UNIT-4

Chapter 13

POWDER METALLURGY

13.1 INTRODUCTION

Powder metallurgy is the process in which fine powdered materials are pressed into a die of the desired shape. The powder particles interlock to form a *green compact*. This compact is removed from the die and sintered at high temperature in a controlled (neutral or reducing) atmosphere to establish desired properties in a component.

The parts which cannot be made by other methods can be processed by powder metallurgy techniques. Powder metallurgy is particularly suitable for metals having low ductility and high melting point. This process is also employed where the desired properties and characteristics would be difficult to obtain by any other methods.

At present powder metallurgy techniques are well established, and it is occupied an important place in the filed of metal processing.

The sequence of operations involved in powder metallurgy, and its applications in various fields are discussed in this chapter.

13.2 CHARACTERISTICS OF METAL POWDERS

A powder can be defined as a finely decided particulate solid. The properties of the product made by powder metallurgy depend on the characteristics of metal powders. The main physical and process characteristics are shape, fineness, size distribution, flowability, compressibility, apparent density, purity, green strength and sintering ability.

Shape : The shape of powder particles is influenced by the way it is made. The shape may be spherical (atomisation), dentritic (electrolysis), flat or angular (mechanical crushing). The particle shape influences the flow characteristics of powders. Spherical shaped particles have excellent sintering qualities and result in uniform physical characteristics in the product. However, irregular shaped particles are preferred for practical moulding.

The shape of a particle can be estimated by *aspect ratio* which is defined as the ratio of maximum dimension to minimum dimension for a given particle. The aspect ratio for a spherical particle is 1.0.

Particle size (fineness) and size distribution : Particle size and size distribution are important factors which control the porosity, compressibility and the amount of shrinkage. Proper particle size and size distribution are determined by passing the powder through a standard sieves ranging from 45 to 150 μm mesh. In general, fine powder is preferred because of smaller particle size and large contact area, which usually results in better physical properties after sintering.

Flowability : It is the ability of the powders to flow readily and confirm to the mould cavity. It also determines the flow rate of metal powder through an orifice. This helps to determine the possible production rate.

Compressibility : Compressibility is defined as the volume of initial powder (powder loosely filled in cavity) to the volume of compact part. It depends on particle shape and size distribution. Compressibility also determines the green strength.

High compressibility is desirable in all powders, since it allows more efficient use of the compacting equipment with corresponding reduction in *pressing force* and die wear.

Apparent density : The apparent density is defined as the weight of a unit volume of powder when packed loosely. It depends on particle size. The apparent density of the powder strongly influence the strength of compact prior to sintering. It helps to fed the same amount of powder into the die for each cycle.

Green strength : It refers to strength of a compact part prior to sintering. It depends on compressibility and helps to handle the parts during the mass production.

It can be increased by using fine particles, powders with irregular shapes and rough surfaces, and decreasing the surface contamination of the particles.

Purity : The purity of metal powders is an important consideration. The impurities in the powder affect sintering and compacting operations, and causes wear on the die parts. Oxides and gaseous impurities can be removed from the parts during sintering by the use of reducing atmosphere.

Sintering ability : It is the ability which promotes bonding of particles by the application of heat. Bond strength is depend upon the area of contact, and is also influenced by the clean surfaces of particles. Oxide layers present difficulties in bonding and thus the metal powders should be free from oxide layer and other dirt on the surfaces.

13.3 PROCESS DESCRIPTION

The manufacture of parts by powder metallurgy process involves the following steps.

1. Manufacture of metal powders with a suitable size and purity.
2. Blending and compacting the metal powders in a suitable die cavity to provide green strength.
3. Sintering the green compact part at high temperature to provide bonding strength, and
4. Secondary processes such as finishing, sizing and heat treatment.

Simplified flow chart of powder metallurgy process is illustrated in Fig. 13.1.

