University of Basrah
College of Engineering
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Chapter Seven – Powder Metallurgy

Introduction

- **Powder metallurgy** (PM) is a metal processing technology in which parts are produced from metallic powders.
- In the usual PM production sequence, the powders are compressed into the desired shape and then heated to cause bonding of the particles into a hard, rigid mass.
- Compression, called ***pressing***, is accomplished in a press-type machine using tools designed specifically for the part to be manufactured.
- The tooling, which typically consists of a die and one or more punches, can be expensive, and PM is therefore most appropriate for medium and high production.
- The heating treatment, called ***sintering***, is performed at a temperature below the melting point of the metal.
- ***Considerations that make powder metallurgy an important commercial technology include:***

➢ PM parts can be mass produced to ***net shape*** or ***near net shape***, eliminating or reducing the need for subsequent processing.

➢ The PM process itself involves very little waste of material; about 97% of the starting powders are converted to product.

➢ Owing to the nature of the starting material in PM, parts having a specified level of porosity can be made. This feature lends itself to the production of porous metal parts, such as filters, and oil-impregnated bearings and gears.

➢ Certain metals that are difficult to fabricate by other methods can be shaped by powder metallurgy. Tungsten is an example; tungsten filaments used in incandescent lamp bulbs are made using PM technology.

➢ Certain metal alloy combinations and cermets can be formed by PM that cannot be produced by other methods.

➢ PM compares favorably with most casting processes in terms of dimensional control of the product. Tolerances of ±0.13 mm (±0.005 in) are held routinely.

➢ PM production methods can be automated for economical production.

- **Limitations and disadvantages associated with PM processing:**

(1) tooling and equipment costs are high,
(2) metallic powders are expensive,
(3) there are difficulties with storing and handling metal powders (such as degradation of the metal over time, and fire hazards with particular metals).
(4) there are limitations on part geometry because metal powders do not readily flow laterally in the die during pressing, and allowances must be provided for ejection of the part from the die after pressing.
(5) variations in material density throughout the part may be a problem in PM, especially for complex part geometries. Although parts as large as 22 kg can be produced, most PM components are less than 2.2 kg.

- A collection of typical PM parts is shown in Figure (7-1).

