Powder metallurgy

Introduction

Powder metallurgy (P-M) uses raw material in the form of very fine powder. are blended (mixed), pressed into a desired shape (compacted), and then heated (sintered) in a controlled atmosphere at a temperature below the melting point of the major constituent for sufficient time to bond the contacting surfaces of the particles and establish desired properties.

This process has many interesting uses – common products that are manufactured using powder metallurgy include: balls used in ball-point pens, gears, cams, cutting tools, porous metal filters, oil-impregnated bearings, piston rings in engines, etc. It’s most common application is in manufacture of precision parts made of metal, since it can be used to make parts with irregular curves and recesses/cavities that are hard to machine. Common metals used for P-M include iron, stainless steel, tin, nickel, titanium, aluminum etc. Some examples are in the image below.

•1930’s carbide tool materials

•1960’s automobile parts

•1980’s aircraft engine turbine parts

Figure (1): Examples of P-M parts

Some important properties of P/M

● Used in mass production of small, intricate parts of high precision,

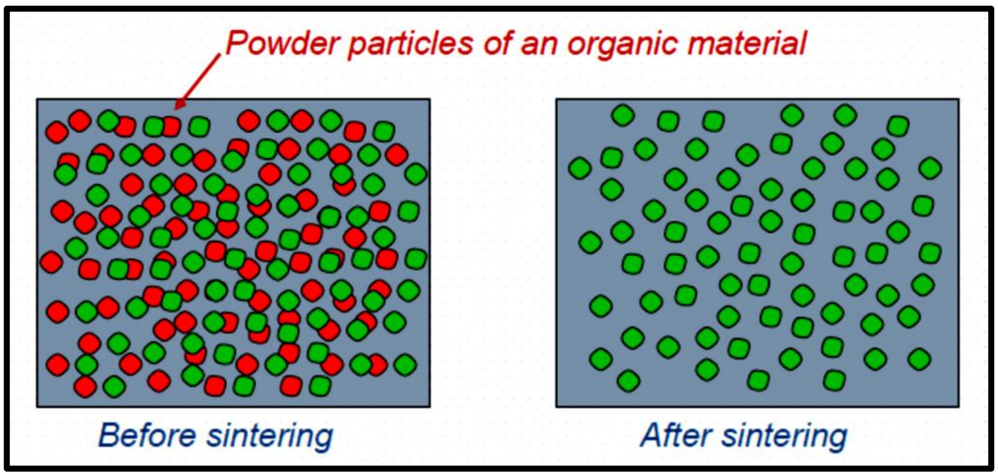
● No or little material is wasted,

● Usually no machining is required,

● Semiskilled labor is sufficient,

● Some unique properties, such as controlled degrees of porosity or built-in lubrication (made by impregnation process) can be obtained.

Controlled Degree of Porosity



Organic material particles burn and disappear during sintering. At their locations small empty volumes are left pores. By controlling the sizes of the organic material particles, and by controlling their percentage in the powder mix, it becomes possible to have controlled degree of porosity.

Powder Properties

● Flow characteristics of the powder is also very important, since it determines the flowing ability of the powder under pressure, which affects the speed of pressing and the final density.

● The strength of a P/M product depends on the chemical composition of the powder and the final density. The greater the density, the higher the strength is.

● Pure metal and non-metal powders can be mixed.

● Pre-alloyed powders can be used.

● Precoated powders can be used.

Basic Steps of P/M

1. Powder manufacture (Producing a fine metallic powder),

2. Powder blending (Mixing and preparing the powder for use),

3.Compacting in a die (Pressing the powder into the desired shape),

4. Sintering (Heating the compacted product).

5. Secondary (Finishing) Operations (Optional)

Powder manufacture

Metal powder can be produced by several processes.

(i). Melt atomization

We commonly use atomizers, for example perfume sprays, cleaning fluid spray bottles etc. The same principle is used to spray liquid metal through a small opening (nozzle); a jet of inert gas or liquid is used to break the flowing liquid into tiny balls and simultaneously cool them to solidify as particles.

(ii). Chemical methods (Reduction of oxides or ores)

Metal oxide can be reduced by passing hydrogen or carbon monoxide over crushed oxide powder at high temperature. Alternatively, the metal is converted first into its Carbonyl, e.g. $Fe(CO)_5$, or $Ni(CO)_4$, which is subsequently reduced to yield back the metal in powder form. Chemical processes are also used to produce **nanoparticles**, which are particles of extremely small size, and which are finding many exciting new applications in modern manufacturing.

