Powder metallurgy –

P/M is a highly developed method of manufacturing reliable ferrous and nonferrous parts. Made by mixing elemental or alloy powders and compacting the mixture in a die, the resultant shapes are then sintered or heated in a controlled-atmosphere furnace to bond the particles metallurgically. P/M typically uses more than 97% of the starting raw material in the finished part, making it an energy and materials-conserving process.

General steps in the P/M process

Powder metallurgy process consists from four major steps:

1- Production of the metallic powder
2- Mixing and preparation of powder.
3- Pressing of powder to the required shape.
4- Heating or sintering of the compacted powder at a relatively high temperature.

In addition to Post Processing as shown in figure 1 & 2.

![Simplified flowchart illustrating the sequence of operations in powder metallurgy process](image)

Fig. 1 Simplified flowchart illustrating the sequence of operations in powder metallurgy process
Characteristics of metal powder:

The processes of manufacturing P/M articles economically depends largely on the physical and chemical characteristics of the initial metal powders. The characteristics of metal powders, in turn, depend upon the method used in the producing these metal powders and consequently there is a wide range in their characteristics. A choice regarding the suitability of manufacturing techniques of metal powders can be made only after considering the required finished product for a specific job. Characteristics of metal powder include:

1-Particle shape: particles of powder can take the form of spherical, rounded, cylindrical, spongy, acicular, flaky, cubic and aggregated. As shown in figure 3.
Fig. 3 morphology of powder particles.

2- **Fineness**: refers to the particle size of powder, can be determined either by pouring the powder through a sieve or by microscopic testing. A standard sieves with mesh size varies between (100) and (325) are used to determine particle size and particle size distribution of powder in a certain range.

3- **Particle size distribution**: refers to amount of each particle size in the powder and have a great effect in determining flowability, apparent density and final porosity of product.

4- **Flow rate**: the ability of powder to be transferred or the rate at which the metal powder will flow under gravity from a container through an orifice both having the specific shape and finish.

5- **Chemical properties**: it usually reveals the impurities, amount of oxides and other elements that can be included in the powder.

6- **Compressibility**: a measure of the powder ability to deform under applied pressure. It is defined as the ratio of the volume of powder poured into the die to the volume of the pressed compact. Compressibility is affected by particle shape and particle size distribution. Green strength (strength of compacted product before sintering) depend on compressibility.
7- Apparent density: Apparent density of a metal powder, or the weight of a unit volume of loose powder expressed in grams per cubic centimeter, is one of the fundamental properties of a powder. This characteristic defines the actual volume occupied by a mass of loose powder, which directly affects processing parameters such as the design of compaction tooling and the magnitude of the press motions required to compact and densify loose powder.

8- Sintering ability: Sintering is the bonding process of powder particles by heating. The compacted product is heated to a high temperature approximately 70% to 90% of the melting point of the metal or alloy.

Control of The Powder Metallurgy Process

Control of the powder metallurgy process of a given product can be done by controlling the following factors:

1- Physical character of powders.
2- Chemical character of powders.
3- The pressure and time cycle during compression.
4- The temperature and time of sintering.
5- Effect of hot pressing.
6- Atmosphere control.
7- Lubricants.
8- Secondary operation.

Secondary Operations

A wide range of additional operations or treatments can be carried out on the parts after they have been sintered, these operation include:

1- Heat Treatment:
Sintered parts may be heat treated to increase strength and also hardness for improved wear resistance.
2-Oil Impregnation:-
The controlled porosity of P/M parts permits their impregnation with oil and resin. This operation is used to give the part self-lubricating properties.

3-Resin Impregnation :-
Used to improve machinability, seal parts gas or liquid tight, or prepare the surface for plating.

4-Infiltration:
The porosity of P/M parts permits their impregnation with a molten metal.

5-Machining :-
All normal machining operations can be carried out on sintered components.

6-Drilling:-
Usually used for holes not in the direction of the pressing.

7-Burr Removal:-
Barreling is used to remove burrs and sharp corners.

8-Corrosion Resistance:-
Various types of surface treatment are available to increase corrosion resistance to withstand the most demanding of environments.

9-Sizing:
Cold pressing to improve dimensional accuracy.

10-Coining:
Cold pressing to press details into surface.
Metal Powder Production

METAL POWDER PRODUCTION techniques are used to manufacture a wide spectrum of metal powders designed to meet the requirements of a large variety of applications. Powders of virtually all metals can be produced. Various powder production processes allow precise control of the chemical composition and the physical characteristics of powders and allow tailoring of specific attributes for targeted applications. Development and technical innovation in metal powder production processes are constantly pursued to meet the quality, cost, and performance requirements of existing and emerging applications.

Metal powders are produced by mechanical methods or chemical methods as shown in figure (1 & 2). The commonly used methods include water and gas atomization, milling, mechanical alloying, electrolysis, and chemical methods including reduction of oxides. Suitable methods for powder production depend on required production rates, powder properties, and the physical and chemical properties of the material. Chemical and electrolytic methods are useful for producing high-purity powders. Mechanical comminution (or milling) is the most widely used method of powder
Fig. 1 Mechanical methods of powder production.
Fig. 2 Chemical and electrochemical methods of powder production.
Methods of powders production

1-Physical Methods

1-1- Machining, Grinding and Filling:

Relatively coarse and bulky powders entirely free from fine particles are obtained by this method, and the powder particles are of irregular shape. This method has a limited application and employed as a raw material in the production of powder by other methods.

