Module 3

Selection of Manufacturing Processes
Lecture 6
Design for Powder Metallurgy
Instructional objectives

By the end of this lecture, the student will learn the basic principles of Powder Metallurgy processes and the critical issues to be considered during design of parts to be manufactured using Powder Metallurgy processes.

Principles of Powder Metallurgy Process

**Powder metallurgy** is the process of *blending* fine powdered materials, *compacting* the same into a desired shape or form inside a mould followed by heating of the compacted powder in a controlled atmosphere, referred to as *sintering* to facilitate the formation of bonding of the powder particles to form the final part. Thus, the powder metallurgy process generally consists of four basic steps, as indicated in Figure 3.6.1: (1) powder manufacture, (2) blending of powders, (3) compacting of powders in a mould or die, and (4) sintering. *Compacting* is generally performed at room temperature and at high pressure. *Sintering* is usually done at elevated temperature and at atmospheric pressure. Often, *compacting* and *sintering* are combined. Optional secondary processing often follows to obtain special properties or enhanced dimensional precision. *Powder Metallurgy* route is very suitable for parts that are required to be manufactured from a single or multiple materials (in powder form) with very high strength and melting temperature that pose challenge for the application of casting or deformation processes.
Figure 3.6.1 Basic steps in Powder Metallurgy process [3]
Powder Manufacture

The manufacturing of the material powder is the first step in powder metallurgy processing route that involves making, characterising, and treating the powder which have a strong influence on the quality of the end product. Different techniques of powder making are:

**Atomising Process**

In this process the molten metal is forced through an orifice into a stream of high velocity air, steam or inert gas [Figure 3.6.2]. This causes rapid cooling and disintegration into very fine powder particles and the use of this process is limited to metals with relatively low melting point.

**Gaseous Reduction**

This process consists of grinding the metallic oxides to a fine state and subsequently, reducing it by hydrogen or carbon monoxide. This method is employed for metals such as iron, tungsten, copper, etc.

**Electrolysis Process**

In this process the conditions of electrode position are controlled in such a way that a soft spongy deposit is formed, which is subsequently pulverised to form the metallic powder. The particle size can be varied over a wide range by varying the electrolyte compositions and the electrical parameters.

**Carbonyl Process**

This process is based upon the fact that a number of metals can react with carbon monoxide to form carbonyls such as iron carbonyl can be made by passing carbon monoxide over heated iron at 50 – 200 bar pressure. The resulting carbonyl is then decomposed by heating it to a temperature of 200 – 300°C yielding powder of high purity, however, at higher cost.

**Stamp and Ball mills**

These are mechanical methods which produce a relatively coarse powder. Ball mill is employed for brittle materials whereas stamps are used for ductile material.

**Granulation Process**

This process consists in the formation of an oxide film in individual particles when a bath of metal is stirred in contact with air.

**Mechanical Alloying**

In this method, powders of two or more pure metals are mixed in a ball mill. Under the impact of the hard balls, the powders are repeatedly fractured and welded together by forming alloy under diffusion.
Other methods

The other less commonly used methods to form metallic powder are by (i) precipitation from a chemical solution, (ii) production of fine metals by machining, and (iii) vapour condensation.

![Diagram of metal-powder production by atomization]

Figure 3.6.2 Methods of metal-powder production by atomization; (a) melt atomization; (b) atomization with a rotating consumable electrode. [3]

Powder Blending

A single powder may not fulfil all the requisite properties and hence, powders of different materials with wide range of mechanical properties are blended to form a final part. Blending is carried out for several purposes as follows.

1. *Blending* imparts uniformity in the shapes of the powder particles,
2. *Blending* facilitates mixing of different powder particles to impart wide ranging physical and mechanical properties,
3. *Lubricants* can be added during the blending process to improve the flow characteristics of the powder particles reducing friction between particles and dies,
4. *Binders* can be added to the mixture of the powder particles to enhance the green strength during the powder compaction process.
**Powder Compaction**

The principle goal of the *compaction process* is to apply pressurize and bond the particles to form a cohesion among the powder particles. This is usually termed as the *green strength*. The *compaction* exercise imparts the following effects.

