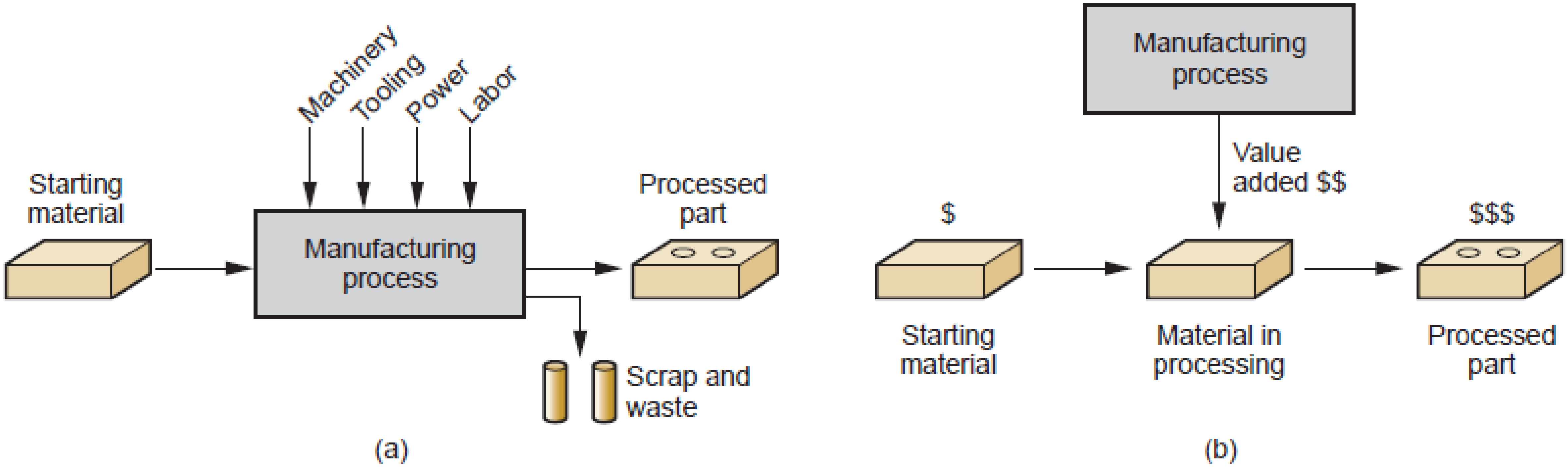
Manufacturing Processes (MEI102)- Overview

Manufacturing – In the modern context, manufacturing can be defined in two ways, (a) technologic, and (b) economic .

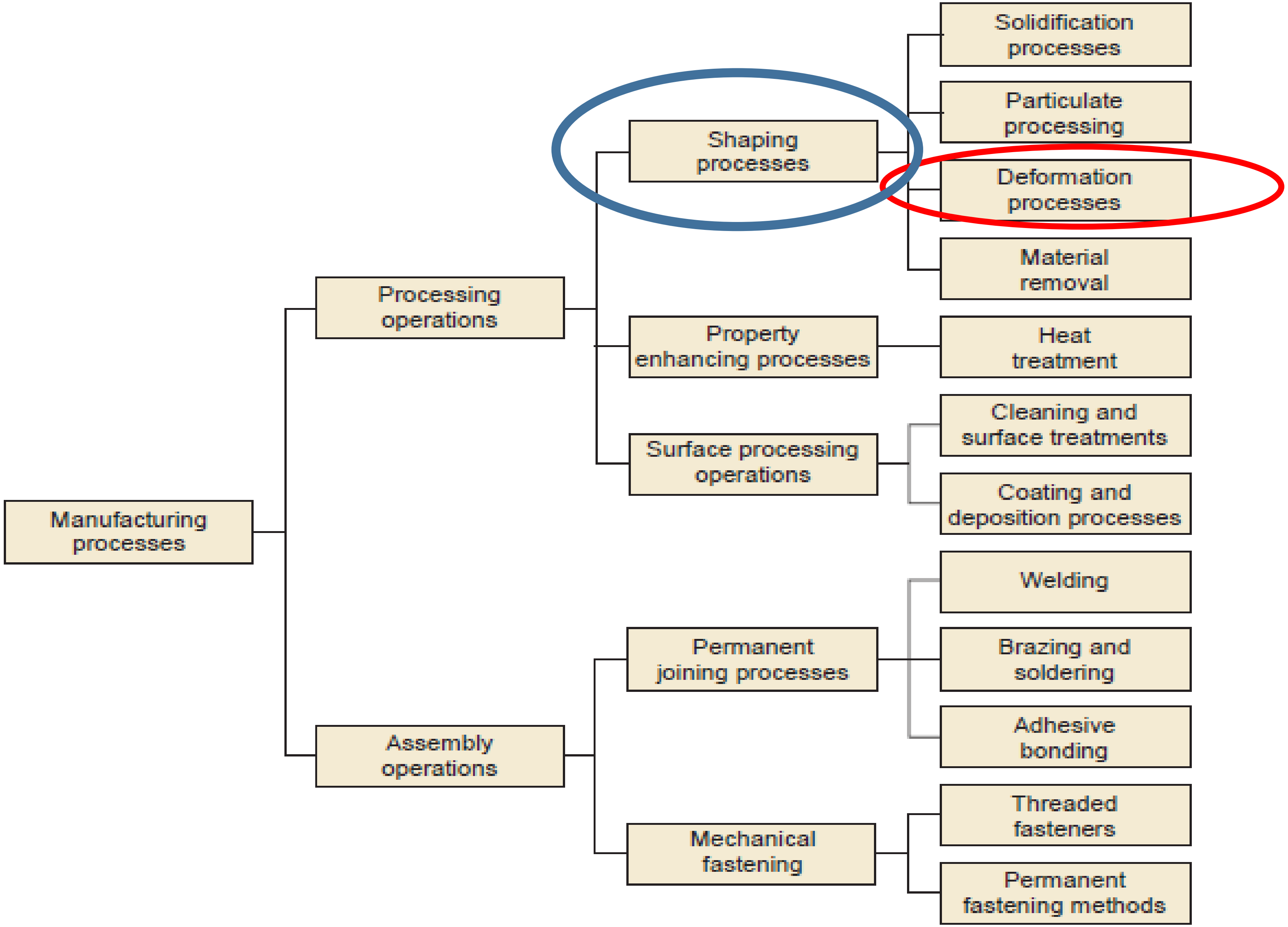


Manufacturing Processes- Brief Overview

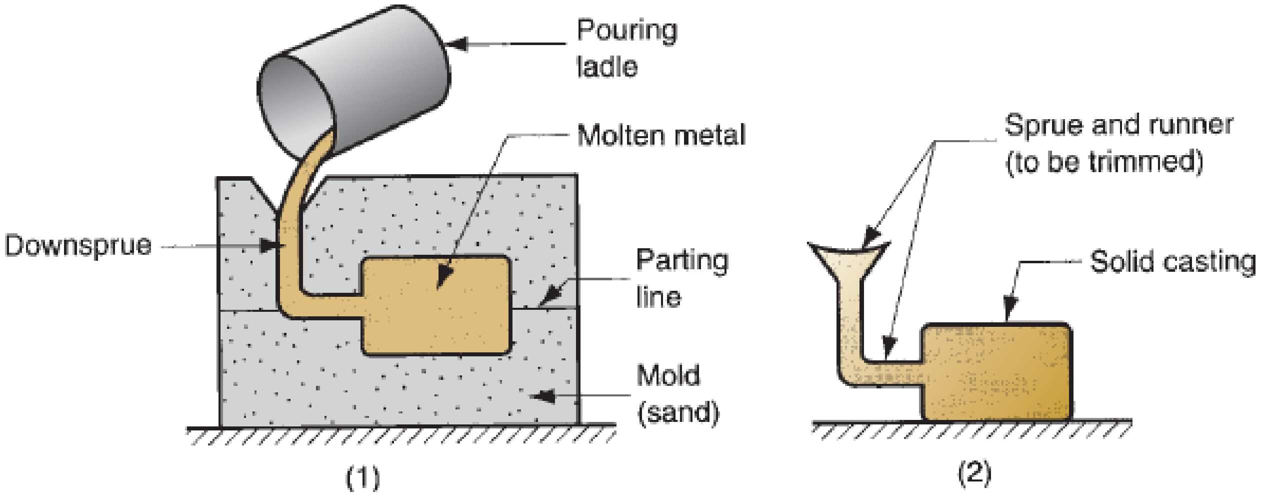
• Technologically, ***manufacturing is the application*** of physical and chemical processes to alter the geometry, properties, or appearance of a given starting material to make parts or products; manufacturing also includes assembly of multiple parts to make products. The processes to accomplish manufacturing involve a combination of machinery, tools, power, and labour.

• Economically, ***manufacturing is the transformation of materials into items of*** greater value by means of one or more processing and/or assembly operations. The key point is that manufacturing ***adds value to the*** material by changing its shape or properties, or by combining it with other materials that have been similarly altered.

