5

CHAPTER

NON-FERROUS MATERIALS

5.1 INTRODUCTION

Engineering materials can be categorized into metals and alloys, ceramic materials, organic polymers, composites and semiconductors. There are large numbers of engineering materials available in the universe such as metals (both ferrous and non-ferrous) and non metals (leather, rubber, asbestos, plastic, ceramics, organic polymers, composites and semi conductor). The elements of tools, machines and equipments should be made of such a material which has properties suitable for the conditions of operation e.g components of ships and naval work requires corrosion resistance against sea water. It is therefore important to know what non ferrous metals are available in the universe, what their characteristics are like strength, hardness, availability and costs, and how they can be processed economically to get the desired product. In addition to this, a product designer, tool designer, equipment design engineer and system design engineer should always be familiar with various kinds of engineering materials including non ferrous metals, their properties, and applications to meet the functional requirements of the design product. They must understand all the effects which the manufacturing processes and heat treatment have on the properties of the non ferrous metals. The non ferrous metals and their alloys have tremendous applications for manufacturing industrial products.

The basic knowledge of non-ferrous metals and their properties is of great significance for a design and manufacturing engineer. Non-ferrous metals contain metals other than iron as their main constituents such as aluminium, copper, zinc, magnesium, lead, tin, nickel and their alloys and non-metallic materials. Various non-ferrous alloys are copper base (brass, bronze), aluminium base alloys (duralumin, Y-alloy, hindalium, magnalium), nickel alloys (inconel, monel and ni-chrome), tin base alloys (bearing or antifriction alloys). The non-ferrous metals are used for the following purposes namely resistance to corrosion, special electrical and magnetic properties, softness, facility of cold working, fusibility, ease of casting, good formability, low density and attractive color. The properties and uses of various non-ferrous metals are given in the following articles.

5.2 ALUMINIUM

It is a white metal produced by electrical processes from the oxide (alumina), which is prepared from a clay mineral called bauxite. Bauxite is hydrated aluminium oxide. The chief impurities are oxide, silica, clay and titanium oxide. It is found in India in the states of Bihar and Madhya Pradesh.

Manufacture

The bauxite is purified and then dissolved in fused cryolite (double fluoride of aluminium and sodium). The aluminium is then separated from this solution by electrolysis at about 910°C.

Properties

Pure aluminium has silvery color and lusture. It is ductile, malleable and very good conductor of heat and electricity. It has a very high resistance to corrosion than the ordinary steel. Its specific gravity is 2.7 and melting point is 658°C. Its tensile strength varies from 95 to 157 MN/m^2. In proportion to its weight it is quite strong. 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. It may be blanked, formed, drawn, turned, cast, forged and die cast. Its good electrical conductivity is an important property and is broadly used for overhead cables. It forms useful alloys with iron, copper, zinc and other metals.

Applications

It is mainly used in aircraft and automobile parts where saving of weight is an advantage. The high resistance to corrosion and its non-toxicity make it a useful metal for cooking utensils under ordinary conditions. Aluminium metal of high purity has got high reflecting power in the form of sheets and is, therefore, widely used for reflectors, mirrors and telescopes. It is used in making furniture, doors and window components, rail road, trolley cars, automobile bodies and pistons, electrical cables, rivets, kitchen utensils and collapsible tubes for pastes. Aluminium foil is used as silver paper for food packing etc. In a finely divided flake form, aluminium is employed as a pigment in paint. It is a cheap and very important non ferrous metal used for making cooking utensils.

5.2.1 Aluminium alloys

The aluminium may be easily alloyed with other elements like copper, magnesium, zinc, manganese, silicon and nickel to improve various properties. The addition of small quantities of alloying elements into other metals helps to converts the soft and weak metal into hard and strong metal, while still retaining its light weight. Various aluminium alloys are

1. Duralumin,
2. Y-alloy,
3. Magnalium and
4. Hindalium

These alloys are discussed as below:

5.2.2 Duralumin

It is an important wrought alloy. Its composition contains following chemical contents.

Copper = 3.5-4.5%
Manganese = 0.4-0.7%
Magnesium = 0.4-0.7%
Aluminium = 94%

Properties

Duralumin can be very easily forged, casted and worked because it possesses low melting point. It has high tensile strength, comparable with mild steel combined with the characteristics lightness of Al. It however possesses low corrosion resistance and high electrical conductivity. This alloy possesses higher strength after heat treatment and age hardening. After working, if this alloy is age hardened for 3 or 4 days. This phenomenon is known as age hardening. It hardens spontaneously when exposed to room temperature. This alloy is soft enough for a workable period after it has been quenched. It is light in weight as compared to its strength in comparison to other metals. It can be easily hot worked at a temperature of 500°C. However after forging and annealing, it can also be cold worked.

Applications

Duralumin is used in the wrought conditions for forging, stamping, bars, sheets, tubes, bolts, and rivets. Due to its higher strength and lighter weight, this alloy is widely used in automobile and aircraft components. To improve the strength of duralumin sheet, a thin film of Al is rolled along with this sheet. Such combined sheets are widely used in air-craft industries. It is also employed in surgical and orthopedic work, non-magnetic work and measuring instrument parts constructing work.

5.2.3 Y -alloy

Y-Alloy is also called copper-aluminium alloy. The addition of copper to pure aluminium increases its strength and machinability. Its composition contains following chemical contents.

Copper = 3.5-4.5%

Manganese = 1.2-1.7%

Nickel = 1.8-2.3%

Silicon, magnesium, iron = 0.6% each

Aluminium = 92.5%.

Properties

The addition of copper in aluminium increases its strength and machinability. Y-alloy can be easily cast and hot worked. Like duralumin, this alloy is heat treated and age hardened. The age-hardening process of Y-alloy is carried out at room temperature for about five days.

