Unit 5: Extrusion & Powder Metallurgy

Extrusion & Powder Metallurgy: Introduction, types of extrusion, process, applications. Powder metallurgy process, applications, advantages.

INTRODUCTION

Metal forming is also known as mechanical working of metals. Metal forming operations are frequently desirable either to produce a new shape or to improve the properties of the metal. Shaping in the solid state may be divided into;

(a) Non-cutting shaping such as forging, rolling, pressing, etc., and
(b) Cutting shaping such as the machining operations performed on various machine tools.

Non-cutting or non machining shaping processes are known as mechanical working processes. The main objectives of metal working processes are to provide the desired shape and size, under the action of externally applied forces in metals. Such processes are used to achieve optimum mechanical properties in the metal and reduce any internal voids or cavities present and thus make the metal dense. The plasticity, ductility and malleability are the properties of a material, which retains the deformation produced under applied forces permanently and hence these metal properties are important for metal working processes.

MECHANICAL PROPERTIES OF METALS

- **Plasticity** is the ability of a material to undergo some degree of permanent deformation without rupture or failure. Plastic deformation will take place only after the elastic range has been exceeded. Such property of material is important in forming, shaping, extruding and many other hot and cold working processes. Materials such as clay, lead, etc. are plastic at room temperature and steel is plastic at forging temperature. This property generally increases with increase in temperature.

- **Ductility** is the property of a material enabling it to be drawn into wire with the application of tensile force. Ductile materials are mild steel, copper, aluminium, nickel, zinc, tin and lead.

- **Malleability** is the ability of the material to be flattened into thin sheets without cracking by hot or cold working. A malleable material should be plastic but it is not essential to be so strong. The malleable materials commonly used in engineering practice in order of diminishing malleability are lead, soft steel, wrought iron, copper and aluminium. Aluminium, copper, tin, lead, steel, etc. are recognized as highly malleable metals.

- **Work hardening**, also known as **strain hardening** is the strengthening of a metal by plastic deformation. This strengthening occurs because of dislocation movements and dislocation generation within the crystal structure of the material.

RECRYSTALISATION

During the process of plastic deformation in metal forming, the plastic flow of the metal takes place and the shapes of the grains are changed. If the plastic deformation is carried out at higher temperatures, new grains start growing at the location of internal stresses caused in the metal. If the temperature is sufficiently high, the growth of new grains is accelerated and continuous till the metal comprises fully of only the new grains. This process of formation of new grains is known as recrystalisation and is said to be complete when the metal structure consists of entirely new grains. That temperature at which recrystalisation is completed is known as the recrystallisation temperature of the metal. Mechanical working of a metal below its recrystalisation temperature is called as *cold working* and that accomplished above this temperature but below the melting or burning point is known as *hot working*.

For pure metals, the recrystallization temperature is normally 0.3 T_m, where T_m is the absolute temperature; for some commercial alloys it may run as high as 0.7 T_m. Plastic deformation operations are often carried out at temperatures above the recrystallization temperature in a process termed hot working. The material remains relatively soft and ductile during deformation because it does not strain harden, and thus large deformations are possible.

S. No.	**Metal**	**Recrystallization temp.(^{0}C)**	**Melting Temp. (^{0}C)**
1	Pb	-4	327
2	Sn	-4	232
3	Zn	10	420
4	Al	80	660
5	Cu	120	1085
6	Ni	370	1455
7	Fe	450	1538

COLD WORKING OF METALS

Cold working of a metal is carried out below its re-crystallisation temperature. Although normal room temperatures are ordinarily used for cold working of various types of steel, temperatures up to the re-crystallisation range are sometimes used.

Purpose of cold working

The common purpose of cold working is given as under

1. Cold working is employed to obtain better surface finish on parts.
2. It is commonly applied to obtain increased mechanical properties.
3. It is widely applied as a forming process of making steel products using pressing and spinning.
4. It is used to obtain thinner material.

Precautions fallowed in cold working

Cold working leads to crack formation and propagation if performed in excess and it should therefore be avoided. Residual stresses developed due to inhomogeneous deformation cause warping or distortion when the part is released from the tooling and during subsequent machining. Magnitude and distribution of residual stresses should therefore be controlled.

Characteristics of cold working

The main characteristics of cold working are given as under.

1. Cold working involves plastic deformation of a metal, which results in strain hardening.

2. It usually involves working at ordinary (room) temperatures, but, for high melting point metals, e.g., tungsten, the cold working may be carried out at a red heat.