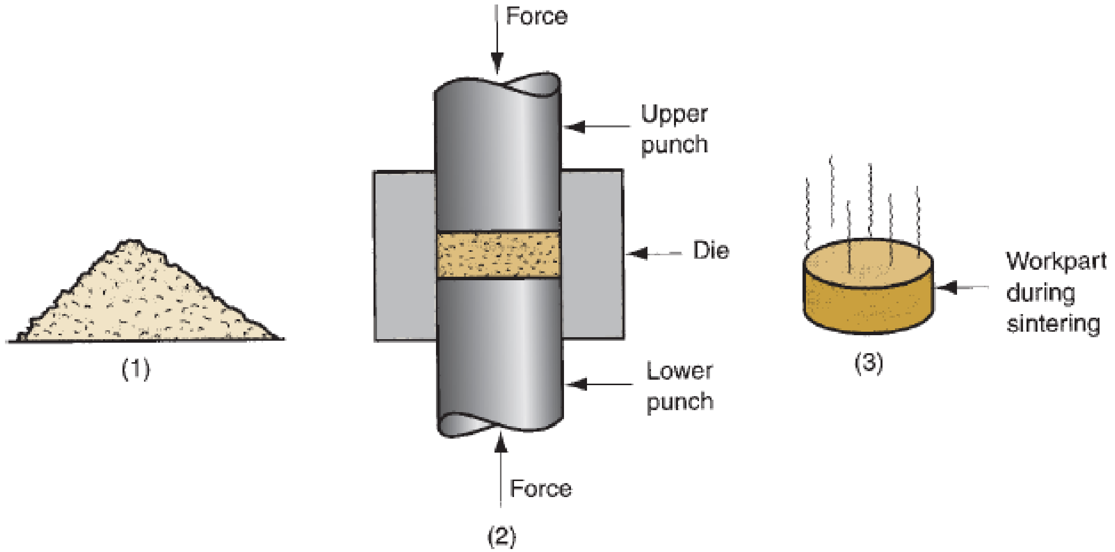
Manufacturing Processes- Types



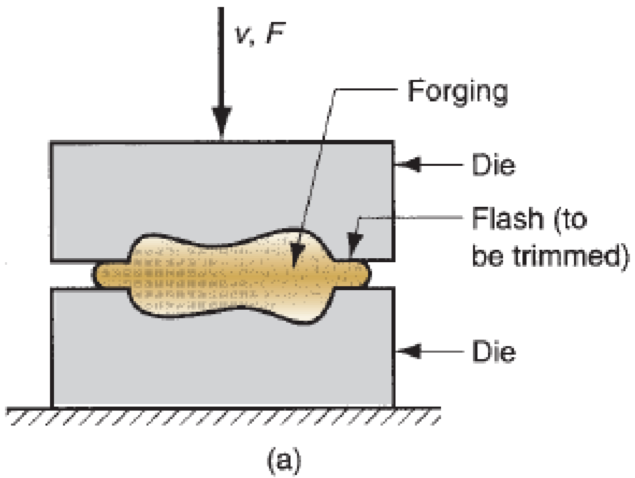
Shaping Processes- Brief Overview

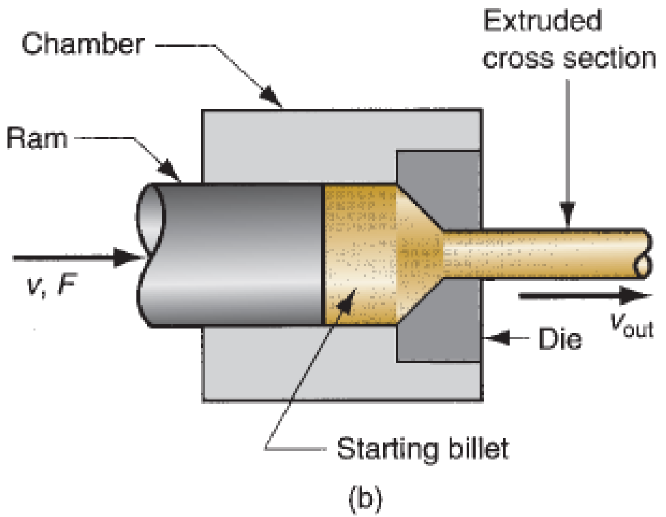


Solidification Processes -Sand Casting



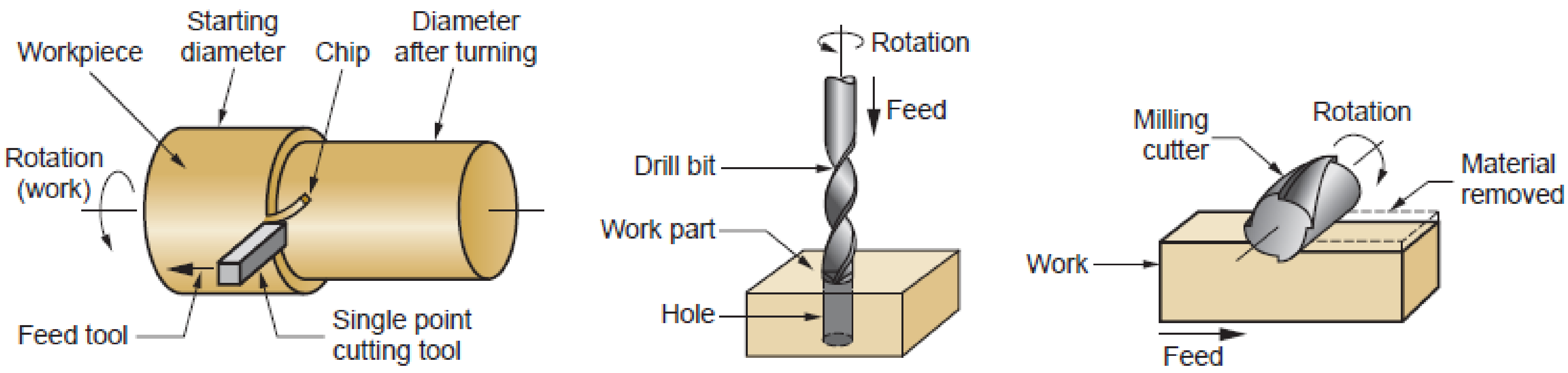
Particulate Processing- Powder Metallurgy





Deformation Processes –Forging and Extrusion

Shaping Processes- Brief Overview



(a) **Turning** (b) **Drilling** (c) **Milling**

Material Removal Processes/Machining

Introduction to Metal Forming

- ***Metal forming*** includes a large group of manufacturing processes in which **plastic deformation** is used to change the shape of metal workpieces.

- Deformation results from the use of a tool, usually called a ***die*** in metal forming, which applies stresses that exceed the yield strength of the metal.

- The metal therefore deforms to take a shape determined by the geometry of the die.

- Metal forming dominates the class of shaping operations

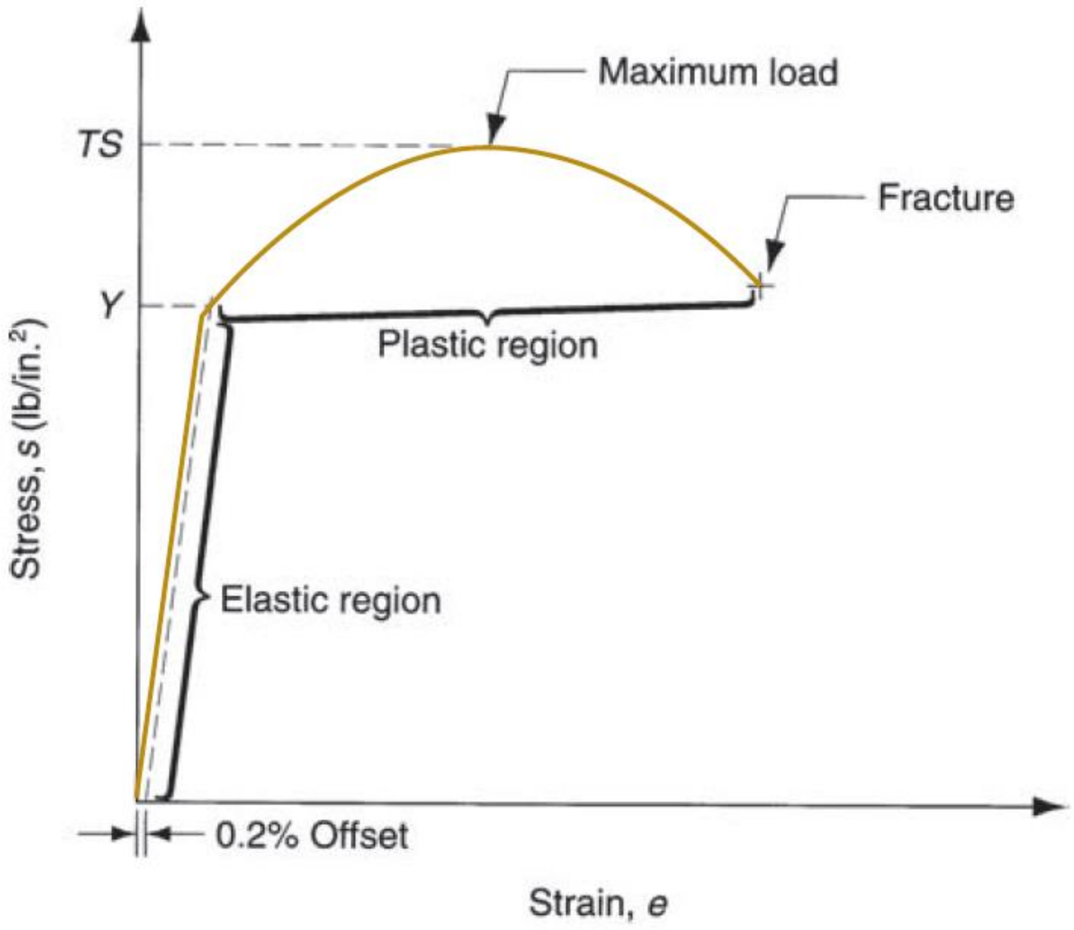
Material Behaviour in Metal Forming under Mechanical Load

- The typical stress–strain curve for most metals is divided into an elastic region and a plastic region.

- In metal forming, the plastic region is of primary interest because the material is plastically and permanently deformed in these processes.

- The typical stress–strain relationship for a metal exhibits elasticity below the yield point and strain hardening above it.

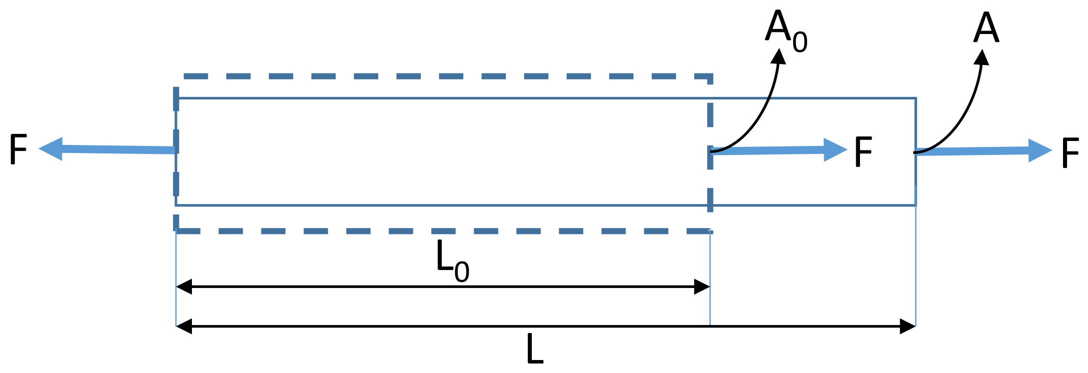
Typical Engineering Stress Strain Plot



Engineering Stress and Strain

The **engineering stress** is defined as the applied external force divided by the undeformed cross-sectional area.

$$s = \frac{F}{A_0}$$



The **engineering strain** is defined as deformation divided by the undeformed length.

$$e = \frac{L - L_0}{L_0}$$

True Stress and True Strain

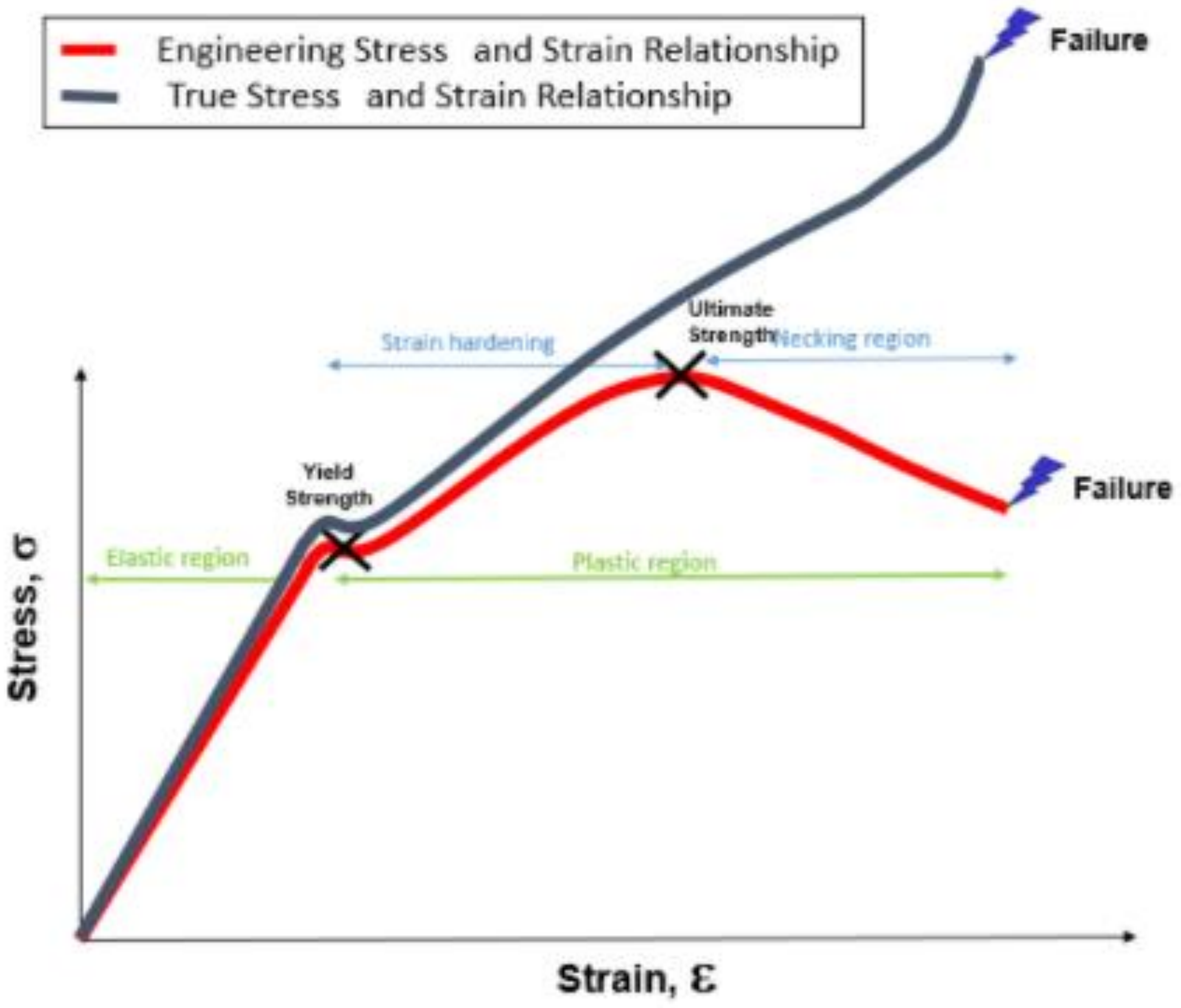
The **true stress** is defined as the applied load divided by the instantaneous cross-sectional area.

$$\sigma = \frac{F}{A}$$

The **true strain** is defined as the instantaneous elongation per unit instantaneous length, expressed as

$$\varepsilon = \int_{L_0}^{L} \frac{dL}{L} = \ln \frac{L}{L_0}$$

Comparison*



Relationship between True Stress and True Strain with Engineering Stress and Engineering Strain.

$$\sigma = s(1+e)$$

$$\varepsilon = \ln(1+e)$$

*figure taken from- *https://yasincapar.com/engineering-stress-strain-vs-true-stress-strain/*

Hooke's Law

In the elastic region, the relationship between stress and strain is linear. This is known as Hooke's law.

$$s = Ee$$

Where, E is the modulus of elasticity (also known as Young's Modulus, unit MPa), a measure of the inherent stiffness of the material. Hooke's law will also hold for true stress and true strain in the elastic region.