Applications

Y-Alloy 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 temperatures, therefore it is much used in aircraft engines for cylinder heads, pistons, cylinder heads, crank cases of internal combustion engines die casting, pump rods etc.

5.2.4. Magnalium

Magnalium is an alloy of aluminium, magnesium, copper, nickel and tin etc. It contains

Al = 85 to 95%,	Cu = 0 to 25%,	Mg = 1 to 5%,
Ni = 0 to 1.2%,	Sn = 0 to 3%,	Fe = 0 to 0.9%,
Mn = 0 to 0.03%,	Si = 0.2 to 0.6%.	

It is made by melting the aluminium with 2-10% magnesium in a vacuum and then cooling it in a vacuum or under a pressure of 100 to 200 atmospheres.

Properties

Magnalium is light in weight and brittle. This alloy possesses poor castability and good machinability. It can be easily welded.

Applications

Due to its light weight and good mechanical properties, it is mainly used for making aircraft and automobile components.

5.2.5 Hindalium

Hindalium is a common trade name of aluminium alloy. It is an alloy of aluminium, magnesium, manganese, chromium and silicon etc. In India, it is produced by Hindustan Aluminium Corporation Ltd., Renukoot (U.P.). Hindalium is commonly produced as a rolled product in 16 gauges. Utensils manufactured by this alloys are strong and hard, easily cleaned, low cost than stainless steels, having fine finish, having good scratch resistance, do not absorb much heat etc.

Applications

Hindalium is mainly used for manufacturing anodized utensil. Utensils manufactured by this alloys are strong and hard, easily cleaned, low cost than stainless steels, having fine finish, having good scratch resistance, do not absorb much heat etc.

5.3 COPPER

Copper is one of the most widely used non-ferrous metals in industry. It is extracted from ores of copper such as copper glance, copper pyrites, melachite and azurite. Copper ores are found in the state of Sikkim and Bihar of India and Bharma.

Manufacture

Copper ore is first ground and then smelted in a reverberatory or small blast furnace for producing an impure alloy. Then the air is blown through the molten metal to remove sulphur and iron contamination to obtain blister copper in the converter. Copper is then refined further using electrolysis processes.

Properties

Pure copper is soft, malleable and ductile metal with a reddish-brown appearance. It is a good conductor of electricity. It is non-corrosive under ordinary conditions and resists weather very effectively. Its tensile strength varies from 300 to 470 MN/m2 and melting point is 1084°C. It is one of the best conductors of heat and it is highly resistant to corrosion. This non ferrous metal can withstand severe bending and forging without failure. It does not cast well. If copper is heated to red heat and cooled slowly it becomes brittle, but if cooled rapidly it becomes soft, malleable and ductile. It can be welded at red heat.

Applications

Copper is mainly used in making electric cables and wires for electric machinery, motor winding, electric conducting appliances, and electroplating etc. It can be easily forged, casted, rolled and drawn into wires. Copper in the form of tubes is used widely in heat transfer work mechanical engineering field. It is used for household utensils. It is also used in production of boilers, condensers, roofing etc. It is used for making useful alloys with tin, zinc, nickel and aluminium. It is used to form alloys like brass, bronze and gun metal. Alloys of copper are made by alloying it with zinc, tin, and lead and these find wide range of applications. Brass, which is an alloy of copper and zinc, finds applications in utensils, household fittings, decorative objects, etc. Bronze is an alloy of copper and tin and possesses very good corrosion resistance. It is used in making valves and bearings. Brass and bronze can be machined at high speeds to fine surface finish.

The following copper alloys are important

1. Copper-zinc alloys (Brasses)
2. Copper-tin alloys (Bronzes)

5.3.1 Brasses

Brasses are widely used alloy of copper (main constituent) and zinc. They also contain small amounts of lead or tin or aluminium. The most commonly used copper-zinc alloy is brass. There are various types of brasses, depending upon the proportion of copper and zinc. The fundamental a binary alloy comprises 50% copper and 50% zinc. By adding small quantities of other elements, properties of brass may be greatly changed. For example addition of lead (1 to 2%) improves the machining quality of brass. It has a greater-strength than that of copper, but has a lower thermal and electrical conductivity. Brasses alloys 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. Some of common phases of brass are discussed as under.

Alpha Phase

If the copper crystal structure is face centered cubic (FCC), there will be up to 36% of zinc. This solid solution is known as alpha brass. It has good mechanical properties, good corrosion resistance but it possesses lower electrical conductivity than copper.

Beta Phase

If the amount of zinc increases beyond 36%, beta brass will appear in the microstructure of the slowly cooled brass. This has body centered cubic structure (BCC). This phase is hard but quite tough at room temperature.

Gamma Phase

When zinc content is increased in brass beyond 45%, then gamma phase is appeared in its structure. This structure is extremely brittle, rendering an alloy which makes it unsuitable for general engineering purposes. The various types of brasses are discussed as under.

5.3.1.1 Red Brass

Red brass is an important material used for heat conducting purposes. Itcontains

$$Cu = 85\%$$
$$Zn = 15\%.$$

Properties

Red brass is having excellent corrosion resistance and workability. It possesses tensile strength ranging from 27-31 kg/mm 2. Percentage elongation of this brass is 42-48.

Applications

Red brass is mainly utilized for making, heat exchanger tubes, condenser, radiator cores, plumbing pipes, sockets, hardware, etc.

5.3.1.2 Yellow Brass or Muntz Metal

Yellow brass is also known as muntz metal. It contains

$$Cu = 60\%$$
$$Zn = 40\%$$

Muntz metal is having high strength and high hot workability. It is having tensile strength 38 Kg/mm^2 (approximately). The percentage elongation of this brass is 45%.

