CHAPTER 2

ALLOYS

2.1 INTRODUCTION

An alloy is an intimately mixed mixture of two or more elements out of which one is essentially a metal. They are classified into:

(a) Ferrous alloys: These contain iron as a major component, e.g. steels.

(b) Non-ferrous alloys: These alloys do not contain iron as a major component, e.g. Al, Cu, Pb, Sn alloys.

2.2 NON-FERROUS ALLOYS

These alloys contain metals like copper, aluminium, zinc, nickel, tin and lead as the principal alloying constituent. The characteristics/properties are:

- They possess attractive colours, softness and lower melting points as compared to ferrous alloys.
- They have good corrosion resistance and low density.
- They have high electrical and thermal conductivity.
- They are easily castable and can be cold worked.
- They have low coefficient of friction and can be fabricated easily.
- Most of the alloys have wide applications in the engineering fields.

2.2.1 Alloys of Copper

These alloys contain copper as the principal constituent e.g. brasses and bronzes.

2.2.2 Essential Properties of Copper

The copper metal is highly resistant to corrosion. It is ductile, malleable, having moderate to high hardness and strength. It possesses good machinability and can

Uses

(a) It is used for making marine fittings, condenser tubes, valves.
(b) It is also used for making springs and chains.

4. Cartridge Brass

Composition: 67% Cu and 33% Zn.

Properties

It has good ductility and strength and can be cold-worked.

Uses

(a) It is used for making cartridge cases, condenser tubes.
(b) It is used in household articles.

2.2.5 Special Brasses

These brasses contain certain other metals in addition to copper and zinc.

1. Admiralty Brass

Composition: 71% Cu and 28% Zn and1% Sn.

Properties

(a) It possesses good strength, hardness, corrosion resistance due to addition of tin.
(b) It is corrosion resistant to sea-water.

Uses

(a) It is used for marine work.
(b) It is used for making motor boats and pump parts.

2. Naval Brass

Composition: 62% Cu, 37% Zn and 1% Sn.

Properties

It has good abrasion and corrosion resistance.

Uses

(a) It is used in marine works.
(b) It is used for making condenser tubes.

3. German Silver Composition

60% Cu, 15% Zn and 25% Ni.

Properties

(a) It has attractive white colour.
(b) It has good resistance to corrosion.

Uses

(a) It is used for making decorative articles, tablewares, etc.
(b) It is also used making coins and utensils.

4. Lead Yellow Brass

Composition: 1% Sn, 1-3% Pb, 24 to 36% Zn and the remaining copper. It may also contain 0.3% Al.

Uses

It is used for hardware, valves, ornamental castings, etc.

5. Silicon Brass

Composition: 14% Zn, 3.5 to 4% Si, 0.5% Pb and the remaining part copper.

Uses

It is used in die cast parts, gears and structural parts.

2.2.6 Important Bronzes

1. Gun Metal

Composition: 5-10% Sn, 2-5% Zn, and the remaining copper.

Properties

It possesses good tensile strength and resistance to corrosion.

Uses

It is used for bearings, steam pipe fittings, marine castings, hydraulic valves, gears, heavy load bearings, etc.

2. Phosphor Bronze

Composition: 93% to 96% copper, 4-7% Sn and P less than 0.4%.

Properties

(a) It is hard, tough and possesses good strength.

(b) It possesses good casting properties and has a low coefficient of friction.

(c) It shows good corrosion resistance particularly to sea water.

Uses

(a) Bronzes with low phosphorus content are used in making springs, electric switches, radio aerial wires and suspension wires for moving coil galvanometers, spindles for valves and pumps, steam fittings in boilers, etc.

(b) Bronzes containing higher percentages of phosphorus and tin (10%) are suitable for purposes where stresses occur. Due to its increased hardness and abrasion resistance, they find use in bearing materials and gears. They are also used for turbine blades, taps, bushes, etc.

3. Aluminium Bronze

Composition: 89-93% Cu and 9-10% Al and minor quantities of elements like Fe, Mn, Ni, etc.

Properties

(a) It has a good golden yellow colour.
(b) It is quite tough and gives good castings.
(c) It possesses good abrasion resistance.
(d) It is resistant to atmospheric corrosion and also corrosion at high temperature.
(e) They possess good tensile strength and shock resistance.

Uses

(a) They are useful for all casting operations, bearings and bushes.
(b) They are useful for making coins, utensils, artificial jewellery and photo frames.

4. Nickel Bronze

Composition: 90% Cu, 9% Ni and 1% Fe.

Properties

(a) They are hard and have better tensile strength.
(b) They have better corrosion resistance compared to that of copper.