Ductility

The amount of strain that the material can endure before fracture is known as its ductility . Common measure of this property is percentage elongation (EL) before fracture. Also, percentage reduction in area (AR) is also regarded as a measure of ductility.

$$EL = \frac{L_f - L_0}{L_0}$$

$$AR = \frac{A_0 - A_f}{A_0}$$

Numerical Problem

A Tensile test specimen has a starting gage length =50 mm and a cross-sectional area= 200mm^2. During the test, the specimen yields under a load of 32,000 N (this is the 0.2% offset) at a gage length of 50.2 mm. The maximum load of 65,000 N is reached at a gage length of 57.7 mm just before necking begins. Final fracture occurs at a gage length of 63.5 mm. Determine (a) yield strength, (b) modulus of elasticity, (c) tensile strength, (d) engineering strain at maximum load, and (e) percentage elongation.

Solution

Solution: (a) Yield strength $Y = 32{,}000/200 = \mathbf{160\ MPa}$.

(b) Subtracting the 0.2% offset, engineering strain $e = (50.2 - 50.0)/50.0 - 0.002 = 0.002$

Rearranging Equation (3.3), modulus of elasticity $E = s/e = 160/0.002 =$ **80,000 MPa**.

(c) Tensile strength = maximum load divided by original area:
$TS = 65{,}000/200 = \mathbf{325\ MPa}$.

(d) By Equation (3.2), engineering strain at maximum load $e = (57.7 - 50)/50 = \mathbf{0.154}$.

(e) Percentage Elongation (Till Fracture)= $\dfrac{63.5-50}{50}\times 100 = 27\%$

Flow stress

Flow stress is defined as the instantaneous value of stress required to continue deforming the material—to keep the metal "flowing." The flow curve is expressed as:

$$\sigma = K\epsilon^{n}$$

where K the strength coefficient (MPa); and n is the strain hardening exponent. The stress and strain in the flow curve are true stress and true strain. The flow curve is generally valid as a relationship that defines a metal's plastic behavior in cold working.

Temperature in Metal Forming

- The flow curve is a valid representation of stress–strain behaviour of a metal during plastic deformation, particularly for cold working operations.
- For any metal, the values of K and n depend on temperature.
- Strength and strain hardening are both reduced at higher temperatures.

Temperature in Metal Forming

- These property changes are important because they result in lower forces and power during forming.

- In addition, ductility is increased at higher temperatures, which allows greater plastic deformation of the work metal.

- Three temperature ranges used in metal forming can be distinguished: cold, warm, and hot working.

Cold Working

- Cold working (also known as ***cold forming***) is metal forming performed at room temperature or slightly above.

- It is to be noted that the work metal must be ductile enough for undergoing cold working

Advantages of Cold Working

Significant advantages of cold forming compared to hot working are

(1) Greater accuracy can be achieved;

(2) Better surface finish;

(3) Higher strength and hardness of the part due to strain hardening;

(4) Desirable directional properties to be obtained in the resulting product;

(5) No heating of the work is required, which saves on furnace and fuel costs and permits higher production rates.

Cold Working

Owing to such advantages, many cold forming processes have become important mass-production operations. The amount of machining required can be minimized so that these operations can be classified as net shape or near net shape processes.

There are certain disadvantages or limitations associated with cold forming operations:

(1) higher forces and power are required to perform the operation;

(2) care must be taken to ensure that the surfaces of the starting work-piece are free of scale and dirt;

(3) ductility and strain hardening of the work metal limit the amount of forming that can be done to the part.

Disadvantages of Cold Working

- In some operations, the metal must be annealed in order to allow further deformation to be accomplished.
- In other cases, the metal is simply not ductile enough to be cold worked.
- To overcome the strain hardening problem and reduce force and power requirements, many forming operations are performed at elevated temperatures.
- There are two elevated temperature ranges involved, giving rise to the terms warm working and hot working.

Warm Working

Because plastic deformation properties are normally enhanced by increasing workpiece temperature, forming operations are sometimes performed at temperatures somewhat above room temperature but below the recrystallization temperature.

- The term *warm working* is applied to this second temperature range.
- The dividing line between cold working and warm working is often expressed in terms of the melting point for the metal.
- The dividing line is usually taken to be $0.3T_m$, where T_m is the melting point (absolute temperature) for the particular metal.

Hot Working

- Hot working involves deformation at temperatures above the recrystallization temperature.

- The recrystallization temperature for a given metal is about one-half of its melting point on the absolute scale.

- In practice, hot working is usually carried out at temperatures somewhat above $0.5T_m$.

Hot Working

- However, the deformation process itself generates heat, which increases work temperatures in localized regions of the part.
- This can cause melting in these regions, which is highly undesirable.
- Also, scale on the work surface is accelerated at higher temperatures.
- Accordingly, hot working temperatures are usually maintained within the range $0.5T_m$ to $0.75T_m$.

Hot Working

- The most significant advantage of hot working is the capability to produce substantial plastic deformation of the metal far more than is possible with cold working or warm working.
- The principal reason for this is that the flow curve of the hot-worked metal has a strength coefficient that is substantially less than at room temperature, the strain hardening exponent is zero (at least theoretically), and the ductility of the metal is significantly increased.

Hot Working

All of this results in the following advantages relative to cold working:

(1) the shape of the work part can be significantly altered,

(2) lower forces and power are required to deform the metal,

(3) metals that usually fracture in cold working can be hot formed,

(4) strength properties are generally isotropic

(5) no strengthening of the part occurs from work hardening

Hot Working

- This strengthening of the metal is often considered an advantage for cold working.

- However, there are applications in which it is undesirable for the metal to be work hardened because it reduces ductility, for example, if the part is to be subsequently processed by cold forming.

Disadvantages of hot working

(1) lower dimensional accuracy,

(2) higher total energy required (due to the thermal energy to heat the workpiece),

(3) work surface oxidation (scale),

(4) poorer surface finish,

(5) shorter tool life.

Hot Working and Recrystallization

- Recrystallization of the metal in hot working is a time-dependent process.
- Metal forming operations are often performed at high speeds that do not allow sufficient time for complete recrystallization during the deformation cycle itself.
- However, because of the high temperatures, recrystallization eventually does occur.
- Recrystallization and the substantial softening of the metal at high temperatures are the features that distinguish hot working from warm working or cold working.

