CHAPTER 2

Ferrous Materials and Non-Ferrous Metals and Alloys

2.1 INTRODUCTION

Ferrous materials/metals may be defined as those metals whose main constituent is iron such as pig iron, wrought iron, cast iron, steel and their alloys. The principal raw materials for ferrous metals is pig iron. Ferrous materials are usually stronger and harder and are used in daily life products. Ferrous material possess a special property that their characteristics can be altered by heat treatment processes or by addition of small quantity of alloying elements. Ferrous metals possess different physical properties according to their carbon content.

2.2 IRON AND STEEL

The ferrous metals are iron base metals which include all varieties of iron and steel. Most common engineering materials are ferrous materials which are alloys of iron. Ferrous means iron. Iron is the name given to pure ferrite Fe, as well as to fused mixtures of this ferrite with large amount of carbon (may be 1.8%), these mixtures are known as pig iron and cast iron. Primarily pig iron is produced from the iron ore in the blast furnace from which cast iron, wrought iron and steel can be produced.

2.3 CLASSIFICATION OF CARBON STEELS

Plain carbon steel is that steel in which alloying element is carbon. Practically besides iron and carbon four other alloying elements are always present but their content is very small that they do not affect physical properties. These are sulphur, phosphorus, silicon and manganese. Although the effect of sulphur and phosphorus on properties of steel is detrimental, but their percentage is very small. Sulphur exists in steel as iron sulphide which produces red shortness or manganese sulphide which does affect its properties.

forging dies. Likewise for production of cold chisels, punches and dies. Springs, broaches and reamers can be produced for steel containing carbon. As the percentage of carbon further increases, it can be used for production of milling cutters, anvils, taps, drills, files, razors, metal cutting tools for lathes, shapers, planner and drawing dies.

2.4 WROUGHT IRON

The meaning of "wrought" is that metal which possesses sufficient ductility in order to permit hot and/or cold deformation. Wrought iron is the purest iron with a small amount of slag forged out into fibres. The typical composition indicates 99 per cent of iron and traces of carbon, phosphorus, manganese, silicon, sulphur and slag. During the production process, first all elements in iron (may be C, S, Mn, Si and P) are eliminated leaving almost pure iron molten slag. In order to remove the excess slag, the final mix is then squeezed in a press and reduced to billets by rolling milling. The resulting material would consist of pure iron separated by thin layers of slag material. The slag characteristic of wrought iron is beneficial in blacksmithy/forging operations and provides the material its peculiar fibrous structure. Further, the non-corrosive slag constituent makes wrought iron resistant to progressive corrosion and also helps in reducing effect of fatigue caused by shocks and vibrations.

Wrought iron is tough, malleable and ductile and possesses ultimate tensile strength of 350 N/mm^2. Its melting point is 1530°C. It can neither be hardened nor tempered like steel. The billets of wrought iron can be reheated to form bars, plates, boiler tubing, forgings, crane hook, railway coupling, bolts and nuts, chains, barbed wire, coal handling equipment and cooling towers, etc.

2.5 CAST IRON

It is primarily an alloy of iron and carbon. The carbon content in cast iron varies from 1.5 to 4 per cent. Small amounts of silicon, manganese, sulphur and phosphorus are also present in it. Carbon in cast iron is present either in free state like graphite or in combined state as cementite. Cast iron contains so much carbon or its equivalent that it is not malleable. One characteristic (except white cast iron) is that much of carbon content is present in free form as graphite. Largely the properties of cast iron are determined by this fact.

Melting point of cast iron is much lower than that of steel. Most of the castings produced in a cast iron foundry are of grey cast iron. These are cheap and widely used.

The characteristics of cast iron which make it a valuable material for engineering applications are:

(1) Very good casting characteristics.
(2) Low cost
(3) High compressive strength
(4) Good wear resistance
(5) Excellent machinability

The main limitation of this metal is brittleness and low tensile strength and thus cannot be used in those components subjected to shocks.

The varieties of cast iron in common use are:

(1) Grey cast iron
(2) White cast iron
(3) Malleable cast iron
(4) Nodular cast iron
(5) Chilled cast iron
(6) Alloy cast iron

2.5.1 Grey Cast Iron

It is the iron which is most commonly used in foundry work. If this iron is machined or broken, its fractured section shows the greyish colour, hence the name "grey" cast iron. The grey colour is due to the fact that carbon is present in the form of free graphite. A very good characteristic of grey cast iron is that the free graphite in its structure acts as a lubricant. This is suitable for those components/products where sliding action is desired. The other properties are good machinability, high compressive strength, low tensile strength and no ductility.

In view of its low cost, it is preferred in all fields where ductility and high strength are not required. The grey cast iron castings are widely utilized in machine tool bodies, automobile cylinder blocks and flywheels, etc.

2.5.2 White Cast Iron

It is so called due to the whitish colour shown by its fracture. White cast iron contains carbon exclusively in the form of iron carbide Fe_3C (cementite). From engineering point of view, white cast iron has limited applications. This is because of poor machinability and possessing, in general, relatively poor mechanical properties. It is used for inferior castings and places where hard coating is required as in outer surface of car wheels. Only crushing rolls are made of white cast iron. But it is used as raw material for production of malleable cast iron.

2.5.3 Malleable Cast Iron

Malleable cast iron is produced from white cast iron. The white cast iron is brittle and hard. It is, therefore, unsuitable for articles which are thin, light and subjected to shock and vibrations or for small castings used in various machine components. The malleable cast iron is produced from white cast iron by suitable heat treatment, i.e., annealing. This process separates the combined carbon of the white cast iron into noddles of free graphite.

The malleable cast iron is ductile and may be bent without rupture or breaking the section. Its tensile strength is usually higher than that of grey cast iron and has excellent machining qualities. Malleable cast iron components are mainly utilized in place of forged steel or parts where intricate shape of these parts creates forging problem. This material is principally employed in rail, road automotive and pipe fittings etc.

