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Powder Metallurgy

4.1 INTRODUCTION

Powder metallurgy is a process of making components from metallic powders. Initially, it was used to replace castings for metals which were difficult to melt because of high melting point. The development of technique made it possible to produce a product economically, and today it occupies an important place in the field of metal process. The number of material products made by powder metallurgy are increasing and include tungsten filaments of lamps, contact points. Self lubricating bearings and cemented carbides for cutting tools.

4.2 CHARACTERISTICS OF METAL POWDER

The performance of metal powders during processing and the properties of powder metallurgy are dependent upon the characteristics of the metal powders that are used. Following are the important characteristics of metal powders.

(a) Particle shape (b) Particle size
(c) Particle size distribution (d) Flow rate
(e) Compressibility (f) Apparent density
(g) Purity

(*a*) *Particle Shape*: The particle shape depends largely on the method of powder manufacture. The shape may be special nodular, irregular, angular, and dendritic. The particle shape influences the flow characteristics of powders. Special particles have excellent sintering properties. However, irregular shaped particles are good at green strength because they will interlook on computing.

(*b*) *Particle Size*: The particle size influences the control of porosity, compressibility and amount of shrinkage. It is determined by passing the powder through standard sieves or by microscopic measurement.

(*c*) *Particle Size Distribution*: It is specified in term of a sieve analysis, the amount of powder passing through 100, 200 etc., mess sieves. Particle size distribution influences the packing of powder and its behaviour during moulding and sintering.

(*d*) *Flow Rate*: It is the ability of powder to flow readily and confirm to the mould cavity. It determines the rate of production and economy.

(*e*) *Compressibility*: It is defined as volume of initial powder (powder loosely filled in cavity) to the volume of compact part. It depends on particle size, distribution and shape.

(*f*) *Apparent Density*: It depends on particle size and is defined as the ratio of volume to weight of loosely filled mixture.

(*g*) *Purity*: Metal powders should be free from impurities as the impurities reduces the life of dies and effect sintering process. The oxides and the gaseous impurities can be removed from the part during sintering by use of reducing atmosphere.

4.3 BASIC STEPS OF THE PROCESS

The manufacturing of parts by powder metallurgy process involves the following steps:

(a) Manufacturing of metal powders
(b) Blending and mixing of powders
(c) Compacting
(d) Sintering
(e) Finishing operations

(*a*) *Manufacturing of Metal Powders*

There are various methods available for the production of powders, depending upon the type and nature of metal. Some of the important processes are:

1. Atomization
2. Machining
3. Crushing and Milling
4. Reduction
5. Electrolytic Deposition
6. Shotting
7. Condensation

1. *Automization*: In this method as shown in Fig. 4.1 (a), molten metal is forced through a small orifice and is disintegrated by a powerful jet of compressed air, inert gas or water jet. These small particles are then allowed to solidify. These are generally spherical in shape. Automation is used mostly for low melting point metals/alloy such as brass, bronze, zinc, tin, lead and aluminium powders.

2. *Machining*: In this method first chips are produced by filing, turning etc. and subsequently pulverised by crushing and milling. The powders produced by this method are coarse in size and irregular in shape. Hence, this method is used for special cases such as production of magnesium powder.

3. *Crushing and Milling*: These methods are used for brittle materials. Jaw crushers, stamping mills, ball mills are used to breakdown the metals by crushing and impact. See Fig. 4.1 (b) and (c).