Applications

Yellow brass or muntz metal is suitable for hot working by rolling, extrusion and stamping. It is utilized for making small various components of machine and electrical equipment such as bolts, rods, tubes, valves and fuses. This metal is utilized for making for pump parts, valves, taps, condenser tubes, sheet form for ship sheathing (because of excellent corrosion resistance).

5.3.1.3 Cartridge Brass

It contains 70% Cu and 30% Zn. It is having good combination of strength and ductility. It is having tensile strength between 31-37 kg/mm^2. Percentage elongation of this brass is 55-66%. It is generally processed into rolled sheets. The metal alloy can be easily cold worked using cold working processes such as wire drawing, deep drawing and pressing.

Applications

It is utilized for making for making tubes, automotive radiator cores, hardware fasteners, rivets, springs, plumber accessories and in tube manufacture.

5.3.1.4 Admiralty Brass

It contains

$$Cu = 71\%$$
$$Zn = 29\%$$
$$Sn = 1\%$$

Properties

1. Admiralty brass is highly resistant to corrosion.
2. It is highly resistant to impingement attack of sea water.
3. It is having tensile strength 30 kg/mm^2 (approx.).
4. It can be cold worked
5. It possesses good corrosion resistance to sea water corrosion.
6. The percentage elongation of admiralty brass is 65%.

Applications

Admiralty brass is utilized for making condenser tubes in marine and other installations. It is used for making plates used for ship building. It is utilized also for making bolts, nuts, washers, condenser plant and ship fittings parts, etc.

5.3.1.5 Naval Brass

Navel brass is commonly used for making marine components. It contains

Cu = 59%

Zn = 40%

Sn = 1%

Properties

Properties of naval brass are similar to muntz metal. As 1% zinc is replaced by 1% tin in Muntz metal to make navel brass, corrosion resistance of this material to sea water is significantly improved. The percentage elongation of navel brass is 47% and its tensile strength is 38 kg/mm^2 (approx.).

Applications

Navel brass is commonly utilized for making marine hardware casting, piston rods, propeller shafts, welding rods etc.

5.3.1.6 Manganese Brass

Manganese brass is sometimes also called manganese bronze. It contains

Cu = 60%

Zn = 38%

Mn = 0.5%

Fe = 1.0%

Sn = 0.5%

Properties

Manganese brass possesses sufficient toughness and good corrosion resistance. It is very active in reducing the oxides of other metals.

Applications

Manganese brass is utilized for making hydraulic rams, valves and cylinders, tubes, pump rods, propellers, bolts, nuts etc.

5.3.1.7 Iron Brass or Delta Metal

Iron brass or delta brass contains

Cu = 60%

Zn = 37%

Fe = 3%

Iron brass or delta metal is hard, strong, tough, and having good corrosion resistance. It can be casted easily.

Applications

If corrosion is to be resisted in mild steel, then some amount of iron brass or delta metal is added in mild steel.

5.3.1.8 Gilding Brass

Gilding brass is a very cheap metal for making jewellery, decorative and ornamental products. It generally contains

$$Cu = 85\%$$
$$Zn = 15\%$$

Applications

Because of better appearance this metal is commonly used for jewellery, decorative and ornamental work.

5.3.1.9 Free Cutting Brass

Free cutting brass contains

$$Cu = 57.5\%$$
$$Zn = 40\%$$
$$Pb = 2.5\%$$

Free cutting brass is highly machinable and it does not allow bending.

Applications

Free cutting brass is used for making cast, forged or stamped blanks to be used for further machining such as high speed turning and screwing.

5.3.1.10 Lead Brass

Lead brass is also known as cloak brass which contains

$$Cu = 65\%$$
$$Zn = 34\%$$
$$Pb = 1\%$$

Applications

Lead brass or cloak brass is used in making small gears and pinions for clock work.

5.3.2 Bronzes

Bronze is a common alloy of copper and tin. The alloys of copper and tin are generally termed as bronzes. The wide range of composition of these alloys comprise of 75 to 95% copper and 5 to 25% tin.

Properties of bronzes

Bronze has higher strength, better corrosion resistance than brasses. It is comparatively hard and resists surface wear and can be shaped or rolled into wire, rods and sheets very easily. It has antifriction or bearing properties. Bronze is costlier than brass. The tensile strength of bronze increases gradually with the amount of tin, reaching a maximum when tin is about 20%. However the percentage of tin content if increases beyond this amount, the tensile strength decreases very rapidly. Bronze is most ductile when it contains about 5% of tin. As the amount of tin increases about 5%, the ductility gradually decreases and practically disappears with about 20% of tin. Whereas presence of zinc in the bronze increases fluidity of molten metal, strength and ductility.

Some of the common types of bronzes are discussed as under:

5.3.2.1 Phosphor Bronze

When bronze contains phosphorus in very small amount, then phosphor bronze is produced. A common type of phosphor bronze has the following composition.

Cu = 89 to 94%
Sn = 6 to 10%
P = 0.1 to 0.3%

Properties

Tensile strength, ductility, elasticity, soundness of castings, good wearing quality and resistance to fatigue of phosphor bronze increases with increase of phosphorus in bronze. This material possesses good corrosion resistance especially for sea water, so that it is much used for propeller blades. Phosphor bronze of proper composition can be easily casted, forged, drawn, and cold rolled.

Applications

Phosphorus bronze is used making for bolts, electric contact springs, bearings, bushes, gears, ship sheathing, valve parts, propeller blades, worm wheels, gears, nuts for machine lead screws, pump parts, linings and for many other purposes. It is also suitable for making springs and corrosion resistance mine cables.

5.3.2.2 Silicon bronze

Silicon bronze contains

Cu = 96%
Si = 3%
Mn or Zn = 1%

Silicon bronze has good general corrosion resistance of copper 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.