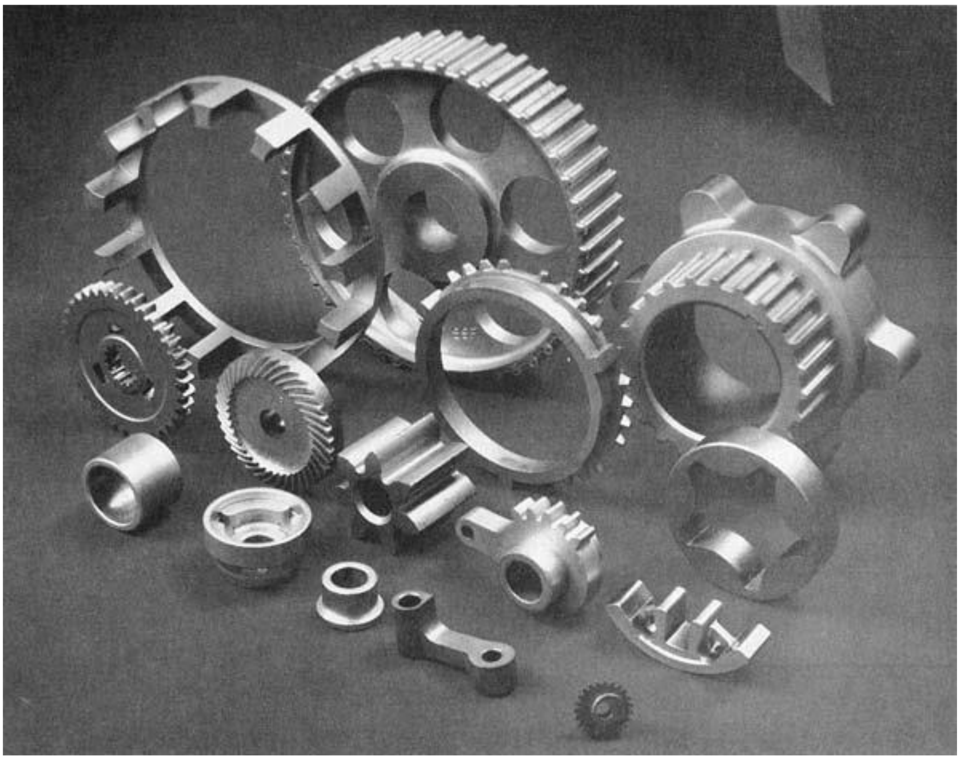

Figure (7-1) A collection of powder metallurgy parts.

- **Metals of PM:**
- The largest tonnage of metals for PM are alloys of iron, steel, and aluminum.
- Other PM metals include copper, nickel, and refractory metals such as molybdenum and tungsten.
- Metallic carbides such as tungsten carbide are often included within the scope of powder metallurgy.

Characterization of Engineering Powders

A ***powder*** can be defined as a finely divided particulate solid.

Geometric Features:

The geometry of the individual powders can be defined by the following attributes:

(1) Particle Size and Distribution:

- Particle size refers to the dimensions of the individual powders.
- If the particle shape is spherical, a single dimension is adequate.
- For other shapes, two or more dimensions are needed.
- There are various methods available to obtain particle size data.
- The most common method uses screens of different mesh sizes.
- The term ***mesh count*** is used to refer to the number of openings per linear inch of screen.
- Higher mesh count indicates smaller particle size.
- A mesh count of 200 means there are 200 openings per linear inch.
- Because the mesh is square, the count is the same in both directions, and the total number of openings per in^2 is $200^2 = 40{,}000$.
- Particles are sorted by passing them through a series of screens of progressively smaller mesh size.
- The powders are placed on a screen of a certain mesh count and vibrated so that particles small enough to fit through the openings pass through to the next screen below.
- The second screen empties into a third, and so forth, so that the particles are sorted according to size.
- A certain powder size might be called size 230 through 200, indicating that the powders have passed through the 200 mesh, but not 230.
- The procedure of separating the powders by size is called ***classification***.
- The openings in the screen are less than the reciprocal of the mesh count because of the thickness of the wire in the screen, as illustrated in Figure (7-2).
- Assuming that the limiting dimension of the particle is equal to the screen opening:

$$\boldsymbol{PS = \frac{K}{MC} - t_w}$$

Where:

PS: particle size, mm(in),

MC: mesh count, openings per liner inch,

t_w: wire thickness of screen mesh, mm(in),

K: a constant whose value=25.4 when size units are mm and *K*=1 when units are in.

