3.1 Introduction

- Mechanical working of a metal is a simply plastic deformation performed to change the dimensions, properties and surface conditions with the help of mechanical pressure.
- Depending upon the temperature and strain rat, mechanical working may be either hot working or cold working, such that recovery process takes place simultaneously with the deformation.
- The plastic deformation of metal takes place due to two factors i.e. deformation by slip and deformation by twin formation.
- During deformation the metal is said to flow, which is called as plastic flow of the metal and grain shapes are changed.
- If the deformation is carried out at higher temperatures, then the new grains start growing at the locations of internal stresses.
- When the temperature is sufficiently high, the grain growth is accelerated and continues till the metal comprises fully of new grains only.
- This process of formation of new grains is called as **recrystallization** and the corresponding temperature is the recrystallization temperature of the metal.
- Recrystallization temperature is the point which differentiates hot working and cold working.
- Mechanical working of metals above the recrystallization temperature, but below the melting or burning point is known as **hot working** whereas; below the recrystallization temperature, is known as **cold working.**

3.2 Hot working

- Hot working is accomplished at a temperature above the recrystallization temperature but below the melting or the burning point of the metal, because above the melting or the burning point, the metal will burn and become unsuitable for use.
- Every metal has a characteristic hot working temperature range over which hot working may be performed.
- The upper limit of working temperature depends on composition of metal, prior deformation and impurities within the metal.
- The change in structure form hot working improves mechanical properties such as ductility, toughness, resistance to shock and vibration, % elongation, % reduction in the area, etc.

- The principal hot working process applied to various metals are as follows:
  1. Hot rolling
  2. Hot extrusion
  3. Hot spinning
  4. Roll piercing
  5. Hot drawing
  6. Hot forging

Advantages

- Due to hot working, no residual stresses are introduced in the metal.
- Hot working refines grain structure and improves physical properties of the metal.
- Any impurities in the metal are disintegrated and distributed throughout the metal.
- Porosity of the metal is minimized by the hot working.
- During hot working, as the metal is in plastic state, large deformation can be accomplished and more rapidly.
- Hot working produces raw material which is to be used for subsequent cold corking operations.

Disadvantages

- As hot working is carried out at high temperatures, a raid oxidation or scale formation takes place on the metal surface which leads to poor surface finish and loss of metal.
- Due to the loss of carbon from the surface of the steel piece being worked, the surface layer loses its strength.
- This weakening of the surface layer may give rise to fatigue crack which results in failure of the part.
- Close tolerances cannot be obtained.
- Hot working involves excessive expenditure on account of high tooling cost.

3.3 Cold working

- The working of metals at temperatures below their recrystallization temperature is called as cold working.
- Most of the cold working process are performed at room temperature.
- Unlike hot working, it distorts the grain structure and does not provide an appreciable reduction in size.
- Cold working requires much higher pressure than hot working.
- If the material is more ductile, it can be more cold worked.

- Residual stresses are setup during the process, hence to neutralize these stresses a suitable heat treatment is required.
- The principal methods of cold working are as follows:

1. Cold rolling	2. Cold drawing
3. Cold spinning	4. Stretch forming
5. Cold forging and swaging	6. Cold extrusion
7. Coining	8. Embossing
9. Cold bending	10. Roll forming
11. Shot peening	12. High Energy Rate Forming (HERF)

Advantages

- Better dimensional control is possible because there is not much reduction in size.
- Surface finish of the component is better because no oxidation takes place during the process
- Strength (tensile strength and yield strength) and hardness of metal are increased.
- It is an ideal method for increasing hardness of those metals which do not respond to the heat treatment.

Disadvantages

- Ductility of the metal is decreased during the process.
- Only ductile metals can be shaped through the cold working.
- Over-working of metal result in brittleness and it has to be annealed to remove this brittleness.
- To remove the residual stresses setup during the process, subsequent heat treatment is mostly required.