2.5.4 Nodular Cast Iron

It is also known as "spheroidal graphite iron" or Ductile iron or High strength "Cast iron". This nodular cast iron is obtained by adding magnesium to the molten cast iron. The magnesium converts the graphite of cast iron from flake to spheroidal or nodular form. In this manner, the mechanical properties are considerably improved. The strength increases, yield point improves and brittleness is reduced. Such castings can even replace steel components.

Outstanding characteristics of nodular cast iron are high fluidity which allows the castings of intricate shape. This cast iron is widely used in castings where density as well as pressure tightness is a highly desirable quality. The applications include hydraulic cylinders, valves, pipes and pipe fittings, cylinder head for compressors, diesel engines, etc.

2.5.5 Chilled Cast Iron

Quick cooling is generally known as chilling and the iron so produced is "*chilled iron*". The outer surface of all castings always gets chilled to a limited depth about (1 to 2 mm) during pouring and solidification of molten metal after coming in contact with cool sand of mould. Sometimes the casting is chilled intentionally and some becomes chilled accidentally to a small depth.

Chills are employed on any faces of castings which are required to be hard to withstand wear and friction. Chilled castings are used in producing stamping dies and crushing rolls railway, wheels cam followers, and so on.

2.5.6 Alloy Cast Iron

Alloying elements are added to cast iron to overcome inherent deficiencies in ordinary cast iron to provide requisite characteristics for special purposes. The alloy cast iron is extremely tough, wear resistant and non-magnetic steel about 12 to 14 per cent manganese should be added.

(5) **Nickel:** It may be termed as one of the most important alloying elements. It improves tensile strength, ductility, toughness and corrosion resistance.

(6) **Chromium:** Its addition to steel improves toughness, hardness and corrosion resistance.

(7) **Boron:** It increases hardenability and is therefore very useful when alloyed with low carbon steels.

(8) **Cobalt:** It is added to high speed steels to improve hardness, toughness, tensile strength, thermal resistance and magnetic properties. It acts as a grain purifier.

(9) **Tungsten:** Tungsten improves hardness, toughness, wear resistance, shock resistance, magnetic reluctance and ability to retain hardness at elevated temperatures. It provides hardness and abrasion resistance properties to steel.

(10) **Molybdenum:** It improves wear resistance, hardness, thermal resistance, ability to retain mechanical properties at elevated temperatures and helps to inhibit temper brittleness.

(11) **Vanadium:** It increases tensile strength, elastic limit, ductility, shock resistance and also acts as a degaser when added to molten steel. It provides improvement to hardenability of steel.

(12) It is a very good deoxidizer and promotes grain growth. It is the strongest carbide former. Titanium is used to fix carbon in stainless steel and thus prevents the precipitation of chromium-carbide.

(13) **Niobium:** It improves ductility, decreases hardenability and substantially improves the impact strength. It also promotes fine grain growth.

2.7 STAINLESS STEELS

The only material known to engineers which possesses a combination of various properties such as: wide range of strength and hardness, high ductility and formability, high corrosion resistance, good creep resistance, good thermal conductivity, good machinability, high hot & cold workability and excellent surface finish is *stainless steel*. Alloy steels have been developed for a specific purpose. We shall study them as follows:

They are known as stainless since they do not corrode or rust easily in most of environment and media. Stainless steels can be further divided into the following three categories:

(1) **Ferritic stainless steel:** It is that steel when properly heat treated and finished, resists oxidation and corrosive attacks from corrosive media. Ferritic stainless steels contain 12–18% chromium, 0.15 to 0.2% carbon besides iron and usual amounts of manganese and silicon. The steels are stainless and relatively cheap. They are magnetic in nature. Structure of these steels consist of ferrite phase which cannot be hardened by heat treatment. These steels are actually iron-chromium alloys and cannot be hardened by heat treatment. Such type of steel is utilized in manufacture of dairy equipment food processing plants, etc.

(2) Martensitic stainless steel: These steels contain 12–18% chromium and 0.1 to 1.8% carbon. These steels can be hardened by heat treatment but their corrosion resistance is decreased. Steels with 12 to 14% chromium and 0.3% carbon are widely used for table cutlery, tools and equipment. Steel with little less carbon percentage and higher percentage of chromium are used as springs, ball bearings and instruments under high temperature and corrective conditions.

(3) Austentic stainless steels: These are the most costliest among all stainless steels. In these steels besides chromium, nickel is also added. Nickel is a very strong austenitic stabilizer and therefore the microstructure of these steels is austentic at room temperature. These steels contain 12 to 21% chromium and 8 to 15% nickel and carbon less than 0.2%. The most familiar alloy of this group is known as 18:8 stainless steel i.e. 18% chromium and 8% nickel plus other. Other elements like carbon, manganese and silicon in very small quantities.

2.8 TOOL STEELS

Tool steels are specially alloyed steels designed for high strength, impact toughness and wear resistance at room and elevated temperatures. They are normally used in forming and machining of metals. So the requirements in a tool steel are that it should be capable of becoming very hard and further that it should be able to retain its hardness at high temperatures normally developed during cutting of materials. This property is known as "red hardness". Further, tool steel should not be brittle for smooth working.

2.8.1 High Speed Steel (H.S.S.)

It is the name given to the most common tool steel. As the name implies, it can cut steel at high cutting speeds. These steels are high in alloy content, have excellent hardenability, maintain their hardness at elevated temperatures around 650°C, are quite resistant to wear and contain relatively large amounts of tungsten or molybdenum, together with chromium, cobalt or vanadium. They are used to produce cutting tools to be operated for various machining operations such as turning, drilling, milling, etc. A typical composition of H.S.S. is tungsten 18%, chromium 4% and vanadium 1%, carbon 0.75 to 0.9% and rest iron.

