Lecture 5. Powder Metallurgy, Sintering, and Forming of Glass

Powder metallurgy (P-M) uses raw material in the form of very fine powder. This is compacted (using a die) to the shape required, and then the powder particles are "joined" by heating the material to just below the melting point. 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.

Figure 1. Examples of P-M parts

5.1. P-M technology

The basic steps of P-M are: (i) powder production (ii) powder blending (iii) compaction in a die (iv) sintering and (v) finishing.

5.1.1. Powder production

Metal powder can be produced by several processes.

(i). 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

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

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.

5.1.2. Blending

If the P-M part is being made form a mixture of metals, then the different powders must be mixed uniformly. Also, 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. The mixing is done in shaking/rotating containers called blenders.

5.1.3. Compaction

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.

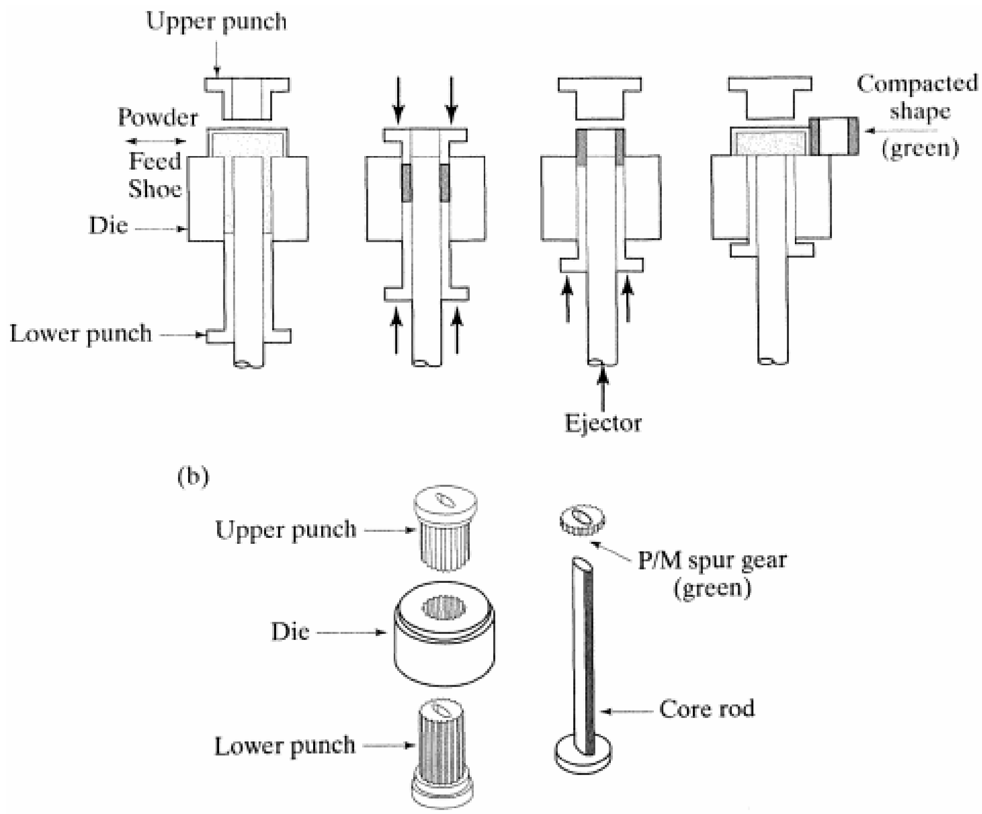

Figure 2. Compaction operation to create a green molded part [source: Kalpakjian & Schmid]

5.1.4. 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.

5.1.5. Finishing

5.5.1. 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).

5.5.2. Impregnation: the P-M part has tiny capillary pores all over, which can be impregnated by oil or other lubricant. 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.

5.5.3. Infiltrations: the pores can also be filled by a metal of lower melting point – e.g. sintered steel parts can be infiltrated by copper or bronze. This adds to the strength and the hardness of the part.

5.2. 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.

5.3. Issues in P-M

5.3.1. 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.

5.3.2 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. A comparison of some typical metals can be done using Tables 2.2 (p 58), Fig 2.14 (p 72) and Table 17.4 (p 455) of the textbook (Kalpakjian and Schmid).

6. 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.

6.1. 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 (see Figure 17.22 in the text book Kalpakjian and Schmid).

6.2. 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. The figure below shows a schematic.

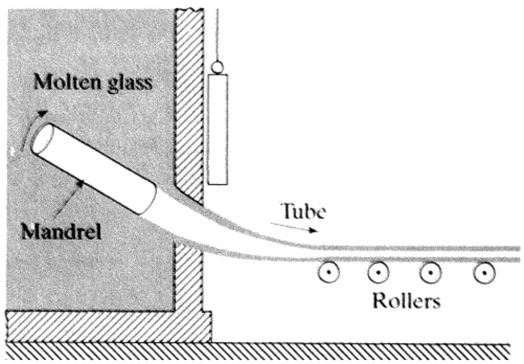

Figure 3. Drawing of glass tubes [source: Kalpakjian & Schmid]

6.3. 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.

