19

CHAPTER

POWDER METALLURGY

19.1 INTRODUCTION

Powder metallurgy is used for manufacturing products or articles from powdered metals by placing these powders in molds and are compacting the same using heavy compressive force. Typical examples of such article or products are grinding wheels, filament wire, magnets, welding rods, tungsten carbide cutting tools, self-lubricating bearings electrical contacts and turbines blades having high temperature strength. The manufacture of parts by powder metallurgy process involves the manufacture of powders, blending, compacting, profiteering, sintering and a number of secondary operations such as sizing, coining, machining, impregnation, infiltration, plating, and heat treatment. The compressed articles are then heated to temperatures much below their melting points to bind the particles together and improve their strength and other properties. Few non-metallic materials can also be added to the metallic powders to provide adequate bond or impart some the needed properties. The products made through this process are very costly on account of the high cost of metal powders as well as of the dies used. The powders of almost all metals and a large quantity of alloys, and nonmetals may be used. The application of powder metallurgy process is economically feasible only for high mass production. Parts made by powder metallurgy process exhibit properties, which cannot be produced by conventional methods. Simple shaped parts can be made to size with high precision without waste, and completely or almost ready for installation.

19.2 POWDER METALLURGY PROCESS

The powder metallurgy process consists of the following basic steps:

1. Formation of metallic powders.
2. Mixing or blending of the metallic powders in required proportions.
3. Compressing and compacting the powders into desired shapes and sizes in form of articles.
4. Sintering the compacted articles in a controlled furnace atmosphere.
5. Subjecting the sintered articles to secondary processing if needed so.

19.2.1 Production of Metal Powders

Metallic powders possessing different properties can be produced easily. The most commonly used powders are copper-base and iron-base materials. But titanium, chromium, nickel, and stainless steel metal powders are also used. In the majority of powders, the size of the particle varies from several microns to 0.5 mm. The most common particle size of powders falls into a range of 10 to 40 microns. The chemical and physical properties of metals depend upon the size and shape of the powder particles. There are various methods of manufacturing powders.The commonly used powder making processes are given as under.

1. Atomization
2. Chemical reduction
3. Electrolytic process
4. Crushing
5. Milling
6. Condensation of metal vapors
7. Hydride and carbonyl processes.

The above mentioned metallic powder making techniques are discussed briefly as under.

1. Atomization

In this process, the molten metal is forced 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. The inert gas is then employed in order to improve the purity of the powder. It is used mostly for low melting point metals such as tin, zinc, lead, aluminium, cadmium etc., because of the corrosive action of the metal on the orifice (or nozzle) at high temperatures. Alloy powders are also produced by this method.

2. Chemical reduction process

In this process, the compounds of metals such as iron oxides are reduced with CO or H_2 at temperatures below the melting point of the metal in an atmosphere controlled furnace. The reduced product is then crushed and ground. Iron powder is produced in this way

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

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

Copper powder is also produced by the same procedure by heating copper oxide in a stream of hydrogen.

$$Cu_2 + H_2 = 2Cu + H_2O$$

Powders of W, Mo, Ni and CO can easily be produced or manufactured by reduction process because it is convenient, economical and flexible technique and perhaps the largest volume of metallurgy powders is made by the process of oxide reduction.

3. Electrolytic process

Electrolysis process is quite similar to electroplating and is principally employed for the production of extremely pure, powders of copper and iron. For making copper powder, copper plates are placed as anodes in a tank of electrolyte, whereas, aluminium plates are placed in to 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, rinsed to remove electrolyte and are then dried. The copper deposited on the cathode plates is then scraped off and pulverized to produce copper powder of the desired grain size. The electrolytic powder is quite resistant to oxidation.

4. Crushing process

The crushing process requires equipments such as stamps, 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 process

The milling process is commonly used for production of metallic powder. It is carried out by using equipments such as ball mill, impact mill, eddy mill, disk mill, vortex mill, etc. Milling and grinding process can easily be employed for brittle, tougher, malleable, ductile and harder metals to pulverize them. 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 of metal powders

This process can be applied in case of metals, such as Zn, Cd and Mg, which can be boiled and the vapors are condensed in a powder form. Generally a rod of metal say Zn is fed into a high temperature flame and vaporized droplets of metal are then allowed to condense on to a cool surface of a material to which they will not adhere. This method is not highly suitable for large scale production of powder.

7. Hydride and carbonyl processes

High hardness oriented metals such as tantalum, niobium and zirconium are made to combine with hydrogen form hydrides that are stable at room temperature, but to begin to dissociate into hydrogen and the pure metal when heated to about 350°C. Similarly nickel and iron can be made to combine with CO to form volatile carbonyls. The carbonyl vapor is then decomposed in a cooled chamber so that almost spherical particles of very pure metals are deposited.