1-2-Milling:

Milling is used in the past to produce powders of the required grade of fineness and the powder particles are of irregular shape, employed as a raw material in the production of powder by other methods. It involves the application of impact force on the material being comminuted. The milling action is carried out by the use of wide variety of equipment such as ball mill, rod mill, impact mill, disk mill, eddy mill (produce a semi-spherical shape particles), vortex mill, etc. Figure 3 shows a schematic diagram of simple ball mill.

![Schematic diagram of simple ball mill](image)

Fig. 3 Schematic diagram of simple ball mill.
1-3- Shotting:

This method consists essentially in pouring a fine stream of molten metal through a vibrating screen into air or neutral atmosphere then it is fallen in water. In this way, molten metal stream is disintegrating into a large number of droplets which solidify as spherical particles during its free fall in air or into feathery particles if it solidify in water.

1-4- Condensation:

This method is used especially to produce a fine powder of Zinc performed by evaporating and condensing of the respective material in a vacuum cylinder filled with a low pressure of an inert gas, the particle fog condenses preferably on cooled substrates that are implemented into a container. The particles build up a spherical powder layer on the cooling wall and can be removed continuously by a scraper.

1-5- Atomization

ATOMIZATION is the dominant method for producing metal powders with low melting temperature from aluminum, brass, zinc, cadmium, lead. Atomization is simply the breakup of a liquid into fine droplets. Any material available in liquid form can be atomized. The general types of atomization processes include: Water, gas and centrifugal. As shown in figures 4, 5 & 6. An oxide film is formed in the case of air atomization and that film can be avoided by using an inert gas. Atomization can give a wide range of particle size (that make this method the most important method used for the production of powders) by controlling the following factors:

1- Diameter of the atomizing nozzle which the metal pass through.
2- Liquid metal superheat or viscosity.
3- Velocity, temperature and type of atomizing agent (air or inert gas).
Fig. 4 Water Atomization process

Fig. 5 Gas Atomization process

Fig. 6 Centrifugal Atomization process
2-Chemical Methods:

2-1-Precipitation:

The principal of precipitating a metal from its aqueous solution by the addition of a less noble metal which is higher in the electromotive series has been applied in numerous metallurgical processes. Ag powder is produced in quantity from its nitrate solution by adding copper or iron according to the reaction:

\[ AgNO_3 + Fe \rightarrow Ag + FeNO_3 \]

This method is used for producing metal powders of Ag, Sn, Pt and iron particles coated with copper. Precipitation is also synonymous with the term electrolytic precipitation to coat metals with a corrosion resistance film. The produced powder take the form of spongy mass which crashed into a hard and brittle powder.

2-2- Carbonyl Method:

Of the group of thermally decomposed powders, those produced by thermal decomposition of carbonyls are the most important. Both iron and nickel are produced by decomposition of the respective carbonyls. Carbonyls are obtained by passing carbon monoxide over spongy metal at specific temperatures and pressures according to the reaction:

\[ Fe + 5CO \rightarrow Fe(CO)_5 \]

This reaction can be controlled by changing temperature and pressure so the following reaction will take place:

\[ Fe + (CO)_5 \rightarrow Fe\text{ powder} + 5CO \]

The chemical purity of the powders can be very high (over 99.5%), with the principal impurities being carbon, nitrogen, and oxygen. Particle size can be controlled very closely. Iron carbonyl powder is usually
spherical in shape and very fine (less than 10 m) used for the production of magnet cores, while the nickel powder is usually quite irregular in shape, porous, and fine but the production process is of high cost.

2-3-Oxide reduction:

Reduction of compounds particularly oxides by the use of reducing agent in the form of either solid or gas according to the reaction:

\[ Fe_2O_3 + 2C \rightarrow 2CO_2 + 3Fe \]

This is a convenient, economical and extremely flexible method for controlling the properties of the product regarding size, shape and porosity over a wide range. The production of iron, copper, tungsten, and molybdenum powders from their respective oxides are well-established commercial processes. On a smaller scale, oxide reduction is also used for production of cobalt and nickel powders. This process yields extremely fine powders with irregularly shape particles, good compactibility (high green strength) and sinterability, low final porosity of such powders and relatively low cost.

2-4-Electrolytic method:

Metal powders can be produced by electro deposition from aqueous solutions and fused salts. This method is reversed adaption of electroplating. A hard and brittle mass is deposited which is subsequently ground to powder having a dendritic shape. This technique is mainly employed for commercial production of iron and copper powders.

3- Special Methods:

3-1-Prealloyed powders:

It is a common practice to use either blended elemental powder mixtures or prealloyed powders. In general, premixes are easy to compact
and effect less tool wear but they need longer sintering times than prealloyed powders. Recently great interest has aroused in the production of prealloyed steel powders; the addition of alloying elements being made to permit the production of a strong material. This technique is mainly employed for production of stainless steel and other alloys with high alloying element content that cannot be produced by mixing or blending of powders. Products of prealloyed powders have a remarkable properties like corrosion resistance, high tensile strength and resistance of high temperatures.

3-2-Precoated powders:

Metals can be coated with a film of a certain element by passing metal powder through an element carrier gas. In this method each powder particle can be coated homogenously and obtaining a powder having some properties of the coating material after sintering. This technique allow the use of cheap powder as a carrier of the effective coating material. This method produce a more homogeneous products after sintering than that produced from mixed or blended powders.