Applications

Silicon bronze is widely used for making boilers, tanks, stoves or where high strength and good corrosion resistance is required. It is used also for making screws, tubing's, pumps etc.

5.3.2.3 Beryllium bronze

Beryllium bronze is a copper base alloy contains

Cu = 97.5%
Br = 2.5%

Beryllium bronze possesses higher tensile strength than other bronzes. It possesses excellent corrosion resistance. It is having high yield point and high fatigue limit. It is having good hot and cold resistance. This can be heat treated by precipitation hardening. It possesses excellent formability in soft condition, and high fatigue and creep resistance in hardened condition. However it involves high cost.

Applications

Beryllium bronze is particularly suitable material for making springs, tubes, diaphragms and electrical contacts, heavy duty electrical switches, cams and bushings. This is used for springs, heavy duty electrical switches, cams and bushings. Having non-sparking characteristics, it is used for making chisels and hammers using for such conditions where spark might cause explosion. It has a film forming and a soft lubricating property, which makes it more suitable as a bearing metal. Since the wear resistance of beryllium copper is five times that of phosphorous bronze, therefore it is used as a bearing metal in place of phosphor bronze.

5.3.2.4 Manganese bronze

Manganese bronze is an alloy of copper, zinc and little percentage of manganese. The usual composition of this bronze is

Copper = 60%

Zinc = 35%

Manganese = 5%

Manganese bronze is highly resistant to corrosion. It is stronger and harder than phosphor bronze.

Applications

Manganese bronze is mainly used for bushes, plungers, feed pumps, rods etc. Worm gears are frequently made from this bronze.

5.3.2.5 Aluminium Bronze

Aluminium bronze possesses

Cu = 85 to 88%

Al = 8 to 11%

Fe = 3%

Sn = 0.5%

Properties

The aluminium bronze with 8% aluminium possesses very good cold working properties. When iron is added to this metal, its mechanical properties are greatly improved by refining the grain size and improving the ductility. The maximum tensile strength of this alloy is 450 MPa with 11 % aluminium. This material possesses good resistance to corrosion and it is somewhat difficult to cast due to oxidation problem.

Applications

Aluminium bronze is generally used for making fluid connection fittings, gears, propellers, air pumps, bushings, tubes, slide and valves etc. Cams and rollers are commonly produced using this alloy.

5.3.2.6 Bell Metal

Bell metal generally contains

Cu = 66.7%

Sn = 33.3%

Bell metal is very strong. It possesses resistance to corrosion water and atmosphere. It is used to make bells.

5.3.3 Constantan

The composition of constantan is

Cu = 55%

Ni = 45%

Properties

(*i*) Constantan is high specific resistance

(*ii*) Specific resistance is unaffected by temperature variation.

Applications

Constantan is used for accurate resistors like thermo-couples,

(*i*) Wheet-stone bridge,

(*ii*) Low temperature heaters and

(*iii*) Resistances

5.4 NICKEL AND ITS ALLOY

Nickel and its alloys are discussed as under.

5.4.1 Nickel

Nickel is a silvery shining white metal having extremely good response to polish. The most important nickel's ore is iron sulphides which contain about 3% of nickel. About 90% of the total production of nickel is obtained by this source. This ore is mainly found in Canada and Norway.

Manufacture

The ore of Nickel is initially roasted to reduce the sulphur content and then smelted to separate the gangue from it. Matte (impure product of the smelting of sulphide ore especially those of nickel or copper, is known as matte) delivered by the smelting furnace is then put in a Bessemer converter to oxidize the iron. The iron oxide thus combines with a limestone and quartz and form the slag. The Bessemer's matte consists chiefly of copper and nickel sulphides.

Properties

Nickel is as hard as steel. It possesses good heat resistance. It is tough and having good corrosion resistance. Its melting point is 1452°C and specific gravity is 0.85. At normal temperature, nickel is paramagnetic. Nickel alloys are sometimes used for their high potential field strengths, some for their permeability and some for their high coercive force. When it contains small amount of carbon, it is quite malleable. It is somewhat less ductile than soft steel, but small amount of magnesium improves ductility considerably.

Applications

Nickel is used in kitchen utensils and appliances, and in laundry and dairy machinery. It is extensively useful for electroplating plating work for protecting surfaces of iron and brass from corrosion. It is also utilized as an important alloying element in some type of cast iron and steel. It is helpful for making stainless steel. Its alloys are discussed as under.

5.4.2 Nickel Alloys

The important nickel alloys are haste alloy, Monel metal, inconel, nomonic and ni-chrome.

5.4.2.1 Haste Alloy or high Temprature Alloy

Haste alloy or high temperature alloy is mainly a nickel base alloy. It contains

Ni = 45%,

Cr = 22%,

Mo = 9%,

Co = 1.5%,

W = 0.5%,

C = 0.15% and

Fe = Remaining

Properties

(*i*) It can be hot and easily cold worked, casted and welded.

(*ii*) It has high resistance corrosion especially to acids and salts except nitric acid (HNO_3).

(*iii*) It can be machined also.

(*iv*) This alloy is used where the resistance to corrosion is of consideration.

Applications

The high temperature alloys are those alloys which can withstand high temperatures about 1100°C. These alloys are used in components of nuclear plants, jet and rocket engines etc.

5.4.2.2 Monel Metal

Monel metal is an important alloy of nickel and copper. It contains 68% Ni, 30% Cu, 1% Fe and small amount of other constituents like iron, manganese, silicon and carbon.

Properties

Monel metal is superior to brass or bronze in resisting corrosion and in retaining its strength at high temperature. It is magnetic at ordinary temperatures. Its mechanical properties are improved by cold working. It can be cast, cold and hot worked, forged and welded. It resembles nickel in appearance and is strong, ductile and tough. It has good mechanical properties and can retain them even at elevated temperatures. It has high excellent corrosion resistance.