Uses

(a) It is used for general purposes.
(b) It is used for making hard bearings and unhardened shafts and valves.

5. High Nickel Bronzes

Composition: 15%–60% Ni, 12% Zn, upto 3% Sn, 0.1% Mg and remaining part copper.

Properties

(a) They are very hard and have very good tensile strength.
(b) They have high corrosion resisting properties.

Uses

They are used for hydraulic components used in contact with salty sea water.

6. Bearing Bronze

Composition: 80% Cu, 10% Sn, 10% Pb.

Properties

It is reasonably hard and possesses good corrosion resistance.

Uses

It is used in making bearings which resist heavy pressures as in railways.

7. Bell Metal

Composition: 80% Cu and 20% Sn.

Properties

It is hard and produces sonorous sound.

Uses

It is used in making bells and gongs.

8. Beryllium Copper

Composition: 98% Cu and 2% Be.

Properties

(a) It has good resistance to wear and corrosion.
(b) It has good conductivity.
(c) It is used in making brushes, relays and switches.

2.2.7 Alloys of Aluminium

Aluminium is a metal known for its light weight, high corrosion and non-toxicity. Its specific gravity is 2.7 with a melting point 658°C and boiling point 2450°C. The properties of aluminium are further improved by alloying with elements like Mg, Cu, Ni, Zn, Si, Mn, etc. The resultant alloys are also light and have good resistance to corrosion. They have good mechanical properties and high electrical conductivity. On account of these properties, they find extensive use in aircraft industry.

Two types of aluminium alloys:

Cast Alloys

These alloys contain copper and silicon as the important alloying elements. They may also contain Mg, Zn, Ni and Fe to a small extent. They are shaped by casting

Wrought Alloys

They contain Cu, Mn, Mg, Si in different amounts. They are non-heat treatable or heat treatable.

The non-heat treatable alloys contain Mg and Mn as major alloying elements. Their strength increases by cold working. They have good corrosion resistance and ductility.

The heat-treatable aluminium alloys improve in their strength by cold working as well as by heat treatment process. They can be heated to the required temperature and then quenched in oil or water for a required period of time to improve their strength and hardness.

The light weight aluminium alloys are characterised by malleability, ductility, high thermal-conductivity, non-magnetic properties, higher coefficient of expansion compared to steel, tensile strength equivalent to structural steel, and above all a good resistance to corrosion.

2.2.7.1. Important alloys of aluminium

1. Duralumin

Composition: 95% Al, 4% Cu, 0.5% Mn and 0.5% Mg.

Properties

(a) It is a light, ductile and tough alloy.

(b) It has good conductivity of heat and electricity.

(c) Though its strength is comparable to that of steel, its density is only one-third of steel.

(d) It possesses good machinability.

(e) Its tensile strength can be increased to 2000 kg/cm^2 by heat treatment without affecting its ductility.

(f) Its corrosion resistance can be improved by the process of cladding (one thin sheet of the alloy is sandwiched between the two thin sheets of pure aluminium).

Uses

(a) Due to its lightness and strength it is used in automobile and aircraft industries in the form of 'Alclad' sheets. It is also used in locomotive parts.

(b) Due to its good electrical conductivity and high ductility, it is used in making surgical instruments, cables, fluoresent tube caps, structural framework, hardware, body of vehicles, rivets, bars, etc.

2. Magnalium

Composition: 90-95% Al and 5-10% Mg.

Properties

(a) It is lighter than pure aluminium and magnesium.

(b) It is quite strong and tough.

(c) It is comparable to brass in its mechanical properties.

(d) It has good corrosion resistance.

Uses

It is used in making chemical balance, scientific instruments, furniture, aeroplane parts, etc.

3. γ-alloy

Composition: 91% Al, 4% Cu, 1.5% Mg, 2% Ni, 0.5% Fe, 0.5% Mn, 0.5% Si.

Properties

(a) It possesses high strength and hardness at high temperatures.

(b) It is an excellent light weight alloy, having very good corrosion resistance.

Uses

(a) It is used in aeroplane parts.

(b) It is used in heat exchange parts, refrigeration, storage containers, etc.

Rose Metal

Composition

Bi-50%, Pb-28%, Sn-22%

Properties: It has a low point of 89°C and is easily fusible.

Uses: It is used for fire alarms, fuse wires, automobile sprinkler systems.

