8

Powder Metallurgy

Contents

8.1 Introduction

- Powder metallurgy is an art and science of producing fine metal powders and then making objects from the individual, mixed or alloyed metal powders with or without the inclusion of non-metallic constituents. Components are produced in their final form by pressing metal powders into the desired shape, usually in a metal mold, and then heating the compacted powder, either concurrently or subsequently, for a period of time at a temperature below the melting point of the major constituent.

For making a component by powder metallurgy,

1. The metal in the powder form must be able to respond to solid-phase welding.
2. The metal powder must be capable of sufficiently close packing under pressure to permit welding to take place and, in case of alloying, be capable of being sufficiently intimately mixed

8.2 Applications of Powder Metallurgy

- Porous products, e.g., bearings and filters.
- Refractory parts, e.g., components made out of Tungsten, Tantalum, and Molybdenum are used in electric bulbs, radio valves, oscillator valves, X-ray tubes in the form of filament, cathode, anode, control grids, etc.
- Products of complex shapes that require considerable machining when made by other processes, e.g., toothed components such as gears.
- Automotive components such as electrical contacts, crankshaft drive or camshaft sprocket, piston rings and rocker shaft brackets, door mechanisms, connecting rods, and brake linings, etc.
- Products made from materials that are very difficult to machine, e.g., tungsten carbide, etc.
- Components are gauges, wire drawing dies, wire guides, deep drawing, stamping and blanking tools, stone hammers, rock drilling bits, etc.
- Products where the combined properties of two metals or of metals and non - metals are desired: non-porous bearings, electric motor brushes, etc.
- Atomic energy applications.
- Tungsten parts are employed in plasma jet engines, etc., which are operated at about 1850°C. Silver infiltrated tungsten is used in nozzles for rockets and missiles. Use as parts in military and defense systems, e.g., in military arms.
- Parts made by powder metallurgy have also been used in clocks and timing devices, typewriters, adding machines, calculators, permanent magnets, laminated bimetallic strips, etc.
- Grinding wheels that incorporate steel and diamond powder may be manufactured by powder metallurgy.

8.3 Advantages of Powder Metallurgy

- The dimensional accuracy and surface finish obtainable are such that for many applications all machining can be eliminated.
- Cleaner and quieter operation and longer life of the components.
- High production rates.
- Control of grain size, relatively much uniform structure and defect (e.g., voids, blowholes, etc.) free components.
- No material is wasted as scrap; the process makes use of 100% raw material unlike casting, press forming, etc.

- Quite complex shapes can be produced
- Component's shapes obtained possess excellent reproducibility. Porous parts can be produced that could not be made in any other way. Parts with wide variations in compositions and materials can be produced. Structure and properties can be controlled more closely than in other fabricating processes.
- Highly qualified or skilled labor is not required.
- Impossible parts (e.g., super-hard cutting tool bits) can be produced.\
- The use of diamond in the industry has been made possible mainly through powder metallurgy.
- Powder metallurgy is free from the limitations imposed by the phase diagram. For example, it is difficult to produce copper -lead bearing alloys containing large amounts of lead, since the two metals are insoluble as liquids. However, mixed powders of copper and lead can be successfully shaped by powder metallurgy.

8.4 Limitations of Powder Metallurgy

- Complicated shapes, such as produced by casting, cannot be made by powder metallurgy, because metallic powders lack the ability to flow to the extent of molten metals.
- Parts made by powder metallurgy, in most cases, do not have as good physical properties as wrought or cast parts.
- Relatively high tool and die cost is associated with the process
- The size of products (as compared to casting) is limited because of the large presses and expensive tools which would be required for compacting.
- Powdered metals are considerably more expensive than those in wrought forms.
- Extreme care is required in handling pyrophoric powders (e.g., Mg, Th, Zr) to prevent fires or explosions and with toxic powders (e.g., U, Be, Th) to minimize health hazards.