Applications

Monel metal is also used for pump fittings, condenser tubes, sea water exposed parts etc. It is widely used for making turbine blades, containers, parts for chemical plants, food handling machinery parts, marine parts, pump impellers, propellers, evaporators and heat exchangers in chemical works.

5.4.2.3 Inconel

Inconel contains

Ni = 80%
Cr = 14%
Fe = 6%

Properties

Inconel has high resistance to corrosion and oxidation at elevated temperatures. It can be readily cold-worked and hot-worked, but does not respond to heat treatment. It contains high mechanical properties coupled corrosion and heat resisting properties. It can be cast, forged, rolled and cold drawn. Its specific gravity is 8.55 and melting point is 1395°C. Its Brinell Hardness is about 160BHN. It can be soft soldered or can be welded by oxyacetylene welding.

Applications

Inconel is used for making springs, exhaust manifold of aircraft engines, machinery for food processing industries, especially milk and milk products. It is widely used for processing uranium and for sheathing for high temperature heating elements.

5.4.2.4 Nomonic alloy

The composition of nomonic alloy is given as under.

Cr = 15 to 18%
Co = 15 to 18%
Ti = 1.2 to 4.0%
Al = 1.5%
Ni = Remaining

Properties

(*i*) Nomonic is a special type of nickel alloy having good strength
(*ii*) It can be easily heat treated to attain excellent properties for very high temperature service.

Applications

Nomonic is widely used for making gas turbine engines

5.4.2.5 Ni-Chrome

Ni-chrome contains

Ni = 60%
Cr = 15%
Fe = 20%

Properties

Ni-chrome is non-corrosive. It can easily withstand high temperatures without oxidation.

Applications

Ni-chrome is commonly used for making electrical resistance wire for electric furnaces and heating elements.

5.5 LEAD

Lead is a bluish grey metal with a high metallic lusture when freshly cut. It is a very durable and versatile material. The heavy metal obtained from the bottom of the furnace is further oxidized in Bessemer's converter to remove most of the impurities.

Properties

Lead has properties of high density and easy workability. It has very good resistance to corrosion and many acids have no chemical action on it. Its melting point is 327°C and specific gravity is 11.35. It is the softest and heaviest of all the common metals. It is very malleable and may be readily formed into foil. It can readily be scratched with fingernail when pure.

Applications

The lead pipes installed by the Romans in the public baths in Bath, England, nearly 2000 years ago are still in use. Lead is used in safety plug in boilers, fire door releases and fuses. It is also used in various alloys such as brass and bronze. It finds extensive applications as sheaths for electric cables, both overhead and underground. Its sheets are used for making roofs, gutters etc. It is employed for chemical laboratory and plant drains. In the soldering process, an alloy of lead and tin is most widely utilized as a solder material for joining metals in joining processes.

5.6 ZINC

Zinc is bluish grey in color and is obtained from common ores of zinc are zinc blende (ZnS), zincite (ZnO), calamine ($ZnCO3$). These ores are commonly available in Burma. The oxide is heated in an electric furnace where the zinc is liberated as vapor. The vapors are then cooled in condensers to get metallic zinc.

Properties

Zinc possesses specific gravity is 6.2 and low melting point of 480°C. Its tensile strength is 19 to 25 MPa. It becomes brittle at 200°C and can be powdered at this temperature. It possesses high resistance to corrosion. It can be readily worked and rolled into thin sheets or drawn into wires by heating it to 100-150°C.

Applications

With regards to industrial applications, zinc is the fourth most utilized metal after iron, aluminium, and copper. Zinc is commonly used as a protective coating on iron and steel in the form of a galvanized or sprayed surface. It is used for generating electric cells and making brass and other alloys. The oxide of zinc is used as pigment in paints. Parts manufactured by zinc alloys include carburetors, fuel pumps, automobile parts, and so on.

5.7 TIN

Tin is recognized as brightly shining white metal. It does not corrode in wet and dry conditions. Therefore, it is commonly used as a protective coating material for iron and steel. The main source of tin is tinstone. Large deposits of tinstone occur in Tairy (Burma) and small quantities in Hazaribagh in Bihar of India

Manufacture

To obtain crude tin, the ores of tins are crushed, calcined, washed and then smelted in a furnace using anthracite coal and sand. The crude tin is then refined in a reverberatory furnace to get commercially pure tin. Chemically pure tin is made by electrolytic deposition from commercial tin.

Properties

Tin is considered as a soft and ductile material. It possesses very good malleability. Its melting point is 232°C and specific gravity is 7.3. It is malleable and hence can be hammered into thin foils

Applications

Tin-base white metals are commonly used to make bearings that are subjected to high pressure and load. Tin is used as coating on other metals and alloys owing to its resistance to corrosion. It is employed in low melting point alloys as a substitute for Bismuth. It is generally preferred as moisture proof packing material. Because of its high malleability, it finds application in tin cans for storing food and food items.

5.7.1 Tin Base Alloy

Tin base alloy is also known as Babbitt metal which contains

Sn = 88%

Sb = 8%

Cu = 4%

Properties

Babbit metal possesses excellent antifriction properties and sufficient mechanical strength. It can be easily casted. It is expensive because of high tin content.

Applications

Because of the above properties, Babbit metal is the most common bearing metal used with cast iron boxes where the bearings are subjected to high pressure and load applications.

5.8. BEARING OR ANTIFRICTION ALLOYS

A bearing alloy or antifriction alloy commonly possesses good wearing quality, low co-efficient of friction, high thermal conductivity, good casting qualities, non-corrosive properties, ability to withstand high pressure and impact, low shrinkage after coating and less cost. Various Bearing Metals are:

5.8.1 Admiralty Gun Metal

The composition of admiralty gun metal generally contains

Cu = 88%

Sn = 10%

Pb = 2%

Properties

Admiralty gun metal is having tensile strength of the order of 270 MN/m^2. It possesses elongation of about 20% and Brinell Hardness of 65 BHN.