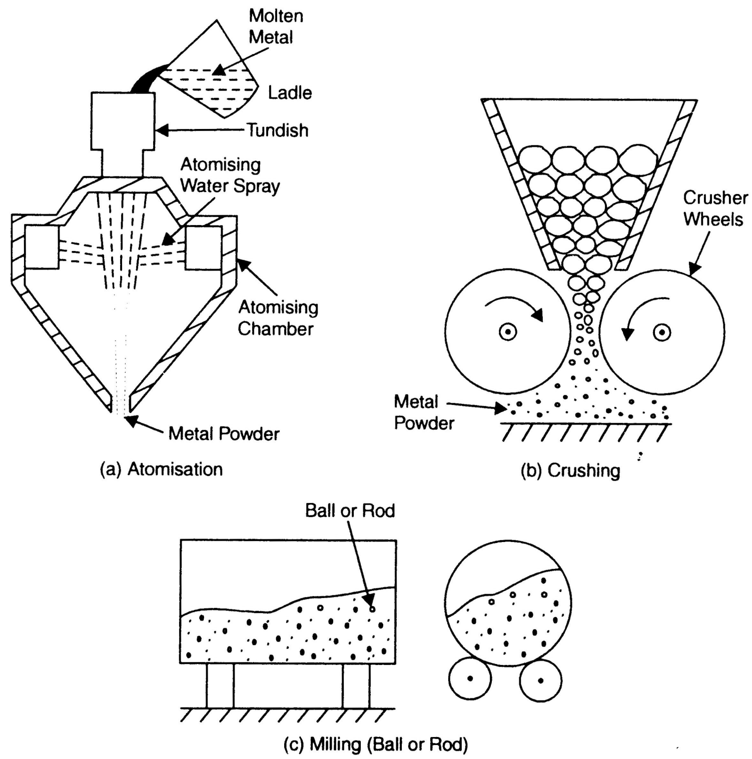

Fig. 4.1 Methods of Producing Metal Powders

In earlier stages of powder preparation gyratory crushers (Fig 4.1(b)) are used to crush brittle metals. For fine powder, the metal particles are fractured by impact. A ball mill (Fig. 4.1 (c)) is a horizontal barret shaped container holding a quantity of balls which are free to tumble about as the container rotates, crushes and abrade the powder particles that are introduced into the container.

4. *Reduction*: Pure metal is obtained by reducing its oxide with a suitable reducing gas at an elevated temperature (below the melting point) in a controlled furnace. The reduced product is then crushed and milled to a powder.

Sponge iron powder is produced this way

$$Fe_3O_4 + 4C = 3Fe + 4CO$$

$$Fe_3O_4 + 4CO = 3Fe + 4CO_2$$

Copper powder by

$$Cu_2O + H_2 = 2Cu + H_2O$$

Tungsten, Molybdenum, Ni and Cobalt are made by the method.

5. *Electrolytic Deposition*: This method is commonly used for producing iron and copper powders. This process is similar to electroplating. For making copper powder, copper plates are placed as anodes in the tank of electrolyte, where as the aluminium plates are placed into electrolyte to act as anode. When D. C. current is passed through the electrolyte, the copper gets

deposited on cathode. The cathode plates are taken out from electrolyte tank and the deposited powder is scrapped off. The powder is washed, dried and pulverised to produce powder of the desired grain size. The powder is further subjected to heat treatment to remove work hardness effect. The cost of manufacturing is high.

6. *Shotting*: In this method, the molten metal is poured through a siever or orifice and is cooled by droping into water. This produces spherical particles of large size. This method is commonly used for metals of law melting points.

7. *Condensation*: In this method, metals are boiled to produce metal vapours and then condensed to obtain metal powders, This process is applied to volatile metals such as zinc, magnesium and cadmium.

(*b*) *Blending and Mixing of Powders*

Powder blending and mixing of the powders are essential for uniformity of the product. Lubricants are added to the blending of powders before mixing. The function of lubricant is to minimise the wear, to reduce friction. Different powder in correct proportions are thoroughly mixed either wet or in a ball mill.