8.5 Powder Metallurgy Process

The principal steps in powder metallurgy process include:

- Obtaining/producing metal powders in a suitable degree of fineness and purity.
- Weighing and mixing of the necessary powders (and lubricants) to arrive at a composition that processes satisfactorily and which produces desired properties in the fabricated part.
- Pressing the powder (mixture) in a suitable mold (of required size and shape) to cause cohesion to occur between the powder particles.
- Presintering the powder compact by heating and holding it at a moderate temperature. Presintering develops additional green strength.
- Finishing and sizing the final product.
- Annealing.
- Repressing for greater density or closer dimensional control.
- Machining, polishing
- Rolling, forging or drawing.
- Surface treatments to protect against corrosion.

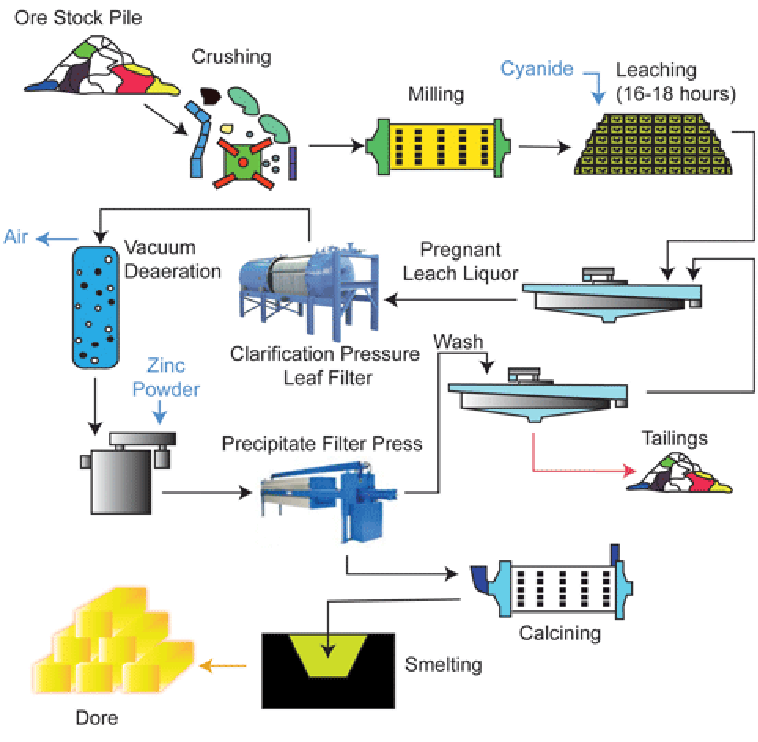

Fig.8.1 - Powder Metallurgy Process

8.6 Production of Metal Powders

The particle size of powders falls into a range of 1 to 100(x (micron), with the range of 10 to 20 (micron) being predominant. There are various methods of manufacturing powders of this size, but those commonly used are:

1. Atomization
2. Reduction
3. Electrolysis
4. Crushing
5. Milling
6. Condensation of metal vapours

1. Atomization

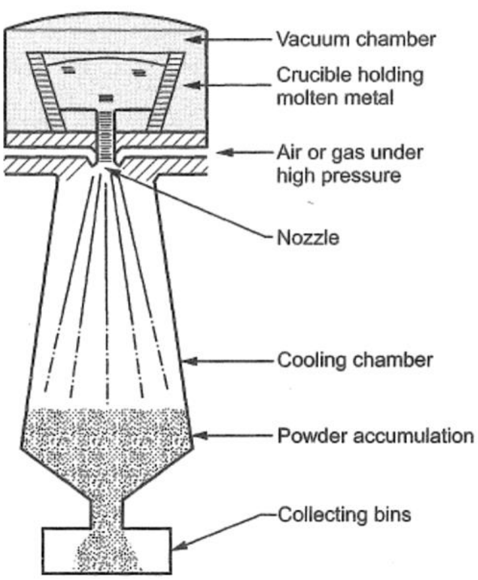

Fig.8.2 - Simple vertical atomizer

- In Atomization, the molten metal is directed through an orifice and as it emerges, a high-pressure stream of gas or liquid impinges on it causing it to atomize into fine particles.
- Frequently an inert gas is employed in order to improve the purity of the powder. Atomization is used mostly for low melting point metals because of the corrosive action of the metal on the orifice (or nozzle) at high temperatures.