Applications

Admiralty gun metal is generally utilized where lubrication is needed and oiling is difficult.

5.8.2 Lead Bronze

Lead bronze generally contains

$$Cu = 80\%$$
$$Sn = 10\%$$
$$Pb = 10\%$$

Properties

Lead bronze possesses tensile strength of 230 MN/m^2 , Brinell Hardness of 65 BHN and elongation of about 15%.

Applications

Lead bronze possesses has antifriction properties and hence is generally utilized where lubrication is doubtful.

5.8.3 Hard Bearing Bronze

Hard bearing bronze basically contains

$$Cu = 85\%$$
$$Sn = 15\%$$

Properties

Hard bearing bronze generally possesses tensile strength of 220 MN/m^2, 100 BHN and percentage elongation of 2%.

Applications

Hard bearing bronze is commonly used for high compressive loads such as locomotive slide valves etc.

5.9 CUTTING TOOL MATERIAL

Few material for cutting tools are generally used which are as follows.

(*i*) **High Speed Steel**

These have superior hot hardness and it can retain the hardness up to 900°C. In it tungsten produces martensite structure with other elements. It is three types

18-4-1 High Speed Steel.

It has 18% tungsten, 4% chromium, 1% vanadium and 0.7% carbon: This is used for machining or metal cutting speed above 50 m/min. But for higher cutting speed vanadium is increased.

Molybdenum high Speed Steel

It has 6% Molybdenum, 4% chromium and 2% vanadium.

Cobalt High Speed Steel

It is also known as super high speed steel. It has 1-12% cobalt, 20% tungsten, 4% chromium and 2% vanadium. It is very good for high cutting speed.

(*ii*) **Cemented Carbides**

The use of tungsten as an alloying elements gives steel the properly of retaining hardness at high temperature up to 900°C to 1000°C. Carbide is made by mixing tungsten metal powder with carbon and heating the mixture to the about 1600°C in the atmosphere of hydrogen until the two substance have under gone the chemical reaction to produce tungsten carbides. Cemented carbide is a powder metallurgical product. The powder of several carbide compounds are pressed and bonded together in a matrix to from a cemented material. Today, the following three groups of cemented carbides are extensively applied for cutting elements of tools.

(*a*) WC + Co + (WC-TiC-TaC-NiC) for use in the machining of steels.

(*b*) WC + Co for use in the machining of cast irons and non ferrous metals.

(*c*) TiC + Ni + Mo for use in the machining of high temperature high strength metals.

Cemented carbides have a very high hardness (second only to diamond) and high wear resistance to abrasion. They do not loose their cutting properties i.e., hardness over a wide range of temperature up to 900-1000°C. Therefore tools tipped with cemented carbides are capable of efficiently machining the hardest metals, including hardened steels at high cutting speeds. Such tools can operate at cutting speeds from 16 to 25 folds those permitted for tools made of carbon tool steels. One drawback of cemented carbides is their brittleness. Very high stiffness (Young's modulus is about three times that of steel) of the cemented carbides requires that they are well supported on a shank of sufficient thickness, for even a small amount of bonding deformation in a material of this stiffness may induce very high tensile stresses. Cemented carbides are weak in tension than in compression. They have a strong tendency to form pressure welds at low cutting speeds. In view of this they should be operated at speeds considerably in excess of those used with high speed steel tools. This caused for machine tools of increased power. Carbides that obtain high cobalt percentage are tougher and stronger than that contain low cobalt. Hence they are used for rough cutting, interrupted cuts and for milling. The low cobalt variety is used for finished operations such as turning with a smooth chip cross-section and a continuous cut. It is recommended to keep the braze metal as thin as possible.

(*iii*) **Ceramics Tool**

The latest development in the metal cutting tools uses Aluminium oxide, generally referred as ceramics. These tools are made by compacting Al_2O_3 powder in a mould at about 280 kg/cm^2 or more. The part is then sintered at 2200°C. This method is also known cold pressing ceramic tool. Hot pressed ceramic tool materials are expensive owing to their higher mould costs. These are made in form of tips that are clamped to metal shanks. These tools have very low heat conductivity and possess extremely high compressive strength. However they are quite brittle. The have low bending strength. They can with stand temperatures up to 1200°C and can be used at cutting speeds 10 times that of high speed cutting tools and 4 times that of cemented carbides. They are chiefly used for single point cutting tools for semi-finish and turning of cast iron, plastics and other work. Heat conductivity of ceramics is very low and hence these tools are generally used without a coolant.

(*iv*) **Carbides tool**

It may be produced from carbides of tungsten, titanium and tantanum with same percentage, of cobalt. The product is obtained by a special technique known as powder metallurgy. Usually it contains 82% tungsten, 8% cobalt and l0% titanium and the product is obtained by a special technique known as power metallurgy. Cobalt acts as a binder and others are very hard substance. This tool contains high degree of hardness and resistance. It is able to retain hardness at elevated temperatures up to l000°C. It can be operated at speeds 5 to 6 times or (more) higher than those with high speed steel.

(*v*) **Diamond**

It is a noble material which is so costly that its application becomes limited. It is a hardest material. It can be used for cutting at a speed 50 times greater than H.S.S. tools. It can retain its hardness even at a temperature of 1650. It has low coefficient of friction and high heat conductivity. Diamond tools are used to produce good surface finish.

5.10 COMPOSTION AND APPLICATIONS OF FEW TYPICAL MATERIALS

The composition and applications of few typical materials is given in Table 5.1.