Principle of Metal Forming, bulk deformation and sheet deformation process

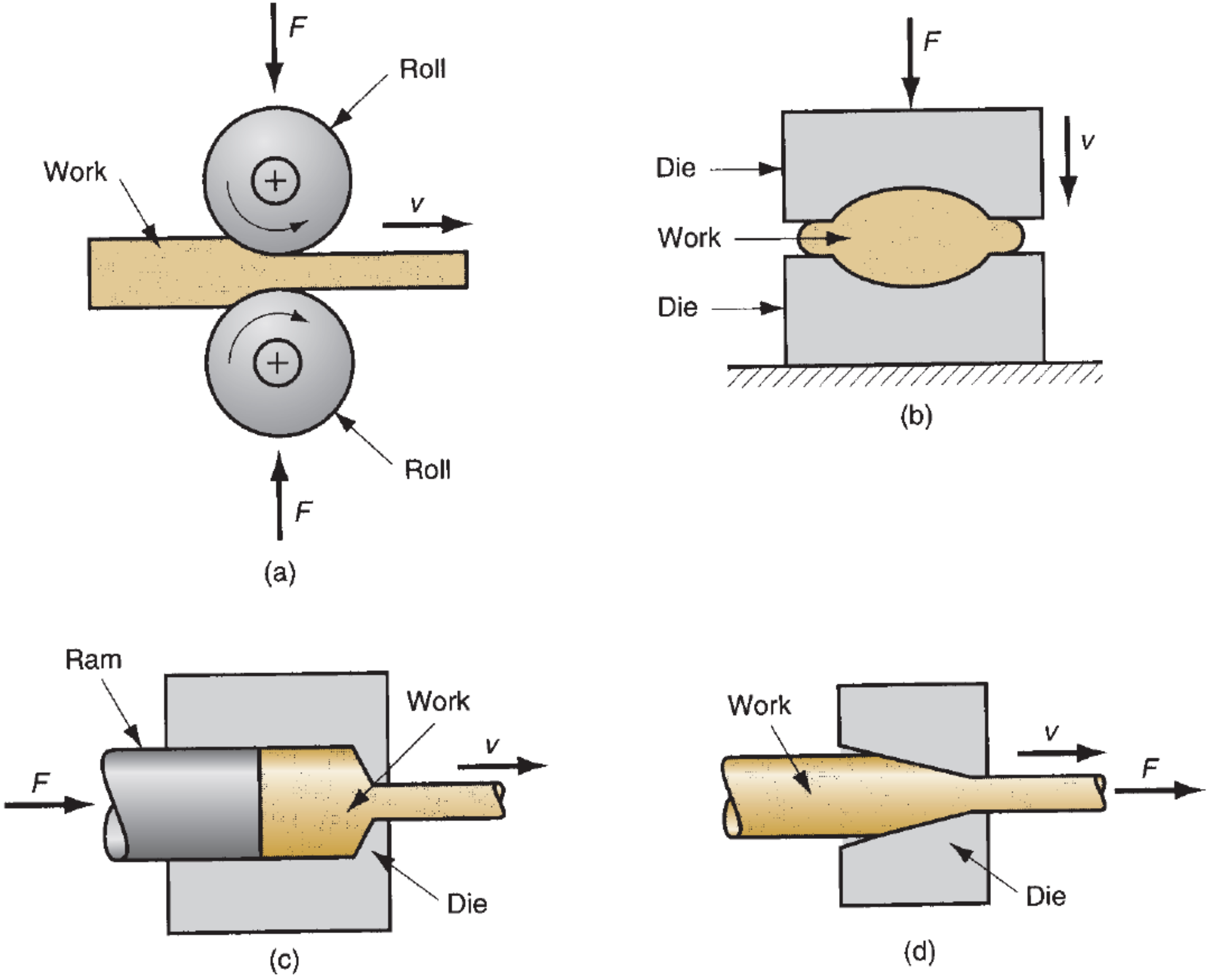
Bulk deformation Processes

(a)Rolling

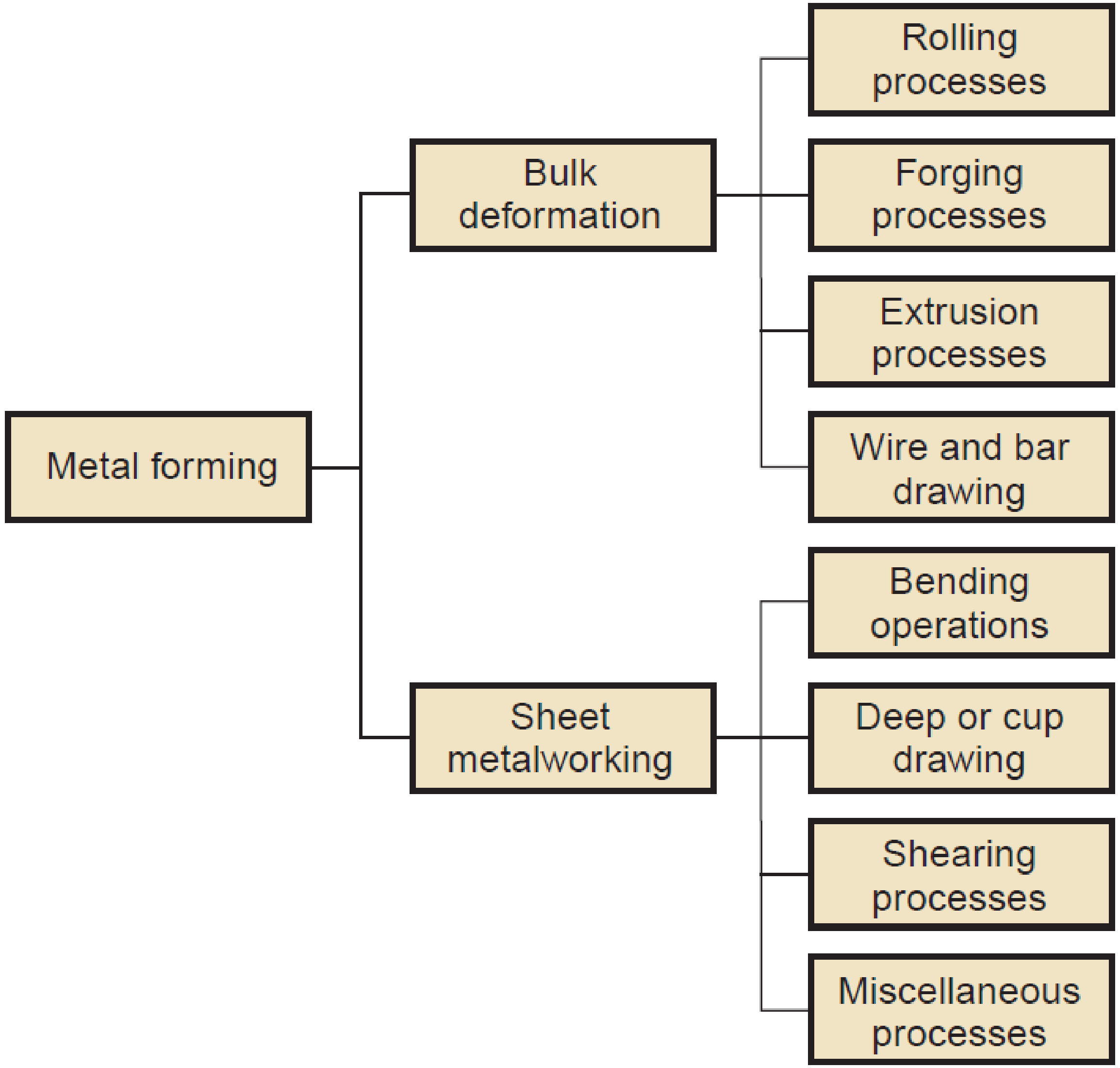
(b)Forging

(c)Extrusion

(d)Drawing



Classification of Metal Forming



Introduction

- Stresses applied to plastically deform the metal are usually compressive.

- However, some forming processes stretch the metal, while others bend the metal, and still others apply shear stresses to the metal.

- To be successfully formed, a metal must possess certain properties.

Introduction

- Desirable properties include low yield strength and high ductility.
- These properties are affected by temperature.
- Ductility is increased and yield strength is reduced when work temperature is raised.

Introduction

- The effect of temperature gives rise to distinctions between cold working, warm working, and hot working.

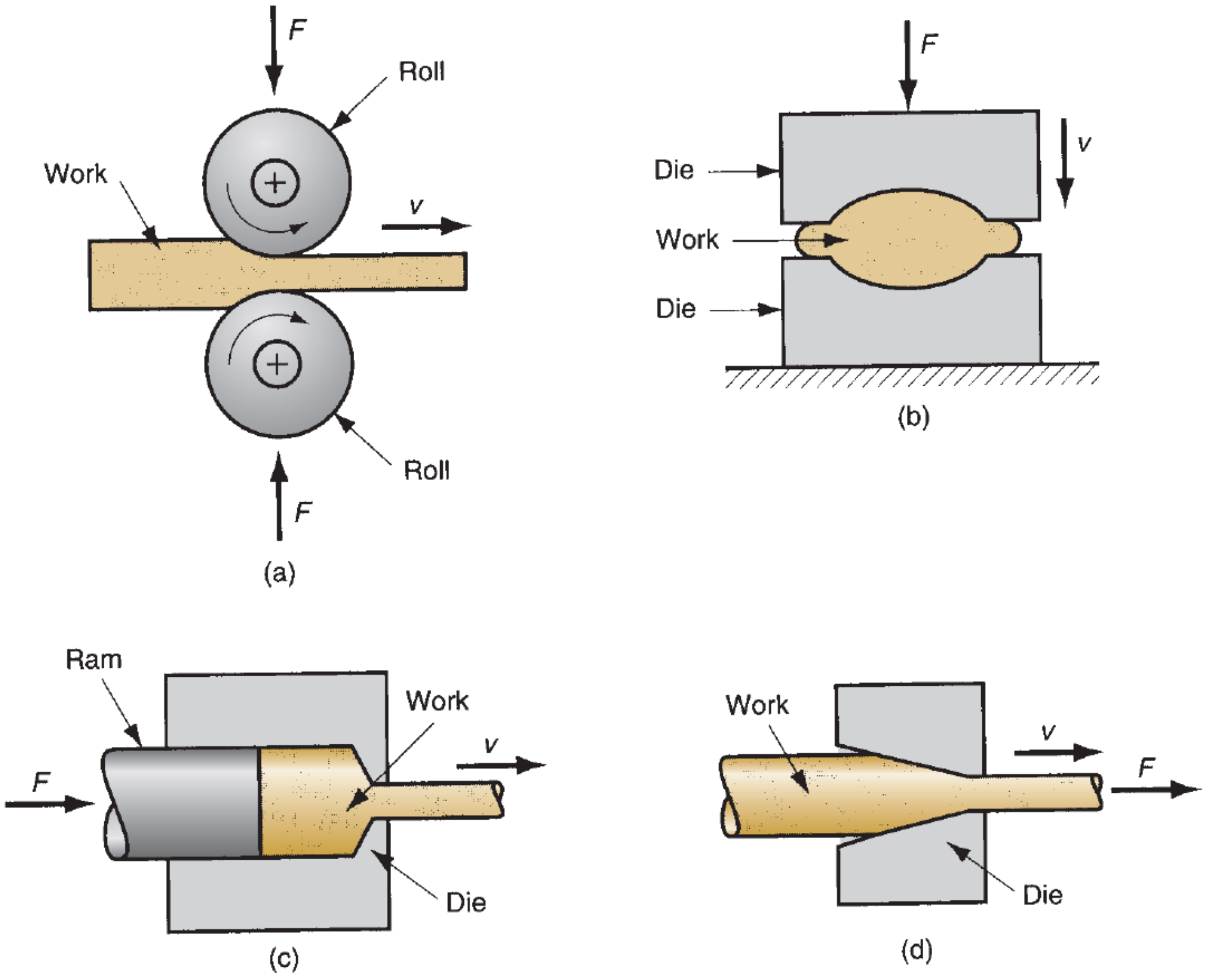
- Strain rate and friction are additional factors that affect performance in metal forming.

Bulk Deformation Processes

- Bulk deformation processes are generally characterized by significant deformations and massive shape changes, and the surface area– to–volume of the work is relatively small.

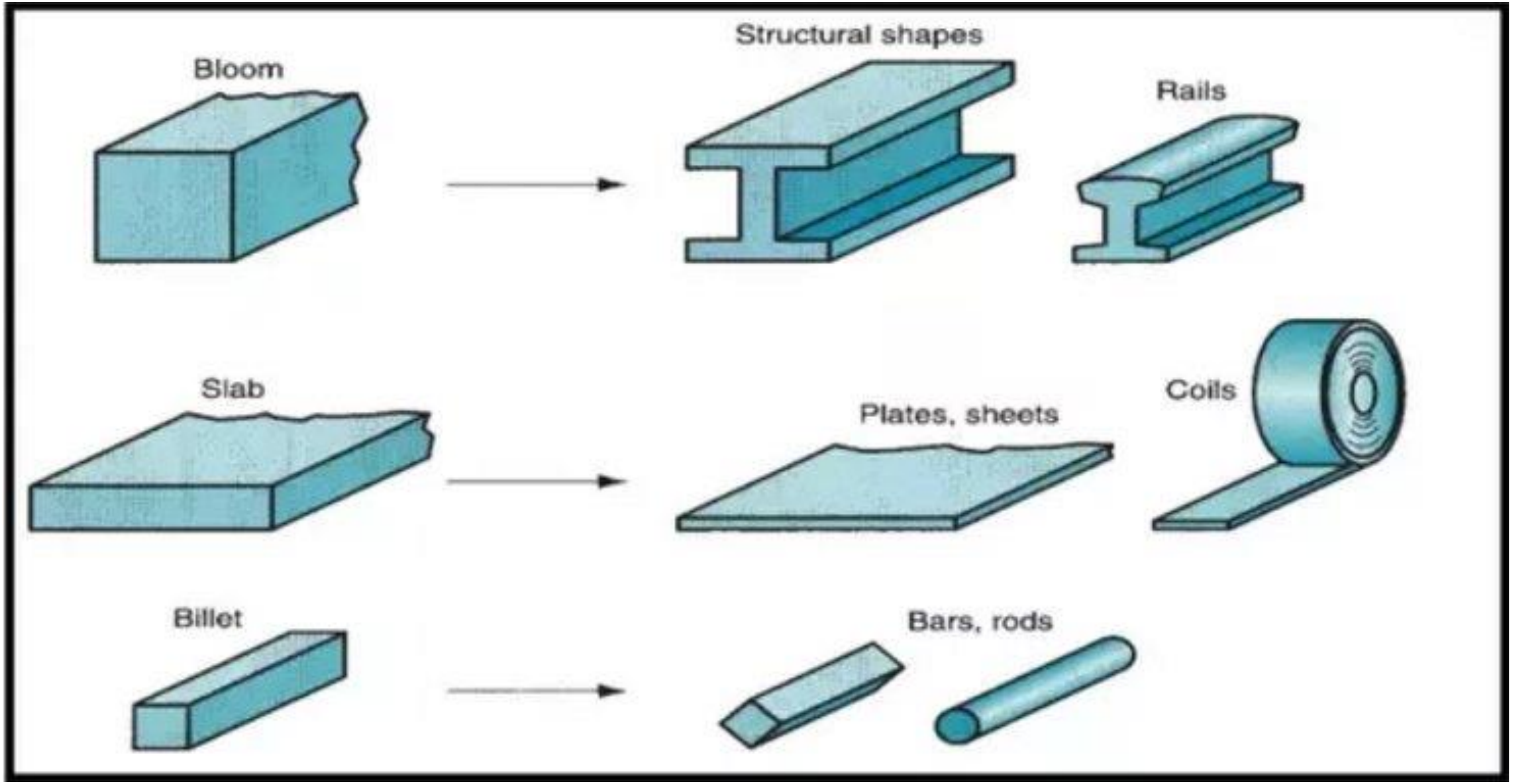
- The term ***bulk*** describes the work parts that have this low area–to–volume ratio.

- Starting work shapes for these processes include cylindrical billets and rectangular bars.



(a) rolling, (b) forging, (c) extrusion, and (d) drawing.

Blooms, Slabs and Billets



Blooms, Slabs and Billets

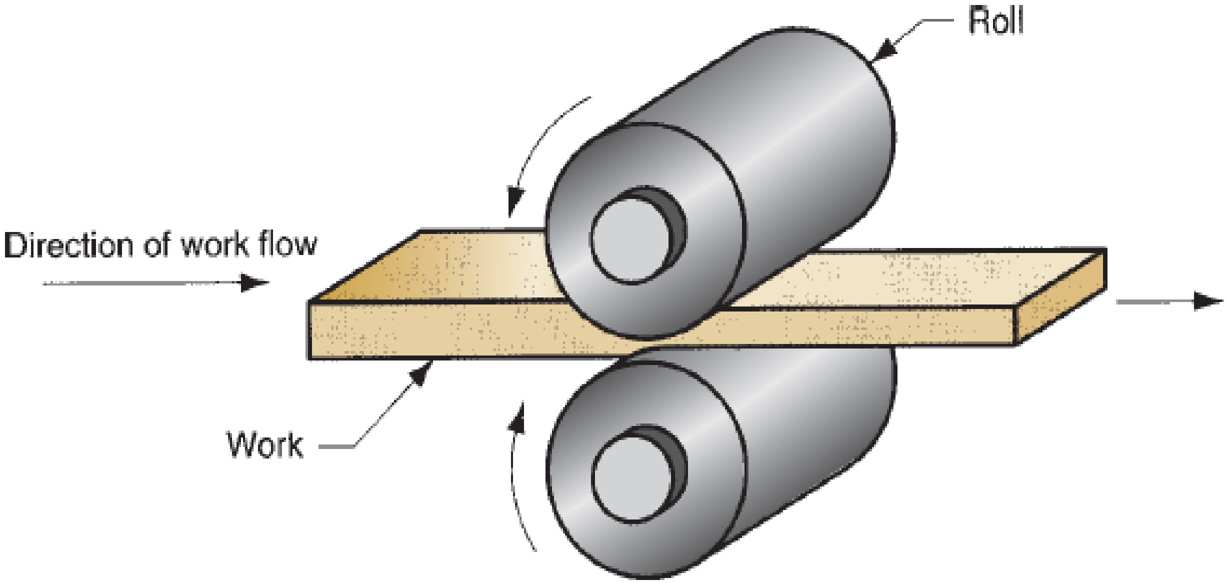
- A bloom is a rolled steel workpiece with a square cross section of about 150 mm by 150 mm. ...