2.8.2 Molybdenum High Speed Steel

This steel contains 6% tungsten, 6% molybdenum, 4% chromium and 2% vanadium and have excellent toughness and cutting ability. The molybdenum high speed steel are better and cheaper than other types of steel. It is particularly utilized in drilling and tapping operations.

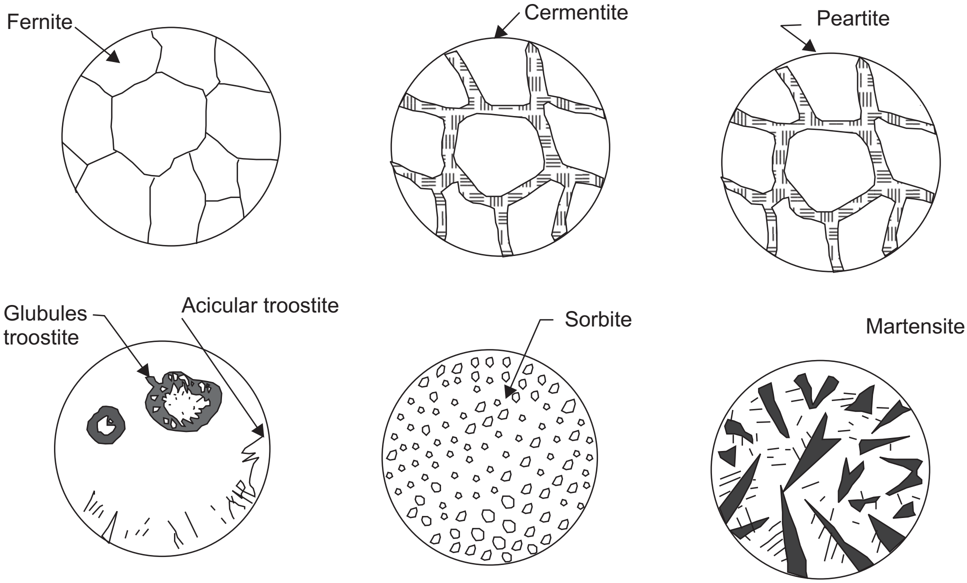

Fig. 2.2: Steel microstructure in heat treatment process

(1) To remove structural inhomogeneity
(2) To relieve internal stresses
(3) To soften the metal for easy machinability
(4) To remove the gases trapped inside the structure
(5) To refine the grain to obtain the desired structure
(6) To alter ductility, toughness and electrical properties

The various types of annealing process are described below:

Full annealing: During this process, heating phase results in fine grained austenite and thus, fine grained structure is obtained on cooling. This results in improvement in mechanical properties, high ductility and high toughness. It is the process where hypoeutectoid steel is heated 30–50°C above the critical temperature, holding it for some time at that temperature which heats the metal thoroughly and phase transformation takes place throughout. This is followed by slow cooling in furnace.

Heating rate is usually 100°C/hr and holding time is 1 hr/ton of metal, cooling rate is kept from 10°C–100°C for alloy steels and can be 200°C/hr for carbon steels.

Partial annealing: It is a process where steel is heated slightly above lower critical temperature and this annealing is applied for hypereutectoid steels only. It is also applied to hypoeutectoid steels where hardness is to be reduced while improving machinability.

In this operation, pearlite is transformed to austenite and ferrite is partially deformed into austenite. Heating and holding period is followed by slow cooling.

Isothermal Annealing: Steel is heated in the same way as it is treated in full annealing and then it is rapidly cooled from 500°C to 100°C below critical temperature. This is followed by keeping steel at this temperature for a long period which results in complete decomposition of iron. Then this is cooled in air.

The isothermal annealing results in improved machinability and more homogenous structure throughout the section.

2.10.2 Normalizing

It is the process of heating the steel to the temperature 50°C or more above the critical temperature 723°C. Then the steel is held at this temperature for a considerable period which results in complete transformation. This is followed by air cooling of steel. In normalizing, complete phase recrystallization takes place and fine grained structure is obtained.

Here in cooling, rate of cooling is faster than furnace cooling. During air cooling, austenite transforms into finer and more abundant pearlite structure in comparison to annealing. Properties obtained by normalizing depend on the size and composition of steel. As the smaller pieces cool more rapidly because of more exposure area, fine pearlite is formed and thus they are harder than larger pieces.

The object of normalizing is to refine the structure of steel and remove strains which may have been caused by cold working. When steel is cold worked the crystal structure is distorted and the metal may be brittle and unrealistic.

2.10.3 Quenching

We have observed that to transform the austenite to martensite efficiently, the cooling must be so rapid that the temperature of transformation is from about 750° to 300°C. This involves very rapid cooling and invites trouble of cracking and distortion. The factors which tend to cause the metal to warp and crack are:

(1) When a metal cooled it generally undergoes a contraction which is normally not uniform, but occurs at the outside surfaces and specially in thin sections of products.

(2) When steel cools through the critical range an expansion occurs.

Now if we would arrange to cool the whole volume of metal suddenly at the same instant, we should not experience much problem with change in volume, etc. but unfortunately this is not possible. When we suddenly plunge the metal into water from furnace at annealing temperature, the outer portion of the metal comes in contact with water and is immediately cooled and undergoes its critical range expansion leading to hard and rigid skin of metal. The inner portion of the metal, however, has not yet felt the quenching effect and is still red hot. When the quenching effect is transferred to outer portion through critical range the outer layer does not crack.

The quenching rate, size and shape of the article affects hardening and elimination of distortion and cracks. A special technique of immersing into the quenching media (may be oil, brine solution or water) is adopted, as described below:

(1) Long articles are immersed with their axis normal to the bath surface.
(2) Thin and flat articles are immersed with their edges first into the bath.
(3) The curved article's curved portion is kept upward during the immersion.
(4) Heavy articles are kept stationary with the quenching media stirred around them.

Very rough surface articles do not respond to uniform hardening, therefore this factor should be taken into account before performing the quenching operation.