Table 5.1 Composition and Applications of Few Typical Materials

S. No	Alloy	Composition	Uses
1	Duralmin,	95% Aluminium + 4% Copper+ 0.5% Manganese + 0.5% Magnesium	Light structures, extruded sections and sheet
2	Gun metal	90% copper + 10% zinc	Small valves, fittings for water services
3	Monel	67% Ni + 28% Copper + remaining carbon, iron and Manganese	Valve parts for superheated steam turbine blades
4	Phosphor bronze	90% Copper + 9.7% Tin + 0.3% Phosphorus	Bearings, worm wheels, rods sheets
5	High carbon steel	0.8% to 1.5% Carbon + remaining iron	Files, dies for wire drawing, clutch disc
6	Spheroidal CI	3.2%-4.5% carbon 1-4% Si 0.1-8% Mn 0.1% P 0-3.5% Ni 0.05-0.1% Mn	For high wear resistance
7	Wrought iron	99% Pig Iron + 0.12% Carbon + 0.25% Phosphorus + 0.05 % Sulphur	Chains, crane hooks, railway couplings

5.11 CERAMICS MATERIALS

Ceramic materials are non-metallic solids made of inorganic compounds such as oxides, nitrides, borides and carbides. Theses materials are fabricated by first shaping the powder with or without the application of pressure into a compact form and after that it is subjected to high temperature. Ceramics possesses electrical, magnetic, chemical and thermal properties which are exceptionally good.

Examples: MgO, CdS, SiC, Al_2O_3, glass, cement, garnets, ferrites, concrete etc.

Applications

Ceramic materials are utilized for making electronic control devices, computers, structures, components of nuclear engineering and aerospace field.

5.12 COMPOSITES

Composites are mixture of materials such as metal and alloys and ceramics, metals and organic polymers, ceramics and organic polymers.

Examples: Vinyl coated steels, steel reinforced concrete, fiber reinforced plastics, carbon reinforced rubber etc.

Applications

These materials are used for making sports items, structures, and electrical devices.

5.13 SEMICONDUCTORS

Semiconductors are solid materials, either non-metallic elements or compounds which allow electrons to pass through them. These materials occupy intermediate position between conductors and insulators. Semiconductors usually have high resistivity, negative temperature coefficient of resistance and are generally hard and brittle.

Examples: Germanium (Ge), Arsenic (As), Silicon (Si), Boron (B), Sulphur (S), Selenium (Se).

Applications

Semiconductors are utilized in making devices used in areas of telecommunication and radio communication, electronics and power engineering, photocells, rectifiers etc.

5.14 ORGANIC POLYMERS

Polymers consist of carbon chemically combined with usually with hydrogen, oxygen or other non- metallic substances. They are formed by polymerization reaction in which simple molecules are chemically combined into long chain molecules.

Examples: Nylon, Teflon, Polyethylene, PVC, Terylene, Cotton etc.

Applications

Polymers are used in making packings, pipes, covers and insulating materials etc.

5.15 PLASTICS

Plastics are commonly known as synthetic resins or polymers. In Greek terminology, the term polymer comprises 'poly' means 'many' and 'mers' means 'parts'. Thus, the term, polymer represents a substance built up of several repeating units, each unit being known as a monomer. Thousands of such units or monomers join together in a polymerization reaction to form a 'polymer'. Some natural polymers like starch, resins, shellac, cellulose, proteins, etc are vary common in today's use. Synthetic polymers possess a number of large applications in engineering work. Therefore plastic materials are fairly hard and rigid and can be readily molded into different shapes by heating or pressure or both. Various useful articles can be produced from them rapidly, accurately and with very good surface quality. They can be easily produced in different colors or as transparent. They are recognized by their extreme lightness, good corrosion resistance and high dielectric strength. Plastics are synthetic resins characterized as a group by plastic deformation under stress. These materials generally are organic high polymers (i.e. consisting of large chain like molecules containing carbon) which are formed in a plastic state either during or after their transition from a low molecular weight chemical to a high molecular weight solid material. These materials are very attractive organic engineering materials and find extensive applications in industrial and commercial work such as electrical appliances, automotive parts, communication products bodies (Telephone, Radio, TV), and those making household goods. They possess a combination of properties which make them preferable to other materials existing in universe.

Properties of plastics

The properties of plastics are given as under.

1. Plastics are light in weight and at the same time they possess good toughness strength and rigidity.
2. They are less brittle than glass, yet they can be made equally transparent and smooth.
3. Their high dielectric strength makes them suitable for electric insulation.
4. They resist corrosion and the action of chemicals.
5. The ease with which they can be mass-produced contributes greatly to their popularity as wrappers and bags.
6. They possess the property of low moisture absorption.
7. They can be easily molded to desired shapes.
8. They can easily be made colored.
9. They are bad conductance of heat.
10. They are hard, rigid and heat resistance.
11. They possesses good deformability, good resiatance against weather conditions, good colorability, good damping characteristics and good resistance to peeling.

Plastics are broadly classified into thermo plastics and thermo-setting plastics.

5.15.1 Thermo Plastics

Those plastics which can be easily softened again and again by heating are called thermoplastic. They can be reprocessed safely. They retain their plasticity at high temperature, i.e. they preserve an ability to be repeatedly formed by heat and pressure. Therefore, they can be heated and reshaped by pressing many times. On cooling they become hard. They are some times also called as cold-setting plastics. They can be very easily shaped into tubes, sheets, films, and many other shapes as per the need.