- A slab is rolled from an ingot or a bloom and has a rectangular cross section of about 250 mm by 40 mm.

- A billet is rolled from a bloom and has a square cross section of about 40 mm by 40 mm.

Rolling

- This is a compressive deformation process in which the thickness of a slab or plate is reduced by two opposing cylindrical tools called rolls.
- Most Rolling operations involve hot working. It is called hot rolling.
- The rolls rotate so as to draw the work into the gap between them and squeeze it.

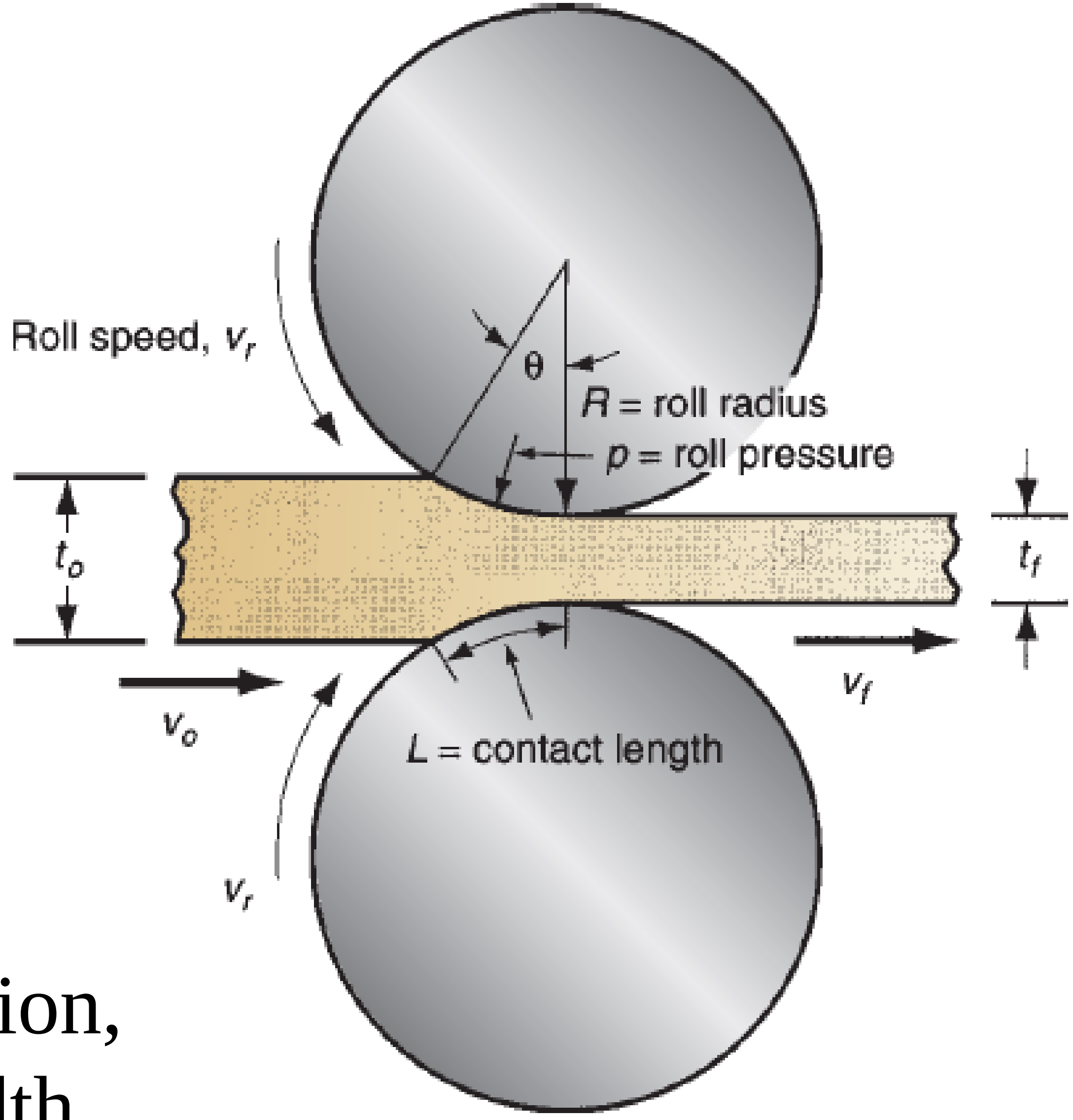


Flat Rolling

- It involves the rolling of slabs, strips, sheets and plates- work parts of rectangular cross-section in which width is greater than the thickness.

- Draft d is defined as $d = t_o - t_f$

- In addition to the thickness reduction, rolling usually increases work width (Spreading).



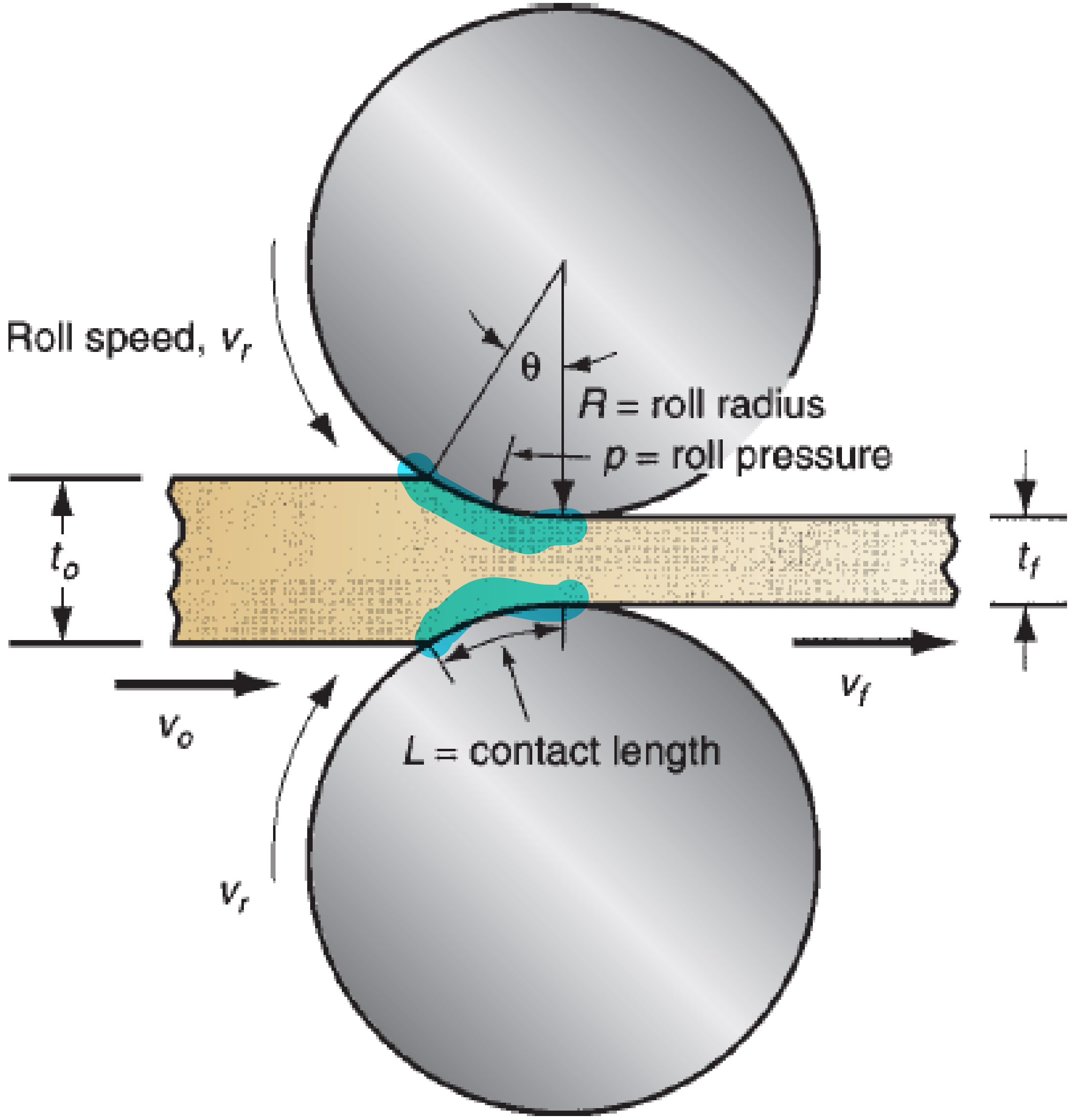
Flat Rolling

- Conservation of matter is preserved, therefore,

$$t_o w_o v_o = t_f w_f v_f$$

- The rolls contact the work along the arc-length defined by the angle θ.

- The roll rotational speed v_r is greater than the entering speed v_o and less than the leaving speed v_f.

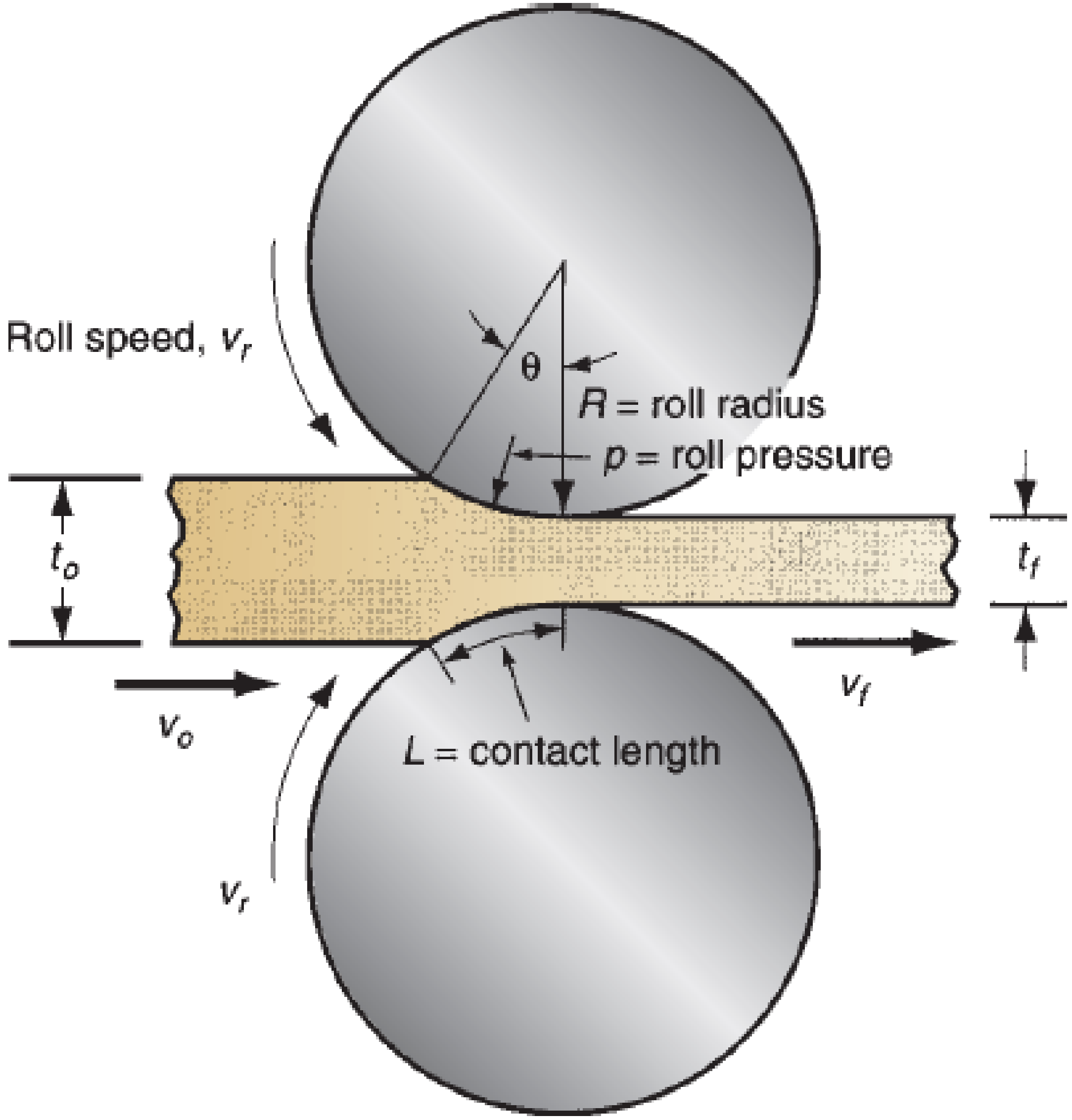


Flat Rolling

- There is one point along the arc where work velocity equals the roll velocity. This is called neutral point (no-slip).