3. The stress required for deformation increases rapidly with the amount of deformation.

4. The amount of deformation, which can be performed without introducing other treatment, is limited.

5. Cold rolling process generally distorts grain structure.

6. Good surface finish is obtained in cold rolling.

7. Excessive cold working gives rise to the formation and propagation of cracks in the metal.

8. The loss of ductility during cold working has a useful side effect in machining.

9. With less ductility, the chips break more readily and facilitate the cutting operation.

10. Heating is sometimes required.

11. Directional properties can be easily imparted.

12. Spring back is a common phenomenon present in cold-working processes.

13. For relatively ductile metals, cold working is often more economical than hot working.

Limitations of cold working

1. The cold worked process possesses less ductility.

2. Strain hardening occurs.

3. Metal surfaces must be clean and scale free before cold working.

4. Hot worked metal has to be pickled in acid to remove scale, etc.

5. Higher forces are required for deformation than those in hot working.

6. More powerful and heavier equipments are required for cold working.

Advantages of cold working

1. In cold working processes, smooth surface finish can be easily produced.

2. Accurate dimensions of parts can be maintained.

3. Strength and hardness of the metal are increased but ductility decreased.

4. Since the working is done in cold state, no oxide would form on the surface and consequently good surface finish is obtained.

5. Cold working increases the strength and hardness of the material due to the strain hardening which would be beneficial in some situations.

6. There is no possibility of decarburization of the surface

7. Better dimensional accuracy is achieved.

8. It is far easier to handle cold parts and it is also economical for smaller sizes.

Disadvantages of cold working

1. Some materials, which are brittle, cannot be cold worked easily.

2. Since the material has higher yield strength at lower temperatures, the amount of deformation that can be given to is limited by the capability of the presses or hammers used.
3. A distortion of the grain structure is created.

4. Since the material gets strain hardened, the maximum amount of deformation that can be given is limited. Any further deformation can be given after annealing.

5. Internal stresses are set up which remain in the metal unless they are removed by proper heat-treatment.

HOT WORKING

Mechanical working processes which are done above recrystallisation temperature of the metal are known as hot working processes.

Merits of hot working

1. At a high temperature, the material would have higher amount of ductility and therefore there is no limit on the amount of hot working that can be done on a material. Even brittle materials can be hot worked.
2. In hot working process, the grain structure of the metal is refined and thus mechanical properties improved.
3. Porosity of the metal is considerably minimized.
4. If process is properly carried out, hot work does not affect tensile strength, hardness, corrosion resistance, etc.
5. Larger deformation can be accomplished more rapidly as the metal is in plastic state.
6. No residual stresses are introduced in the metal due to hot working.
7. Concentrated impurities, if any in the metal are disintegrated and distributed throughout the metal.

Demerits of hot working

1. Due to high temperature in hot working, rapid oxidation or scale formation and surface de-carburization take place on the metal surface leading to poor surface finish and loss of metal.

2. On account of the loss of carbon from the surface of the steel piece being worked the surface layer loses its strength. This is a major disadvantage when the part is put to service.
3. Some metals cannot be hot worked because of their brittleness at high temperatures.
4. Because of the thermal expansion of metals, the dimensional accuracy in hot working is difficult to achieve.
5. Handling and maintaining of hot working setups is difficult and troublesome.

COMPARISON OF HOT AND COLD WORKING PROCESSES

S. No.	Hot working	Cold working
1	It is carried out above the recrystallization temp. but below the melting point. Hence the deformation of metal and recovery takes place simultaneously.	It is carried out below the recrystallization temp. as such there is no appreciable recovery.
2	No internal or residual stresses are set-up in the metal	Internal or residual stresses are set-up in the metal.
3.	Close tolerance can not be maintained.	Bwtter tolerance can be easily maintained.
4	Surface finish is comparatively not good	Surface finish is comparativelytgood.
5.	The stresses required for deformation is much less	The stress required to cause deformation is much higher.
6.	If cracks and blow holes are present in the metal, they are finished through hot working	The esisting cracks propagates and new cracks may develop.
7	Of properly performed, it does not affect UTS, hardness, corrosion resistance, yield strength and fatigue strength of the metal.	It improves UTS, hardness, yield strength but reduces the corrosion resistance

CLASSIFICATION OF METAL WORKING PROCESSES

The classification of metal working processes is given as under.