19.2.2 Characteristic of Metal Powders

The performance of powder metallurgical parts is totally dependent upon the characteristics of metal powders. Most important characteristics of metal powders are powder particle size, size distribution, particle shape, purity, chemical composition, flow characteristics and particle microstructure. Some of the important properties are discussed as under.

Powder particle size and size distribution

Particle size of metal powder is expressed by the diameter for spherical shaped particles and by the average diameter for non-spherical particle as determined by sieving method or microscopic examination. Metal powders used in powder metallurgy usually vary in size from 20 to 200 microns. Particle size influences density/porosity of the compact, mold strength, 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 20 or 40 mesh sieves.

Particle shape

There are various shapes of metal powders namely spherical, sub-rounded, rounded, angular, sub-angular, flakes etc. Particles shape influences the packing and flow characteristics of the powders.

Chemical composition

Chemical composition of metallic powder implies the type and percentage of alloying elements and impurities. It usually determines the particle hardness and compressibility. The chemical composition of a powder can be determined by chemical analysis methods.

Particle microstructure

Particle microstructure reveals various phases, inclusions and internal porosity.

Apparent density

Apparent density is defined as the weight, of a loosely heated quantity of powder necessary to fill a given die cavity completely.

Flow characteristics

Flow-ability of metal powders is most important in cases where moulds have to be filled quickly. Metal powders with good flow characteristics fill a mould cavity uniformly.

19.2.3 Mixing or Blending of Metallic Powders

After the formation of metallic powders, proper mixing or blending of powders is the first step in the forming of powder metal parts. The mixing is being carried out either wet or dry using an efficient mixer to produce a homogeneous mixture.

19.2.4 Compacting of Powder

Compacting is the technique of converting loose powder in to compact accurately defined shape and size. This is carried out at room temperature in a die on press machine. The press used for compacting may be either mechanically or hydraulically operated. The die consists of a cavity of the shape of the desired part. Metal powder is poured in the die cavity and pressure is applied using punches, which usually work from the top and bottom of the die as shown in Fig. 19.1. Dies are usually made of high grade steel, but sometimes carbide dies are used for long production runs. In compacting process, the pressure applied should be uniform and applied simultaneously from above and below. The pressure applied should be high enough to produce cold welding of the powder. Cold welding imparts a green strength, which holds the parts together and allows them to be handled.

The metal parts obtained after compacting are not strong and dense. To improve these properties, the parts should be sintered.

19.2.5 Sintering

Sintering is the process of heating of compacted products in a furnace to below the melting point of at least one of the major constituents under a controlled atmosphere. The sintering temperature and time vary with the following factors

- Type of metal powder
- Comp[illegible] load used [illegible]
- S[illegible] finish[illegible]

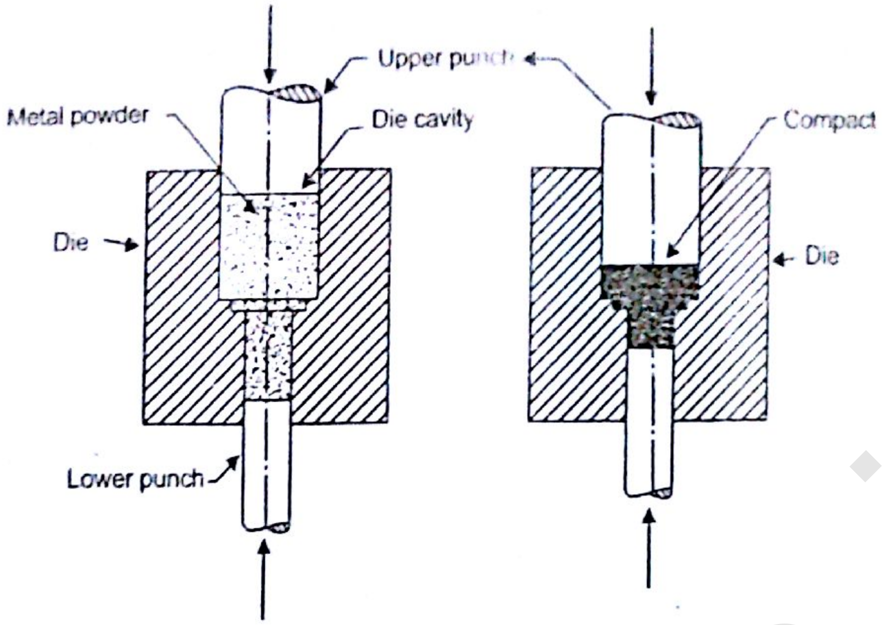

Fig. 19.1 Powder metallurgy die set-up

In the sintering furnace, the metal parts are gradually heated and soaked at the required temperature. During this gradually heating process, powders bond themselves into coherent bodies. Sintering results in strengthening of fragile green compacts produced by the pressing operation. It also increases electrical conductivity, density and ductility of the powder metal parts. Fig. 19.2 presents a flow chart showing the relationship among the various powder metallurgy processes.