2.10.4 Tempering

Martensitic structures formed by direct quenching of high carbon steel are hard and strong but also brittle. They contain internal stresses which are severe and unequally distributed to cause cracks or even fracture of hardened steel. The tempering is carried out to obtain one or more of the following objectives:

(1) To reduce internal stresses produced during heat treatment operations.
(2) To stabilize the structure of metal.
(3) To make steel tough to resist shock and fatigue.
(4) To reduce hardness and improve ductility.

Thus, tempering consists of heating quenched hardened steel in martensitic condition to a temperature below lower critical temperature, holding it at that temperature for sufficient time and then cooling it slowly down to room temperature. Tempering is classified into the following three types:

(1) Low Temperature Tempering: The work is heated between 150 and 250°C for a specific time. The objective of this procedure is to relieve internal stresses and to increase the ductility with much reduction in hardness. Low temperature tempering is applied in the heat treatment of carbon and low alloy steel cutting tools as well measuring instrument and components that have been carburised and surface hardened.

(2) Medium Temperature Tempering: The work is heated between 350 and 450°C for a specific time before being allowed to cool off in air or quenched in certain media. The martensite is converted into secondary troostite. The results provide reduction in hardness and strength of metal and improvement in ductility. The process is utilized in production of laminated springs and coils to ensure toughness.

(3) High temperature tempering: It is done between temperature of 500 to 650°C which completely eliminates internal stresses and provides toughness. Hardness is practically

Due to prolonged heating during carburizing process grains of core become relatively coarse and refinement of core is essential. Refining of components is achieved by heating them to 850°C then cooling in air or quenching it in oil.

In this manner carburizing provides a hard case with a soft core. If there is brittleness of core it is removed by tempering normally between 180°C–270°C.

(2) Cyaniding: The process of creating a hard wear resistant case with a tough core to low carbon steels by liquid cyanide bath is known as cyaniding. In this process, the piece of low carbon steel is immersed in a molten soft bath containing cyanide (normally it contains 20 to 50% sodium cyanide upto 40% sodium carbonate and varying quantities of sodium and barium chloride) at 840°C to 940°C and then quenching the steel in water or oil. Before quenching the steel is kept in the bath from 15 to 20 minutes. The soaking time varies with depth of case to be hardened and size of the component. Under average conditions as discussed above, a case depth of 0.125 mm would be obtained, i.e., in 15 minutes and at 840°C. This technique is chiefly utilized for cases not exceeding 0.8 mm in thickness. The hardness generated is due to the presence of compounds of nitrogen as well as carbon in the surface layer.

The chemistry of the cyaniding process is as follows:

$$2NaCN + 2O_2 \longrightarrow 2Na_2CO_3 + CO + 2N$$

$$2CO \rightleftharpoons CO_2 + C$$

$$2NaCN + O_2 \longrightarrow 2NaCNO \text{ (Sod cyanate)}$$

and

$$NaCN + CO \longrightarrow NaCNO + CO$$

$$3NaCNO \longrightarrow NaCN + Na_2CO_3 + C + 2N$$

Due to these equations the generated C&N are absorbed by the surface. Nitrogen imparts inherent hardness, whereas absorbed carbon contents in steel respond to quenching treatment.

Advantages of cyaniding:

(1) The bright finish of machined part if required can be maintained.
(2) Distortion is easily avoidable.
(3) The hardness from case to the core is more gradual and flaking core is eliminated.

(3) Nitriding: This process of surface hardening is used to obtain hard surface of steel components only. The technique is normally employed for those steels which are alloyed with aluminium, chromium, molybdenum and manganese, etc. The nitriding operation is the last operation being performed after performing operations such as oil hardening at 840°C to 900°C, tempering, rough machining, stabilizing (for removing internal stresses) final machining of the components. The machined and finished steel components are placed in an airtight container of nickel chromium steel provided with inlet and outlet tubes through with NH_3 is circulated. The process is carried out at 450°C to 540°C. The NH_3 in the furnace gets dissociated to liberate nascent nitrogen which reacts with the surface of components and form nitrides which are very hard.

The nitriding process is used in the production of machine components which require high wear resistance at elevated temperatures such as pump shafts, gauges, drawing dies, gears, mandrels, automobile and aeroplane valves, crankshafts and cylinder lines. It also finds applications in the production of ball and roller bearing parts.

Advantages

(1) Very high surface hardness with good wear resistance.
(2) Due to elimination of quenching, the distorsion and cracks are minimum.
(3) Economical for base production and machining and finishing is completed for applying this method.
(4) Nitrided components retain hardness upto 510°C.

Limitations

(1) The operation time is long for small depth of case hardened component and may lead to oxidation.
(2) Applicable for limited steels only as discussed above which can form good nitrides.

(4) Carbonitriding: It is the technique of producing hard case by addition of nitrogen and ammonia on the surface of the steel with the help of gases. Ammonia, carbon monoxide and hydrocarbons are used for carbonitriding. Carbonitriding is carried out at a temperature of 780°C to 875°C with 840°C being most common for 6 to 9 hours. The process is carried out in a furnace with the supply of carrier gas (hydrocarbon, ammonia and carbon monoxide) under positive pressure to check and prevent air infiltration. Thus, making the process control easier.

At the furnace temperature the added ammonia breaks up to provide nitrogen on the surface of the steel.

Nitrogen in the surface layer of steel components increases hardenability and permits hardening by oil quench (instead of water quench). Thus, chances of distortion and cracking are eliminated. The portion of steel components which is not to be carbonitrided can be protected by a layer of copper.

(5) Flame Hardening: It is the process of surface hardening in which hard wear resistant layer on a tough core steel component is produced by application of heat with the flame of an oxyacetylene torch and then cooling the surface by water. The flame is directed on the desired part without heating the remaining portion of work efficiently to affect it.