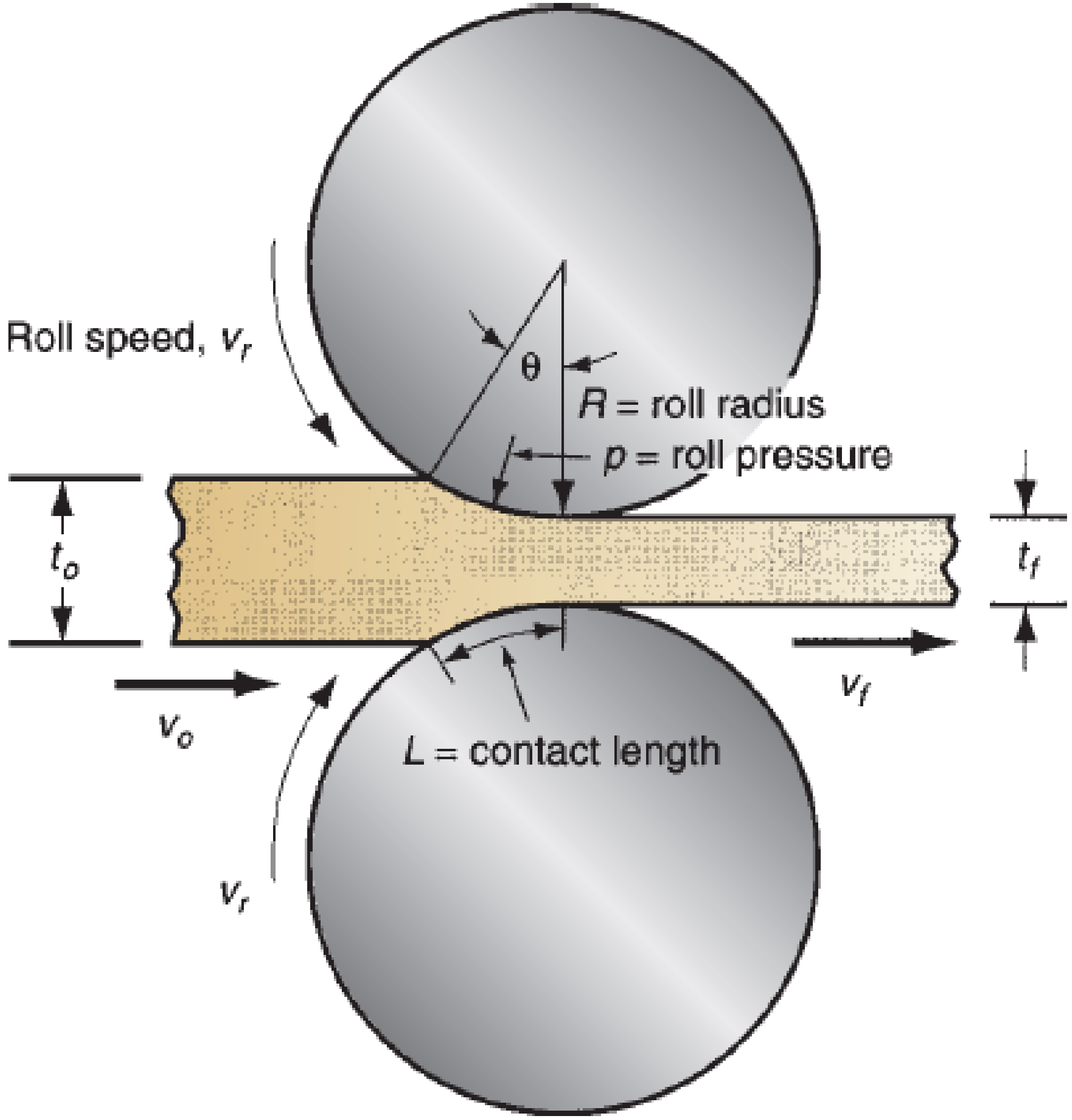
- On the entrance side of no-slip, sliding friction is forward. On the other side, friction is backward.

- Maximum possible draft is given by $d_{max} = \mu^2 R$.



Flat Rolling - Numerical

A 300 mm wide strip 25 mm thick is fed through a rolling mill each of radius 250 mm. The work thickness is to be reduced to 22 mm in one pass. Assume the coefficient of friction to be 0.12 . Is this operation possible.



Shape Rolling

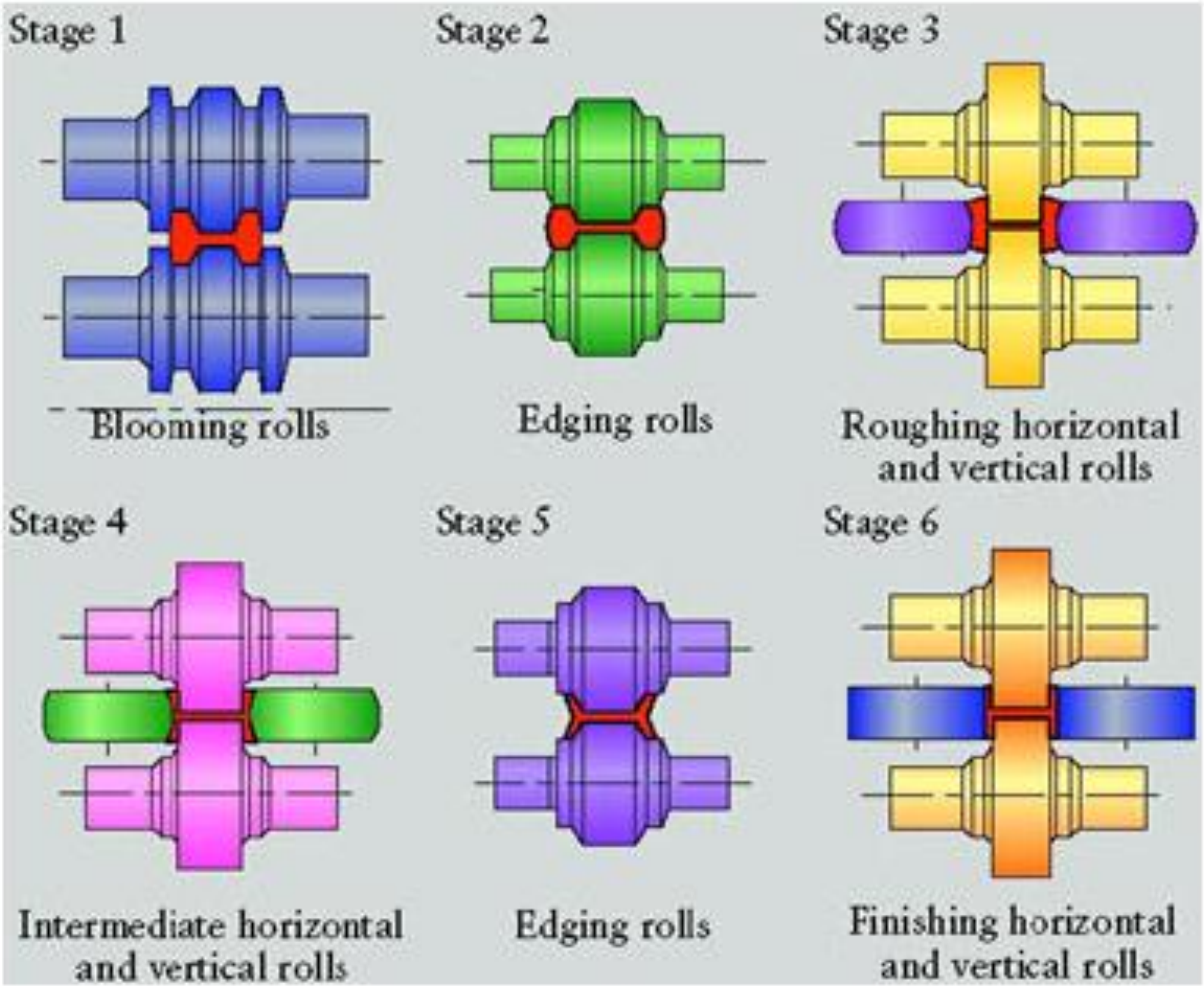
- Shape rolling is a process in which a square cross-section is formed into a shape such as an I-beam. The work is deformed into a contoured cross-section. Examples, construction shapes like, I-beam, L-beams and U-channels.

- More complicated; requires a gradual transformation through several rolls to achieve the final cross-section.

- Designing the sequence of intermediate steps and corresponding rolls is called the roll-pass design.

Shape Rolling - Illustration

The stages in shape rolling of an H-section part can be seen in the Figure



Rolling- Some important aspects

- Steel is a strong material that is highly resistant to shaping at normal temperatures but this resistance lessens considerably at higher temperatures.

- The process of heating the starting work material till it reaches the desired temperature for rolling, throughout the material, is called soaking.

Forging

- In forging, a workpiece is compressed between two opposing dies, so that the die shapes are imparted to the work.

- The compression is provided either through impact or by using gradual pressure.

- A forging machine that applies an impact load is called a forging hammer, while one that applies gradual pressure is called forging press.

Forging - Types

- Difference among forging operations is the degree to which the flow work metal is constrained by the dies. Based on this, there are three types of forging operations:

1. Open-Die Forging

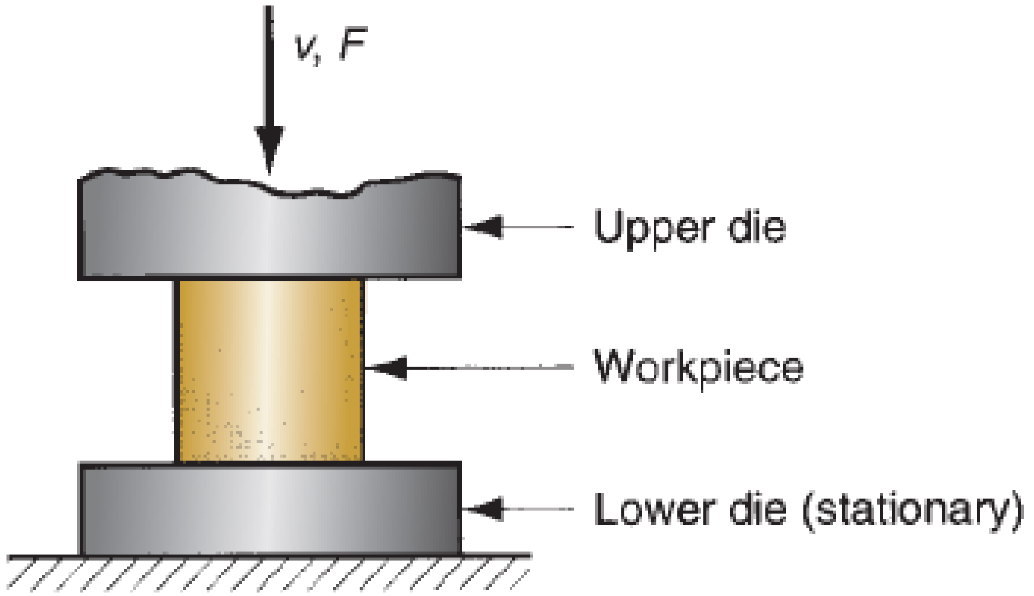
2. Impression Die Forging

3. Flashless Forging

Open Die Forging

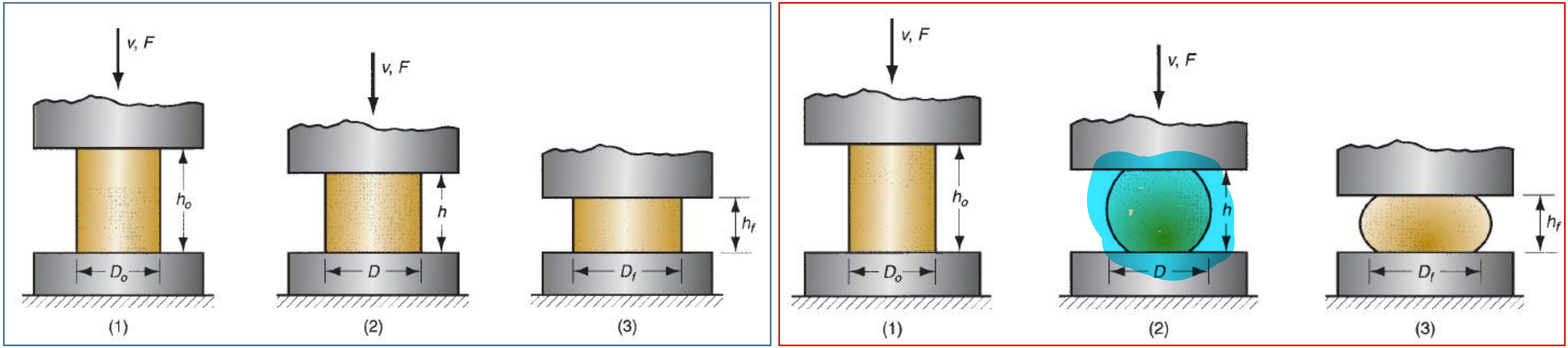
- In open die forging the work is compressed out between two flat dies.