3.4 Comparison between Hot working and Cold working

Sl.No.	Hot Working	Cold Working
1.	Hot working is carried out above the recrystallization temperature but below the melting point, hence deformation of metal and recovery takes place simultaneously.	Cold working is carried out below the recrystallization temperature and as such there is not appreciable recovery of metal.
2.	During the process, residual stresses are not developed in the metal.	During the process, residual stresses are developed in the metal.
3.	Because of higher deformation temperature used, the stress required	The stress required to cause deformation is much higher.

	for deformation is less.	
4.	Hot working refines metal grains, resulting in improved mechanical properties.	Cold working leads to distortion of grains.
5.	No hardening of metal takes place.	Metal gets work hardened.
6.	If the process is properly perfumed, it does not affect ultimate tensile strength, hardness, corrosion and fatigue resistance of the metal.	It improves ultimate tensile strength, yield and fatigue strength but reduces corrosion resistance of the metal.
7.	It also improves some mechanical properties like impact strength and elongation.	During the process, impact strength and elongation are reduced.
8.	Due to oxidation and scaling, poor surface finish is obtained.	Cold worked parts carry better surface finish.
9.	Close dimensional tolerance cannot be maintained.	Superior dimensional accuracy can be obtained.
10.	Hot working is most preferred where heavy deformation is required.	Cold working is preferred where work hardening is required.

3.4.1 Warm working

Warm working refers to plastic deformation carried out at intermediate temperatures of hot and cold working. Thus, the temperature during warm working is above the room temperature and below the crystallization temperature. Also, the working temperature is usually about 0.3 to 0.5 times the melting temperature of metal. Warm working requires less force to perform an operation than cold working hence it is more preferable than the cold working.

3.5 METAL FORMING

- Metal forming includes a large number of manufacturing processes in which plastic deformation property is used to change the shape and size of metal workpieces.
- During the process, for deformation purpose, a tool is used which is called as **die.** It applies stresses to the material to exceed the yield strength of the metal.
- Due to this the metal deforms into the shape of the die. Generally, the stresses applied to deform the metal plastically are compressive.
- But, in some forming processes metal stretches, bends or shear stresses are also applied to the metal.

- For better forming of metal, the desirable properties of metal are low yield strength and high ductility.
- These properties are highly affected by the temperature. When the temperature of the metal is increased, its ductility increases and yield strength decreases.
- The other factors which affect the performance of metal forming process are, strain rate, friction, lubrication, etc.
- Metal forming processes can be classified as follows:

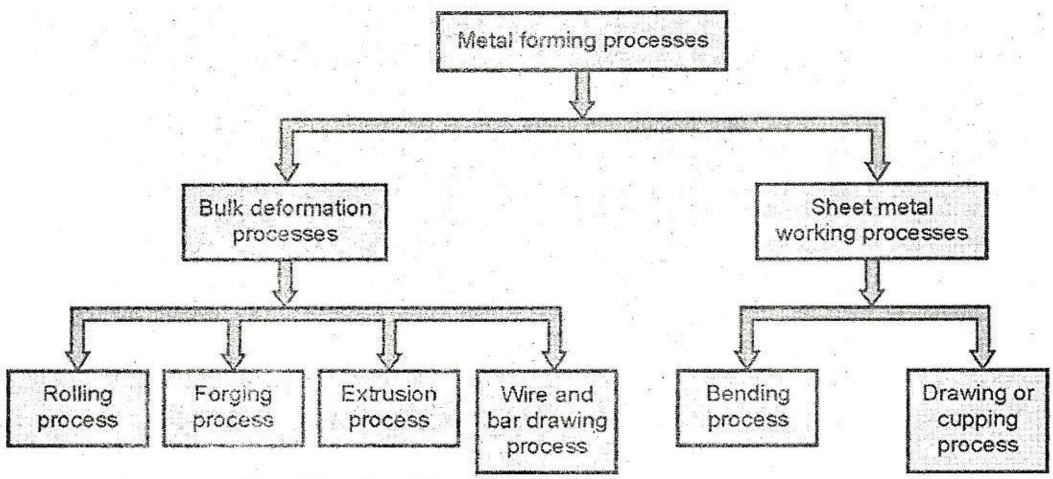

Fig. 3.1 : Classification of metal forming processes

3.5.1 Bulk Deformation Processes

These process are characterized by significant deformations and massive shape changes but the surface area to the volume of the work is relatively small. The workpieces which have this low area to volume ratio is called as bulk. Initial workpiece shape for bulk deformation processes include cylindrical billet (hot material) and rectangular bars. Figure 3.2 shows the basic operations in bulk deformation process.