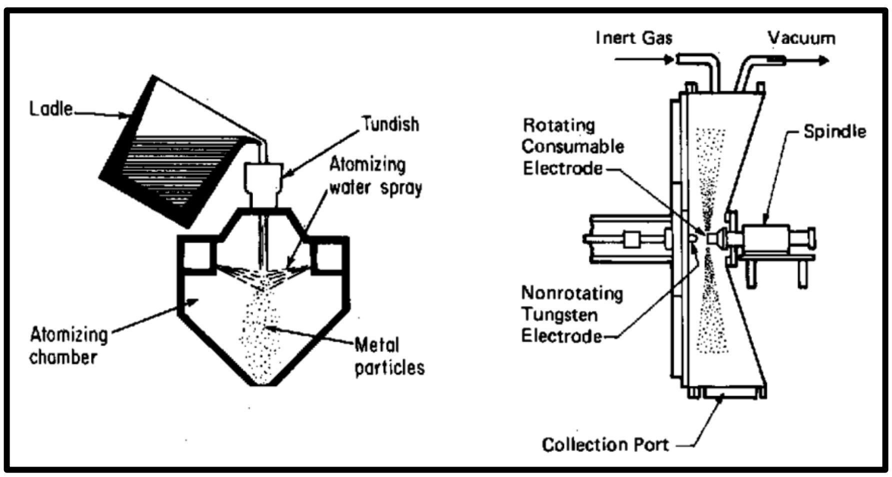
(iii). Electrochemical action (Electrolytic deposition from solutions or fused salts)

A solution of a salt of the metal can undergo electrolysis to yield the metal in

powder form. You can easily try this at home: Take a battery cell (1.5V); connect the anode (+) to some copper wire, and cathode (-) to a graphite rod (e.g. lead from mechanical pencil); immerse them into a solution of Copper Sulphate ($CU\ SO_4$) – this blue crystalline chemical is easily obtained from any High School chemistry lab. After some time, you will see that the graphite bar is coated with Copper powder.

Lesser used processes are:

1. Pulverization or grinding,
2. Thermal decomposition of hydrides or carbonyls,
3. Condensation of metal vapors.



Melt Atomization Rotating Electrode Method

Powder Blending

Before compacting, powder is mixed and blended to,

1. Obtain uniform particle size distribution,
2. Mix powders of different materials must be mixed uniformly. It is done in shaking/rotating containers called blenders.
3. Coat powder particles with lubricants. In some cases, a lubricant is added to the powder to improve the compaction of the powder in the die, as well as to improve the compaction die life.

- Can be done wet or dry.
- Water or solvent can be used for better mixing. Dusting is reduced, explosion hazards are lessened.
- Lubricants such as graphite or stearic acid are used to improve flow characteristics, to reduce die wear.
- Obtaining a uniform mix aids in the pressing operation and helps to assure uniformity throughout a run.

Compacting (Pressing)

This is the step when the powder is given the shape of the part being produced. The method is similar to forming processes – the die is a cavity in the shape of the lower half of the part, and the powder is poured into the cavity. The upper portion of the shape is made by the punch, which is pressed down on the powder to achieve the required compaction. Metal injection molding may also be used in some cases to force-flow the metal powder through the die in a manner similar to plastic injection molding.

Loose powder is compressed and densified into a shape known as a green compact. Compacting is an important step, since,

1. Powder is formed into the desired shape,
2. It determines the density of the product,
3. It determines the uniformity of the density.

Compacting properties

- The powder does not flow like a liquid, but develops an opposing force in the opposite direction of the applied force by means of friction between the particles themselves and the die surfaces.
- Generally, it is not possible to transmit uniform pressures, and obtain uniform density throughout the compact.

● Maximum pressure occurs near the plunger and decreases with the distance from the plunger. Maximum density also occurs near the plunger.

● The thickness/width ratio should be kept below 2 whenever possible.

● Dies used for compacting are made from hardened tool steel. Their surfaces are highly polished. They should be heavy and strong enough to withstand high pressing pressures.