2.3 POWDER METALLURGY

2.3.1 Introduction

Metals and alloys can be fabricated in order to obtain desired shape by hot working or cold working processes. A new technique called powder metallurgy has been developed for fabricating metallic parts from metal powder. Powder metallurgy can be defined as the technique of producing metal powders, and fabricating them into desired shape of articles. This technique is used to make objects of high melting alloy metals, refractory composites, etc. Metal powders find use in various industries such as catalyst, paints, explosive, printing inks, etc.

2.3.2 Principle of Powder Metallurgy

Powder metallurgy is essentially the art of producing metallic powders of a single metal or different metals. The powders are thoroughly mixed, compacted at high pressure into a particular shape and then heated at elevated temperature below the melting point of the solid powder. The shaping by pressure is called compaction and heat treatment process is called sintering.

2.4 CHARACTERISTICS OF METAL POWDERS

For the manufacture of products by powder metallurgy, accurate knowledge of metal powders and their characteristics are needed. The important characteristics of the metal powders are as follows:

(1) *Purity*: The impurities present in a metal powder cause adverse effects on the products. Better mechanical properties can be obtained by using pure metal powders.

(2) *Density*: Density is mass per unit volume. Apparent density is the weight of a unit volume of a powder when packed loosely.

(3) *Particle size & shape*: The particle size used in powder metallurgy varies form 5 – 200 microns. The particle size influences the strength, density, and porosity of the product.

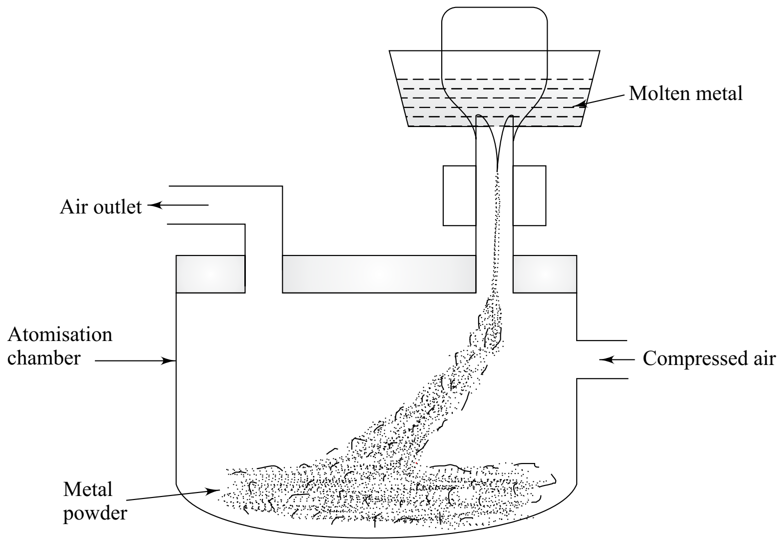


Fig. 2.1 Atomization.

Advantages of atomisation

- The metal powder obtained has high purity.
- Low initial cost and rate of production is high.

2.5.3 Electrolytic Deposition

Copper, silver and molybdenum powders are manufactured by this process. This process is similar to electrolysis. For making copper powder, copper plate is placed as anode and aluminium plate is placed as cathode in a tank of electrolyte. On passing electric current, copper powder deposits on the aluminium cathode and is scrabbed off. It is washed with water to remove the traces of electrolyte and then dried.

Advantages of electrolytic deposition

- Pure powder can be obtained by this process.
- It is an easily controllable process.

The only disadvantage of this process is its operating cost. It is very high and production rate is very low.

2.5.4 Chemical Methods

Reduction, precipitation and condensation chemical methods are used to produce metallic powders.

Reduction: High melting metallic powders of metals like copper, cobalt, nickel, tungsten, molybdenum, etc. are produced by this method. In this process, metallic oxides are heated in a current of hydrogen to reduce them to metallic powders (Fig. 2.2). The spongy powder obtained is suitable for cold pressing due to its softness and plasticity.

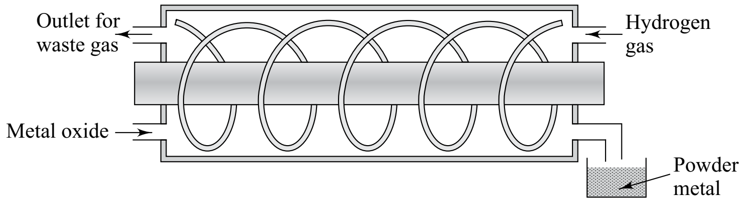


Fig. 2.2 Reduction process.

Precipitation: Extremely pure metal powders of silver, nickel and iron are produced by this method. Iron and nickel react with carbon monoxide to produce carbonyl $Fe(CO)_5$ and $Ni(CO)_5$ under suitable temperature and pressure. This liquid carbonyl decomposes resulting in metal precipitation at reduced pressure and elevated temperature. The precipitate is then dried and condensed to form powder.