(*c*) *Compacting*

The main purpose of compacting is converting loose powder into a green compact of accurate shape and size. The following methods are adopted for compacting:

1. Pressing
2. Centrifugal compacting
3. Slip casting
4. Extrusion
5. Gravity sintering
6. Rolling
7. Isostatic moulding
8. Explosive moulding

1. *Pressing*: The metal powders are placed in a die cavity and compressed to form a component shaped to the contour of the die as illustrated in Fig. 4.2. The pressure used for producing green compact of the component vary from 80 Mpa to 1400 Mpa, depending upon the material and the characteristics of the powder used. Mechanical presses are used for compacting objects at low pressure. Hydraulic presses are for compacting objects at high pressure. (See Fig. 4.2)

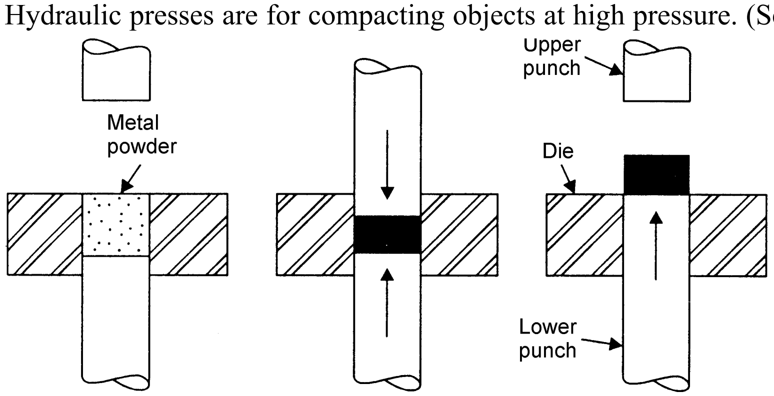

Fig. 4.2 Steps in Pressing Operations

2. *Centrifugal Compacting*: In this method, the moulder after it is filled with powder is centrifugal to get a compact of high and uniform density at a pressure of 3 Mpa. This method is employed for heavy metals such as tungsten carbide.

3. *Slip Casting*: In this method, the powder is converted into slurry with water and poured into the mould made of plaster of paris. The liquid in the slurry is gradually absorbed by the mould leaving the solid compact within the mould. The mould may be vibrated to increase the density of the compact.

This technique is used for materials that are relatively incompressible by conventional die compaction. The main drawback of this process is relatively slower process because it takes larger time for the fluid to be absorbed by the method.

4. *Extrusion*: This method is employed to produce the components with high density. Both cold and hot extrusion processes are for compacting specific materials. In cold extrusion, the metal powder is mixed with binder and this mixture is compressed into billet. The binder is removed before or during sintering. The billet is charged into a container and then forced through the die by means of ram. The cross-section of product depends on the opening of the die. Cold extrusion process is used for cemented carbide drills and cutters of ram. The cross-section of products depends on the opening of the die. Cold extrusion process is used for cemented carbide drills and cutters.

In the hot extrusion, the powder is compacted into billet and is heated to extruding temperature in non-oxidising atmosphere. The billet is placed in the container and extruded through a die. This method is used for refractive berium and nuclear solid materials.

5. *Gravity Sintering*: This process is used for making sheets for controlled porosity. In this process. the powder is poured on ceremic tray to form an uniform layer and is then sintered up to 48 hours in ammonia gas at high temperature. The sheets are then rolled to desired thickness. Porous sheet of stainless steel are made by this process and popularly used for fitters.

6. *Rolling*: This method is used for making continuous strips and rods having controlled porosity with uniform mechanical properties. In this method, the metal powder is fed between two rolls which compress and interlock the powder particles to form a sheet of sufficient strength as shown in Fig. 4.3. It then situated, rerolled and heat treated if necessary. The metals that can be rolled are Cu, Brass, Bronze, Ni, Stainless steel and Monel.

7. *Isostatic Moulding*: In this method, metal powder is placed in an elastic mould which is subjected to gas pressure in the range of 65-650 Mpa from all sides. After pressing. the compact is removed from gas chamber. If the fluid is used as press medium then it is called as hydrostatic pressing. The advantages of this method are: uniform strength in all directions, higher green compact strength and low equipment cost. This method is used for tungsten, molybdenum, niobium etc.

8. *Explosive Compacting*: In this method, the pressure generated by an explosive is used to compact the metal powder. Metal powder is placed in water proof bags which are immersed in water container cylinder of high wall thickness. Due to sudden deterioration of the charge at the

end of the cylinder, the pressure of the cylinder increase. This pressure is used to press the metal powder to form green compact.