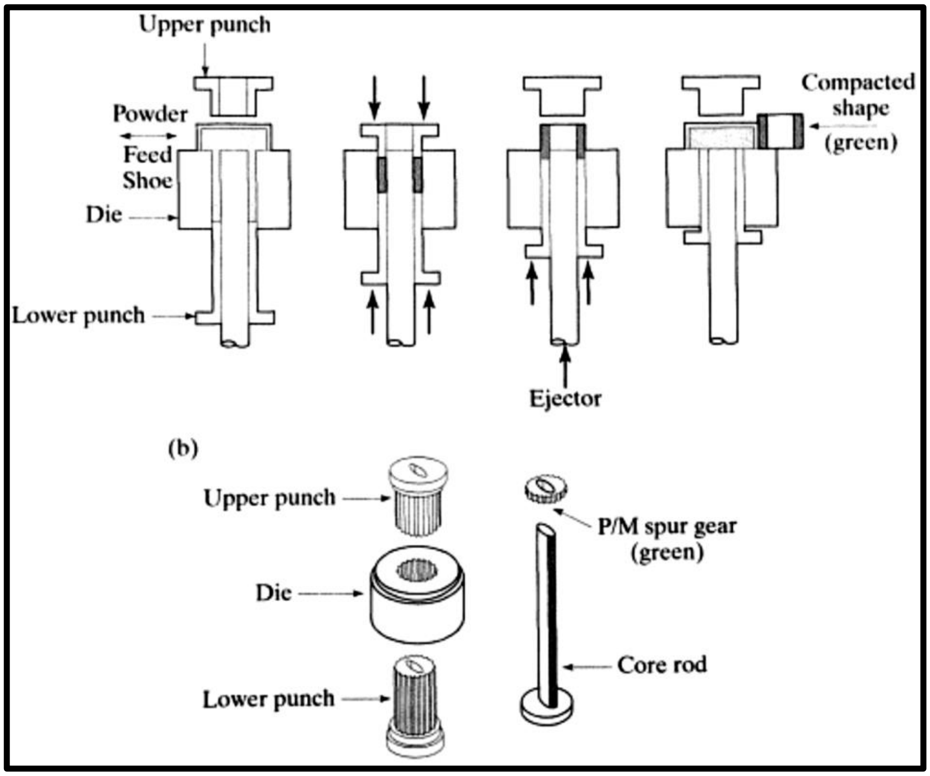
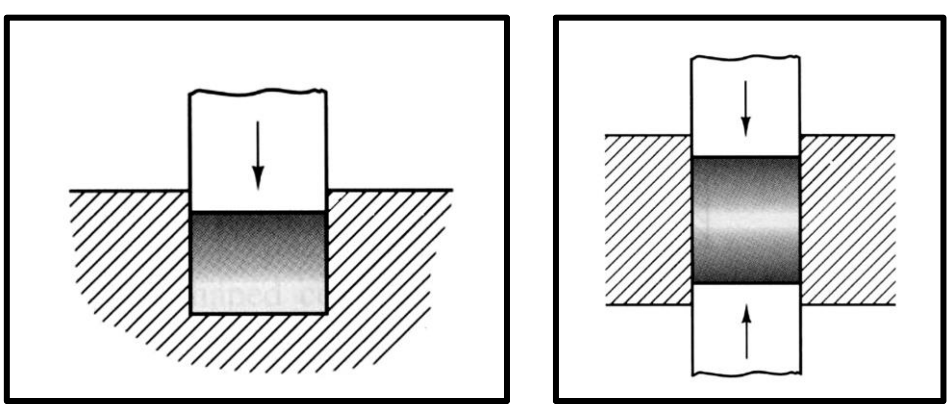
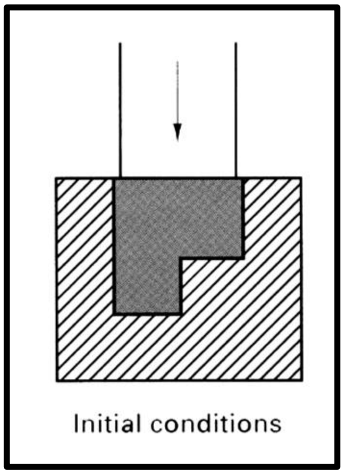