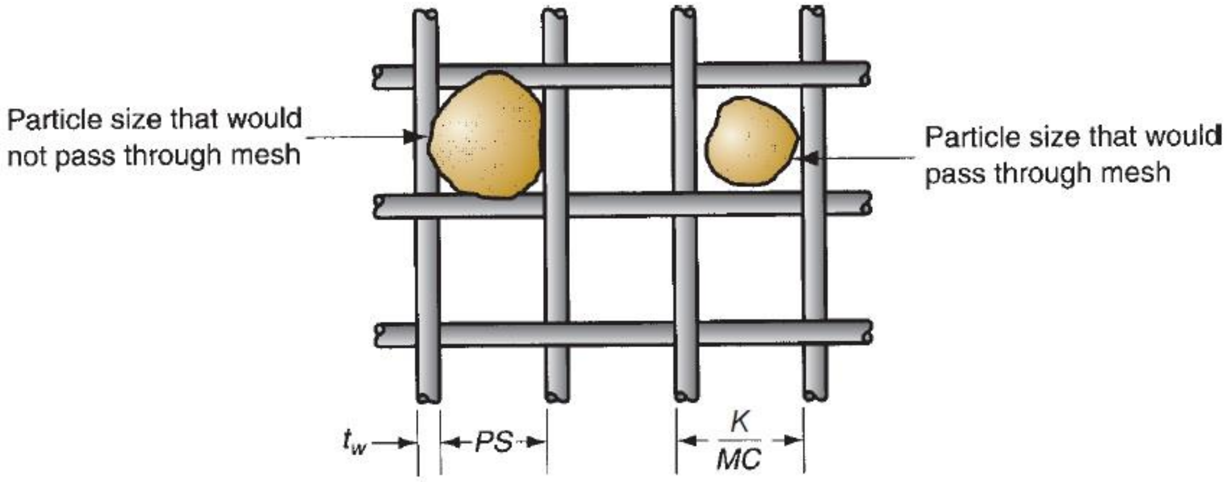

Figure (7-2) Screen mesh for sorting particle sizes.

Notes:

- Variations occur in the powder sizes sorted by screening owing to differences in particle shapes, the range of sizes between mesh count steps, and variations in screen openings within a given mesh count.
- Also, the screening method has a practical upper limit of MC=400 (approximately), because of the difficulty in making such fine screens and because of agglomeration of the small powders.
- Other methods to measure particle size include microscopy and X-ray techniques.
- Typical particle sizes used in conventional powder metallurgy (press and sinter) range between 25 and 300 *mm* (0.001 and 0.012 in).
- The low end of the range corresponds to a mesh count of about 500, which is too small to be measured by the mesh count method; and the high end of the range corresponds to a mesh count of around 50.

(2) Particle Shape and Internal Structure:

- Metal powder shapes can be cataloged into various types, several of which are illustrated in Figure (7-3).
- There will be a variation in the particle shapes in a collection of powders, just as the particle size will vary.
- A simple and useful measure of shape is the aspect ratio - the ratio of maximum dimension to minimum dimension for a given particle. The aspect ratio for a spherical particle is 1.0, but for an acicular grain the ratio might be 2 to 4.
- Any volume of loose powders will contain pores between the particles.
- These are called ***open pores*** because they are external to the individual particles.
- Open pores are spaces into which a fluid such as water, oil, or a molten metal, can penetrate.
- In addition, there are ***closed pores* -** internal voids in the structure of an individual particle.
- The existence of these internal pores is usually minimal, and their effect when they do exist is minor, but they can influence density measurements.

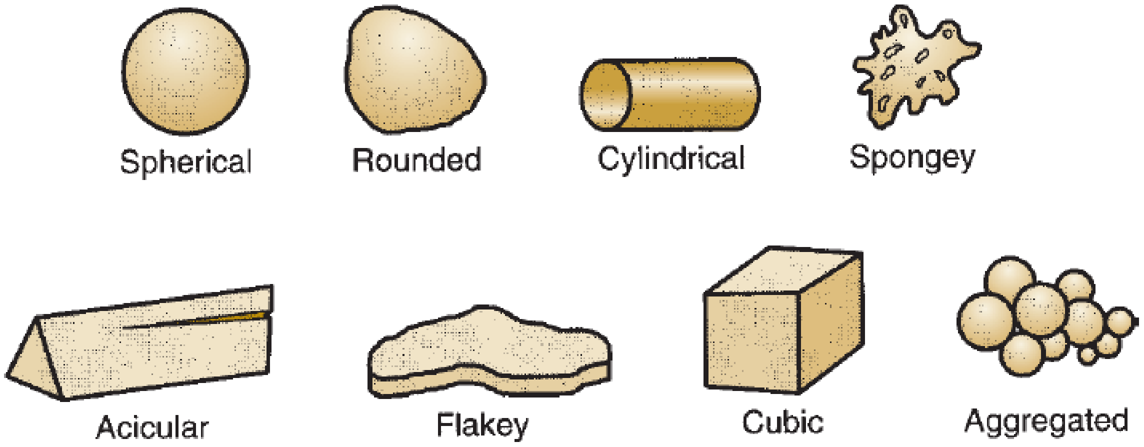

Figure (7-3) Several of the possible (ideal) particle shapes in powder metallurgy.