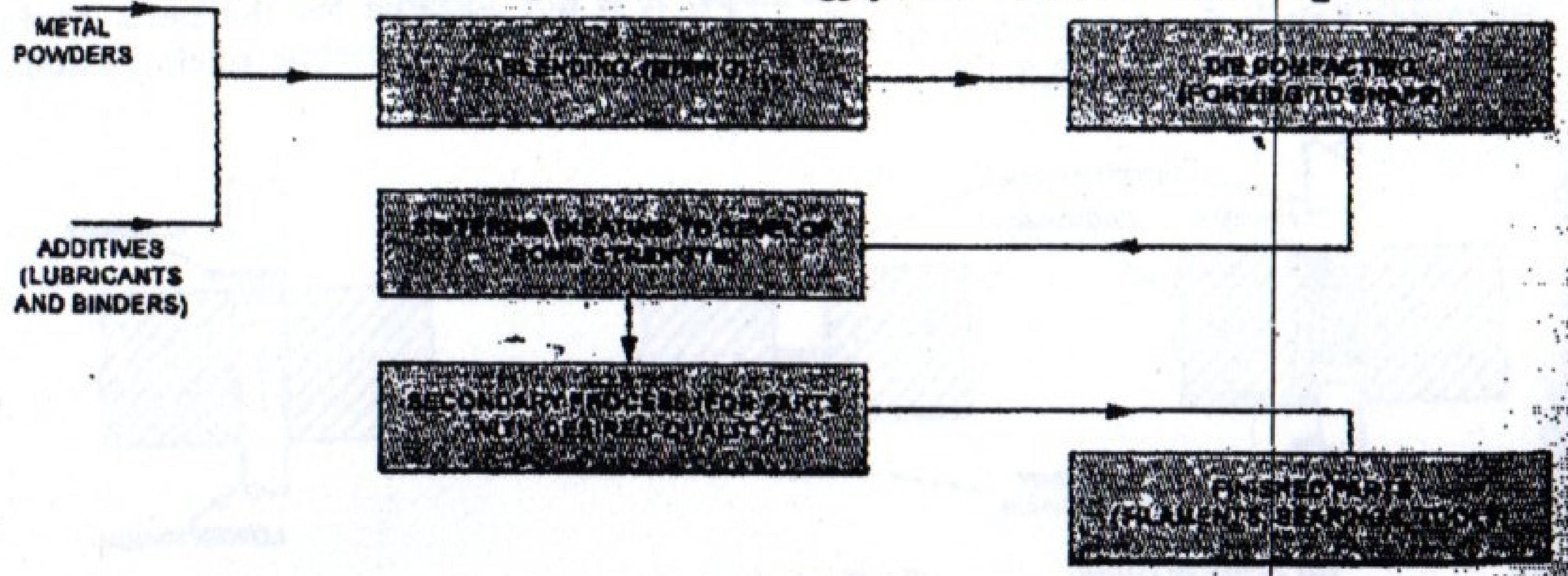


Fig. 13.1

Products made by powder metallurgy may contain metal and non-metallic constituents to improve the bonding qualities and properties in the final product. Cobalt is necessary in the bonding of tungsten carbide particles whereas graphite is added to improve lubricating qualities of the finished bearings.

13.4 PRODUCTION OF METAL POWDERS

Different techniques are adopted for producing metal powders depending upon the *nature* of metals and *desired properties* in the product. The following methods are most commonly used for production of metal powders.

1. Mechanical pulverisation
2. Shotting
3. Atomisation
4. Electrolytic deposition
5. Chemical methods
   (a) Carbonyle method (b) Reduction method

1. *Mechanical Pulverisation :*

Metal powders can be made by machining, milling or grinding. *Machining* produces coarse particles (flack form) and is employed for production magnesium powders.

Milling or *grinding* is suitable for brittle materials and employs ball mill and crushers. This method involves the application of impact forces on the materials to disintegrate and convert them into powders. This method is very simple, and the powders are obtained in the controlled size. However, the quality of powders is comparatively poor.

2. *Shooting :*

In this method the molten metal at a temperature greater than the melting point is made to pass through a sieve or small orifice into the water. Solidification in the water produces spherical particles of large size. This method is commonly used for metals having low melting point.

3. *Atomisation :*

In this method molten metal is dropped down through an orifice. A stream of compressed air, steam or inert gas is directed to it to break up into fine particles. These particles are so small that they solidify immediately. The size of the particles can be controlled by varying the size of orifice, temperature of molten metal and velocity of stream of air or gas.

Atomisation is widely used for producing lead, aluminium, zinc, tin, copper and iron powders. In this method high purity powders can be produced, and their characteristics can be easily controlled.

4. *Electrolytic deposition :*

Metal powders can be conveniently produced by electrolytic deposition. This method is adopted for producing copper, iron, tin, nickel, cadmium and lead powders. These powders have crystalline and dentritic structure with a low apparent density and flow rate.

Electrolytic deposition consists of depositing metal on cathode plate by conventional electrolysis process. The cathode plates are removed and the deposited powder is scrapped off. The powder is washed, dried, screened and over sized particles are milled or ground for fineness. The powder is further subjected to annealing to remove the work hardening effect. The powders produced will be pure and resist the oxidation. However, the cost of manufacture is high.

5. *Carbonyle method :*

This method is mainly used to produce iron powders. In this method iron reacts with carbon monoxide to form iron carbonyle, Fe $(CO)_5$. But iron carbonyle is unstable, and at suitable temperature and pressure it decomposes as per the reaction,

$$Fe\,(CO)_5 \rightarrow Fe + 5\,CO$$

The iron produced will be in a fine powder form with spherical shape. Nickel powder can be also produced by this method, but it is very expensive.