- This allows the metal to flow without constraint in the lateral direction relative to the die surfaces.



Open Die Forging

- The simplest case of open-die forging, compression of a cylindrical work part. This known as upsetting or upset forging.
- In actual upsetting, friction opposes the flow of work metal.

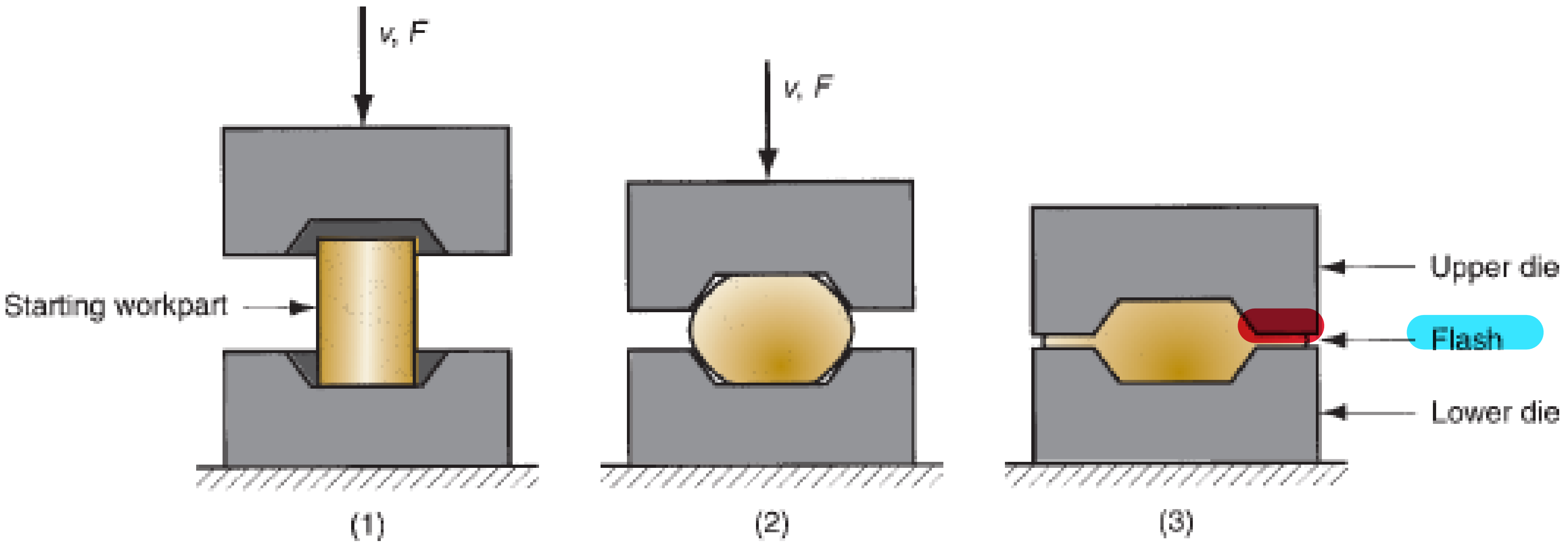


Homogeneous deformation → **Actual deformation**

This is known as the barrelling effect

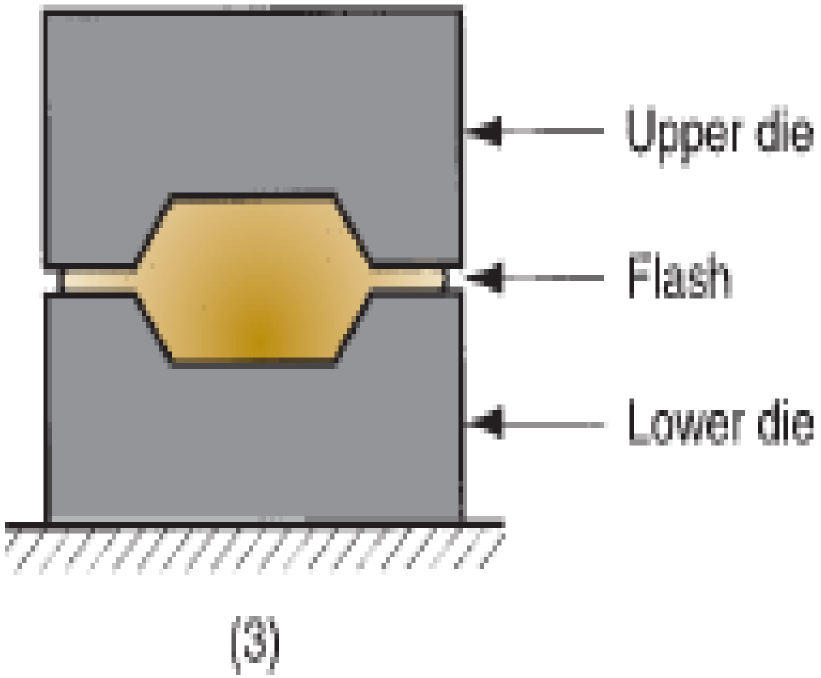
Impression Die Forging

- Impression-die forging, sometimes called ***closed-die forging***, is performed with dies that contain the inverse of the desired shape of the part. The process is illustrated in a three-step sequence:



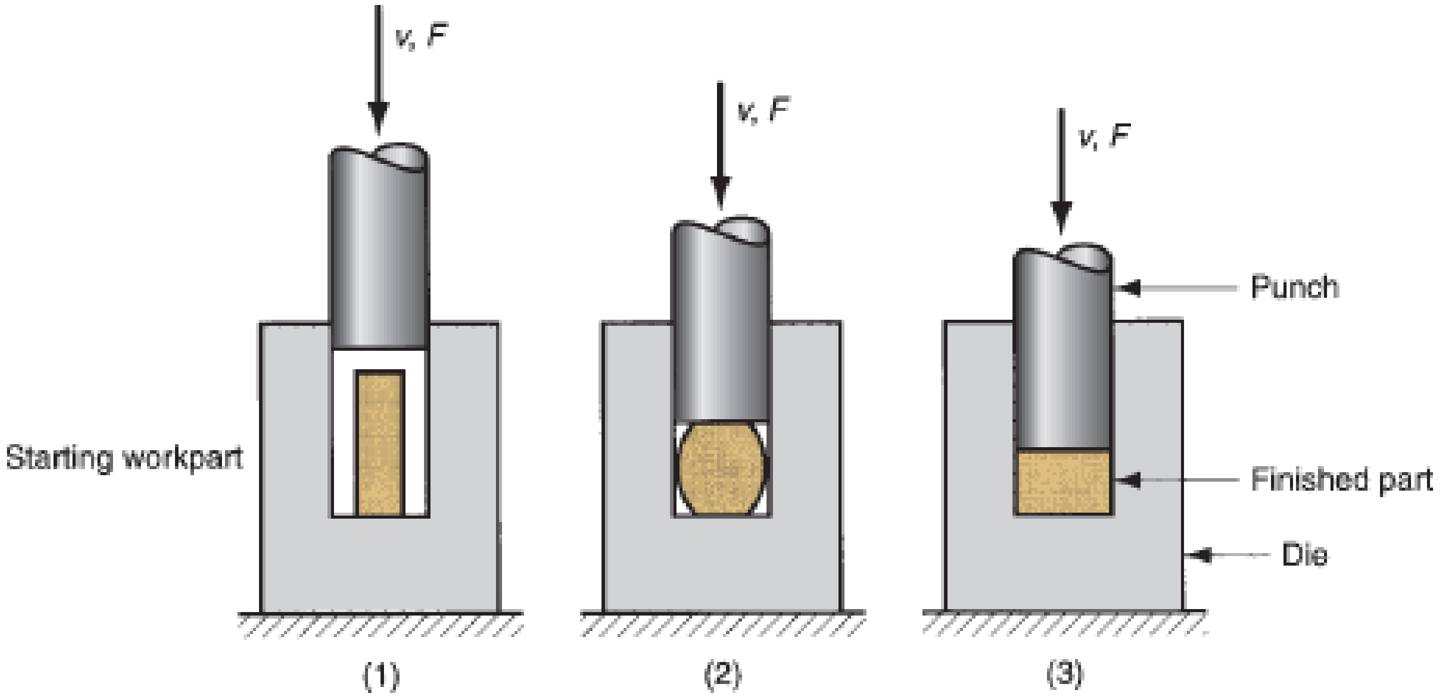
Impression Die Forging

- As the flash begins to form in the die gap, friction resists continued flow of metal into the gap, thus constraining the bulk of the work material to remain in the die cavity.
- Restricting metal flow in the gap causes the compression pressures on the part to increase significantly, thus forcing the material to fill the sometimes intricate details of the die cavity to ensure a high-quality product.



Flashless Forging

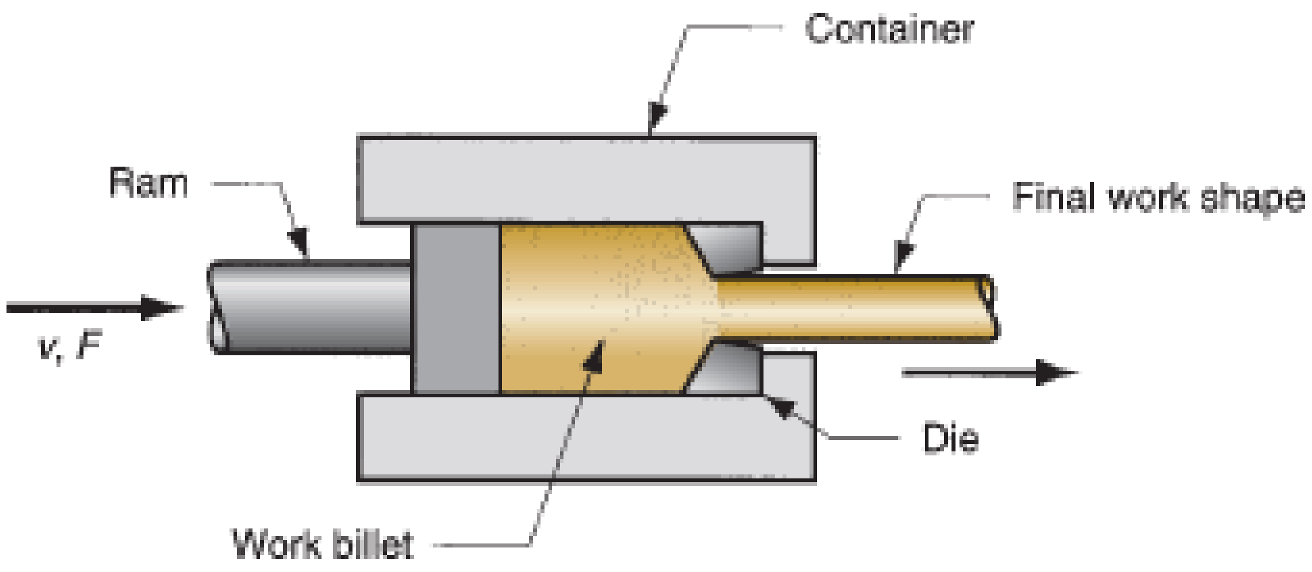
- In ***flashless forging***, the work is completely constrained within the die and no excess flash is produced. The volume of the starting work piece must be controlled very closely so that it matches the volume of the die cavity.