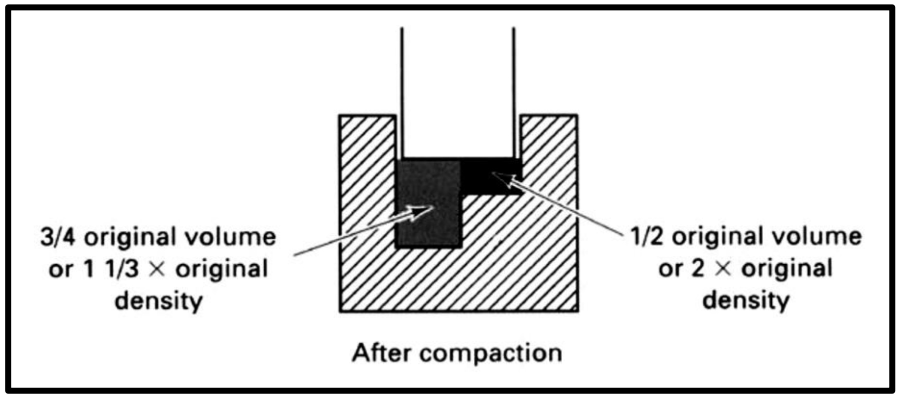
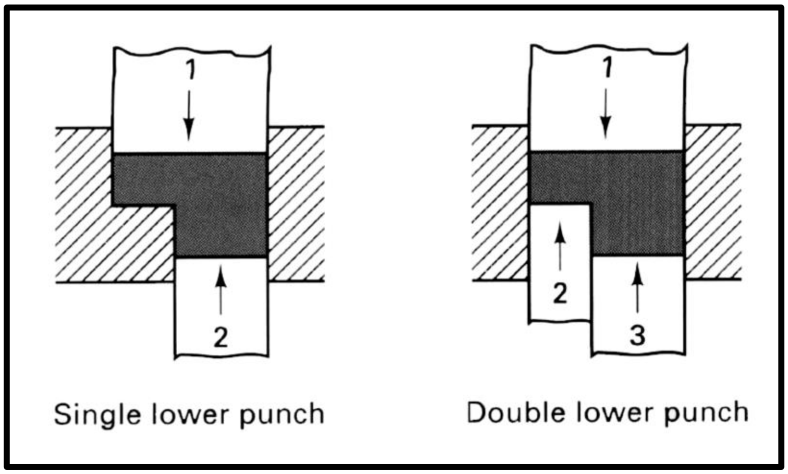