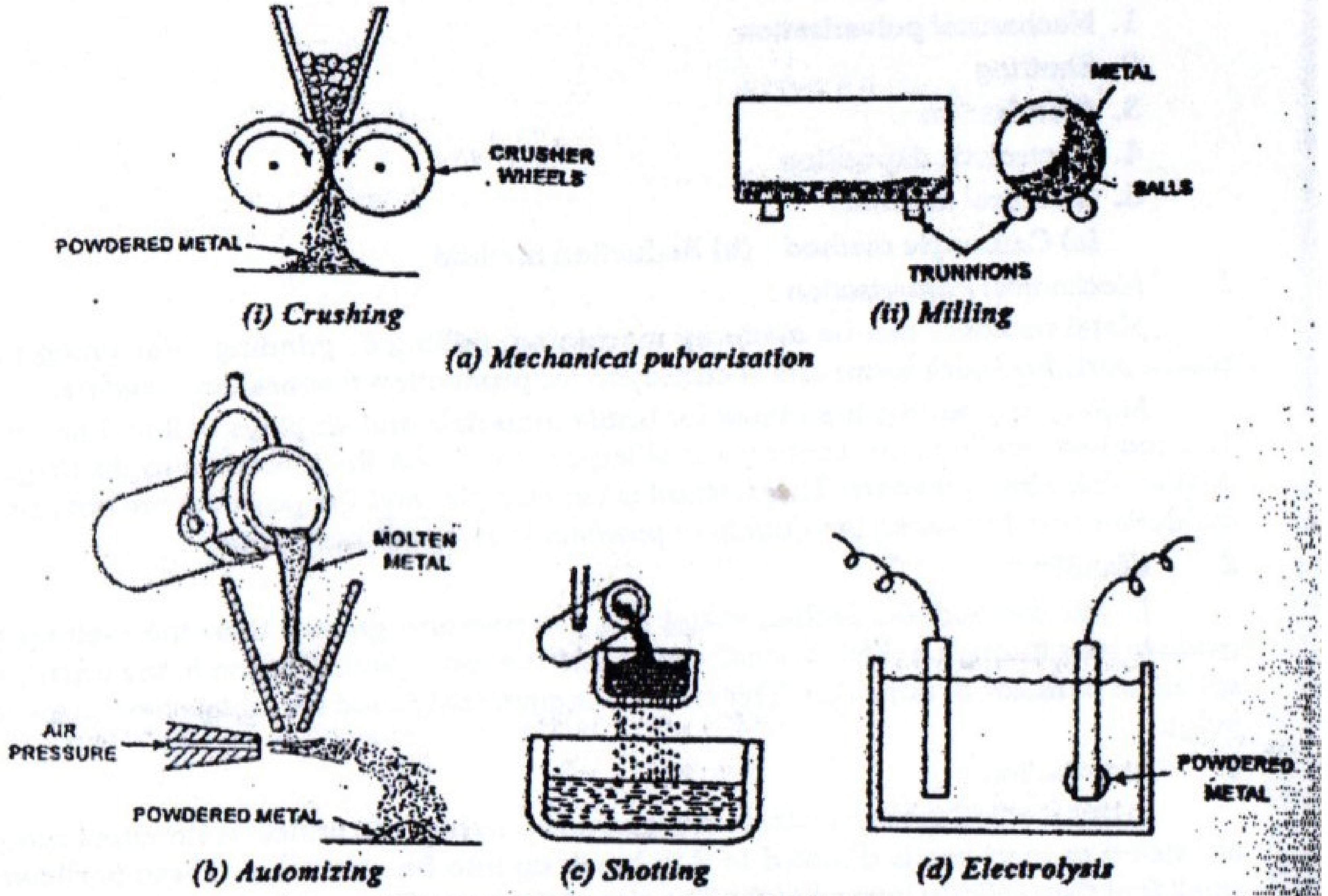


Fig. 13.2 *Production of Metal Powders*

6. *Chemical reduction :*

This method is used for producing iron, copper, tungsten, molybdenum, nickel and cobalt powders. The process consists of reducing the metal oxides by means of carbon monoxide or hydrogen. After reduction the powder is usually ground and sized.

In this process particle size of powder can be easily controlled, and powders obtained show good compactibility. However, the process is suitable to only easily reducible oxides.

13.5 BLENDING OF METAL POWDERS

Blending is an operation of *mixing* different powders or various grades of the same powder. During blending some additives such as binders and lubricants may be added to achieve desired strength and porosity, and also to ensure economical production. Lubricants reduce the die wear and help ejection during compact process. The main objective of blending is to obtain uniform distribution of powder in order to get consistent performance during pressing and sintering. Time of blending is an important factor as excessive blending may cause work hardening. The operation may be carried in controlled atmosphere to avoid oxidation of powders.

13.6 BRIQUETING OF METAL POWDERS

Briqueting is the process by which metal powders are pressed to form a green compact having the final shape and size of a component. The strength of green compact is adequate to handle without damaging or breaking during subsequent operations. Final bond strength is obtained by sintering.

The following methods are adopted for compacting metal powders :

1. Cold pressing in a die
2. Centrifugal compacting
3. Slip casting
4. Extruding
5. Rolling
6. Isotatic moulding
7. Explosive compacting

1. *Cold pressing in a die :*

Metal powder is fed automatically into die cavity which accommodates two to three times the volume of the component. The powder is then compressed to form a component which has the same shape as that of the contour of the die. The pressure usually applied for producing green compact of desired shape and size vary from 80 MPa to 1400 MPa. Light pressure is applied for soft metal powders which are used for porous bearings, and high pressure is required for producing high density components from fine and hard metal powders.

The principle of cold pressing in die is illustrated in Fig. 13.3.

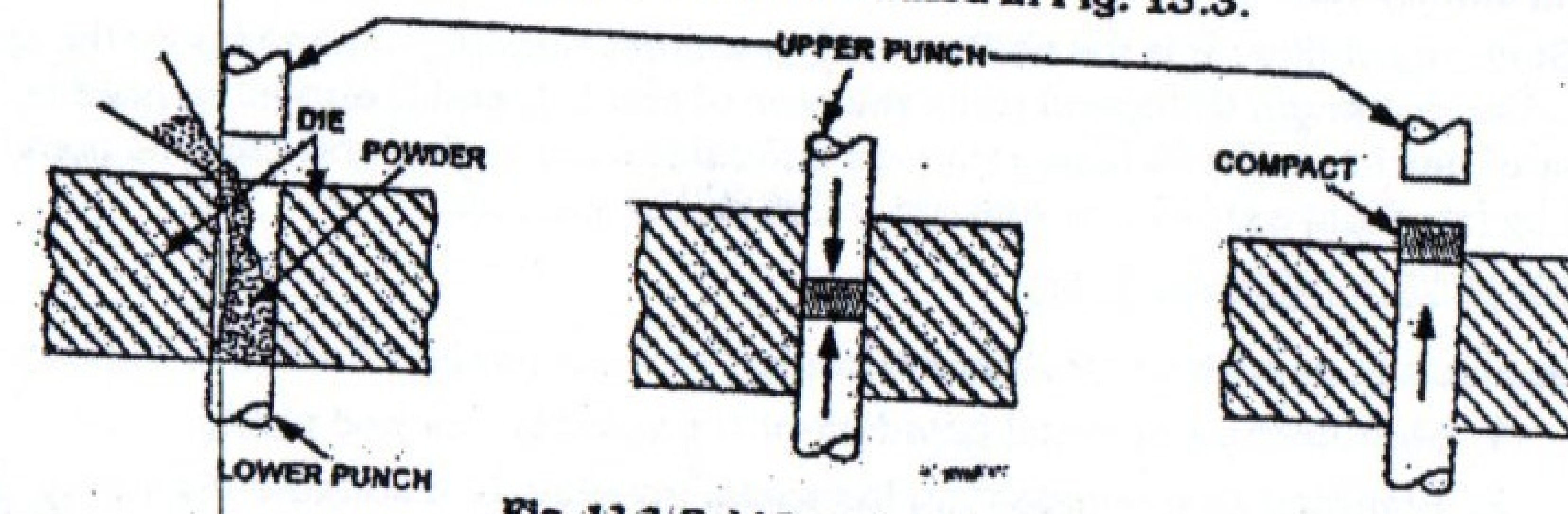


Fig. 13.3 *Cold Pressing in a Die*

Cold pressing may be carried either in a single action press or double actin press.