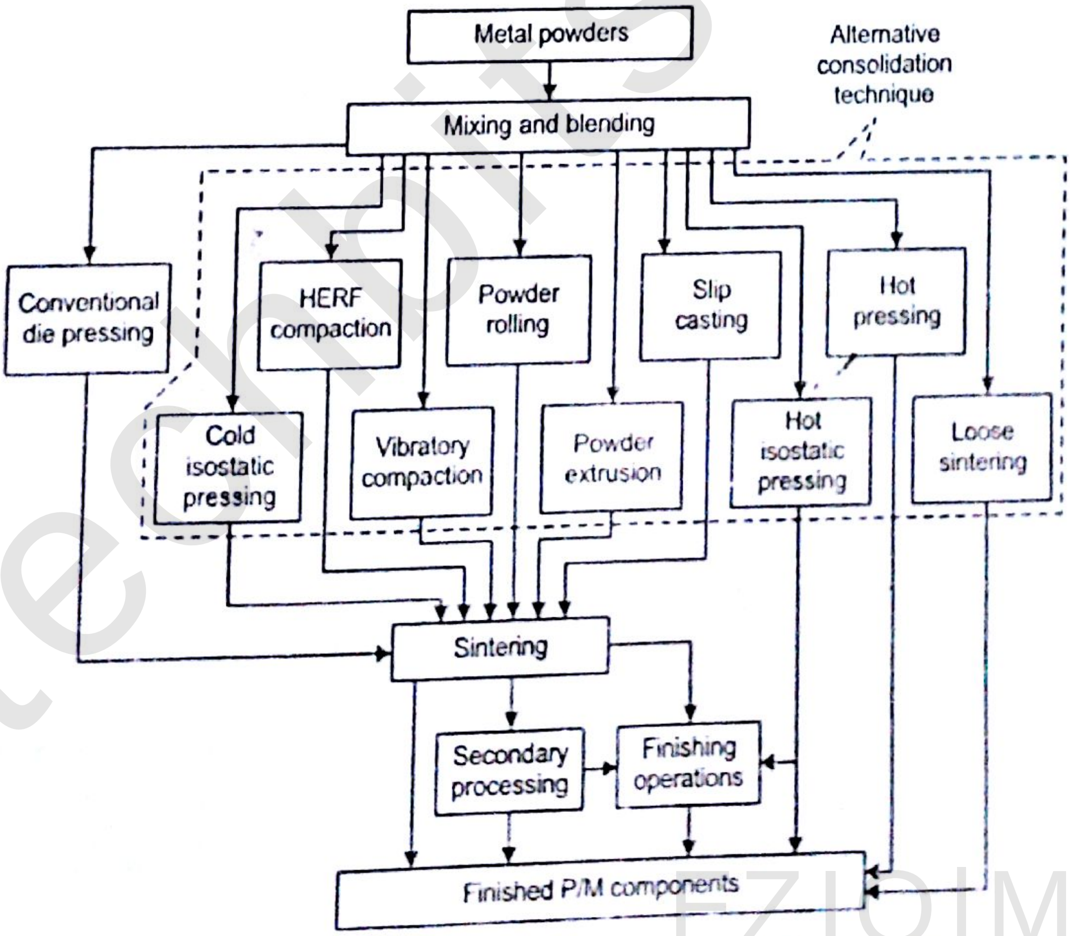

Fig. 19.2 Relationship among the various powder metallurgy processes

19.2.6 Secondary Operations

Some powder metal parts may be used in the sintered condition while in some other cases additional secondary operations have to be performed to get the desired surface finish, close tolerance etc.. The secondary operations may be of following types-

1. Annealing.
2. Repressing for greater density or closer dimensional control.
3. Machining.
4. Polishing.
5. Rolling, forging or drawing.
6. Surface treatments to protect against corrosion.
7. In some cases infiltration is needed to provide increased strength, hardness, density obtainable by straight sintering.
8. The procedures for plating powdered metal parts are quite different from those used for wrought or cast metal parts. In powdered metal parts, porosity must be eliminated before the part is plated. After the porosity has been eliminated regular plating procedures can be used.