The steel required for flame hardening normally contains 0.4 to 0.6 per cent of carbon. The component or part is heated in the austenitic range. Since the heating is localized, stresses are not developed, therefore, chances of distortion and cracking are reduced. ***Advantages* of flame hardening are as follows**:

(1) The time taken for heating is comparatively less than when the requisite metal is heated in the furnace.
(2) The method is advantageous as selective surface can be hardened even on very large machines/components that are too large or too inconvenient to place in the furnace.
(3) The flame hardening is convenient when hardness is required only for a limited depth, the remainder retaining it original toughness and ductility.

Limitation

The only limitation is since the temperature control is not precise overheating can cause distorsion and cracking of components.

Applications: It finds applications in the following:

(1) Teeth of gears
(2) Pulleys
(3) Spindles
(4) Worms
(5) Steel dies
(6) Value ends
(7) Ways of lathes
(8) Open end wrenches

(6) **Induction hardening:** In this process, the surface hardening is achieved by placing the part in a inductor (consisting of copper) which is primary of a transformer. The components are placed in such a way that it does not touch the inductor coil. In this process a high frequency current of about 2000 cycles/second is passed. The heating effect is by virtue of induced eddy current and hysteresis loss in the surface material. The hardening temperature is from 750°C to 760°C for 0.5% carbon steel and 790°C to 810°C for alloy steels. The heated areas are then quenched immediately by spray of water under pressure. A depth of case of roughly 3 mm is achieved in about 5 seconds. But the actual time depends upon the frequency used, power input and depth of hardening required.

Advantages

1. Heating time is extremely small so distortion if any is considerably reduced.

2. Permits automation of heat treatment process and no surface oxidation takes place.
3. Induction hardening provides high hardness, higher wear resistance, higher impact strength and higher fatigue limit when compared with ordinary hardened steels.

Limitation

The cost of equipment is high and application is limited to medium carbon and alloy steels only.

Applications

The induction hardening process is utilized for hardening of surface of crankshafts camshafts, gears, breaked rums and spindles, etc.

2.11 NON-FERROUS METALS AND ALLOYS

Non-ferrous metals are those which do not contain significant quantity of iron or iron as base metal. These metals possess low strength at high temperatures, generally suffer from hot shortness and have more shrinkage than ferrous metals. They are utilized in industry due to following advantages:

1. High corrosion resistance
2. Easy to fabricate, i.e., machining, casting, welding, forging and rolling
3. Possess very good thermal and electrical conductivity
4. Attractive colour and low density

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

2.11.1 Copper

The crude form of copper extracted from its ores through series of processes contains 68% purity known as Blister copper. By electrolytic refining process, highly pure (99.9%) copper which is remelted and casted into suitable shapes. Copper is a corrosion resistant metal of an attractive reddish brown colour.

Properties and Uses

(1) High Thermal Conductivity: Used in heat exchangers, heating vessels and appliances, etc.

(2) **High Electrical Conductivity:** Used as electrical conductor in various shapes and forms for various applications.
(3) **Good Corrosion Resistance:** Used for providing coating on steel prior to nickel and chromium plating
(4) **High Ductility:** Can be easily cold worked, folded and spun. Requires annealing after cold working as it loses its ductility.

2.11.2 Aluminium

Aluminium is white metal which is produced by electrical processes from clayey mineral known as bauxite. However, this aluminium ore bauxite is available in India in plenty and we have a thriving aluminium industry.

Properties and Uses

(1) Like copper it is also corrosion resistant.
(2) It is very good conductor of heat and electricity although not as good as copper.
(3) Possesses *high ductility and light weight* so widely utilized in aircraft industry.
(4) Needs frequent annealing if cold worked since it becomes hard after cold working.
(5) In view of its ductility and malleability it has replaced copper in electrical transmission and appliances to some extent.
(6) It is used in manufacturing of household utensils including pressure cookers.

2.11.3 Lead

Lead is the heaviest of the common metal. Lead is extracted from its ore known as **galena**. It is bluish grey in colour and dull lusture which goes very dull on exposure to air.

Properties and Uses

(1) Its specific gravity is 7.1 and melting point is 360°C.
(2) It is resistant to corrosion and many chemicals do not react with it (even acids).
(3) It is soft, heavy and malleable, can be easily worked and shaped.
(4) Lead is utilized as alloying element in producing solders and plumber's solders.
(5) It is alloyed with brass as well as steel to improve their machinability.
(6) It is utilized in manufacturing of water pipes, coating for electrical cables, acid tanks and roof covering etc.

2.11.4 Tin

It is a brilliant white metal with yellowish tinge. Melting point of tin is 240°C

Properties and Uses

(1) Tin is malleable and ductile, it can be rolled into very thin sheets.
(2) It is used for tinning of copper and brass utensils and copper wire before its conversion into cables.
(3) It is useful as a protective coating for iron and steel since it does corrode in dry or wet atmosphere.
(4) It is utilized for making important alloys such as fine solder and moisture proof packing with thin tin sheets.

2.11.5 Zinc

The chief ores of zinc are **blende** (ZnS) and **calamine** ($ZnCO_3$). Zinc is a fairly heavy, bluish-white metal principally utilized in view of its low cost, corrosion resistance and alloying characteristics. Melting point of zinc is 420°C and it boils at 940°C.

Properties and Uses

(1) High corrosion resistance: Widely used as protective coating on iron and steel. Coating may be provided by dip galvanizing or electroplating.
(2) High fluidity and low melting point: Most suitable metal for pressure die casting generally in the form of alloy.
(3) When rolled into sheets, zinc is utilized for roof covering and for providing a damp proof non-corrosive lining to containers.
(4) The galvanized wires, nails, etc. are produced by galvanizing technique and zinc is also used in manufacture of brasses.

2.11.6 Nickel

About at least 85% of all nickel production is obtained from sulphide ores.