In *single action press* the die and lower punch are kept stationary and pressure is applied hrough the upper punch. After compression of the powder, the lower punch is raised in order o eject the part from the die cavity. This technique is used for the manufacture of small parts f uniform cross-section i.e., parts without steps. It is not suitable for the parts having onsiderable height due to variation of density in the parts. The principle of single action ompacting is shown in Fig. 13.3.1.

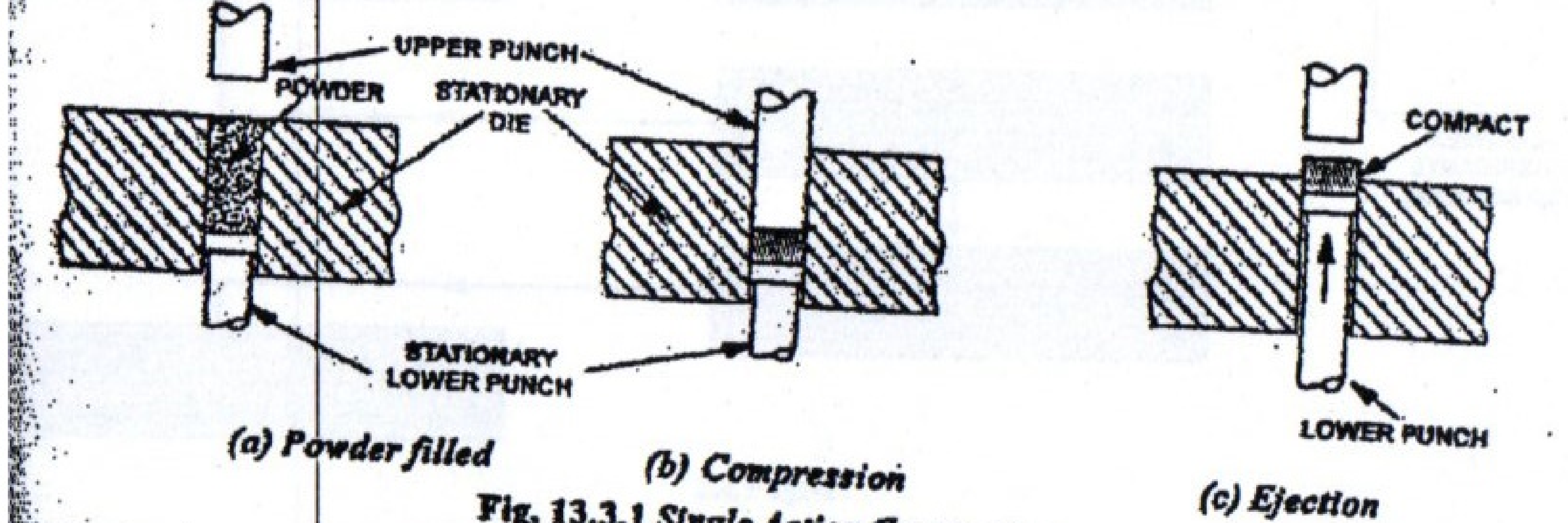
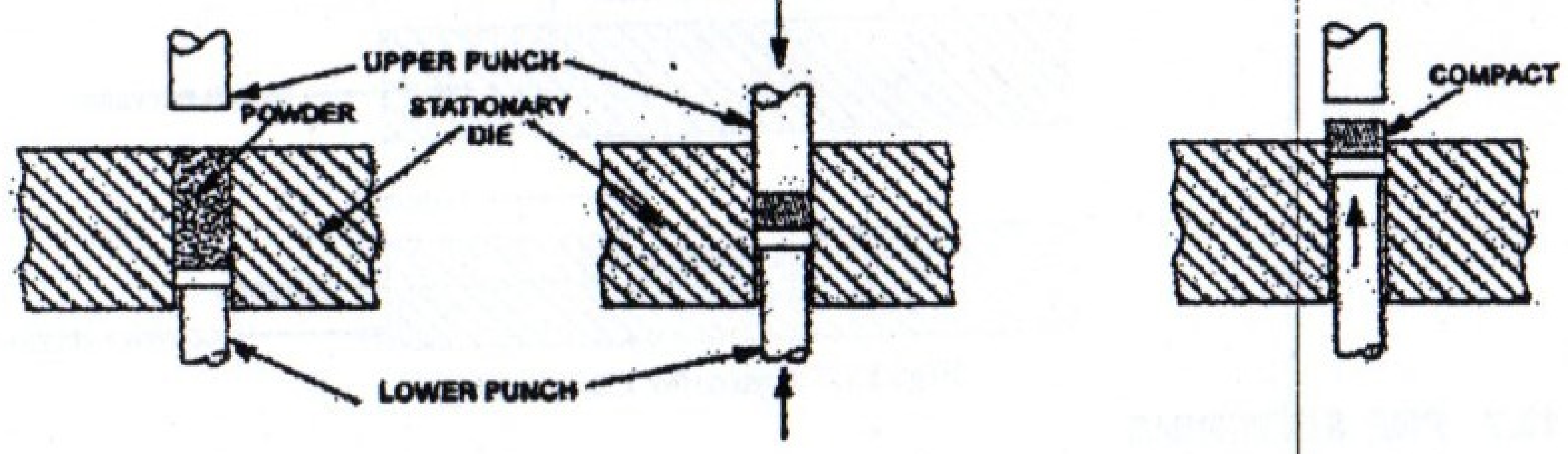


Fig. 13.3.1 *Single Action Compacting*

In *double acting press*, the die is kept stationary and the powder in a die cavity is pressed simultaneously by top and bottom punches moving in opposite direction. After the compression, the part is ejected by the upward movement of the lower punch. The principle of double action compacting is shown in Fig. 13.3.2.



