete and thus it serves as a suitable reinforcement.** Moreover, **steel is not rapidly corroded in the cement environment and also a relatively strong adhesive bond is formed between it and the curved concrete.** One can enhance this adhesion by the incorporation of contours into the surface of the steel member. This permits a greater degree of interlocking.

There is **another reinforcement technique** of strengthening concrete. This involves the **introduction of residual compressive stresses** into the structural member. The resulting material is called ***pre-stressed concrete***. The characteristic of brittle ceramics, i.e. they are stronger in compression than in tension is utilized in this method. Obviously, to fracture a pre-stressed concrete member, the magnitude of the pre-compressive stress must be exceeded by an applied tensile stress.

In one pre-stressed technique, inside the empty moulds high-strength steel wires are positioned and stretched with a high tensile force, which is maintained constant. After placing the concrete and allowing them to harden, the tension is released. As the wires contract, they put the structure in a state of compression because the stress is transmitted to the concrete through the concrete-wire bond that is formed.

There is also another technique known as ***post-tensioning***. In this technique stresses are applied after the concrete hardens. Sheet metal or rubber tubes are situated inside and pass through the concrete forms, around which the concrete is cast. Steel wires are fed through the resulting holes after the cement has hardened and tension is applied to the wires through jacks attached and abutted to the faces of the structure. A compressive stress is imposed on the concrete piece, this time by the jacks. To protect the wire from corrosion, the empty spaces inside the tubing are filled finally with a grout. We must note that the concrete that is pre-stressed should be of a high quality and there must be a low shrinkage and low creep rate. Usually, pre-stressed concretes are prefabricated and used mostly for railway bridges and highway.

Polymer-Matrix Composites (PMCs)

These materials consist of a **polymer resin** (here resin denote a high-molecular weight reinforcing plastic) **as the matrix, with fibres as the reinforcement medium**. In light of their room-temperature properties, ease of fabrication, and cost, these PMCs are used in the greatest diversity of composite applications, as well as in huge quantities. In accordance with reinforcement type (i.e., glass, carbon and aramid), various classifications of PMCs, along with their applications and the various polymer resins that are used, are as follows:

(a) Glass Fibre-Reinforced Polymer (GFRP) Composites Fiberglass is a composite consisting of glass fibres, which may be continuous or discontinuous and contained within a polymer matrix. These are commonly produced in '*E*' glass (*E* is for electrical), because it draws well and has good strength and stiffness. A typical composition (Wt%) would be $52SiO_2$, $17CaO$, $14Al_2O_3$, $10Ba_2O_3$ with some oxides of Mg, Na and K, and molten glass is gravity fed into a series of platinum bushings each of which has several hundred holes in its base. Fine glass filaments are drawn mechanically as the glass exudes from the holes, then wound on to drums at speeds of several thousand metres per minute. The strength of the glass fibres is dependent upon the surface damage arising when they rub against each other during processing. The application of a size coating early at an early stage during manufacture minimises this degradation in properties, by reducing the propensity for forming these 'Griffith' cracks. The size consists of an emulsified polymer in water, and also has the effect of binding the fibres together for ease of further processing.

Fibre glass **applications**; e.g. automotive and marine bodies, plastic pipes, industrial floorings, and containers. In order to decrease vehicle weight and boost fuel efficiencies, the transport industries are utilizing to maximum extent of glass fibre-reinforced plastics.

(b) Carbon Fibre-Reinforced Polymer (CFRP) Composites: These consist of small crystallites of graphite. The atoms in the basal planes are held together by very strong covalent bonds, and there are weak Vander Waals forces between the layers. To obtain high modulus and high strength the layer planes of the graphite have to the aligned parallel to the axis of the fibre, and the Composites modulus of carbon fibres depends on the degree of perfection of alignment of atom planes. This varies considerably with the particular manufacturing route adopted, of which there are three main possibilities:

(i) Starting with the polymer PAN (polyacrylonitride), which closely resembles polyethylene in molecular confirmation, it is converted into a fibre and then stretched to produce alignment of the molecular chains along the fibre axis. While still under tension, it is heated in oxygen to form cross-links between ladder-molecules and finally chemically reduced to give (at high temperatures) a graphic structure. The final graphitisation temperature determines whether the fibres have maximum stiffness but a relatively low strength (Type-I fibres), or whether they develop maximum strength (Type-II).

(ii) Alternatively, fibres may be produced by melt-spinning molten pitch. During the spinning process, the orifice causes the planar molecules to become aligned. It is then treated, whilst held under tension in order to maintain its preferred orientation, at temperatures upto 2000 C to form the requisite grains of graphite.