1. Reduces voids between the power particles and enhance the density of the consolidated powder,
2. Produces adhesion and bonding of the powder particles to improve green strength in the consolidated powder particles,
3. Facilitates plastic deformation of the powder particles to conform to the final desired shape of the part,
4. Enhances the contact area among the powder particles and facilitates the subsequent sintering process.

Compaction is carried out by pouring a measured amount of metallic powder into the die cavity and applying pressure by means of one or more plungers. To improve uniformity of pressure and reduce porosity in the compacted part, compressive forces from both the top and the bottom sides are necessary. The requisite compacting pressure depends on the specific characteristics and initial shape of the particles, the method of blending and the application of the lubricants. Extremely hard powders are slower and more difficult to press. Some organic binder is usually required to hold the hard particles together after pressing until the sintering process is performed. *Figure 3.6.3* depicts a schematic view of the powder compaction process to manufacture a typical bushing.

![Figure 3.6.3](image)

*Figure 3.6.3*  Compaction of metal powder to form a bushing [3]
Sintering

Sintering refers to the heating of the compacted powder perform to a specific temperature (below the melting temperature of the principle powder particles while well above the temperature that would allow diffusion between the neighbouring particles). Sintering facilitates the bonding action between the individual powder particles and increase in the strength of the final part. The heating process must be carried out in a controlled, inert or reducing atmosphere or in vacuum for very critical parts to prevent oxidation. Prior to the sintering process, the compacted powder perform is brittle and confirm to very low green strength. The nature and strength of the bond between the particles depends on the mechanism of diffusion and plastic flow of the powder particles, and evaporation of volatile material from the in the compacted preform. Bonding among the powder particles takes places in three ways: (1) melting of minor constituents in the powder particles, (2) diffusion between the powder particles, and (3) mechanical bonding. The time, temperature and the furnace atmosphere are the three critical factors that control the sintering process. Sintering process enhances the density of the final part by filling up the incipient holes and increasing the area of contact among the powder particles in the compact perform. 

Figures 3.6.4 and 3.6.5 schematically show the sintering process by solid-state diffusion process and liquid-phase transport of powder particles.

Finishing Operation

After sintering, some finishing operations such as re-pressing (to impart dimensional accuracy) and machining are carried out to further improve the quality of the final part. Parts made through the powder metallurgy based processes are also subjected to other finishing operations such as heat treatment, machining and finishing depending on the requirements.
Several design rules must be considered to make parts efficiently and economically by the powder metallurgy process:

1. The design must be such that the part can be ejected from the mould or die. Parts with straight wall are preferred. No draft should be required for the ejection of a part from a lubricated die [as shown in Figure 3.6.6(a)].

2. In designing the part, consideration should be given to the need for the powder particles to flow properly into all parts of the mould or die. Therefore, thin walls, narrow splines, or sharp corner should be avoided (should be thicker than 0.762 mm).

3. The shape of the part should permit the construction of strong tooling. Dies and punches should have no sharp edges. Reasonable clearance must be provided between the top and the bottom dies during pressing.
4. Since pressure is not transmitted uniformly through a deep bed of powder, the length of the part should not exceed about two and half times of the diameter.

5. Very close tolerance in the direction of compression should be avoided.

6. Shape of the parts should be kept as simple as possible and should contain with few levels and axial variation. Holes should not be designed in the direction of pressing \([as \textit{illustrated in Figure 3.6.6}(b)]\)

7. Provide sufficiently wide dimensional tolerance whenever possible. Wide tolerance means that the part can be made more economically with a longer tool life.

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**Figure 3.6.6**  Examples of suggested design changes in powder metallurgy parts
8. In designing flat section of high density, enough section thickness should be provided otherwise the punch may break under pressure.

9. Parts made through powder metallurgy may be bonded by assembling in the green condition and then sintering together to form a bond assembly.

10. As far as possible, abrupt changes in the section thickness should be avoided. [as illustrate in Figure 3.6.6(c)]
**Exercise**

Fill in the blanks:

1. ______ process produces a relatively coarse powder with a high percentage of oxide.
2. During sintering, ordinarily, the density of compact is ______ and results in ______.
3. In ______ process the molten metal is forced through an orifice into a stream of high velocity air, steam or inert gas.

Ans. 1. Granulation 2. increased, shrinkage 3. atomising

**References**