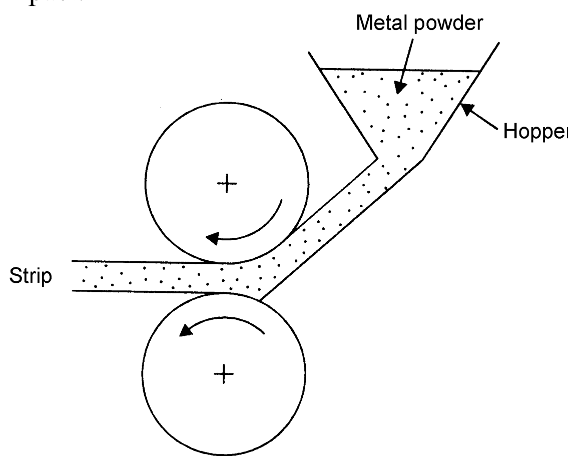

Fig. 4.3 Rolling

(*d*) *Sintering*

Sintering involves heating of the green compact at high temperatures in a controlled atmosphere [reducing atmosphere which protects oxidation of metal powders]. Sintering increases the bond between the particles and therefore strengthens the powder metal compact. Sintering temperature and time is usually 0.6 to 0.8 times the melting point of the powder. In case of mixed powders of different melting temperature, the sintering temperature will usually be above the melting point of one of the minor constituent [Ex : cobalt and cemented carbides] and other powders remain in soild state. The important factors governing sintering are temperature, time and atmosphere.

The sintering temperature and time of sintering for different metal powders are given below:

Type of powders	*Sintering temperature* °C	*Sintering Time*
Al & its alloys	370-520	24 hrs.
Cu, Brass & Bronze	700-900	30 min.
Iron	1025-1200	30 min.
Stainless Steel	1180	20-40 min
Tungsten Carbide	1480	20-40 min

Hot pressing

Hot pressing involves applying pressure and temperature simultaneously, so that the compacting and sintering of the powder takes place at the same time in a die. Its application is limited and can be used for compacting. Fe and Brass powders at much lower pressure than conventional pressing and sintering operations.

(*e*) *Finishing Operations*

These are secondary operations intended to provide dimensional tolerances, physical and better surface finish. They are:

1. Sizing
2. Coining
3. Machining
4. Impregnation
5. Infiltration
6. Heat treatment
7. Plating

1. *Sizing*: It is repressing the sintered component in the die to achieve the required accuracy.

2. *Coining*: It is repressing the sintered components in the die to increase density and to give additional strength.

3. *Machining*: Machining operation is carried out on sintered part to provide under cuts, holes, threads etc. which can not be removed on the part in the powder metallurgy process.

4. *Impregnation*: It is filling of oil, grease or other lubricants in a sintered component such as bearing.

5. *Infiltration*: It is filling of pores of sintered product with molten metal to improve physical properties.

6. *Heat Treatment*: The process of heating and cooling sintered parts are to improve

(i) Wear Resistance
(ii) Grain Structure
(iii) Strength

The following heat treatment process are used to the parts made by powder metallurgy:

1. Stress relieving
2. Carburising
3. Nitriding
4. Induction Hardening

7. *Plating*: Plating is carried out in order to:

1. Import a pleasing appearance (Cr plating)
2. Protect from corrosion (Ni plating)
3. Improve electrical conductivity (Cu and Ag plating)

4.4 DESIGN CONSIDERATIONS FOR POWDER METALLURGY PARTS

In designing of powder metallurgy parts, the following are the some of tooling and pressing considerations.

1. Side holes and side ways are very difficult to achieve during pressing and must be made by secondary machining operations.
2. Threads, kurling and other similar shapes should not be formed compacting. They should be produced by machining.
3. Abrupt changes in section thickness and narrow and deeper sections should be avoided as far as practicable.