Figure (2): Compaction operation to create a green molded part [source: Kalpakjian & Schmid]



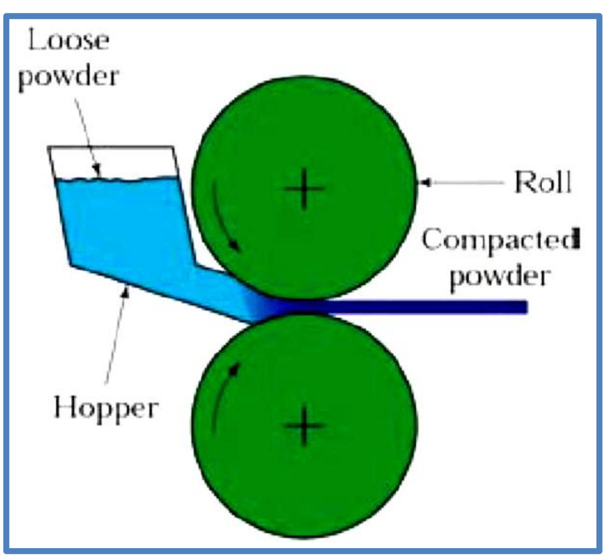




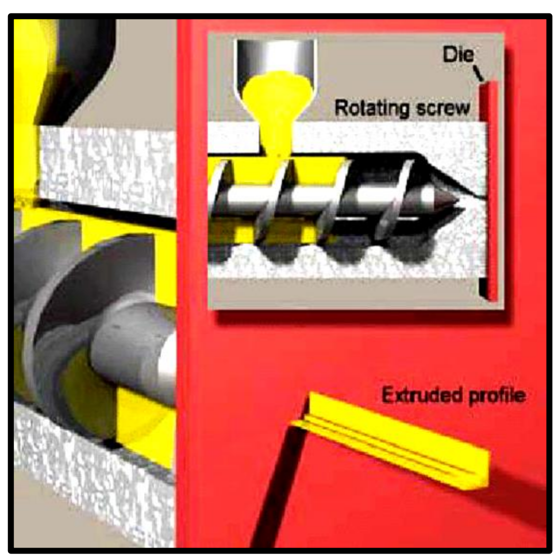


Other Compacting Techniques

Powder Rolling



Powder Extrusion

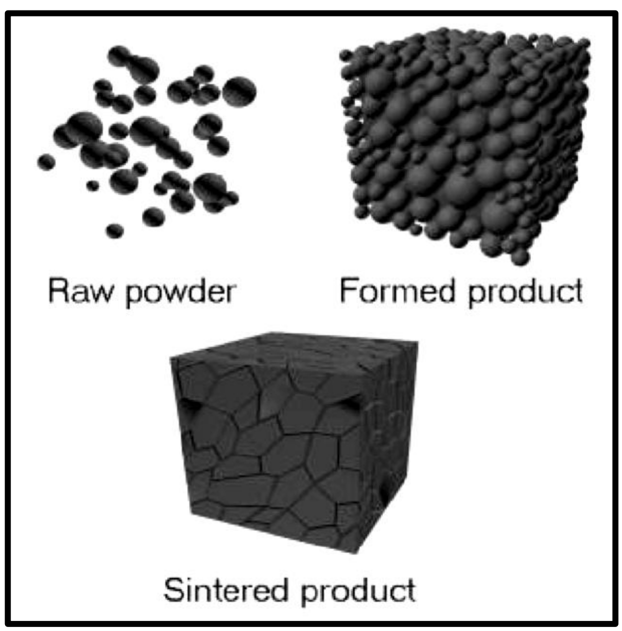


Sintering

The compacted part is called a **green part**, or a **green compact**. It is weak, since the particles are held together mostly by friction. The green compact is put into an oven and heated to a high temperature -- approximately 70% to 90% of the melting point of the metal or alloy. Most sintering furnaces have three chambers: the first chamber burns off the lubricants; the second chamber does the sintering; and the third chamber allows the part to cool down at a desired rate.

The sintering process joins the metal particles together. There are two mechanisms for this. Firstly, at the interface between two particles, metal atoms diffuse across the boundary and re-crystallize. This diffusion process effectively forms a welded joint. Anther phenomenon is that at the high temperature, some metal atoms get vaporized and then get re-deposited on the boundaries. If they re-deposit at an interface, a welded joint is formed.

- The compacts are subjected to elevated temperatures in a controlled atmosphere.
- Sintering strips contaminants from the surfaces of the powder particles, permitting diffusion bonding to occur and results in a single piece of material.
- Sintering is carried out below the melting point of the major constituent.
- Sintering atmospheres must be controlled carefully to prevent oxidation and combustion.



Secondary Operations (Finishing)

For many applications, P/M parts are ready for use as they come from the sintering oven. However, many products require one or more secondary operations to provide enhanced precision or special characteristics.

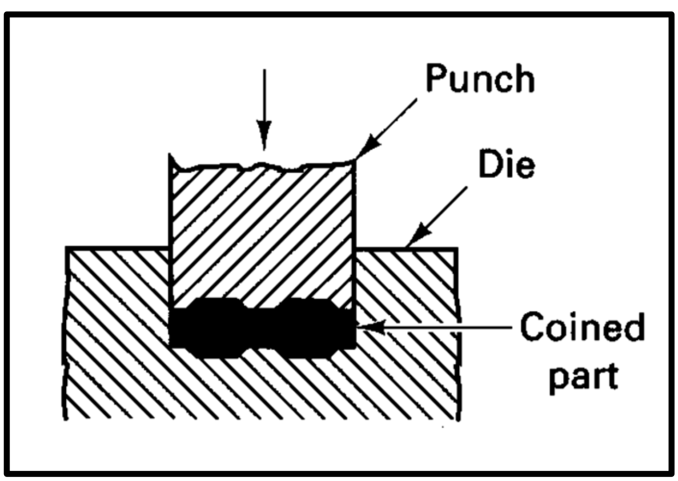
- Repressing, coining or sizing
- P/M Forging
- Impregnation
- Infiltration

Repressing, coining or sizing

A second pressing operation, known as repressing, coining or sizing, may be used to restore dimensional precision.