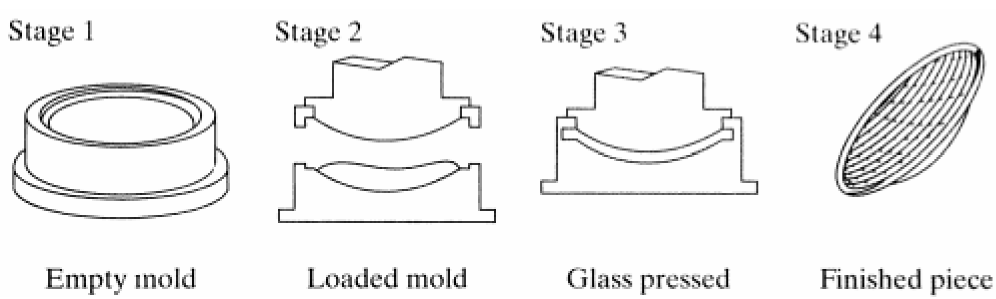

Figure 4. Molding of lenses [source: Kalpakjian & Schmid]

6.4. Bottle manufacture

Most glass and plastic bottle are made by a process called **blow molding**. The basic process is shown in the figure below.

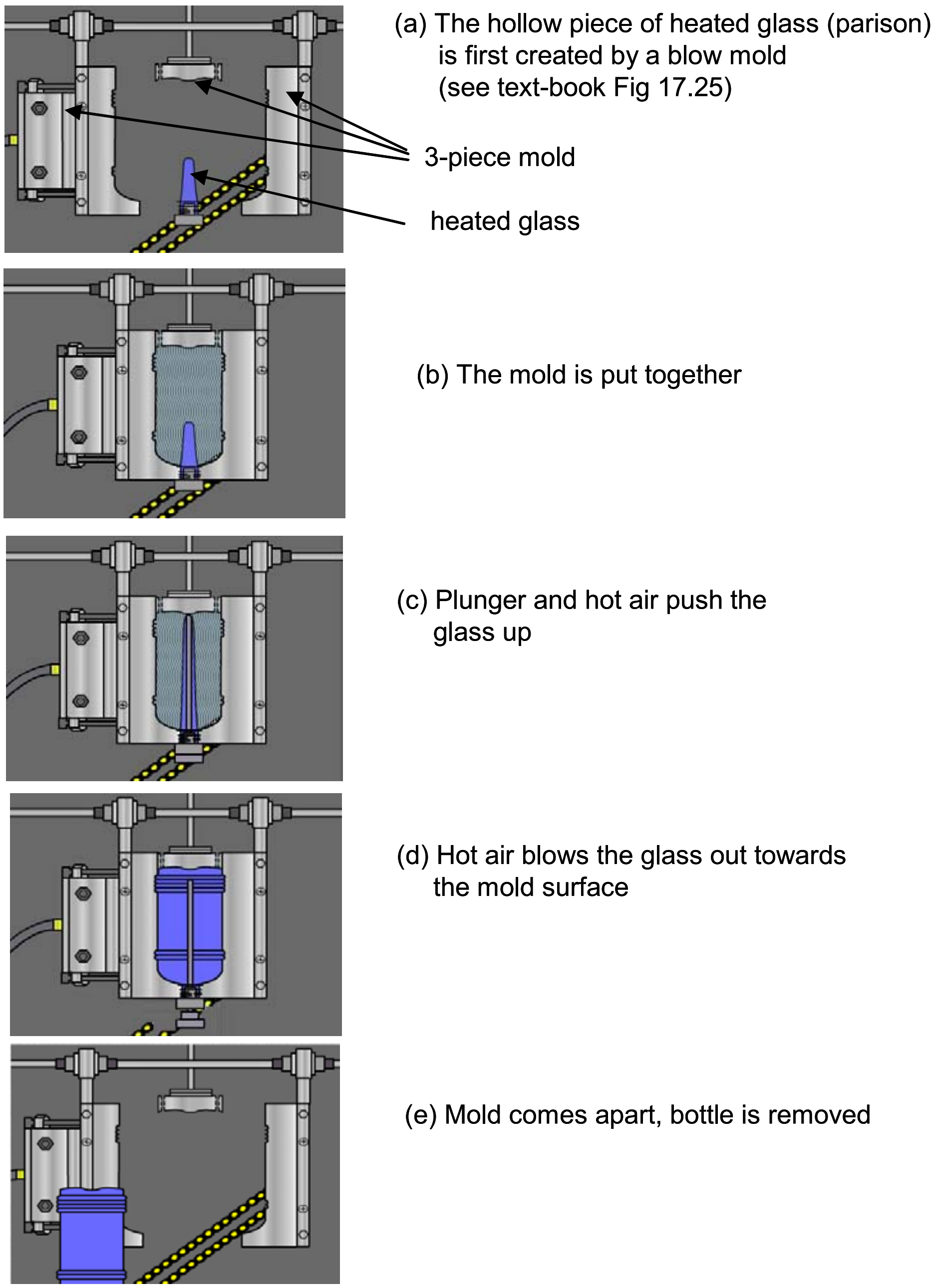

Figure 5. Stages in blow molding of bottles [source: http://www.pct.edu/prep/bm.htm]