1. Rolling
2. Extrusion
3. Wire drawing
4. Forging

ROLLING

Rolling is the process of forming metal into desired shapes by plastic deformation through compressive stresses using two or more than two rolls. It is one of the most widely used of all the metal working processes. The coarse structure of cast ingot is convened into a fine grained structure using rolling process as shown in Fig. 1. Significant improvement is accomplished in rolled parts in their various mechanical properties such as toughness, ductility, strength and shock resistance. The majority of steel products are being converted from the ingot form by the process of rolling. The crystals in parts are elongated in the direction of rolling, and they start to reform after leaving the zone of stress. Hot rolling process is being widely used in the production of large number of useful products such as rails, sheets, structural sections, plates etc. There are different types of rolling mills, which are described as under.

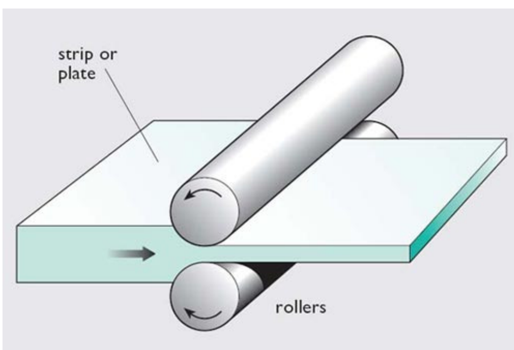


Fig. 1. Rolling process

Applications of Rolling

In the rail mill, the heavier structural sections and rails are made. Rolling mills produce girders, channels, angle irons and tee-irons. Plate mill rolls slabs into plates. The materials commonly hot rolled are aluminium, copper magnesium, their alloys and many grades of steel.

EXTRUSION

It is the process of enclosing the heated billet or slug of metal in a closed cavity and then pushing it to flow from only one die opening so that the metal will take the shape of the opening. The pressure is applied either hydraulically or mechanically. Extrusion process is identical to the squeezing of tooth paste out of the tooth paste tube. Tubes, rods are some typical products of extrusion. Using extrusion process, it is possible to make components, which have a constant cross-section over any length as can be had by the rolling process. The intricacy in parts that can be obtained by extrusion is more than that of rolling, because the die required being very simple and easier to make. Also extrusion is a single pass process unlike rolling. The amount of reduction that is possible in extrusion is large. Generally brittle materials can also be easily extruded. The extrusion setup consists of a cylinder container into which the heated billet or slug of metal is loaded. On one end of the container, the die plate with the necessary opening is fixed. From the other end, a plunger or ram compresses the metal billet against the container walls and the die plate, thus forcing it to flow through the die opening, acquiring the shape of the opening. The extruded metal is then carried by the metal handling system as it comes out of the die.

Extrusion process is classified as

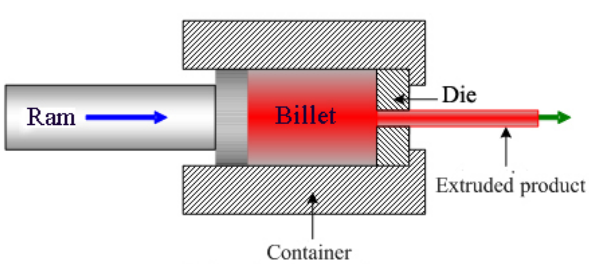
1. Direct or forward extrusion
2. Indirect or backward extrusion
3. Tube extrusion

(a) Direct or Forward Hot Extrusion

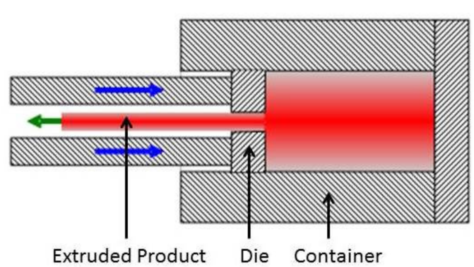
Fig. 4(a) shows the direct extrusion operational setup. In this method, the heated metal billet is placed in to the die chamber and the pressure is applied through ram. The metal is extruded through die opening in the forward direction, i.e. the same as that of the ram. In forward extrusion, the problem of friction is prevalent because of the relative motion between the heated metal billet and the cylinder walls. To reduce such friction, lubricants are to be commonly used. At lower temperatures, a mixture of oil and graphite is generally used. The problem of lubrication gets compounded at the higher operating temperatures. Molten glass is generally used for extruding steels.

(b) Indirect or Backward Hot Extrusion

Fig. 4(b) shows the indirect extrusion operational setup. In indirect extrusion, the billet remains stationary while the die moves into the billet by the hollow ram (or punch), through which the backward extrusion takes place. Since, there is no friction force between the billet and the container wall, therefore, less force is required by this method. However this process is not widely used because of the difficulty occurred in providing support for the extruded part.