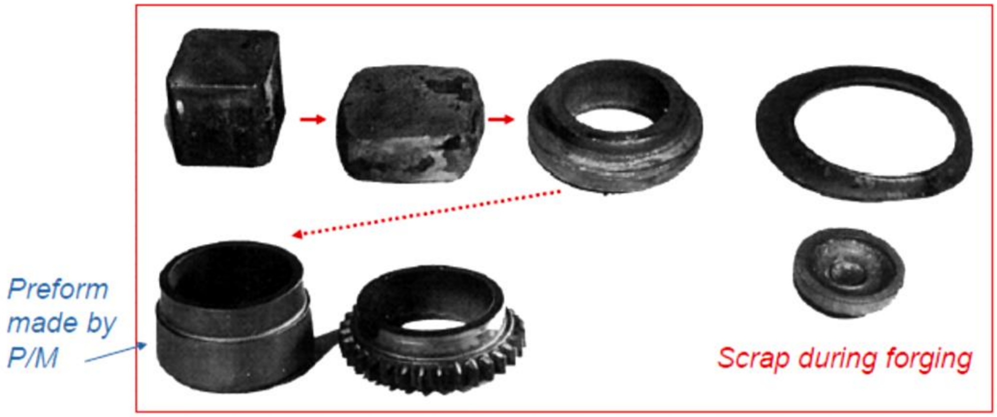
Coining and sizing operations are compaction operations, again, utilizing a die and a punch that press the sintered part to give it the exact shape required (below, we discuss why the sintered part is not accurate in size). The part is placed in a die and subjected to pressures equal to or greater than the initial pressing pressure.

A small amount of plastic flow takes place, resulting in a very uniform product with respect to size and sharpness of detail.



P/M Forging

If massive metal deformation occurs in the second pressing, the operation is known as P/M forging. Here P/M is used to produce preforms for forgings.



Impregnation:

The P-M part has tiny capillary pores all over, which can be impregnated by forcing oil or other lubricant or other liquid into the pores by either immersing the part in a bath and applying pressure or by a combination of vacuum-pressure process. (e.g. used to make oil-impregnated or self lubricating bearings.). This gives rise to self-lubricated parts that require no grease to be applied during use. This is commonly used to manufacture universal joints using P-M.

Infiltration:

The pores can also be filled by a molten metal of a lower melting point than the major constituent is forced into the product under pressure or absorbed by capillary action – e.g. sintered steel parts can be infiltrated by copper or bronze. This adds to the strength and the hardness of the part.

Properties of P/M Products

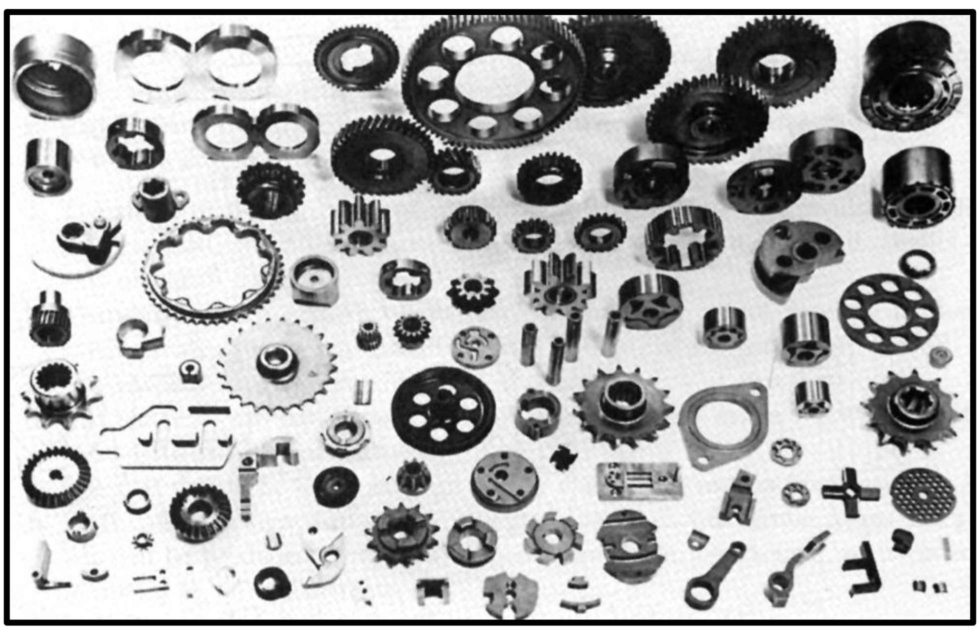
- In general, the strength properties of P/M products are inferior to pure wrought or cast metals. This is also true for alloys.