2. Reduction process

- In the Reduction process, the compounds of metals (usually oxides, e.g., iron oxide)are reduced with CO or H2 at temperatures below the melting point of the metal (e.g., iron) is an atmosphere-controlled furnace. The reduced product is then crushed and ground.

Sponge-iron powder is produced this way.

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

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

- The copper powder can be produced by the same method i.e., by heating copper oxide in a stream of hydrogen,

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

- Powders of W, Mo, Ni, and CO are also manufactured by the reduction process. The reduction process is a convenient, economical and flexible method and perhaps the largest volume of metallurgical powders is made by the process of oxide reduction.

3. Electrolysis

- Electrolysis is principally used for the production of extremely pure powders of copper (and Iron). Electrolysis is similar to electroplating.
- For making copper powder, copper plates are placed as anodes in a tank of electrolyte, whereas aluminium plates are placed into the electrolyte to act as cathodes. High amperage produces a powdery- deposit of anode metal on the cathodes.
- After a definite time period, the cathode plates are taken out from the tank, are rinsed to remove electrolytes and are dried. The (Cu) deposit on the cathode plates, is then scraped off and pulverized to produce powder of the desired grain size.

4. Crushing

- Crushing requires equipment such as stamps, hammers, jaw crushers or gyratory crushes. Various ferrous and non-ferrous alloys can be heat-treated in order to obtain a sufficiently brittle material which can be easily crushed into powder form.

5. Milling Operation

- Milling operation is carried out by using equipment such as ball mill, impact mill, eddy mill, disk mill, vortex mill, etc. Milling (or grinding) can be classified as a combination of brittle, friable, tough and hard materials and pulverization of malleable and ductile metals.
- A ball mill is a horizontal barrel-shaped container holding a quantity of balls which, being free to tumble about as the container rotates, crush and abrade any powder particles that are introduced into the container.
- Generally, a large mass to be powdered, first of all, goes through heavy crushing machines, then through crushing, rolls and finally through a ball mill to produce successively finer grades of powder.

6. Condensation

- This technique can be applied in the case of metals, such as Zn, Cd, and Mg, which can be boiled and the vapour are condensed in a powder form. A rod of metal (say Zn) is fed into a high-temperature flame.
- The vaporized droplets of metal are allowed to condense on to a cool surface of a material to which they will not adhere.

8.7 Characteristics of Metal Powders

The most important characteristic of metal powder are:

1. Purity,
2. Chemical composition,
3. Particle size,
4. Size distribution.
5. Particles shape,
6. Particle microstructure
7. Apparent density, and
8. Flow rate.

- **Chemical Composition** implies the type and percentage of alloying elements and impurities and usually determines the particle hardness and compressibility. The chemical composition of a powder can be determined by chemical analysis methods.
- **Particle Size** is expressed by the diameter for spherical shaped particles and by the average diameter for non-spherical particles as determined by the sieving method or microscopic examination. Metal powders used in powder metallurgy usually vary in size from 4 to 200 microns. Particle size influences mold strength, density/porosity of the compact, permeability, flow and mixing characteristics, dimensional stability, etc.
- **Particle-size distribution** is specified in terms of a sieve analysis, i.e., the amount of powder passing through 100-, 200-, etc., mess sieves. Particle-size distribution influences the packing of the powder and its behavior during molding and sintering.
- **Particle Shape** influences the packing and flow characteristics of powders. There are various shapes of metal powders, e.g.
  - Spherical (Condensed zinc)
  - Rounded (Atomized copper)
  - Angular (Mechanically atomized antimony). Acicular, dendritic, flakes, irregular, etc.
- **Particle Microstructure** reveals various phases, impurities, inclusions, fissures, and internal porosity.
- **Apparent Density** is defined as the weight of a loosely heaped quantity of powder necessary to fill a given die cavity completely. Apparent density is influenced by chemical composition, particle shape, size, size distribution, method of manufacture, etc. The apparent density of iron powder (electrolytic) having an average particle size of 63 microns is 2.56 gm/cc.
- **Flow Rate** is defined as the rate at which a metal powder will now under gravity from a container through an orifice both having the specific shape and finish.
- Flow rate measures the ability of a powder to be transferred. Flow rate is an important characteristic because the die must be filled rapidly with powder to achieve a high rate of production and economy.
- The flow rate depends upon particle size, shape, apparent density, etc. Spherical shaped metal powders possess maximum flow rates whereas dendritic ones the least.