(3) Surface Area:

- Assuming that the particle shape is a perfect sphere, its area A and volume V are given by:

$$A = \pi D^2$$

$$V = \frac{\pi D^3}{6}$$

Where:

D: diameter of the spherical particle, mm (in).

- The area-to-volume ratio A/V for a sphere is then given by:

$$\frac{A}{V} = \frac{6}{D}$$

- In general, the area-to-volume ratio can be expressed for any particle shape - spherical or nonspherical- as follows:

$$\frac{A}{V} = \frac{K_s}{D} \quad or \quad K_s = \frac{AD}{V}$$

Where:

K_s: shape factor;

D: in the general case = the diameter of a sphere of equivalent volume as the nonspherical particle, mm (in).

K_s = 6.0 for a sphere. For particle shapes other than spherical, K_s > 6.

- The following can be inferred from these equations:

1. Smaller particle size and higher shape factor (K_s) mean higher surface area for the same total weight of metal powders. This means greater area for surface oxidation to occur.

2. Small powder size also leads to more agglomeration of the particles, which is a problem in automatic feeding of the powders. The reason for using smaller particle sizes is that they provide more uniform shrinkage and better mechanical properties in the final PM product.

Other Features:

Other features of engineering powders include the following parameters:

(1) Interparticle Friction and Flow Characteristics:

- Friction between particles affects the ability of a powder to flow readily and pack tightly.
- A common measure of interparticle friction is the ***angle of repose***, which is the angle formed by a pile of powders as they are poured from a narrow funnel, as in Figure (7-4).
- Larger angles indicate greater friction between particles.
- Smaller particle sizes generally show greater friction and steeper angles.
- Spherical shapes result in the lowest interparticle friction; as shape deviates more from spherical, friction between particles tends to increase.
- Flow characteristics are important in die filling and pressing.
- Automatic die filling depends on easy and consistent flow of the powders.
- In pressing, resistance to flow increases density variations in the compacted part; these density gradients are generally undesirable.
- A common measure of flow is the time required for a certain amount of powder (by weight) to flow through a standard-sized funnel.
- Smaller flow times indicate easier flow and lower interparticle friction.
- To reduce interparticle friction and facilitate flow during pressing, lubricants are often added to the powders in small amounts.

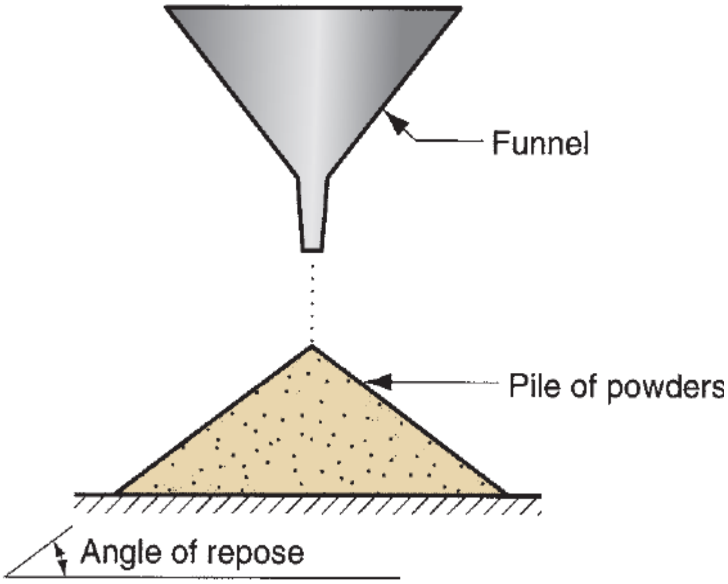

Figure (7-4) Interparticle friction as indicated by the angle of repose of a pile of powders poured from a narrow funnel. Larger angles indicate greater interparticle friction.