Types of Thermo Plastics

(A) Amorphous

1 Polystyrene

2 Acrylonitrite-butadiene-styrene

3 Mrthacrylate

4 P.V.C (Polyvinyl chloride)

5 Polychloroacetal

6 Auorinated polymers,

7 Polycarbonate etc.

(B) Crystalline

1 Polyethylene

2 Polyamides

3 Polyacetal

4 Polypropylene

The reason for the re-softening of thermoplastic resins with heat is that they are composed of linear or long chain molecules. Application of heat weakens the intermolecular bonds by increasing thermal agitation of the molecules, and the material softens and thus plastic can be easily molded and remolded without damage

5.15.2 Thermo-Setting Plastics

Those plastics which are hardened by heat, effecting a non-reversible chemical change, are called thermo-setting. Alternatively these plastics materials acquire a permanent shape when heated and pressed and thus cannot be easily softened by reheating. They are commonly known as heat-setting or thermosets.

Thermosetting resins

(*i*) Phenol-formaldehyde resins

(*ii*) Urea-formaldehyde resins

(*iii*) Melamine-formaldehyde resins

(*iv*) Polyester resins

(*v*) Epoxy resins

(*vi*) Silicone resins

Other thermosetting compounds are phenol furfural, polysters, alkyds, and polyurethanes. The most common thermosetting compound is phenol formaldehyde which is discussed as under.

Phenol formaldehyde

Phenol formaldehyde is called as bakelite due to the name of its inventor Bakelite. It is the most commonly and widely used plastic. It is made by the reaction of phenol with formaldehyde. It has high strength, hardness, stability, rigidity and can be easily casted or laminated. It is highly resistant to heat, electricity and water. It is made in dark color shades. Its general uses are in making articles such as stereo cabinets, radio cabinets, plugs, knobs, dials, bottle cap, pulleys, wheels, telephones, switches and handles.

Thermosetting resins, when subjected (once only) to the heat and pressure required for forming, change into a hard and rigid substance. Once done so, they cannot be softened again by the application of heat. The reason for the above phenomenon is that the thermosetting plastics consist of linear, relatively low molecular weight thermoplastic polymer chains with cross-links which bond the chains together with primary valence bonds. Such three-dimensional polymers, once cross-linked, will not soften when heated (but may decompose disintegrate at higher temperatures) because this process is an irreversible chemical reaction and the entire structure becomes essentially a single molecule. In contrast the thermoplastic resins can be re-softened and remolded by application of heat and pressure. They retain their plasticity at high temperature, i.e. they preserve an ability to be repeatedly formed by heat and pressure.

5.15.3 Comparison Between Thermo Plastic and Thermosetting Plastic

Thermoplastic are those which are obtained from the substituted derivatives of ethylene which can be made to polymerize under the influence of heat and catalyst. These materials are softened by heat and affected by certain solvent. A notable feature of these resins is the ability of their scrap or rejects to be reworked along with the new material. Cellulose nitrate (celluloid) and polythene are the example of these materials. Where as thermosetting are those which are formed into shape under heat and pressure and results in a permanently hard product. The heat first softens the material, but as additional heat and pressure is applied, it becomes hard phenol formaldehyde (bakelite). Phenol furfural (Durite) is the example of thermosetting plastics. The comparison between thermo plastic and thermosetting plastic is given in Table 5.2.

Table 5.2 Comparison between Thermo Plastic and Thermosetting Plastic

S.No	Thermo Plastic	Thermosetting Plastic
1	They can be repeatedly softened by heat and hardened by cooling.	Once hardened and set, they do not soften with the application of heat.
2	They are comparatively softer and less strong.	They are more stronger and harder than thermoplastic resins
3	Objects made by thermoplastic resins can not be used at comparatively higher temperature as they will tend to soften under heat.	Objects made by thermosetting resins can be used at comparatively higher temperature without damage
4	They are usually supplied as granular material	They are usually supplied in monomeric or partially polymerized material form in which they are either liquids or partially thermoplastic solids.
5	Applications. Toys, combs, toilet goods, photographic films, insulating tapes, hoses, electric insulation, etc.	Applications. Telephone receivers, electric plugs, radio and T.V. cabinets, camera bodies, automobile parts, tapes, hoses, circuit breaker switch panels, etc.

5.15.4 Fabricating of Plastics

(*a*) Themo-plastics can be formed by

(*i*) Injection molding.

(*ii*) Extrusion.

(*iii*) Blow molding.

(*iv*) Calendaring

(*v*) Thermo-forming.

(*vi*) Casting.

(*b*) Thermosetting plastics can be formed by

(*i*) Compression or transfer molding.

(ii) Casting

Thermoplastics can be joined with the help of

(*i*) Solvent cements.

(*ii*) Adhesive bonding

(*iii*) Welding

(*iv*) Mechanical fasteners

Thermosetting plastics can be joined with the help of

(*i*) Adhesive bonding

(*ii*) Mechanical fasteners.

5.15.5 Additions in Polymer

To make polymer more for further processing of products, plastics, and some other material are added to the polymers before or during polymerization. These materials are

Catalysts

They are also known accelerator or hardener. They act as catalysts to accelerate the chemical reactions during polymerization of plastics.

Fillers

Fillers are added to synthetic resins for increasing strength, stiffness and thermal resistance of the plastics. These are clay, talc, alumina, carbon black, calcium carbonate, wood flour, mica, quartz, asbestos, glass fibres etc.

Modifiers

Modifiers are added to plastics for improving mechanical properties

Plasticizers

Plasticizers are fluids of high molecular weight. They are added for softening the resins at forming temperature and to improve their toughness at the finished stage and to impart flexibility to their finished products.

Stabilizers

The additions of stabilizers to plastics help in preventing deterioration due to the action of heat and light.

Initiators

Initiators help in starting the reaction i.e. polymerization.

Dyes and pigments

Dyes and pigments are the coloring agents, added to impart different colors and shades to plastic materials.

5.16 MATERIALS FOR NUCLEAR ENGINEERING PURPOSES

The various metals for producing nuclear energy are used as main materials namely moderators, reflectors, fuel elements, fuel canning materials, control elements, and pressure