(iii) It is also possible to stretch either of the fibre types described above during the graphitization stage, giving further orientation of the layers parallel to the fibre axis. Carbon fibres have the highest specific modulus and specific strength of all reinforcing fibre materials. Carbon fibres retain their high tensile modulus and high strength at elevated temperatures. However, high temperature oxidation may be a problem. Carbon fibres are not affected by moisture or a wide variety of solvents, acids and bases at room temperature. Carbon fibres exhibit a diversity of physical and mechanical characteristics, allowing composites incorporating these fibres to have specific engineering properties. On the basis of tensile modulus, carbon fibres can have four classes: *standard, intermediate*, *high* and ultrahigh moduli. Fibre diameters generally range between 4 and 10 mm. Both *continuous* and *chopped* forms of these fibres are available. Moreover, carbon fibres are usually coated with a protective epoxy size that also improves adhesion with the polymer matrix. Carbon-reinforced polymer composites are extensively used in sports and recreational equipment (fishing rods, golf clubs), filament-wound rocket motor cases, pressure vessel and aircraft structural components— both military and commercial, fixed wing and helicopters.

(c) Aramid Fibre-Reinforced Polymer Composites

Aramid fibres are high-strength, high modulus materials, especially desirable for their outstanding strength-to-weight ratios, which are superior to metals. Chemically, this group of materials is called as poly paraphenylene terephthalamide. There are a number of aramid materials. **Trade names of two of these most common materials are Kevlar and Nomex.** Kevlar has several grades (viz **Kevlar 29, 49, and 149**) that have different mechanical behaviours. Mer chemistry and mode of chain alignment for aramid (Kevlar) are shown in Fig. 8. These fibres have longitudinal tensile strengths and tensile moduli and they are higher than for other polymeric fibre materials, but they are relatively weak in compression. This material is also known for its toughness, impact resistance, and resistance to creep and fatigue failure. Although aramids are thermoplastics, they are nevertheless, resistant to combustion and stable to relatively high temperatures. The temperatures range over which aramids retain their high mechanical properties is between –200 and 200°C. Aramids are susceptible to degradation by strong acids and bases, but they are relatively inert in other solvents and chemicals. Usually, aramid fibres are used in composites having polymer matrices. Common matrix materials are the epoxies and polyesters. Aramid fibres are relatively flexible and somewhat flexible. Aramid composites are used in ballistic products (bullet-proof vests), sporting goods, tyres, ropes, missile cases, pressure levels, and as a replacement for asbestos in automotive brake and clutch linings, and gaskets.

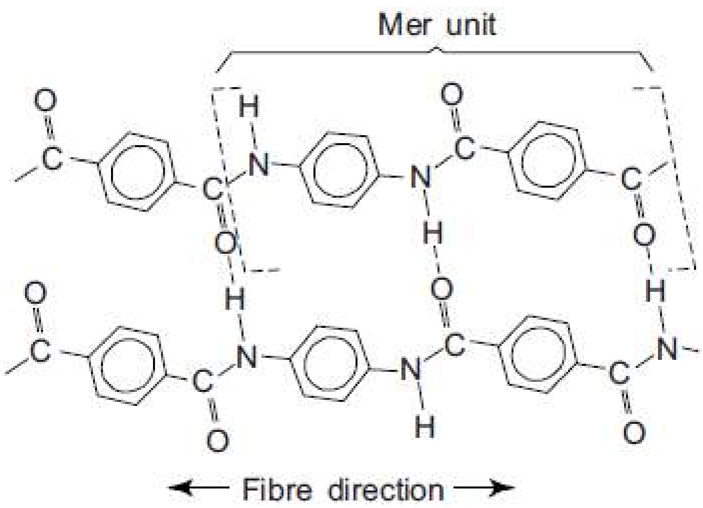

Fig. 8 Mer and chain structures for aramid (Kevlar) fibres

(d) REINFORCED POLYMERS

These are polymers whose properties have been altered through the use of reinforcement material. Glass, mineral and carbon fibres can be added to polymers to alter their properties. Most polymers are available as glass fibre-reinforced products. The glass fibres, whose diameters range from 0.0002 to 0.001 inch in diameter, are coated with a *resin* and a coupling agent. Property increase of 200% or better can be obtained through the glass fibre reinforcement. The strength of these reinforced polymers depends on the type and quantity of *filler* used and the degree to which the resin has wetted the reinforcement material. One of the more common filler materials is glass fibre. Carbon fibre-reinforced materials are more expensive than fibre-reinforced materials. Carbon fibre reinforced materials have high tensile strength, stiffness, and greater related mechanical properties. They also produce lower coefficients of expansion, improved creep resistance, better wear resistance, greater toughness, and higher strength-to-weight ratios than glass fibre-reinforced materials. Glass and carbon are the most common fibre reinforcements. Other materials used in fibre reinforcements include graphite, boron, and cotton. Reinforcement materials are available in several forms, including mat, fibre bundles, chopper fibres, and cloth. Most of the reinforced thermosetting polymers (90% to 95%) are polyesters and epoxies, with the majority being polyesters. These reinforced polymers are manufactured through a variety of methods, including hand lay-up, spray up, matched moulding, premixed moulding, and vacuum-or pressure bag casting. These materials are replacing metals in a variety of applications. They offer similar or better strength, characteristics at lower weight and often, at lower cost. They are frequently easier to produce, are resistant to corrosion and chemicals, and offer a wide variety of manufacturing processes, from the very simple and inexpensive to the higher volume and more intricate processes.