(2) Packing, Density, and Porosity:

- Packing characteristics depend on two density measures.
- First, ***true density*** is the density of the true volume of the material. This is the density when the powders are melted into a solid mass.
- Second, ***bulk density*** is the density of the powders in the loose state after pouring, which includes the effect of pores between particles. Because of the pores, bulk density is less than true density.
- The ***packing factor*** is the bulk density divided by the true density.
- Typical values for loose powders range between 0.5 and 0.7.
- The packing factor depends on particle shape and the distribution of particle sizes.
- If powders of various sizes are present, the smaller powders will fit into the interstices of the larger ones that would otherwise be taken up by air, thus resulting in a higher packing factor.
- Packing can also be increased by vibrating the powders, causing them to settle more tightly.
- Finally, the external pressure applied during compaction greatly increases packing of powders through rearrangement and deformation of the particles.
- Porosity represents an alternative way of considering the packing characteristics of a powder.
- ***Porosity*** is defined as the ratio of the volume of the pores (empty spaces) in the powder to the bulk volume.
- In principle:

Porosity + Packing factor = 1.0

- The issue is complicated by the possible existence of closed pores in some of the particles.
- If these internal pore volumes are included in the above porosity, then the equation is exact.

(3) Chemistry and Surface Films:

- Characterization of the powder would not be complete without an identification of its chemistry.
- Metallic powders are classified as either elemental, consisting of a pure metal, or pre-alloyed, wherein each particle is an alloy.
- Surface films are a problem in powder metallurgy because of the large area per unit weight of metal when dealing with powders.
- The possible films include oxides, silica, adsorbed organic materials, and moisture.
- Generally, these films must be removed before shape processing.

Production of Metallic Powders

- In general, producers of metallic powders are not the same companies as those that make PM parts.
- The powder producers are the suppliers; the plants that manufacture components out of powder metals are the customers.
- Virtually any metal can be made into powder form.
- There are three principal methods by which metallic powders are commercially produced, each of which involves energy input to increase the surface area of the metal.
- The methods are:

(1) atomization,
(2) chemical, and
(3) electrolytic.

(1) Atomization:

- This method involves the conversion of molten metal into a spray of droplets that solidify into powders.
- It is the most versatile and popular method for producing metal powders today, applicable to almost all metals, alloys as well as pure metals.
- There are multiple ways of creating the molten metal spray, several of which are illustrated in Figure (7-5).
- Two of the methods shown are based on ***gas atomization***, in which a high velocity gas stream (air or inert gas) is utilized to atomize the liquid metal.
- In Figure (7-5a), the gas flows through an expansion nozzle, siphoning molten metal from the melt below and spraying it into a container.
- The droplets solidify into powder form.
- In a closely related method shown in Figure (7-5b), molten metal flows by gravity through a nozzle and is immediately atomized by air jets.
- The resulting metal powders, which tend to be spherical, are collected in a chamber below.
- The approach shown in Figure (7-5c) is similar to (7-5b), except that a high-velocity water stream is used instead of air.
- This is known as ***water atomization*** and is the most common of the atomization methods, particularly suited to metals that melt below 1600°C.
- Cooling is more rapid, and the resulting powder shape is irregular rather than spherical.
- The **disadvantage** of using water is oxidation on the particle surface.
- A recent innovation involves the use of synthetic oil rather than water to reduce oxidation.
- In both air and water atomization processes, particle size is controlled largely by the velocity of the fluid stream; particle size is inversely related to velocity.
- Several methods are based on ***centrifugal atomization***.
- In one approach, the ***rotating disk method*** shown in Figure (7-5d), the liquid metal stream pours onto a rapidly rotating disk that sprays the metal in all directions to produce powders.