- As larger pressures are applied and secondary operations such as coining or P/M forging are employed to provide greater density, the strength properties of P/M products increase and be more nearly equal those of wrought materials.

(wrought: Beaten out or shaped with the hammer or other tools.)

Classification of P/M Products

1. Porous products, such as bearings, filters, and pressure or flow regulators.
2. Products of complex shapes that would require considerable machining when made by other processes. (e.g. Small gears, pawls, cams, small activating levers.)
3. Products made from materials that are very difficult to machine. (e.g. Tungsten carbide cutting tools.)
4. Products where the combined properties of two metals, or of metals and nonmetals are desired. (e.g. Motor generator brushes, electrical contacts, bearings.)



Sample Parts made by P/M

Other P-M techniques

Another important P-M variation uses pre-formed alloy powder compacts (green molds), and subjects them to hot- or cold-forging and even impact forging method to get the required final part. This method has been used for producing high strength, high tolerance and high surface finish parts used in automotive and even jet engines.

Dimensional accuracy

The sintering process causes merging of the particles by diffusion. This mechanism causes the powder particles to move a little closer, and therefore some amount of shrinking occurs in the size of the green compact. If the shrinkage is non-uniform, or if some dimensions are critical, then the sintered part must be subjected to finishing operations to get it within specs.

Mechanical properties

In general, the strength, elongation and hardness of P-M parts is somewhat lower than parts of the same material manufactured by casting/forging. However, several post-processing techniques can be used to improve the mechanical properties of sintered parts.

Forming operations on Glass

Glass is a very commonly used substance. Most common objects of glass around us include bottles, glass sheets (tables, windows, doors, mirrors etc.), tubes (laboratory and medical devices), and glass fiber (which is the raw material used in making some composites, and lenses (eye-glasses, sunglasses, headlamps of vehicles). We take a quick look at basic glass forming processes.

Sheet making

The operations used are drawing or rolling. Different types of glass melt

between 1000°C and 1200°C. Drawing or rolling operations use a large, melted basin of molten glass, which is pulled out and formed into sheets using powered rollers that rotate at controlled speed.

Glass tubes and rods

These are made by a drawing process – molten glass is drawn out through a (circular) hole in a large basin. To make tubing, a rotating cylinder/ cone (called a mandrel) is placed inside the basin near the hole, and air is blown through it – the air passes through the soft glass as it is drawn out of the hole, and stops the glass tube from collapsing.

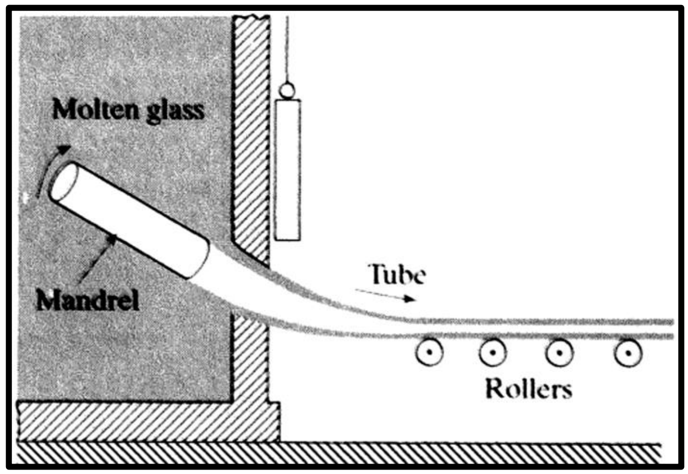


Figure (3): Drawing of glass tubes [source: Kalpakjian & Schmid]

Lenses, Headlamps manufacture

Most glass lenses, automobile headlamp covers, etc. are made by a molding process very similar to injection molding. the molding process is simple – a measured amount of the raw material is placed in the heated mold and formed by pressure and heat. A similar operation is used to manufacture other products with plastic and rubber, e.g. soles of athletic shoes.