Condensation: This method is used to produce zinc, cadmium and magnesium powders. A metal rod is heated on a high temperature flame where it gets vaporised. The vapours of the metal are allowed to condense by passing through a cold surface of the material. The pure metal condenses in the form of fine powder. It is not economical for large-scale production of powder.

2.6 VARIOUS STEPS INVOLVED IN POWDER METALLURGY

Production of Metallic Powders: Metal powders are produced by mechanical pulverisation, atomisation, electrolytic deposition or chemical methods.

Mixing or blending of powders: Uniformity in the finished product can be achieved by proper mixing of powders. To reduce die wall friction lubricants are added in most of the powders during mixing e.g., stearic acid, lithium stearate, etc.

Pressing or Compacting: Metal powder after mixing is pressed to shape in steel dies under pressure at room temperature. The solid mass obtained is known as green compact. This process of converting loose powder into green compact of accurate size and shape is known as compacting.

The compaction methods are subdivided into cold compaction and hot compaction.

(a) Cold compaction method: It takes place in the ambient range of temperature within which high temperature deformations like diffusion or dislocations are negligible. Several methods of cold compaction are available.

(i) *Cold pressing:* It is the most important compaction method in powder metallurgy. The starting material is the bulk powder with or without small amount of binder or lubricant. The cold pressing process may involve axial die pressing or isostatic pressing principles.

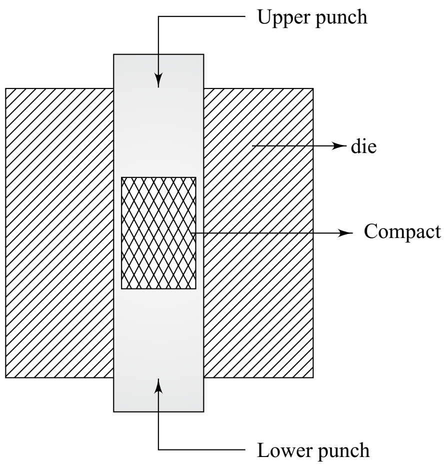
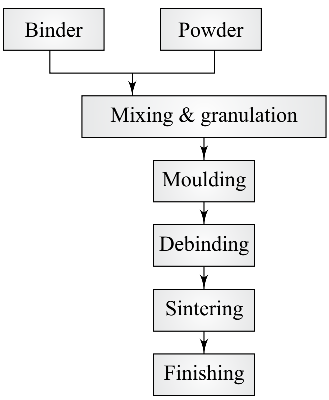


Fig. 2.3 Axial pressing.

In axial pressing, the powder is compacted in rigid dies by axially loaded punches. The main process variable in this technique is the axial compaction pressure which is defined as the ratio of the punch load and the punch surface area.

(ii) *Powder injection moulding:* It is well known process in the large scale manufacture of parts from thermoplastic polymers. When this process is applied for powder metallurgy it is called metal injection moulding. Steps involved in PIM.



(iii) Cold-powder Extrusion: This is plastic forming method (similar to injection moulding) in which a plasticised powder system is forced by a piston or screw unit into forming die, by using typical equipment. Tubes and rods can be prepared by this method.

(iv) Roll compaction: In this method, metal powders are compacted in the gap between two rollers. This is an alternative technique for producing semifinished products like strips and sheets. Production of high purity strips and sheets of cobalt and nickel is most notable commercial application of this process. The strips are used for making coin blanks for the mint, electronic tubes, batteries, thermostats and other bimetal applications.

(b) Hot compaction: In this process, the deformation mechanism of the powder are activated by simultaneous applications of higher processing temperature and pressure. The major hot compaction techniques:

(i) Axial hot pressing
(ii) Hot forging
(iii) Hot extrusion
(iv) Isostatic hot pressing.

Effects of compacting are:

(a) The porosity of the material decreases and the surface irregularities are removed as the particles are forced together under pressure.
(b) Compaction increases tensile as well as the compressive strength of the material.
(c) Cold welding occurs between adjacent particles.

Presintering: This process involves heating of the green compact below the sintering temperature to remove the lubricants added during blending.

Sintering: The mechanical and physical properties can be improved by heating the compacts in a furnace under controlled atmospheric conditions. The particles are pressed into a more compact mass by the application of heat. During sintering the fluidity of the component increases. This results in better interlocking of atoms of the constituents. Gases and other volatile materials present in the constituents are also eliminated by heat. The temperature of sintering is always kept below the melting point of the metal. The temperature and time of sintering of some materials are as follows.