(e) Laminar Composites

When multidirectional stresses are imposed within a single plane, aligned layers that are fastened together one on top of another at different orientations are frequently utilized. These are called ***laminar composites***. These are generally designed to provide high strength and low cost at a lighter weight. A familiar laminar composite is plywood, where the veneers are joined by adhesives, typically phenolic or amine resins. The individual odd number of piles are staked so that the grain in each layer runs perpendicular to that of the layers above and below it (Fig. 6). This technique offers plywood that is strong and yet cheaper.

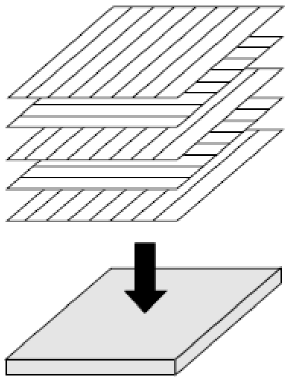

Fig. 6 Laminar composite. The stacking of successive oriented, fibre-reinforced layers

Some safety glass is a laminated structure, where an adhesive such as **polyvinyl butyl** is used between two outer layers of glass to keep the glass from flying when broken Formica is another common laminate used for countertops. Laminates require two or more layers be bonded together.

Modern ski is one example of a relatively complex *laminated structure.*

Applications involving totally multidirectional applied stresses generally use discontinuous fibres, which are randomly oriented in the matrix material. For a particular composite, Consideration of orientation and fibre length will depend on the level and nature of the applied stress as well as fabrication cost.

ASSIGNEMENT: UNIT 4: BASICS OF MECHANICAL ENGINEERING

1. How do you classify materials for engineering use?
2. What are the factors to be considered for the selection of materials for a particular machine elements? Discuss.
3. Enumerate the most commonly used engineering materials and state at least one important property and one application of each.
4. Why are metals in their pure form unsuitable for industrial use?
5. Define 'mechanical property' of an engineering material. Name any six mechanical properties, give their definitions and one example of the material possessing the properties.
6. Define the following properties of a material:
   (*i*) Ductility, (*ii*) Toughness, (*iii*) Hardness, and (*iv*) Creep.
7. Distinguish clearly amongst cast iron, wrought iron and steel regarding their constituents and properties.
8. How cast iron is obtained? Classify and explain different types of cast irons.
9. How is grey cast iron designated in Indian standards?
10. Discuss the effect of silicon, manganese, sulphur and phosphorus on cast iron.
11. Define plain carbon steel. How it is designated according to Indian standards?
12. Define alloy steel. Discuss the effects of nickel, chromium and manganese on steel.
13. What are the common materials used in Mechanical Engineering? How can the properties of steel be improved?
14. Name the different alloying elements added to steel to make alloy steels and their effect on the steel. Give at least one example of each.
15. Give the composition of 35 Mn 2 Mo 45 steel. List its main uses.
16. Write short notes on free cutting steel, and stainless steel.
17. Select suitable material for the following cases, indicating the reason;
    a) A shaft subjected to variable torsional and bending load;
    b) Spring used in a spring loaded safety valve;
    c) Nut of a heavy duty screw jack; and
    d) Low speed line-shaft coupling.

18. Select suitable materials for the following parts stating the special property which makes it most suitable for use in manufacturing:
    1. Turbine blade, 2. Bush bearing, 3. Dies,
    4. Carburettor body, 5. Keys (used for fastening), 6. Cams,
    7. Heavy duty machine tool beds, 8. Ball bearing,
    9. Automobile cylinder block, 10. Helical springs.

19. Suggest suitable materials for the following parts stating the special property which makes it more suitable for use in manufacturing:
    a) Diesel engine crankshaft; b) Automobile tyres; c) Roller bearings;
    d) High pressure steam pipes; e) Stay bar of boilers; f) Worm and worm gear;
    g) Dies; h) Tramway axle; i) Cam follower;
    J) Hydraulic brake piston.

20. Write short notes on high speed tool steel and spring steel.
21. Write short note on the different types of bearing metals.
23. Discuss the important non-metallic materials of construction used in engineering practice.
24. What do you understand by composite materials? Give some examples of composite materials with their applications.
25. What are the reasons for making composite materials.