8.8 Blending and Mixing of Powders

Before the powders are pressed into shape, they are usually blended for the following reasons:

- To add lubricants (such as stearic acid, graphite, oils, paraffin, glycerin, etc.) (to powder) to reduce friction during the pressing operations. Powder particles get coated with lubricants. This reduces die wear and lowers the pressure required for pressing.
- To mix powders of different materials (i.e., alloying action), in order to obtain properties of heat resistance, friction, heavyweight, and hardness.
- To obtain a uniform distribution of particle sizes.

- To add volatilizing agents to give a desired amount of porosity.
- Different powders in correct proportions are thoroughly mixed either wet or dry, in a ball mill. In wet mixing, water or a solvent is used to obtain better mixing. Moreover, wet mixing.
- Reduces dust,
- Lessens explosion hazards which are present with some finely divided powders, and
- Prevents surface oxidation.
- Proper blending and mixing of the powders are essential uniformity of the finished product. However, over-mixing should be avoided since it may decrease particle size and work hardens the particles.

8.9 Compacting

After blending and mixing, the next step is that of compacting or pressing the powders into their semi-finished form preparatory to sintering.

The purpose of compacting is to consolidate the powder into the desired shape and as closely as possible to final dimensions, taking into account any dimensional changes that result from sintering. Compacting also imparts

1. The desired level and type of porosity, and
2. Adequate strength for handling**.**

Powders are compacted by using high pressures. The degree of pressure depends upon:

1. The required density of the final product, and
2. The ease with which the powder particles will weld together. Compacting pressures may be applied in the following ways:
    1. Die Pressing
    2. Roll pressing
    3. Extrusion

1. Die pressing is done in special presses that include a feed hopper for the powder, the shaping die to form the product, an upper punch, and a lower punch to apply correct pressures onto the powder being compacted. Weighed-quantity of powder is placed in the die through the hopper and is compressed under pressure ranging from 8 to 158 kg/sq. mm
2. Roll pressing is used for the production of a continuous strip section, using a system. There are two rolls of appropriate size into which a regulated stream of powder is guided so that the rolls are able to apply the necessary compacting pressure in a continuous sequence.
3. The Extrusion method of compacting does not give such efficient control as that given by pressing or by rolling. It is difficult to obtain high densities and some porosity is always left.

8.10 Presintering and Sintering

Presintering

- Frequently, powder metallurgy is used to make parts from materials that are very difficult to machine.
- When some machining is required on such parts, one goes a lot presintering before the actual sintering operation.
- After presintering operation, the compacted part acquires sufficient strength to be handled and machined without difficulty. Moreover, very little dimensional change takes place, then in the final sintering, therefore, machining after final sintering may be eliminated.
- For presintering, the compacted parts are heated for a short time at a temperature considerably below the final sintering temperature.

- Presintering is necessary when holes are to be drilled in hard to machine parts. Presintering, in addition, removes lubricants and binders added to the powders during the blending operation.
- Presintering can be eliminated if no machining of the final product is required.