1. Rolling

It is a compressive deformation process in which the thickness of a plate or slab (hot) is reduced by two opposing cylindrical rolls. The rolls rotate in order to draw the workpiece into the gap between them and squeeze the workpiece. Refer Figure 3.2 (a).

2. Forging

In this process, the workpiece is compressed between the two opposing dies in order to produce the die shapes on the workpiece. Refer Figure3.2 (b). It is generally a hot working process but sometimes it can be included in cold working also.

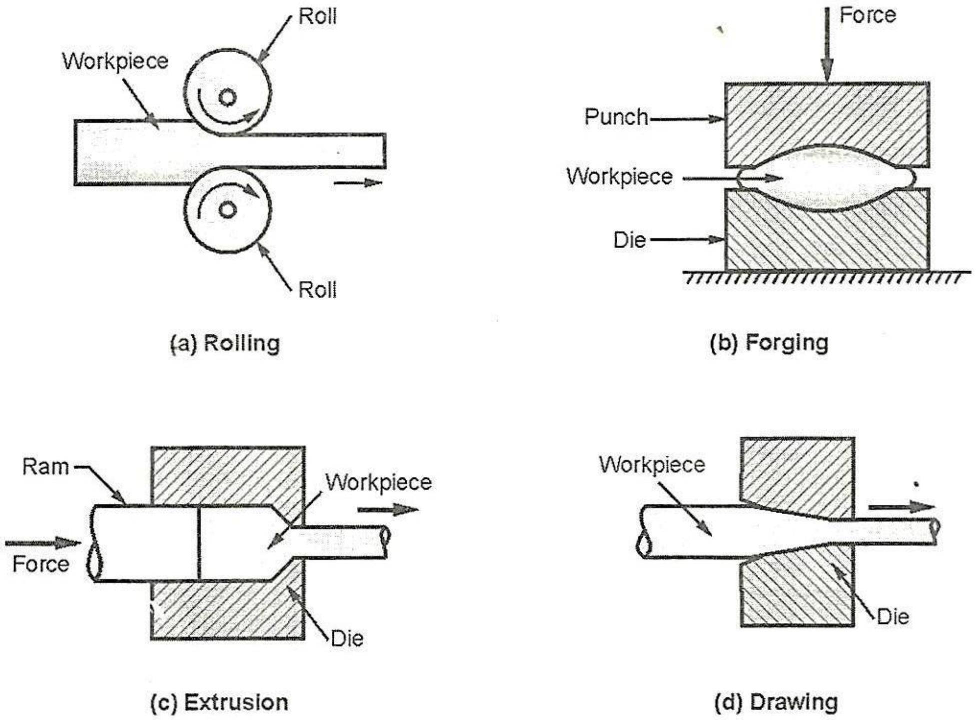

Fig. 3.2 : Basic bulk deformation processes

3. Extrusion

It is a compressive deformation process in which the work metal is forced to flow through a die opening as shown in figure3.2 (c). During the flow through a die, the work metal takes the shape of the opening as its cross-section.

4. Wire drawing

In this type of forming process, the diameter of a round bar (billet) is reduced by pulling it through a die opening. Figure 3.2 (d) shows the drawing process.

3.5.2 Sheet Metal Working Processes

In this type of metal forming processes, the operations are performed on metal sheets, strips and coils. In these processes, the surface area to volume ratio is high.