4. It is recommended that sharp corners be avoided wherever possible. Fillets with generous radii are desirable.
5. Chambers can be made.
6. Under cuts that are perpendicular to the pressing direction can not be made, since they prevent the part ejection.

4.5 ADVANTAGES OF POWDER METALLURGY

1. Although the cost of making powder is high there is no loss of material. The components produced are clean, bright and ready for use.
2. The greatest advantage of this process is the control of the composition of the product.
3. Components can be produced with good surface finish and close tolerance.
4. High production rates.
5. Complex shapes can be produced.
6. Wide range of properties such as density, porosity and particle size can be obtained for particular applications.
7. There is usually no need for subsequent machining or finishing operations.
8. This process facilitates mixing of both metallic and non-metallic powders to give products of special characteristics.
9. Porous parts can be produced that could not be made any other way.
10. Impossible parts (cutting tool bits) can be produced.
11. Highly qualified or skilled labour is not required.

4.6 LIMITATION OF POWDER METALLURGY

1. The metal powders and the equipment used are very costly.
2. Storing of powders offer great difficulties because of possibility of fire and explosion hazards.
3. Parts manufactured by this process have poor ductility.
4. Sintering of low melting point powders like lead, zinc, tin etc., offer serious difficulties.

4.7 APPLICATIONS OF POWDER METALLURGY

Powder metallurgy techniques are used for making large number of components. Some of the application are as follows:

1. *Self-Lubricating Bearing and Filters*: Porous bronze bearings are made by mixing copper and tin powder in correct proportions, cold pressed to the desired shape and then sintered. These bearings soak up considerable quantity of oil. Hence during service, these bearings produce a constant supply of lubricant to the surface due to capillary action. These are used where lubricating is not possible. Porous filters can be manufactured and are used to remove, undesirable materials from liquids and gases.

2. *Friction Materials*: These are made by powder metallurgy. Clutch liners and Brake bands are the example of friction materials.

3. *Gears and Pump Rotors*: Gears and pump rotor for automobile oil pumps are manufactured by powder metallurgy. Iron powder is mixed with graphite, compacted under a pressure of 40 kg/cm and sintered in an electric furnace with an atmosphere and hydrocarbon gas. These are impregnated with oil.

4. *Refractor Materials*: Metals with high melting points are termed as refractory metals. These basically include four metals tungsten, molybdenum, tantalum and niobium. Refractory metals as well as their alloys are manufactured by powder metallurgy. The application are not limited to lamp filaments and heating elements, they also include space technology and the heavy metal used in radioactive shielding.

5. *Electrical Contacts and Electrodes*: Electrical contacts and resistance welding electrodes are made by powder metallurgy. A combination of copper, silver and a refractory metal like tungsten. molybdenum and nickle provides the required characteristics like wear resistant, refractory and electrical conductivity.

6. *Magnet Materials*: Soft and permanent magnets are manufactured by this process. Soft magnets are made of iron, iron-silicon and iron-nickle alloys. These are used in D.C. motors, or generators as armatures and in measuring instruments. Permanent magnets known as Alnico which is a mixture of nickle, aluminium, cobalt, copper and iron are manufactured by this technique.

7. *Cemented Carbides*: These are very important products of powder metallurgy and find wide applications as cutting tools, wire drawing dies and deep drawing dies. These consist of carbides of tungsten, tantalum, titanium and molybdenum. The actual proportions of various carbides depend upon its applications, either cobalt or nickle is used as the bonding agent while sintering.

Diamond Impregnated Tools

These are made from a mixture of iron powder and diamond dust. Diamond dust acts as a cutting medium and iron powder acts as the bond. These tools are used for cutting porcelain and glass. These bits are welded or brazed to a steel shank.

QUESTIONS

1. Discuss the characteristics of metal powders.
2. Describe various methods of producing metal powders.
3. Write shortly on (a) Centrifugal compacting (b) Extrusion (c) Slip casting.
4. Discuss advantages and limitations of powder metallurgy.
5. What are the various finishing operations used in powder metallurgy.
6. Discuss various applications of powder metallurgy.