Sintering

- After being compressed into a briquette of the shape required in the finished component, the agglomerated metals are sintered. Sintering is done to achieve all possible final strength and hardness needed in the finished product.
- Sintering consists of heating pressed metal or cermet compacts in batch or continuous furnaces' to a temperature below the melting point of the major constituent in an inert or reducing atmosphere (of hydrogen, dissociated ammonia or cracked hydrocarbon), where time, temperature, heating rate, and cooling rate are automatically controlled. Most metals are sintered at 70 to 80% of the melting temperature. Certain refractory materials may be sintered at 90% of the melting point.
- The sintering time varies from thirty minutes up to several hours. Sintering temperatures and times vary considerably with different materials, e.g., Porous bronze bearings require treatment for only a few minutes at 800°C; iron base compacts and cemented carbides require treatment for up to 2 hours at 1200-1250°C, etc.
- Sintering is essentially a process of bonding solid bodies (particles) by atomic forces.
- Bonding of powder particles during sintering can take place in any of the three ways:

1. Melting of a minor constituent,
2. Volume diffusion, although surface diffusion, evaporation, and condensation also contribute to bonding.

8.11 Secondary Operations

In many cases, the metal parts may be used in the as-sintered condition, but in other cases where the desired surface finish, tolerance or metal structure cannot be obtained by briquette size and shape. The briquette is considered fairly fragile, but it can be handled), certain additional operations must follow. They are

1. Sizing	4. Impregnation	7. Heat treatment
2.Coining	5. Infiltration	8. Joining
3.Machining	6.Plating	

1. Sizing

The sintering process produces some distortion and alterations in size. After the part has been sintered, in order to make it dimensionally correct, it is placed in a die and is repressed. Sizing improves the surface finish of the component also. However, a slight change in density occurs during sizing.

2. Coining

The sintered part is repressed in the die to reduce the void space and impart the required density.

3. Machining

Features such as threads, undercuts, grooves, etc., are usually not practical for powder metallurgy fabrications and are generally machined on parts after they have been pre-sintered. Boring, turning, drilling, tapping, etc., can be done on presintered parts using tungsten carbide cutting tools.

4. Impregnation

Sintered parts may be impregnated with oil, grease, wax or other lubricating materials, in case self-lubricating properties are desired. Parts are immersed in lubricants heated to approximately 93°C. The porous structure gets completely (about 90%) impregnated in 10 to 20 minutes. The lubricant is retained in the part by capillary action.

The sintered part may be impregnated with plastics also. This is done in order to,

1. Improve corrosion resistance,
2. Seal prior to plating.
3. Improve machinability.
4. Introduce pressure tightness.

5. Infiltration

A part is first pressed and sintered from iron powder to about 77% of theoretical density. Then a replica (or infiltration) blank of copper (or brass) is placed over the part which is sent through the furnace. The infiltrant melts and soaks through the porous part, producing a density close to 100%.

6. Plating

Plating is carried out in order to,

1. Impart a pleasing appearance (Cr plating).
2. Protect from corrosion (Ni plating).
3. Improve wear resistance (Ni or Cr plating).
4. Improve frictional (Tin plating) and hardness characteristics (Cr plating)
5. Improve electrical conductivity (Cu and Ag plating).
6. Before plating, the part is impregnated with plastic resin so that the electrolyte is not entrapped in the porous structure during plating.
7. Sintered parts, then, maybe plated with Cr, Ni, Co, Cd, Zn, brass, etc.

7. Heat treatment

Sintered parts are heat treated in order to improve:

1. Wear resistance
2. Grain structure
3. Hardness
4. Strength.

To prevent oxidation of the internal structure, the heat treatment is carried out in a controlled atmosphere. The porosity of sintered parts decreases the heat conductivity, therefore longer heating and shorter cooling periods are required.

Following heat treatment processes are usually applied to parts made by powder metallurgy.

1. Stress relieving
2. Carburizing
3. Carbonitriding
4. Nitriding
5. Through hardening
6. Induction hardening

8. Joining of sintered parts

Parts may be joined after they have been sintered or the joining may be incorporated into sintering operation. Various joining, techniques are

1. Soldering (on A1 and Cu based sintered parts).
2. Brazing (carried out in a vacuum or controlled atmosphere. High-frequency heating is preferred).
3. Welding (TIG welding, projection welding, friction welding, electron beam welding,).

Material is that from which anything can be made. It includes a wide range of metals and non-metals that a

8.12 References

O. P. Khanna “Material Science and Metallurgy” Dhanpat Rai Publications.