Properties and Uses

1. Pure nickel is tough, silver coloured metal, harder than copper having some but less ductility but of about same strength.
2. It is plated on steel to provide a corrosion resistance surface or layer.
3. Widely used as an alloying element with steel. Higher proportions are advantageously added in the production of steel such as monel or in conel.
4. It possesses good resistance to both acids and alkalis regarding corrosion so widely utilized in food processing equipment.

2.11.7 Magnesium

Principal ores of magnesium are **magnesite**, **carnallite** and **dolomite**. Magnesium is extracted by electrolytic process.

Properties and Uses:

(1) It is the lightest of all metals weighing around two-thirds of aluminium.
(2) The tensile strength of cast metal is the same as that of ordinary cast aluminium, i.e., 90 MPa.
(3) The tensile strength of rolled annealed magnesium is same as that of good quality cast iron.
(4) Magnesium can be easily formed, drawn forged and machined with high accuracy.
(5) In powdered form it is likely to burn, in that situation adequate fire protection measures should be strictly observed.
(6) Its castings are pressure tight and achieve good surface finish. Magnesium castings include motor car gearbox, differential housing and portable tools.

2.11.8 Vanadium

It occurs in conjunction with iron pyrite, free sulphur and carbonaceous matter.

Properties and Uses:

(1) It is silvery white in colour.
(2) Its specific gravity is 5.67.
(3) Its melting point is 1710°C.
(4) When heated to a suitable temperature it can be hammered into any shape or drawn into wires.
(5) It is used in manufacture of alloy steels.
(6) Vanadium forms non-ferrous alloys of copper and aluminium from which excellent castings can be produced.

2.11.9 Antimony

Chief ore of antimony is **stibnite**. To a small extent, antimony is obtained as a by-product in refining of other metals such as lead, copper silver and zinc.

Properties and Uses

(1) It is silvery white, hard, highly crystalline and so brittle that it may be readily powdered.
(2) Its specific gravity is 6.63 and melting point is 630°C.
(3) It is generally used as an alloying element with most of heavy metals.
(4) Lead, tin and copper are the metals which are most commonly alloyed with antimony.

2.11.10 Cadmium

It is obtained commercially as a by-product in the metallurgy of zinc and to some extent of lead.

Properties and Uses

(1) White metal with bluish tinge, capable of taking a high polish.
(2) Its specific gravity is 8.67 and melts at 321°C.
(3) It is slightly harder than tin but softer than zinc.
(4) It is malleable and ductile and can be readily rolled and drawn into wires.

It is chiefly utilized in antifriction alloys for bearings. It is also used as rust proof coating for iron and steel. Components of automobiles and refrigerator such as nuts, bolts and trimmings, locks and wire products are plated with it.

2.12 ALLOYS OF COPPER

Copper alloys are among the best conductors of heat and electricity and they have good corrosion resistance. The common types of copper alloys are brasses and bronzes. The various alloys of copper are discussed as follows:

2.12.1 Brass

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

(1) Alfa brass: Contains upto 36% Zn and rest copper for cold working.
(2) Alfa-Betabrass: Contains 36 to 45% Zn and remainder is copper for hot working.

The tensile strength and ductility of brass both increase with increase in content of Zn upto 30% zinc. With further increase in zinc content beyond 30%, the tensile strength continues to increase upto 45% of Zn, but ductility of brasses drops significantly. β-phase is less ductile than α-phase but it is harder and stronger.

Thus, there are various types of brasses depending upon proportion of copper and zinc. Fundamentally brass is a binary alloy of copper with as much as 50% zinc. Various classes of brasses such as cartridge brass, Muntzmetal leaded brass, Admirality brass, naval brass and nickel brass depending upon the proportion of copper and zinc plus third alloying metal are available for various uses. Suitable type of brasses can undergo the processes of casting, hot forging, cold forging, cold rolling into sheets, drawing into wires and extrusion for obtaining requisite special cross-section bars. The melting point of brass varies according to its composition but most of the brasses in the common range liquefy between temperatures of 840°C to 960°C. By adding small quantities of other elements, the properties of brass may be greatly affected. For example, addition of 1 to 2% zinc improves the machinability of brass. Brass has a greater strength than that of copper but has a lower thermal and electrical conductivity. Brasses possess very good corrosion resistance and can be easily soldered. Brasses are used in hydraulic fittings, pump linings, utensils, bearings and bushes, etc.

2.12.2 Bronze

The alloy of copper and tin are usually termed **bronzes**. The useful range of composition is 75 to 95% copper and remainder tin. In general, it possesses superior mechanical properties and corrosion resistance to brass. The alloy can be easily cold rolled into wire, rods and sheets. With increase in tin content, the strength of this alloy and its corrosion resistance increases. It is then known as hot working bronze. Bronze is generally utilized in hydraulic fittings, bearings, bushes, utensils, sheets, rods and many other stamped and drawn products.

The generally used bronzes are as follows:

(1) Phosphor bronze: When bronze contains phosphorus, it is known as phosphor bronze. Phosphorus present in such alloy increases the strength, ductility and soundness of castings. Various compositions of this alloy are available for different applications. The composition of the alloy varies according to whether it is to be forged, wrought or cast. A common type of phosphor bronze has the following composition as per Indian standards. Copper = 93.6%, tin = 9%, and phosphorus = 0.1 to 0.3%.

The alloy possesses good wearing qualities and high elasticity. The alloy is resistant to salt water corrosion.

Cast phosphor bronze is utilized for production of bearings and **gears**. Bearings of bronze contain 10% tin and small addition of lead. This is also used in making gears, nuts, for machine lead screws, springs, pump parts, linings and many other such applications.

(2) Gun metal: Gun metal contains 2% zinc, 10% tin and 88% copper. It is a very famous composition. Sometimes very small amount of lead is also added to improve castability and machinability. The presence of zinc improve its fluidity. This bronze is used for bearing bushes, glands, pump valves and boiler fittings, etc.