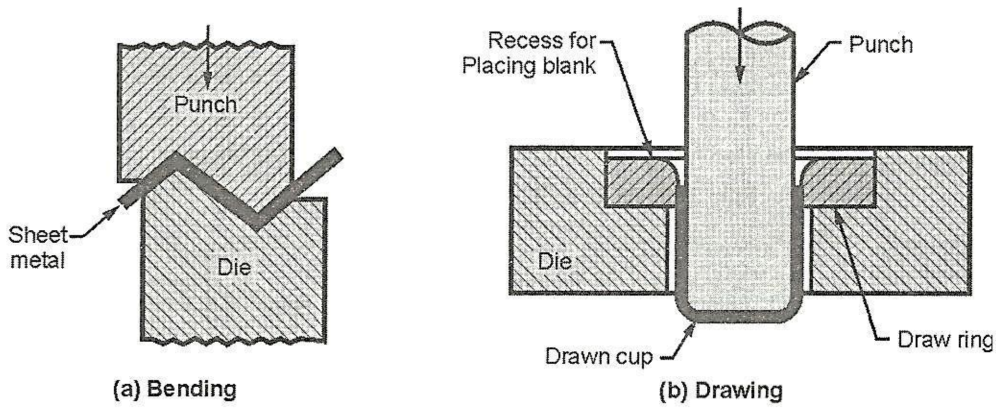

Fig. 3.3 : Basic sheet metal working operations

Generally, the sheet metal working processes are carried out on punching press machine, hence sheet metal working is also called as press working. A component produced by sheet metal working process is called as stamping. These operations are performed as cold working processes. The tools used for the operations is called as punch and die. The punch is a positive portion whereas the die is a negative portion of the tool set. Figure 3.3 shows the basic operations in sheet metal working process.

1. Bending

In this process, there is straining of metal sheet or plate to take an angle along a straight axis. Refer figure 3.3(a). The bending may be of V shape, U shape or any other shape.

2. Drawing or Cupping

It refers to the forming of a flat metal sheet into a hollow or concave shape like a cup by stretching the metal. During the process, a blank holder is used to hold the blank and the punch pushes into the sheet metal. Refer figure 3.3(b).

HOT WORKING PROCESSES

3.6 HOT ROLLING:

The process of rolling consists of passing the hot ingot through the two rolls, rotating in opposite directions, at a uniform peripheral speed. To confirm the desired thickness of the rolled section, the space between the rolls is adjusted and is always less than the thickness of the ingot being fed. Hence, to reduce the cross-section and increase the length of passing ingot, the rolls are squeezed. Refer Figure 3.4.

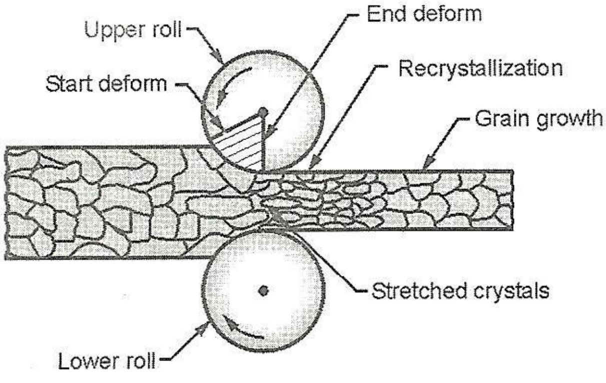

Fig. 3.4 : Hot rolling recrystallisation

When the metal passes through the rolls, there is change in its grain structure. Due to squeezing, the grains are elongated in the direction of rolling and the velocity of material at the exit is higher than that at the entry. After crossing the stress zone, the grains start refining.

3.6.1 Basic Definitions

The following are the basic terms used related to rolling process:

1. **Ingot:** Ingot is a large casting section of suitable shape made for further processing.
2. **Bloom:** A bloom is a square or rectangular piece formed after reducing ingots. The size of bloom ranges between 150 mm × 150mm to 250 mm × 250 mm. Rolling products from bloom: Structural shapes, Rails, etc.
3. **Billets:** Billets also formed after reducing ingot but have smaller cross sections. The size of billet ranges from 50 mm × 50 mm to 150 mm × 150mm. Rolling product from billets: Road, wires, etc.
4. **Slabs:** Slabs are metal pieces with rectangular cross section. It has thickness between 50-150 mm and width between 300-1500 mm. Rolling products from slabs: Sheets, plates, strips, etc.

3.6.2 Rolling of Various Sections

- The main purpose of rolling is to convert larger sections such as ingots into smaller sections, which can be used directly in as rolled state or stock for working through other processes.
- As a result of rolling, there is an improvement in physical properties of cast ingot such as strength, toughness, ductility, shock resistance, etc.