19.3 ADVANTAGES OF POWDER METALLURGY

1. The processes of powder metallurgy are quite and clean.
2. Articles of any intricate or complicated shape can be manufactured.
3. The dimensional accuracy and surface finish obtainable are much better for many applications and hence machining can be eliminated.
4. Unlike casting, press forming machining, no material is being wasted as scrap and the process makes utilizes full raw material.
5. Hard to process materials such as diamond can be converted into usable components and tools through this process.
6. High production rates can be easily achieved.
7. The phase diagram constraints, which do not allow an alloy formation between mutually insoluble constituents in liquid state, such as in case of copper and lead are removed in this process and mixtures of such metal powders can be easily processed and shaped through this process.
8. This process facilitates production of many such parts, which cannot be produced through other methods, such as sintered carbides and self-lubricating bearings.
9. The process enables an effective control over several properties such as purity, density, porosity, particle size, etc., in the parts produced through this process.
10. The components produced by this process are highly pure and bears longer life.
11. It enables production of parts from such alloys, which possess poor cast ability.
12. It is possible to ensure uniformity of composition, since exact proportions of constituent metal powders can be used
13. The preparation and processing of powdered iron and nonferrous parts made in this way exhibit good properties which cannot be produced in any other way.

14. Simple shaped parts can be made to size with 100 micron accuracy without wast

15. Porous parts can be produced that could not be made in any other way.

16. Parts with wide variations in compositions and materials can be produced.

17. Structure and properties can be controlled more closely than in other fabricating processes.

18. Highly qualified or skilled labor is not required. in powder metallurgy process.

19. Super-hard cutting tool bits, which are impossible to produce by other manufacturing processes, can be easily manufactured using this process.

20. Components shapes obtained possess excellent reproducibility.

21. Control of grain size, relatively much uniform structure and defect such voids and blowholes in structure can be eliminated.

19.4 LIMITATIONS OF POWDER METALLURGY

1. Powder metallurgy process is not economical for small-scale production.
2. The cost of tool and die of powder metallurgical set-up is relatively high.
3. The size of products as compared to casting is limited because of the requirement of large presses and expensive tools which would be required for compacting.
4. Metal powders are expensive and in some cases difficult to store without some deterioration.
5. Intricate or complex shapes produced by casting cannot be made by powder metallurgy because metallic powders lack the ability to flow to the extent of molten metals.
6. Articles made by powder metallurgy in most cases do not have as good physical properties as wrought or cast parts.
7. It may be difficult sometimes to obtain particular alloy powders.
8. Parts pressed from the top tend to be less dense at the bottom.
9. A completely deep structure cannot be produced through this process.
10. The process is not found economical for small-scale production.
11. It is not easy to convert brass, bronze and a numbers of steels into powdered form.

19.5 APPLICATIONS OF POWDER METALLURGY

The powder metallurgy process has provided a practical solution to the problem of producing refractory metals, which have now become the basis of making heat-resistant materials and cutting tools of extreme hardness. Another very important and useful item of the products made from powdered metals is porous self-lubricating bearing. In short, modern technology is inconceivable without powder metallurgy products, the various fields of application of which expand every year. Some of the powder metal products are given as under.

1. Porous products such as bearings and filters.
2. Tungsten carbide, gauges, wire drawing dies, wire-guides, stamping and blanking tools, stones, hammers, rock drilling bits, etc

3. Various machine parts are produced from tungsten powder. Highly heat and wear resistant cutting tools from tungsten carbide powders with titanium carbide, powders are used for and die manufacturing.
4. Refractory parts such as 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, electric contact points etc.
5. Products of complex shapes that require considerable machining when made by other processes namely toothed components such as gears.
6. Components used in automotive part assembly such as electrical contacts, crankshaft drive or camshaft sprocket, piston rings and rocker shaft brackets, door, mechanisms, connecting rods and brake linings, clutch facings, welding rods, etc.
7. Products where the combined properties of two metals or metals and non-metals are desired such as non-porous bearings, electric motor brushes, etc.
8. Porous metal bearings made which are later impregnated with lubricants. Copper and graphite powders are used for manufacturing automobile parts and brushes.
9. The combinations of metals and ceramics, which are bonded by similar process as metal powders, are called cermets. They combine in them useful properties of high refractoriness of ceramics and toughness of metals. They are produced in two forms namely oxides based and carbide based.

QUESTIONS

1. What do you under stand by powder metallurgy? What are the main stages of powder metallurgy process?
2. What important considerations should be made in designing the powder metallurgy products?
3. Explain the objectives of powder compaction and list important products of powder metallurgy.
4. Describe briefly the methods by which powders suitable for powder metallurgy can be produced. Also enumerate the main characteristics of metal powder.
5. Describe the atomization process of making powder in detail.
6. What are the effects of sintering on the powder compact produced by pressing?
7. Describe the process of blending, compacting and sintering in detail.
8. What are the effects of sintering on the powder compact produced by pressing?
9. Name the products of powder metallurgy.
10. List the advantages, dis-advantages and applications of powder metallurgy process.
11. It is necessary to use lubricants in the press compaction of powders? Explain.
12. What are 'cermets'? Give a few examples of useful applications.
13. State briefly the process of making a powder metallurgy product having improved properties.
14. What are cemented carbides? How are they processed?