(a) Powder filled *(b) Compression* *(c) Ejection*

Fig. 13.3.2 *Double Acting Compacting*

2. *Centrifugal compacting :*

This method is used for compacting heavy metal powders such as tungsten carbides. The power is filled in the cavity and is whirled in a cavity to produce pressures upto 3 MPa. The powder is packed uniformly due to centrifugal action. The uniform density in the compact is achieved as a result of centrifugal force acting on each individual particle of the powder.

3. *Slip casting :*

Green compact of metal powder may be obtained by slip casting. In this method the slurry consisting of metal powder is poured into a porous mould. The free liquid in a slurry is absorbed by the mould leaving the solid layer of material on the surface of the mould. The mould may be vibrated to increase the density of component. The component is dried and sintered in the usual manner. This process is very simple and is used to produce parts from tungsten, molybdenum and other powders.

4. *Extruding :*

Powder extrusion is used to produce the components with high density and excellent mechanical properties. Both cold and hot extrusion methods are used for compacting special powders. In *cold extrusion* the powder is mixed with binder and the mixture is often compressed into billet before being extruded. The binder must be removed before or during sintering.

The billet (pre-pressed mixture) is charged into container and then forced through the die by means of ram (plunger). The cross-section of the product depends upon the aperture in the die. Cold extrusion is used for cemented carbide drills and cutters. The principle of powder extrusion process is shown in Fig. 13.4.