(3) Silicon bronze: Silicon bronze has an average composition of 3 per cent silicon, 1 per cent manganese and rest copper. It possesses good general corrosion resistance of copper with higher strength and toughness. It can be cast rolled, stamped, forged and pressed either hot or cold and can be welded by all the usual methods.

Silicon bronze is widely utilized for parts of boilers, tanks, stoves or where high strength as well as corrosion resistance is required.

(4) Bell metal: This alloy contains 20 to 21% tin and rest copper. It is hard and resistant to surface wear. It can be readily cast, is generally utilized for casting bells, gongs and utensils, etc.

(5) Manganese Bronze: It is an alloy of copper, zinc and manganese. It contains 55 to 60% copper, 40% zinc, with 3.5% manganese. This alloy is highly resistant to corrosion. It is stronger and harder than phosphor bronze. It has poor response to cold working but can be easily hot worked.

It is generally utilized for producing bushes, plungers, feed pumps and rods, etc. Worm gears are frequently made of manganese bronze.

(6) Muntz Metal: The composition of this alloy is 60 per cent copper and 40 per cent zinc. Sometimes a small quantity of lead is also added. This alloy is stronger, harder and more ductile than normal brass. While hot working between 700°C to 750, it responds excellently for process but does not respond to cold working.

This alloy is utilized for a wide variety of small components of machines, bolts, rods, tubes, electrical equipment as well as ordinance works. It is widely employed in producing such articles which are required to resist wear.

2.12.3 Alloys of Aluminium

Aluminium may be alloyed with one or more alloying elements such as copper, manganese, magnesium, silicon and nickel. The addition of small quantities of alloying elements converts the soft and weak aluminium into hard and strong metal, while it retains its light weight. The main alloys of aluminium are: Duralumin, Y-alloy, Magnalium and Hindalium which are discussed as follows:

(1) Duralumin: A famous alloy of aluminium containing 4% copper, 0.5% manganese, 0.5% magnesium and a trace of iron with remainder as aluminium is known as duralumnin. It possesses high strength comparable with mild steel and low specific gravity. However, its corrosion resistance is much lower as compared with pure aluminium. The strength of this alloy increases significantly when heat treated and allowed to age for 3 to 4 weeks it will be hardened. The phenomenon is termed age hardening. To improve upon the corrosion resistance of it, a thin film of aluminium is rolled on the duralumin sheets. These sheets are known as Alclad by trade name and are widely used in aircraft industry.

It is widely utilized in wrought conditions for forging, stamping, bars, tubes and rivets. It can be worked in hot condition at 500°C. However, after forging and annealing it could also be cold worked. Due to light weight and high strength this alloy may be used in automobile industry.

(2) Y-Alloy: It is also known as copper-aluminium alloy. The addition of copper to pure aluminium improves its strength and machinability. Y-alloy contains 93% aluminium, 2% copper, 1% nickel and magnesium. This alloy is heat treated as well as age hardened just like duralumin. A heat treatment of Y-alloy castings, consisting of quenching in boiling water from 510°C and then aging for 5 days develops very good mechanical characteristics in them. Since Y-alloy has better strength at elevated temperature than duralumin therefore it is much used in aircraft cylinder heads and piston. It is also used in strip and sheet form.

(3) **Magnalium:** It is produced by melting the aluminium 2 to 10% magnesium in a vacuum and then cooling it in vacuum or under a pressure of 100 to 200 atmospheres. About 1.75% copper is also added to it. Due to its light weight and good mechanical characteristics, it is mainly used for aircraft and automobile components.

(4) **Hindalium:** It is an alloy of aluminium and magnesium with small quantity of chromium. It is manufactured as rolled product in 16 gauge mainly used in manufacture of anodized utensils.

2.12.4 Alloys of Nickel

(1) **German silver:** The composition of this alloy is 60% Cu, 30% Ni and 10% zinc. It displays silvery appearance and is very ductile and malleable. It is utilized for electrical contacts, casting of high quality valves, taps and costume jewellery. It is also used in producing electrical wires.

(2) **Monel metal:** It contains 68% Ni, 30% Cu, 1% iron and remainder small additions of Mn and other elements. It is corrosion resistant and possesses good mechanical properties and maintains them at elevated temperatures.

(3) **Nichrome:** It is an alloy of nickel and chromium which is utilized as heat resistant electrical wire in electrical applicances such as furnaces, geysers and electric iron, etc.

(4) **Inconel and incolony:** These alloys principally contain, Ni, Cr, Fe, Mo, Ti and very small proportions of carbon. These are used as high temperature alloys. Inconel does not respond to heat treatment.

2.12.5 Bearing Materials

A bearing material should possess the following characteristics:

(1) It should possess enough compressive strength to provide adequate load carrying capacity.
(2) It should possess good plasticity to negate small variations in alignment and fitting.
(3) Its wear resistance should be adequate to maintain a specified fit.
(4) The coefficient of friction of the bearing material should be low to avoid excessive heating.

Some significant bearing metals are as follows:

Babbitt's metal: It is utilized for production of heavy duty bearings. It is white in colour containing 88% tin, 8% antimony and 4% copper. It is a soft material with a low coefficient

13. What are the various kinds of cast iron and their distinguishing characteristics?
14. What are alloy steels? Why is alloying done? How are alloy steels classified?
15. How are alloy steels classified according to their principal alloying elements? Describe them in brief.
16. Name the different materials used in the manufacture of alloy steels. What is the effect of these alloys on the characteristics of steel in general? Explain the effect of nickel, chromium, cobalt, manganese on properties of steel.
17. Write a brief note about stainless steels. What constituents of such steels render them corrosion resistant?
18. What are high speed steels? What are the principal alloying elements in them? Explain their characteristics in brief.
19. Give the objectives of heat treatment of metals and alloys.
20. What are the objectives of annealing process?
21. Discuss the following:
    (i) Full annealing
    (ii) Partial annealing
    (iii) Isothermal annealing.
22. Explain the ferritic, martensitic and austentic stainless steels.
23. What is tempering? Why is it done? Describe the various types of tempering.
24. What do you understand by case hardening? Name the various case hardening processes.
25. Explain the following case hardening processes:
    (i) Carburizing
    (ii) Cyaniding
    (iii) Nitriding
    (iv) Flame hardening
    (v) Induction hardening
26. Which types of metals and their alloys are used in various cutting and machining tools? Give reasons in brief.
27. Why non-ferrous metals are used in industry in spite of their higher cost in comparison with ferrous metals?
28. Discuss the characteristics, uses and applications of the following:
    (i) Copper
    (ii) Aluminium
    (iii) Zinc
    (iv) Lead
    (v) Tin
    (vi) Nickel
    (vii) Magnesium
    (viii) Vanadium
    (ix) Antimony