Direct Extrusion

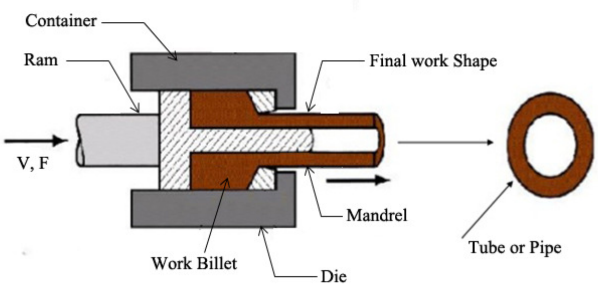


Indirect Extrusion

Fig. 4(a) Fig. 4(b)

(c) Tube Extrusion

Fig. 4(c) shows the tube extrusion operational setup. This process is an extension of direct extrusion process where additional mandrel is needed to restrict flow of metal for production of seamless tubes. Aluminium based toothpaste and medicated tubes are produced using this process.



Tube Extrusion

Fig. 4(c)

WIRE DRAWING

The wire drawing die setup is shown in Fig.5. The process of producing the wires of different diameters is accomplished by pulling a wire through a hardened die usually made up carbide. However a smaller diameter wires are drawn through a die made of diamond. The larger diameter oriented wire is first cleaned, pickled, washed and then lubricated. Cleaning is essentially done to remove any scale and rust present on the surface, which may severely affect the die. It is normally done by acid pickling. The hot rolled steel is de-scaled, pickled in acid, washed in water and coated with lime and other lubricants. To make for an easier entrance of wire into the die, the end of the stock is made pointed to facilitate the entry. A pointed or reduced diameter at the end of wire duly lubricated is pushed or introduced through the die which is water cooled also. This pointing is done by means of rotary swaging or by simple hammering. It is then gripped and pulled for attaching it to a power driven reel. The wire diameter is reduced in die because of the ductility property of the material to the smaller diameter through one set of die. However, for more reduction in diameter of the wire, various sets of dies can be used in line for subsequent reduction in diameter at each stage as shown in Fig 5. The reduction in each pass through the die range about 10% for steel and 40% for ductile materials such as copper.

In this process, there is no force is applied for pushing the wire into the die from the entrance side. The material should be sufficiently ductile since it is pulled by the tensile forces. Hence, the wire may have to be annealed properly to provide the necessary ductility. Further, the wire is to go through the conical portion and then pulled out through the exit by the gripper. The other aspect of preparation needed is the cleaning of the wire and lubricating it as it flows through the die. The dies used for wire drawing are severely affected because of high stresses and abrasion. The various die materials that are used are chilled cast iron, tool steels, tungsten carbide and diamond.

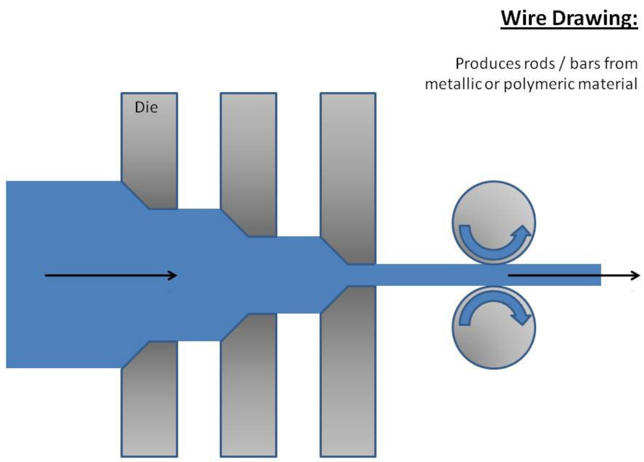
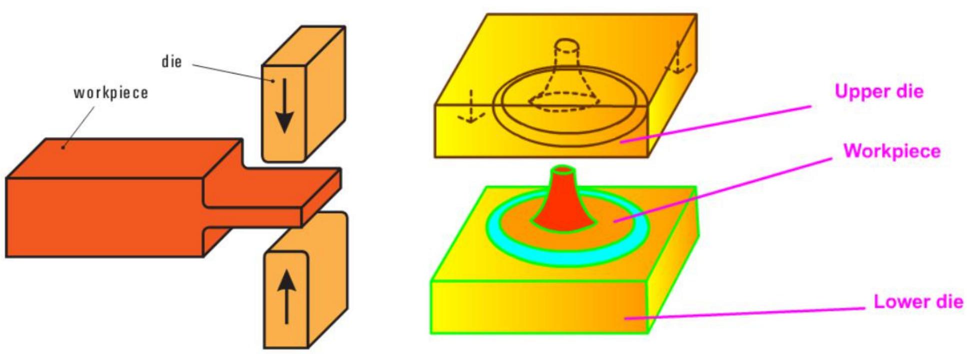


Fig. 5: Wire drawing

FORGING

Forging is a metal forming process (fig. 6) in which the work piece or billet is shaped into finished part by the application of compressive and tensile forces with the help of a pair of tools called die and punch. Forging can be done in open dies or closed dies. Open die forging is usually used for preliminary shaping of raw materials into a form suitable for subsequent forming or machining.