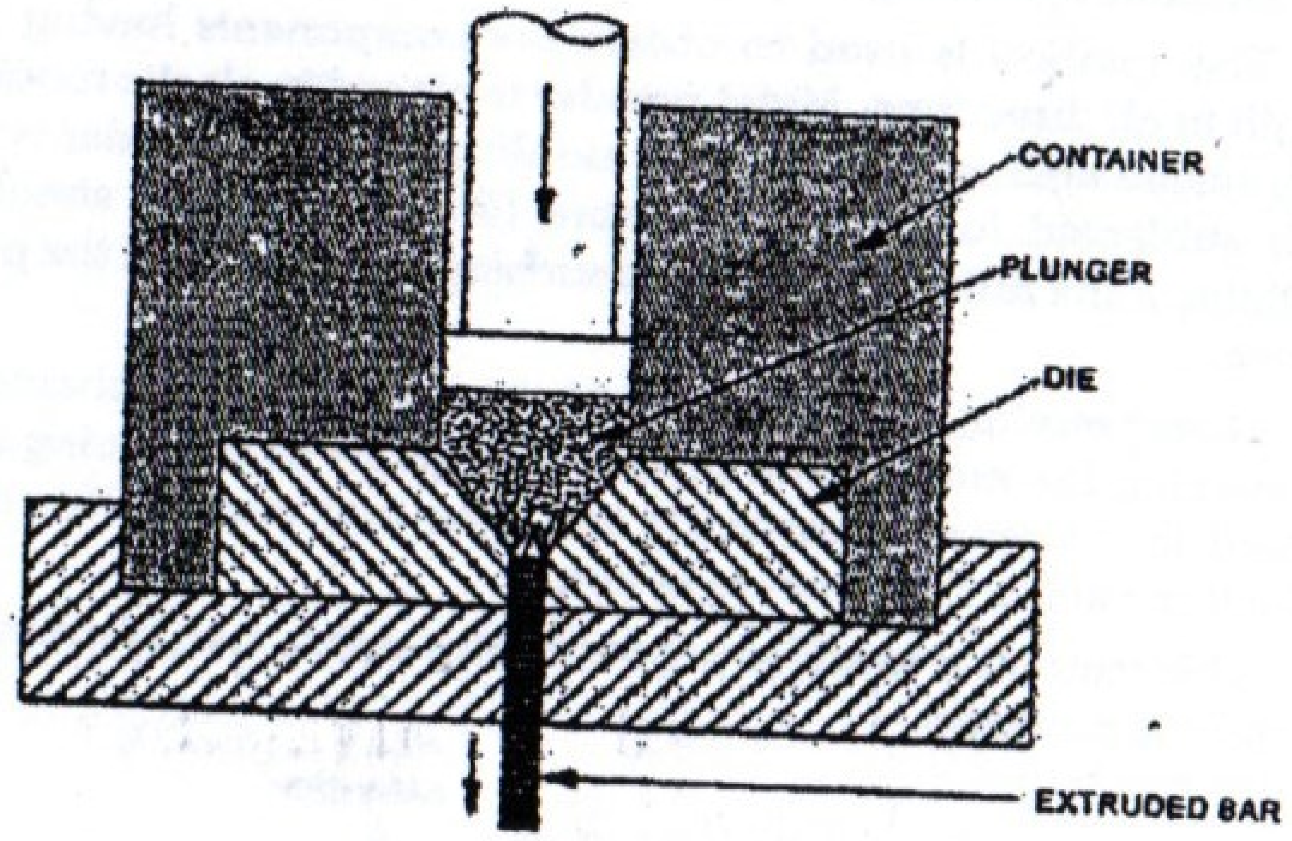


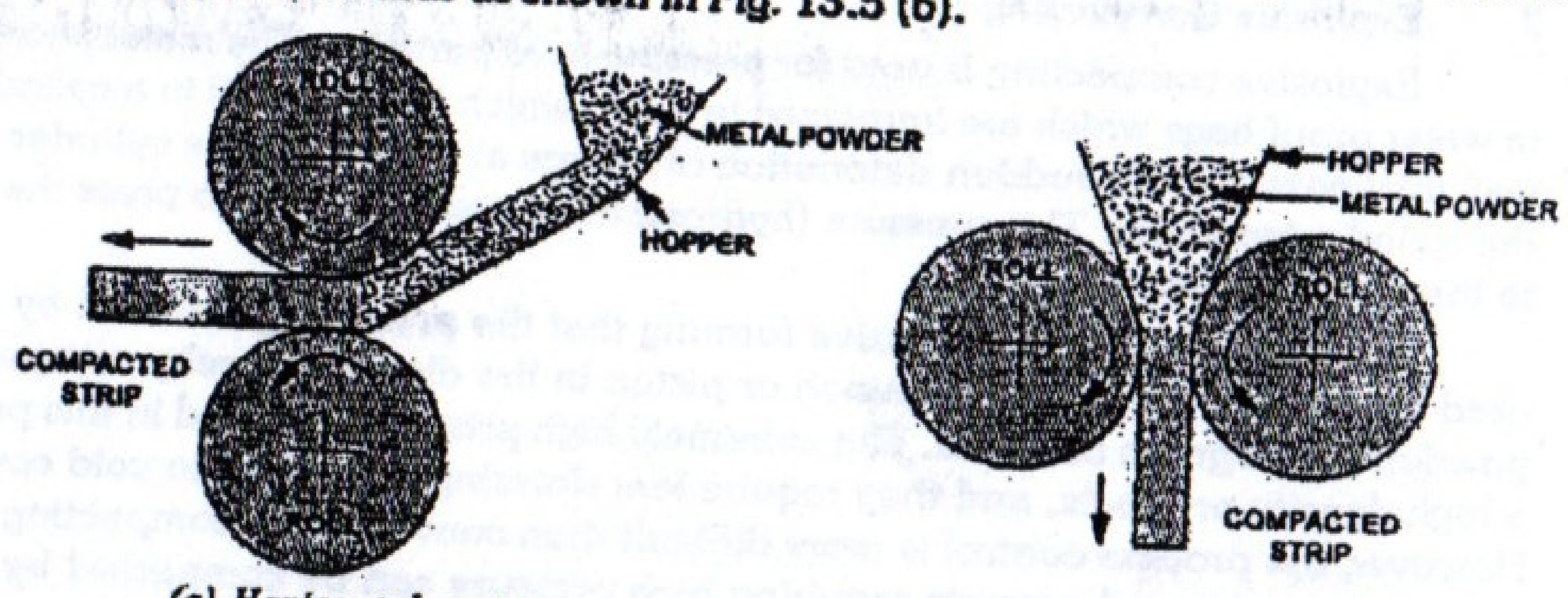
Fig. 13.4 *Powder Extrusion*

In hot extrusion the powder is pre-pressed into a billet and is then heated to extruding temperature in non-oxidising atmosphere. The hot billet is placed in a container and extruded through the die. The hot extrusion is mostly used for refractory metals, beryllium and nuclear solid fuels.

5. *Rolling :*

This method is used for producing continuous strips and rods having controlled porosity with uniform mechanical properties. In this method the metal powder is fed between two rolls. The rolls revolving in opposite direction queeze and interlock the powder particles to form a sheet of sufficient strength. It is then sintered, re-rolled and heat treated if necessary. The characteristics of finished strip depends on finish on roll surfaces, roll speed, rate of powder feed to the rolls, shape and size distribution of particles and sintering temperature.

Metal powders which can be compacted into strips include copper, brass, bronze, nickel, monel and stainless steel. For rolling metal powders horizontal and vertical systems can be adopted. In horizontal system the rolls are set one above the other so that the strip emerges horizontally as in Fig. 13.5 (a). In vertical system the rolls are set side by side so that the strip emerges vertically downwards as shown in Fig. 13.5 (b).



(a) Horizontal system *(b) Vertical system*

Fig. 13.5 *Powder Rolling*

6. *Isostatic Moulding :*

This method is used to obtain the components having uniform density and uniform strength in all directions. Metal powder is placed in elastic mould or flexible envelop which is tightly sealed against leakage. The mould containing powder is placed in a pressure chamber, and is subjected to uniform pressure (65 to 650 MPa) simultaneously and equally in all directions. If the fluid is used as pressurising medium, then the process is termed as *hydrostatic pressing.*

After pressing, the component is removed from the chamber after releasing the pressure and opening the mould. The process is capable of producing complex shapes, and pressure required for as green compact is less than that required for die compacting. However, the production rate in this process is low.

This method is used for processing tungsten, molybdenum, niobium and other refractory and carbide powders.