Type of powder	*Temperature in °C*	*Time*
Aluminium and its alloys	400	3 hrs
Iron and its alloys	1100	2 – 3 hrs
Brass	900	5 hrs

Ceramic Powders: Naturally occurring silicate ceramics raw materials such as clay, kaolin are commonly used. The advanced ceramics requires pure and well-defined powders which are prepared synthetically. Manufacture of advanced

Uses: Due to high thermal and electrical conductivity used in muffle and electric arc furnaces. It is used in the manufacture of powder oxide ceramics of higher strength (carborandom).

(2) Solid state reactions—Most of the oxide ceramics are produced by the thermal decomposition of hydroxides, oxalates, sulphates, carbonates, etc.

(3) Solid gas reactions—Oxides, carbides and nitrides are synthesized by the reaction of metals with O_2, hydrocarbons, N_2 or NH_3 respectively. For example,

$$3Si + 2N_2 \longrightarrow \underset{\text{Silicon nitride}}{Si_3N_4}$$

(4) Gas phase reactions—Ceramic powder having high specific surface area are produced by this method. This process consists of vapour phase decomposition or hydrolysis in a flame and specially used to produce SiO_2 and TiO_2 from $Ti-Cl_4$ and $Si-Cl_4$ respectively.

$$SiCl_4 + H_2O \longrightarrow SiO_2 + 4HCl$$

The most important non-oxide ceramics which are widely used are silicon carbide (SiC), silicon nitrides (Si_3N_4) and boron carbide (B_4C) are also synthesized.

2.7 APPLICATIONS OF POWDER METALLURGY

Lamp Industry: Tungsten metal has very high melting point and is very difficult to cast. Dr W.D. Coolidge developed tungsten powder by reduction of tungsten oxide with hydrogen. The tungsten filament is made from pure tungsten powder which is compacted and sintered to form a bar of tungsten. This tungsten bar is then converted into 2 mm or less in diameter and drawn through tungsten carbide dies to about 0.2 mm diameter which can be further reduced through diamond dies at about 650°C. This tungsten wire has more strength than the hardest steel. It is used as a filament in incandescent lamp industry.

Refractory Metal Composites (Cermets): The high melting metal powders like tungsten, molybdenum, etc. can be mixed with ceramic oxides to form refractory composites using powder metallurgy technique.

Diamond Tools: Diamond tools are prepared by blending 30 per cent diamond dust with iron powder. They are used for cutting hard materials like porcelain and glass.

Cemented Carbides: Tungsten, molybdenum, carbides are used to make cutting tools by powder metallurgy.

Porous Metal Sheets: Metal powders like copper, brass, bronze and stainless steel are rolled into porous sheets having controlled porosity using this technique.

- Discuss four important types of bronze stating their composition properties and uses.
- Give composition, properties and uses of the following alloys:
  (i) German silver (ii) Duralium (ii)Tinmann's solder (iv) Magnelium (v) Rose metal (vi) Wood's metal (vii) γ-alloy (viii) Dutch metal (ix) Cartridge brass. (x) Commercial brass.
- What is powder metallurgy? What are the salient features?
- What are the advantages and disadvantages of powder metallurgy?
- How metal powders are prepared?
- Explain the processes involved in powder metallurgy.
- What are the applications of powder metallurgy?
- Explain the terms (i) Atomization (ii) Sintering.

MUMBAI UNIVERSITY QUESTIONS

May 2002

- Give composition, properties and uses of:
  (i) German silver (ii) Commercial brass.

Dec. 2002

- What are the various purpose of making alloys?
- Give the composition and uses of soft solders.
- What are various alloys of aluminium? Explain composition and uses of any two of them.

May 2003

- Distinguish between brasses and bronzes.
- What are the special effects of alloying elements on alloy steels?
- Give the composition, properties and uses of:
  (i) Nichrome, (ii) German silver

Dec. 2003

- Name two alloys of aluminium. State their composition and uses.
- State the effect of chromium, cobalt and tungsten on properties of alloy steels.
- What are alloys? Explain the purpose of making alloys.

- Write composition, properties and uses of the following:
  (i) German Silver (ii) Duralumin

Dec. 2007

- What is the purpose of making alloys? Explain with examples.
- Write a note on solders.

May 2008

- Write composition, properties and uses of duralumin. (3)
- What is powder metallurgy? How are metal powders prepared? (6)
- Write composition and uses of Wood's method. (2)
- Write note on atomisation and sintering. (5)