(a) Open die forging (b) closed die forming

Fig.6: Forging processes

Open die forming is done using a pair of flat faced dies for operations such as drawing out, thinning, etc. Closed die forming is performed by squeezing the raw material called billet inside the cavity formed between a pair of shaped dies. Formed products attain the shape of the die cavity. Valve parts, pump parts, small gears, connecting rods, spanners, etc are produced by closed die forming.

POWDER METALLURGY

Powder technology is the science for the manufacture of parts from metal powders by compaction and heating that creates a homogeneous mass. Heating is executed in a furnace and is called sintering. The temperature at which sintering is performed is lower than the melting point of the powdered material. Sintering consists of diffusion in solid state by which particles of compacted powder are bonded together. This is the basic working principle of powder technology.

Applications of Powder Metallurgy in Industries

The powder metallurgy technique finds use in various industries and manufacturing processes. It has become very popular in a very short span of time because of its efficiency and reliable output. Some of them are mentioned here.

- Manufacturing metal bonded diamond tools and materials.
- Manufacturing power tools and modern home appliances.
- Aerospace and Automobile Industry have a huge scope for power metallurgy for making large equipment and machine parts.
- Manufacturing of friction materials, refractory metals, switch materials and electric contact materials.
- Production and processing of metals with high melting points like Tungsten and Molybdenum that are used in electronics industry.

Parts with irregular curves or recesses that are hard to machine can be manufactured using the powder metallurgy techniques. It is suitable for high-volume and mass production with practically negligible wastage of the manufacturing material. The process of secondary machining is virtually eliminated or reduced to negligible extent by the technique of powder metallurgy and it helps in improving efficiency by a huge margin. Cams, sprockets, pawls, iron bearings, sintered bronze, ratchets and carbide tool tips are the most commonly manufactured items with the help of powder technology.

Processes of Powder Technology

The processes involved in powder metallurgy are the following:

Blending and Mixing: This is carried out to achieve uniformity of the product manufactured. Distribution of properly sized particles is attained by mixing elementary powder with alloy powders to obtain a homogeneous mixture. Lubricants are also mixed with powders to minimize the wear of dies and reduce friction between the surfaces of dies and particles of powder during compaction. Mixing time will depend upon the results desired, and over-mixing should be prevented, or otherwise the size of particles will be decreased and they will be hardened.

Pressing: The cavity of the die is filled with a specified quantity of blended powder, necessary pressure is applied, and then the compacted part is ejected. Pressing is performed at room temperature, while the pressure is dependent upon the material, properties of the powder used, and the density required of the compaction. Friction between the powder and the wall of the die opposes application of a proper pressure that decreases with depth and thus causes uneven density in the compact. Thus the ratio of length and diameter is kept low to prevent substantial variations in density.

Sintering:

In this process, the mixture of metal powders is heated in a protective atmosphere furnace to a suitable temperature, which is 70 to 90% of the melting point of the metal or alloy.it is a solid state process which is responsible for producing physical and mechanical properties in the part by developing metallurgical bond among the powder particles. It also serves to remove the lubricant from the powder, prevents oxidation, and controls carbon content in the part. The structure and porosity obtained in a sintered compact depend on the temperature, time, and processing details. It is not possible to completely eliminate the porosity because voids cannot be completely closed by compaction and because gases evolve during sintering. Porosity is an important characteristic for making bearings and filters through powder metallurgy.

Properties of Metal Powders

Properties of metal powder depend upon the process employed for its production. Therefore, it is essential to determine the physical and chemical properties of powders to prevent variations in the desired characteristics of the compactions. Significant properties of metal powders are:

- Chemical composition that is determined by chemical analysis.
- Shape of particles that is affected by methods employed for production of powder.
- Particle size influences the properties of flow and density of powder metal. It can be measured by a microscope, sieve, or by sedimentation.
- Distribution of particle size has a significant effect on physical properties of powder, and can be determined by sieving test.
- Flowability is the relative ease of the flow of powder through an orifice.
- Bulk density can be measured by filling a pot whose volume is known with powder, and then obtaining the weight of the powder.
- Other properties include compressibility, compatibility, sintering ability, and specific surface.