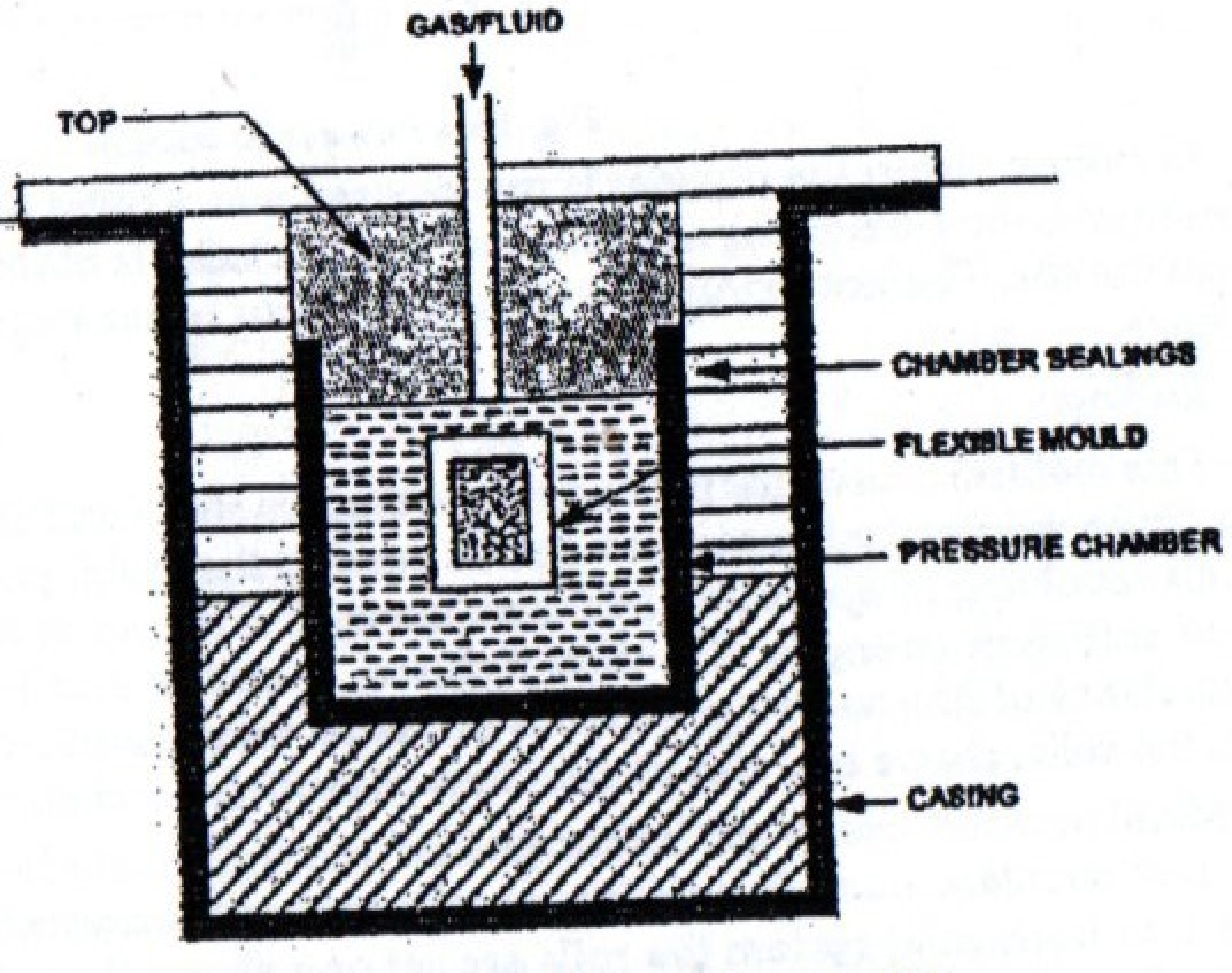


Fig. 13.6 *Hydrostatic/Isostatic Compaction*

7. *Explosive Compacting :*

Explosive compacting is used for pressing hard particles. The metal powders are placed in water proof bags which are immersed in water which is contained in a cylinder having high wall thickness. Due to sudden detonation of charge at the end of the cylinder the pressure in the cylinder increases. This pressure (hydrostatic pressure) is used to press the metal powders to form green compact.

It is also possible in explosive forming that the pressure generated by an explosive is used for the movement of the punch or piston in the die and thereby compacting the metal powders into a green compact. The extremely high pressure involved in this process results in a high density products, and they require less sintering compared to cold compacting parts. However, the process control is more difficult than conventional compacting. Hard powders such as ceramics and cermets requiring high pressure can be compacted by this technique. The principle of explosive compacting is schematically shown in Fig. 13.7.

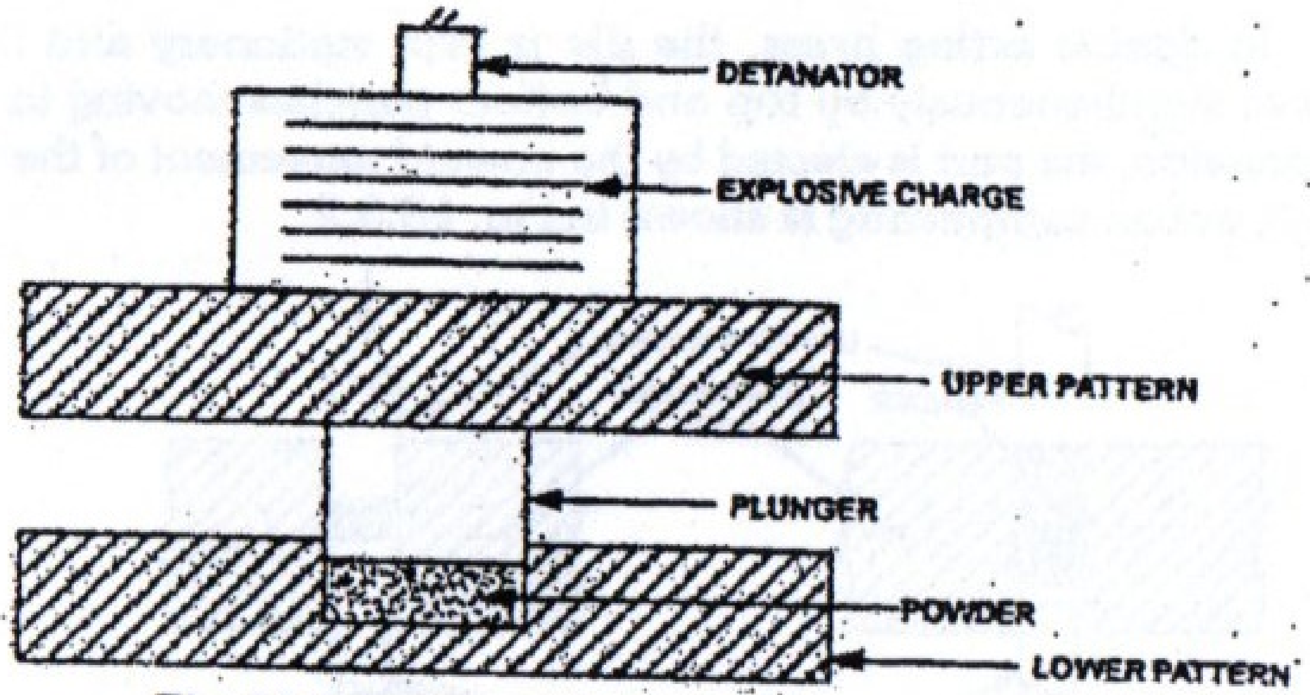


Fig. 13.7 *Explosive Compacting*

13.7 PRE SINTERING

The green compacts are generally heated to temperatures below the sintering temperature. This process is usually called as *pre-sintering. It* imparts additional strength to green compact, and also removes lubricants and binders added to the powders during the blending operation.