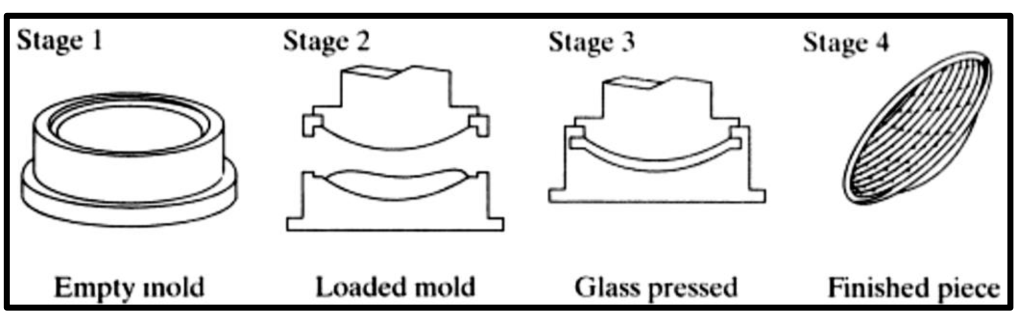


Figure 4. Molding of lenses [source: Kalpakjian & Schmid]

Bottle manufacture

Bottle are made by a process called **blow molding**. The basic process is shown in the figure below

Most glass and plastic botiles

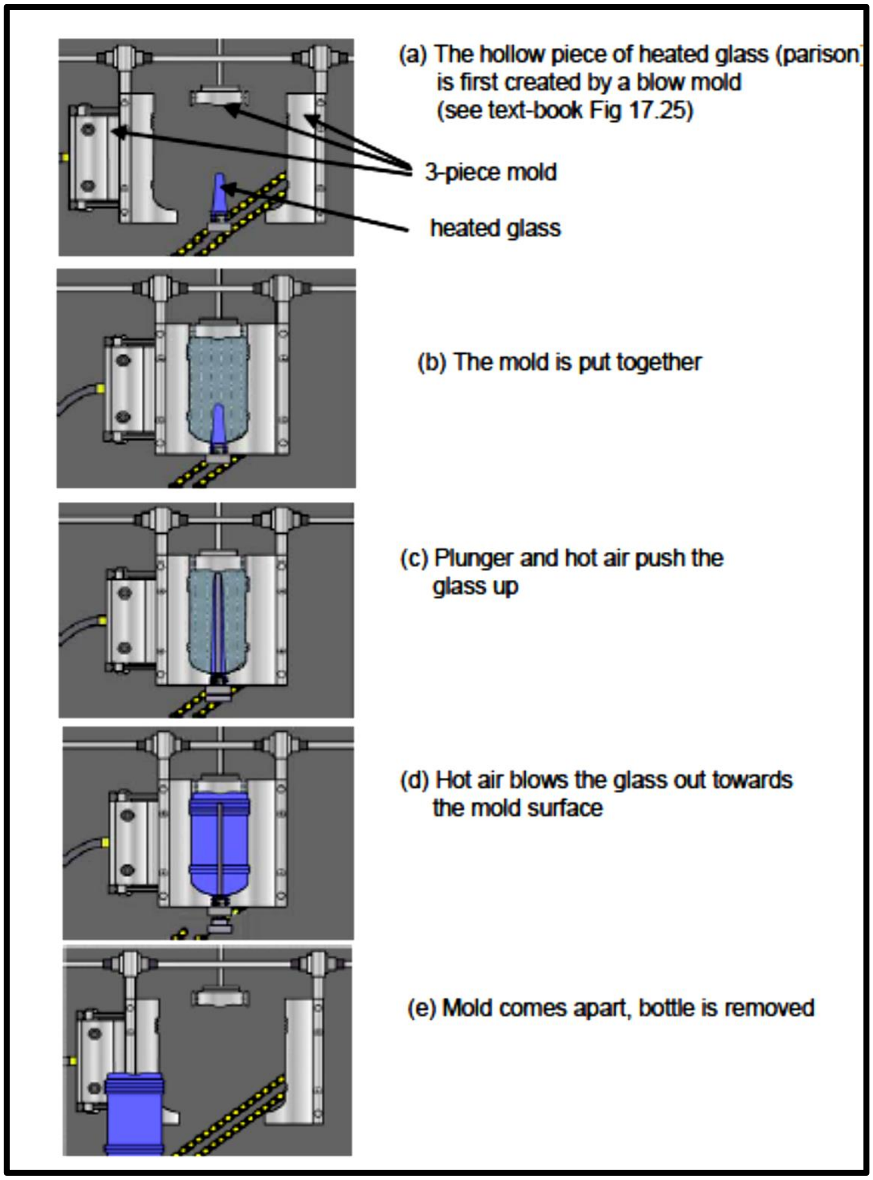


Figure 5. Stages in blow molding of bottles [source: http://www.pct.edu/prep/bm.h] tm