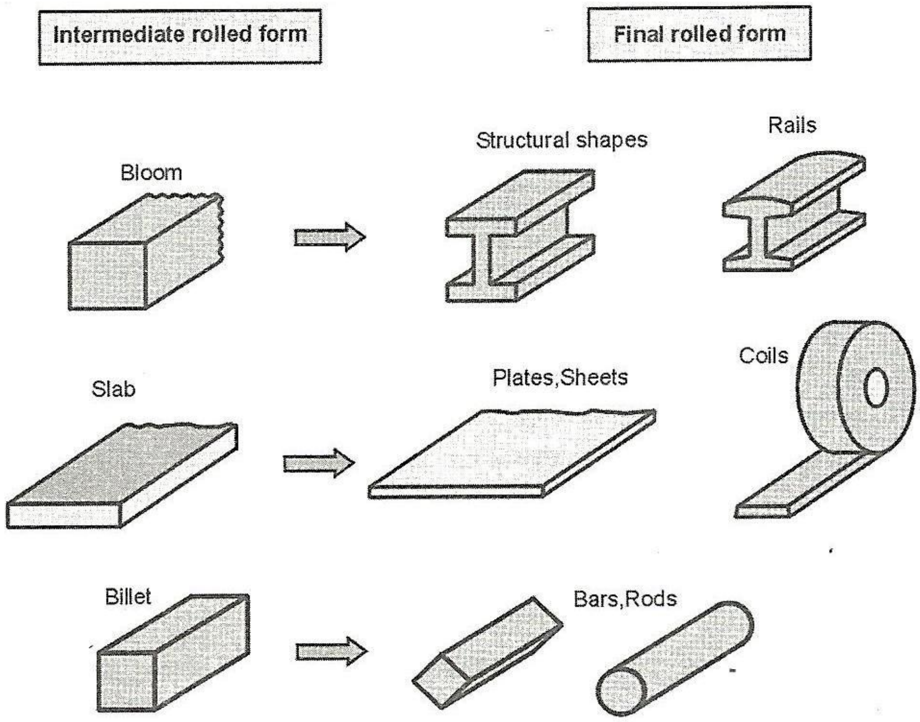

Fig. 3.5 : Steel components made from rolling

- Various useful articles like structural section, sheets, rails, plates and bars, etc. are produced through rolling.

- Figure 3.5 shows some commonly used rolled steel sections.
- The desired reduction in the cross-section of the billet and the required shape of the rolled section are not obtained in a single pass.

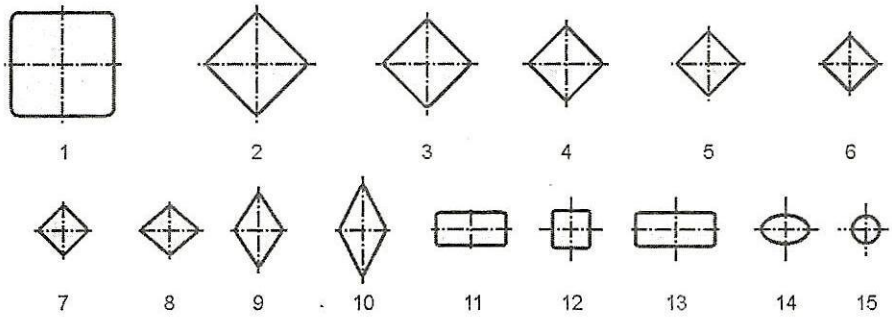

Fig. 3.6 : Various stages of rolling and number of passes for converting a steel billet into a round bar

- Figure 3.6 shows the sequence of rolling and the number of passes required to reduce the cross-section of a billet to a round steel bar.
- The process starts with the reduction of ingots which have been heated in a gas fired furnace up to a temperature of 1200 °C.
- The ingots are then taken to the rolling mill where they are rolled into immediate shapes as blooms, billets or slabs.
- A bloom has a square cross section with minimum size of 150 × 150 mm and a billet is smaller than bloom and it may have any square section from 38 mm up to the size of a bloom.
- Slabs have a rectangular cross section with a minimum width of 250 mm and minimum thickness of 38 mm.

3.6.3 Types of Rolling Mills

According to the number and arrangement of the rolls, rolling mills are classified as follows:

1. Two-high rolling mill
2. Three-high rolling mill
3. Four-high rolling mill
4. Tandem rolling mill
5. Cluster rolling mill
6. Planetary rolling mill
7. Universal rolling mill

1. Two-high rolling mill:

- It consists of two heavy horizontal rolls placed exactly one over the other.
- The space between the two rolls can be adjusted by raising or lowering the upper roll, whereas the position of the lower roll is fixed.
- Both the rolls rotate in opposite direction to each other. Refer figure 3.7 (a).