13.8 SINTERING

Sintering is the operation of heating the green compact at high temperature but below the melting point of main constituent powders. The sintering is usually carried out in a controlled atmosphere. The use of reducing atmosphere in sintering helps to prevent oxidation of metal powders and thus ensures strong bond between powders. After sintering, the component develops the desired strength and hardness required in the finished product.

Sintering temperature and time of sintering depend on the type of powders and strength required in a final product. The sintering temperature is usually 0.6 to 0.8 times the melting point of powders. But in case of mixed powders of widely different melting points, the sintering temperature will be usually above the melting point of one of the minor constituents such as cobalt in cemented carbides and other powders remain solid state.

The sintering temperature and time of sintering for different metal powders are given below (Table 13.1).

Table 13.1

Type of powders	Sintering temperature, °C	Time
Aluminium and its alloy	370 - 520	24 hours
Copper, Brass and Bronze	700 - 900	30 min.
Iron, Iron Carbide etc.	1025 - 1200	30 min.
Nickel	1010 - 1150	40 min.
Stainless Steel	1180	20 - 40 min.
Tungsten	2340	8 hrs.
Tungsten Carbide	1480	20 - 40 min.
Molybdenum	2050	2 hrs.

13.8.1 Gravity Sintering :

This process is used for making sheets having controlled porosity. In this process, the powder is placed on a ceramic tray to form a uniform layer and then sintered upto 48 hours in ammonia gas at high temperature to form sheets. The sheets are then rolled to desired thickness and to obtain surface finish. Porous stainless steel sheets for filters are produced by this process.

13.8.2 Spark Sintering :

Spark sintering is the process of simultaneously pressing and sintering of metal powders by high energy spark. This spark which is discharged from capacitor bank removes the surface contaminants from the powder particles. This causes the particles to form a solid cohesive mass. Immediately after spark, the current is continued for about 10 seconds which further strengthens the bond due to high temperature. This process is used for sintering aluminium, copper, iron and stainless steel.

This process gives rapid production of high density components. However, the process is not widely used due to complexity.

13.8.3 Hot Pressing :

Hot pressing is a process of compacting metal powders at high temperature such that simultaneously they are sintered. Thus two processes i.e., compacting and sintering are combined in hot pressing. Its applications are limited due to considerable difficulties, and can be used for compacting iron and brass powders. In this case, the pressure applied is much lower than the conventional pressing and sintering operations.

13.9 FINISHING OPERATIONS

Many parts made by powder metallurgy may be used in as sintered condition. However, when the desired specifications are not achieved by the previous operations, sintering must be followed by other finishing operations. These operations such as sizing, coining, machining, infiltration, impregnation, heat treatment etc. are called secondary operations.

Sizing :

When green compact is subjected to sintering operation variation of size is always takes place. Therefore, the sintered components are usually subjected to sizing operation in order to achieve accurate size with good surface finishing. It involves shaping the component in a die-set. Oil lubrication is provided to minimise the die wear.

Coining :

The porosity in sintered component can be reduced by *coining*. It involves repressing the sintered component in the die. Coining imparts additional strength and increases density of the component. The components may be heat-treated to relieve internal stresses.

Machining :

Removing excess material in the form of chips by using cutting tool is called *machining*. Machining is required to produce the components with threads, grooves and undercuts which are not practicable in powder metallurgy process.

Infiltration :

This method is used to reduce porosity and improve the physical properties of sintered product. It involves filling the pores of sintered product with molten metal whose melting point is generally less than the metal with pores. The molten metal is drawn into the pores by capillary action.

Impregnation :

Self lubricating bearings produced by powder metallurgy need impregnation of their pores with lubricants such as oil or greases. This can be achieved by immersing the bearing in oil at a temperature of 80 to 90°C for about 30 minutes. About 90% of pores are impregnated with oil and oil is retained in pores by capillary action. For self lubricating bearings no external lubrication is necessary.

Heat treatment :

Process of controlled heating and cooling is called heat treatment. It refines the grain structure and improve the strength and hardness. For powder metallurgy parts, the heat treatment must be carried out in a controlled atmosphere to prevent the oxidation of internal structure.

Plating :

Plating is used on the surfaces for better appearances and also to resist corrosion. For powder metallurgy products, it is necessary to eliminate porosity before regular plating process by electrolysis ; otherwise, any electrolyte penetrated into the pores causes galvanic corrosion leading to failure.

13.10 ADVANTAGES AND LIMITATIONS OF POWDER METALLURGY

Powder metallurgy process is becoming increasingly popular due to its several advantages. However, some limitations are also associated with this process.

The advantages limitations of powder metallurgy as a manufacturing process are discussed below :

Advantages :

1. Metals and non-metals can be combined to get wide range of properties.
2. No wastage of raw materials.
3. Labour cost is low; and the process is economical for mass production.
4. Parts produced have accurate size and good surface finish. Thus the machining is eliminated.
5. Only the method of producing parts from tungsten, hard carbides and other refractory materials.
6. Parts with controlled porosity and physical properties can be made.
7. There is an excellent consistency in reproduction.

Limitations :

1. Difficult to attain intricate shapes in product.
2. Manufacture of metal powders is an expensive and difficult to store them without deterioration.
3. Equipment cost is high.
4. The size is limited by the capacity of the press.
5. Presents difficulties in sintering operation.
6. Difficult to produce the parts with uniform density.
7. Strength and toughness of the parts produced are inferior to the forgings.