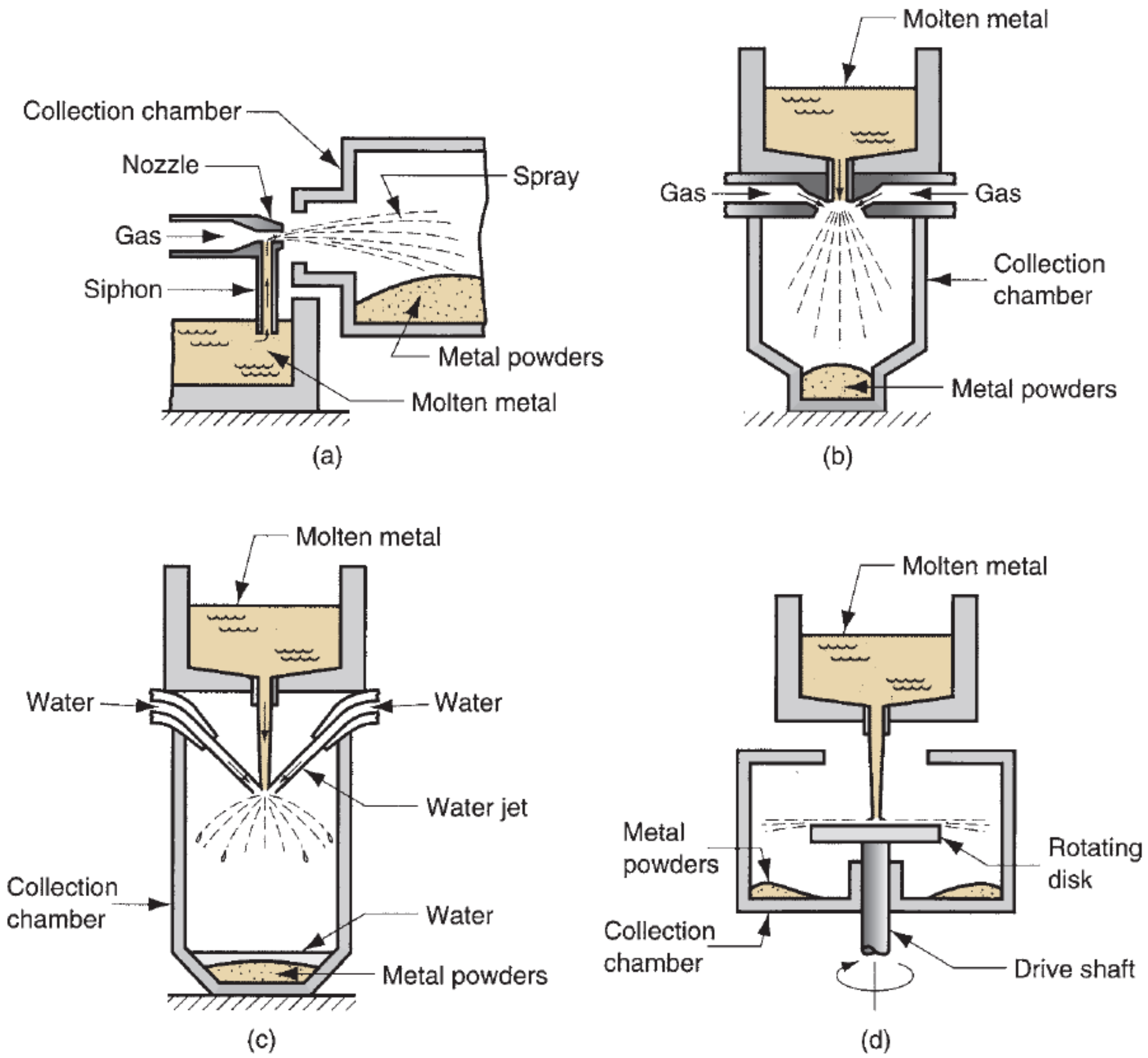

Figure (7-5) Several atomization methods for producing metallic powders: (a) and (b) two gas atomization methods; (c) water atomization; and (d) centrifugal atomization by the rotating disk method.

(2) Other Production Methods:

Chemical Reduction:

- includes a variety of chemical reactions by which metallic compounds are reduced to elemental metal powders.
- A common process involves liberation of metals from their oxides by use of reducing agents such as hydrogen or carbon monoxide.
- The reducing agent is made to combine with the oxygen in the compound to free the metallic element.
- This approach is used to produce powders of iron, tungsten, and copper.
- Another chemical process for iron powders involves the decomposition of iron pentacarbonyl ($Fe(Co)_5$) to produce spherical particles of high purity.