29. What is brass? Describe the composition and properties of important types of brasses.
30. What is bronze? Explain the composition, properties and applications of different types of bronzes.
31. What is the difference between brass and bronze?
32. What are bearing metals? What important characteristics should they possess?
33. Explain the following:
    (i) Babbit's metal
    (ii) Lead Alloys
    (iii) Cupro Nickels
    (iv) German silver
    (v) Montel metal
    (vi) Nichrome
34. Write notes on:
    (i) Gun metal
    (ii) Bell metal
    (iii) Muntz metal
35. Duralumin is used in making aircraft. Why?
36. Discuss the following alloys of aluminium:
    (i) Hindalium
    (ii) Magnalium
    (iii) Duralumin
    (iv) Y-alloy
37. How do you classify the different heat treatment processes?
38. Why normalizing and quenching in done? Explain these processes.
39. Explain with the help of a neat sketch the heat treatment process of carbon steel.
40. Give the advantages, limitations and applications of case hardening processes.
41. What are bronzes? Write short notes on the following types of bronzes:
    (i) Phosphor bronze
    (ii) Silicon bronze
    (iii) Gun metal
    (iv) Manganese bronze
42. Enlist the important properties which a bearing metal should possess. Describe some important bearing metals.

OBJECTIVE TYPE QUESTIONS

1. Combined carbon in iron makes the metal.
    (a) Soft and gives a coarse grained crystalline structure
    (b) Soft and provides a fine crystalline structure

10. Shock resistance of steel is increased by adding:
    (a) Nickel
    (b) Sulphur, lead and phosphorus
    (c) Nickel and chromium
    (d) Chromium
11. The steel widely used for motor car crankshaft is
    (a) Chrome steel
    (b) Nickel steel
    (c) Nickel-chrome steel
    (d) High speed steel
    (e) All of these
12. The cutting tools are made from
    (a) Nickel chrome steel
    (b) Silicon steel
    (c) Chrome steel
    (d) High speed steel
    (e) Silicon steel
    (f) None of these
13. Ball bearings are usually made from
    (a) High speed steel
    (b) High carbon steel
    (c) Medium carbon steel
    (d) Chrome steel
    (e) Low carbon steel
    (f) None of these
14. 18-4-1 high speed steel contains
    (a) Tungsten 18%, chromium 4% and vanadium 1%
    (b) Tungsten 1%, chromium 4% and vanadium 18%
    (c) Vanadium 18%, tungsten 4% and chromium 1%
15. 18:8 steel contains
    (a) 18% nickel and 8% chromium
    (b) 18% chromium and 8% nickel
    (c) 18% chromium and 18% nickel
    (d) 8% chromium and 8% nickel
16. The aluminium alloy, mainly used for anodized utensil manufacture is:
    (a) Y-alloy
    (b) Durlumin
    (c) Hindalium
    (d) Magalium

(c) white metal
(d) silicon bronze

26. Phosphor bronze has
    (a) good bearing characteristic and high elasticity
    (b) high resistance to corrosion
    (c) valuable cold working property
    (d) all of the above
27. The process which improves the machinability of steels, but lowers the hardness and tensile strength is
    (a) normalizing
    (b) full annealing
    (c) partial annealing
    (d) spheroidizing
28. The process used for relieving internal stresses previously set up in the metal and for increasing the machinability of steel is
    (a) normalizing
    (b) partial annealing
    (c) full annealing
    (d) spheroidizing
29. The heat treatment process used for castings is
    (a) carburizing
    (b) annealing
    (c) normalizing
    (d) tempering
30. The heat treatment process used for softening hardened steel
    (a) annealing
    (b) tempering
    (c) normalizing
    (d) carburizing
31. Which of the following is a case hardening process
    (a) flame hardening
    (b) cyaniding
    (c) nitriding
    (d) carburizing
    (e) all of the above
32. The process in which carbon and nitrogen get absorbed by the metal surface to get it hardened is known as:
    (a) induction hardening
    (b) flame hardening
    (c) cyaniding
    (d) carburizing

41. The melting point of steel increases with
    (a) reduced carbon content
    (b) increased carbon content
    (c) none of these
42. Which of the following surface hardening processes do not need quenching?
    (a) induction hardening
    (b) flame hardening
    (c) nitriding
    (d) case carburising
43. Guideways of lathe beds are hardened by
    (a) carburizing
    (b) cyaniding
    (c) nitriding
    (d) flame hardening
44. Stainless steel contains
    (a) 10% vanadium, 8% chromium
    (b) 18% chromium, 8% nickel
    (c) 18% tungsten, 8% nickel
    (d) 18% tungsten, 8% chromium
45. The electric bulb filaments are made of
    (a) tungsten
    (b) nichrome
    (c) constantan
    (d) german silver
46. Heating elements and electrical resistance wires are generally made of
    (a) nichrome
    (b) invar
    (c) perminvar
    (d) white metal
47. The clock pendulums, measuring tapes and thermostats are usually made of
    (a) invar
    (b) inconel
    (c) white metal
    (d) german metal
48. Which of the following is a copper free alloy?
    (a) White metal
    (b) Muntz metal
    (c) Gun metal
    (d) German metal