- Powders produced by this method are illustrated in the photomicrograph of Figure (7-6).

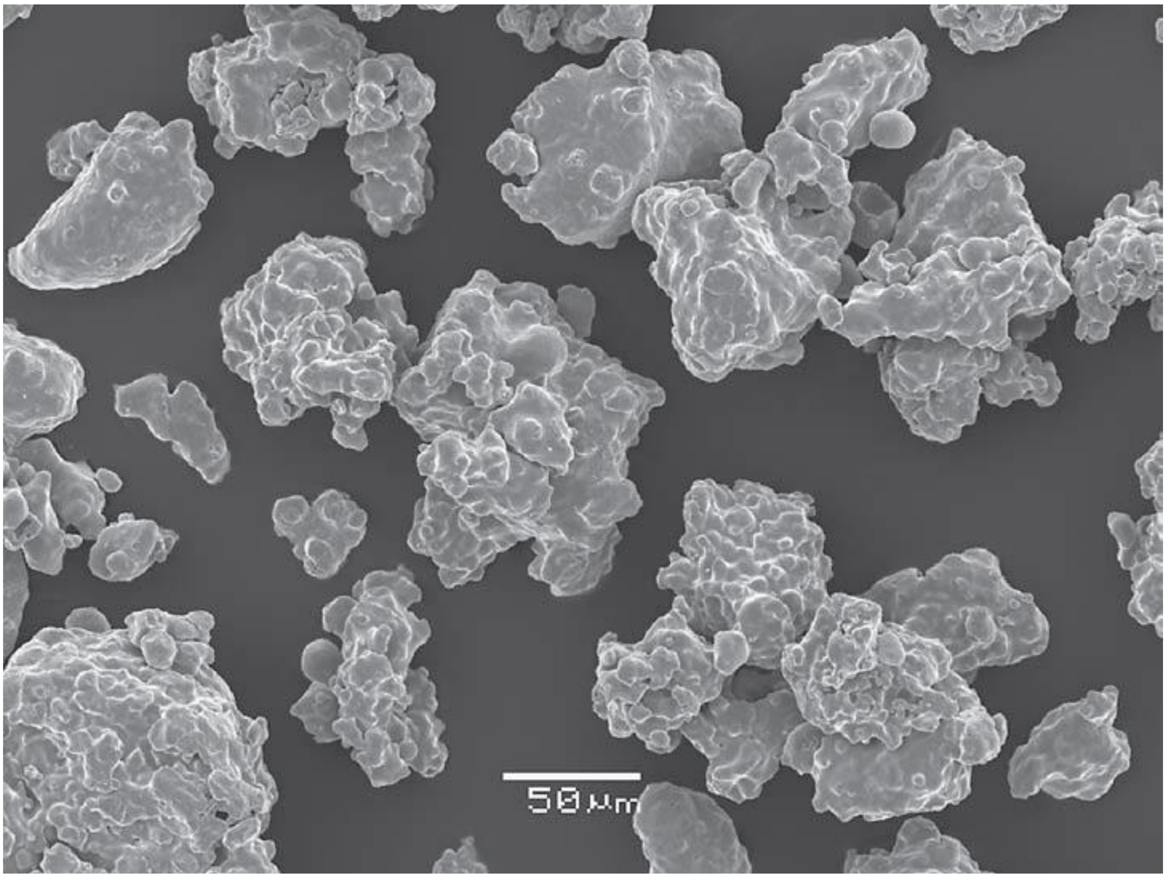

Figure (7-6) Iron powders produced by water atomization; particle sizes vary.

Precipitation Reaction:
- Precipitation of metallic elements from salts dissolved in water.
- Powders of copper, nickel, and cobalt can be produced by this approach.

Electrolysis:
- An electrolytic cell is set up in which the source of the desired metal is the anode.
- The anode is slowly dissolved under an applied voltage, transported through the electrolyte, and deposited on the cathode.
- The deposit is removed, washed, and dried to yield a metallic powder of very high purity.
- The technique is used for producing powders of beryllium, copper, iron, silver, tantalum, and titanium.