Extrusion

- ***Extrusion***- This is a compression process in which the work metal is forced to flow through a die opening, thereby taking the shape of the opening as its own cross section.

The process can be likened to squeezing a toothpaste out of a toothpaste tube.



Extrusion

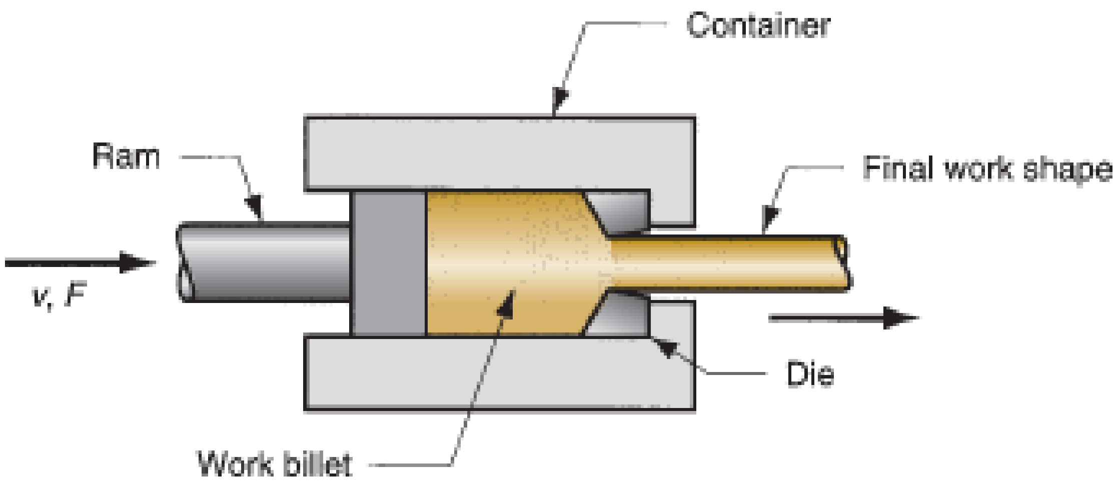
Advantages:

- A variety of shapes are possible with warm/hot extrusion
- Strength properties are enhanced in cold extrusion
- Fairly close tolerances are possible in cold extrusion

Types- a) Direct Extrusion b) Indirect Extrusion

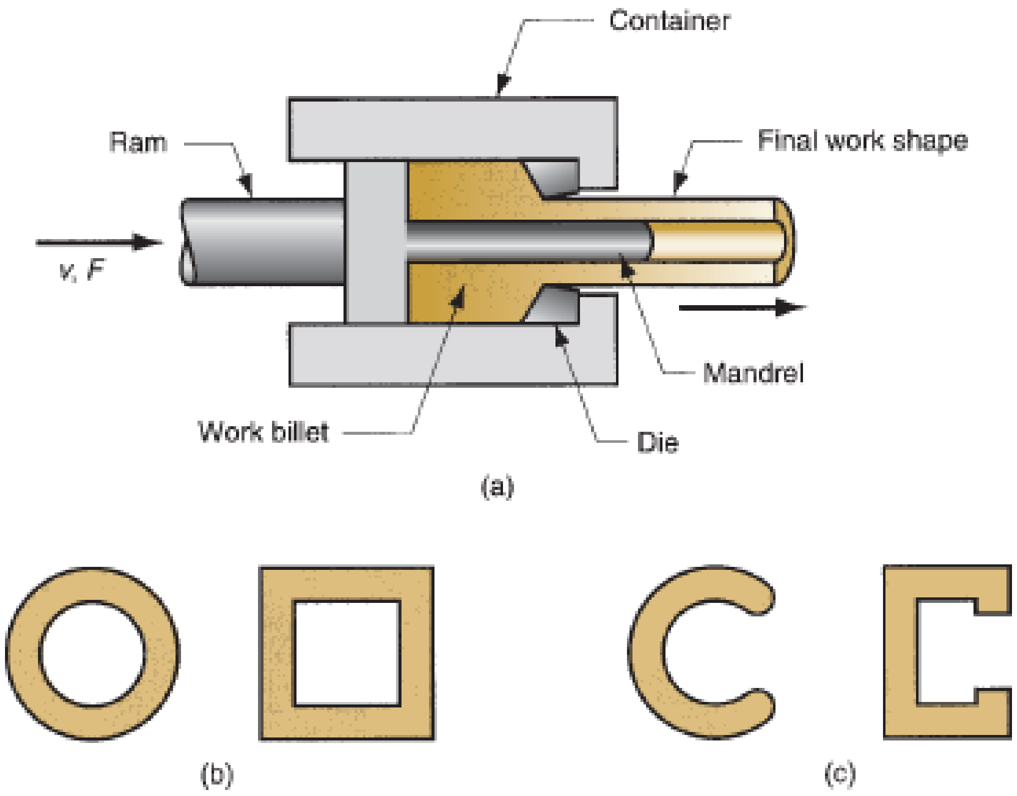
Extrusion- Direct

For solid sections, a metal billet is loaded into a container, and a ram compresses the material, forcing it to flow through one or more openings in a die at the opposite end of the container. As the ram approaches the die, a small portion of the billet remains that cannot be forced through the die opening. This extra portion, called the ***butt***, is separated from the product by cutting it later.



Extrusion- Direct

Hollow sections (e.g., tubes) are possible in direct extrusion by the process setup shown. The starting billet is prepared with a hole parallel to its axis. This allows passage of a mandrel that is attached to the dummy block. As the billet is compressed, the material is forced to flow through the clearance between the mandrel and the die opening. The resulting cross section is tubular.

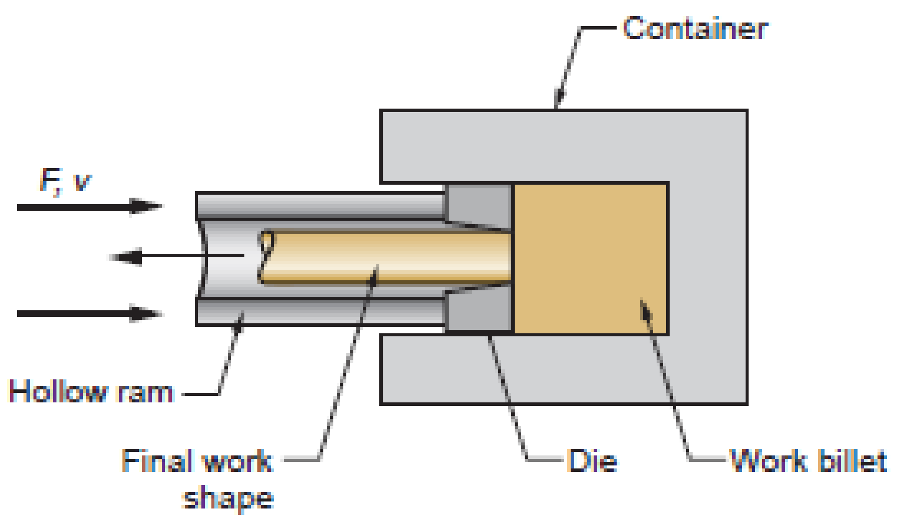


Limitation- *High friction between the billet and the container*

Extrusion- Indirect

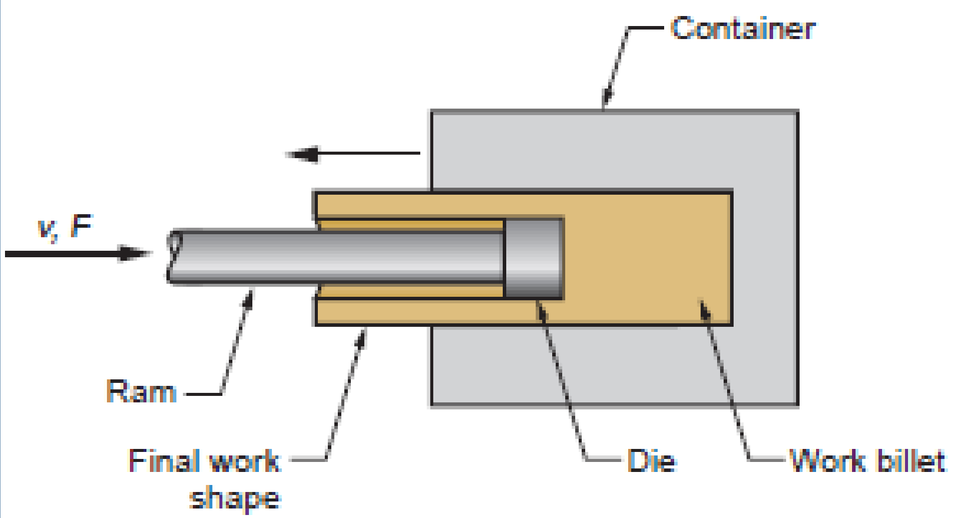
In ***indirect extrusion***, also called ***backward extrusion*** and ***reverse extrusion***, the die is mounted to the ram rather than at the opposite end of the container. As the ram penetrates into the work, the metal is forced to flow through the clearance in a direction opposite to the motion of the ram. Since the billet is not forced to move relative to the container, there is no friction at the container walls, and *the ram force is therefore lower than in direct extrusion.*

Solid sections



(a)

Tubular sections



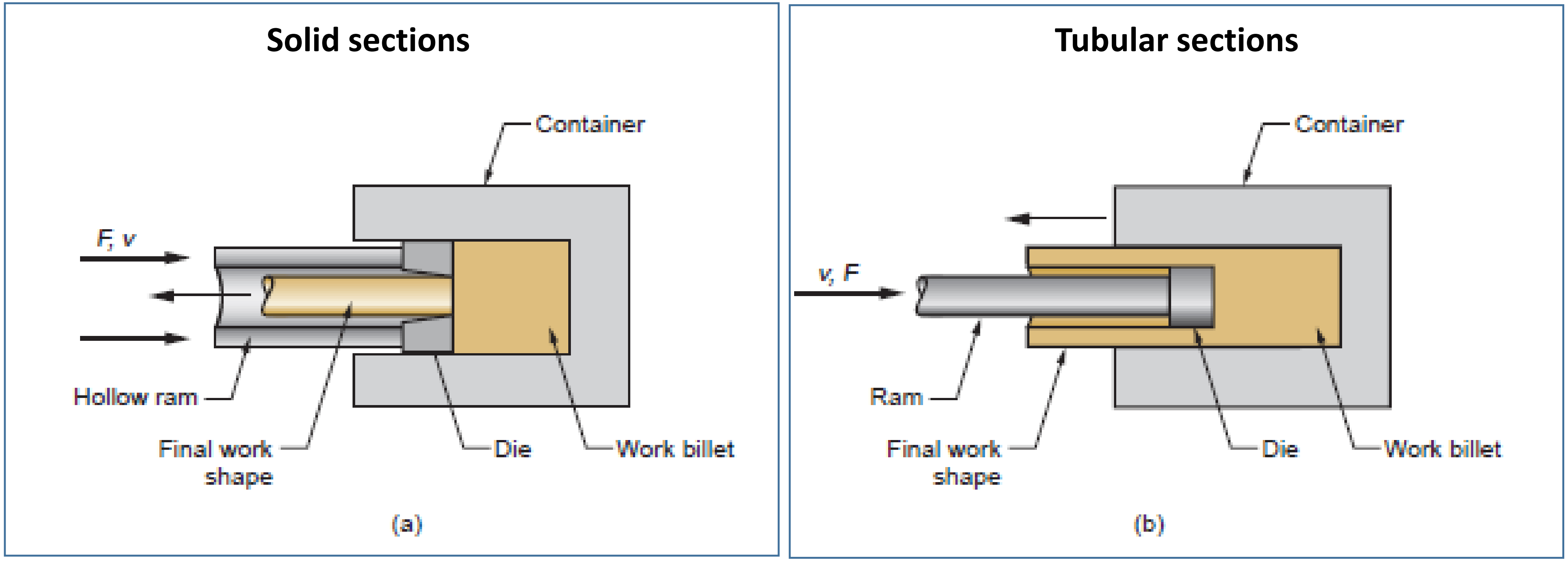
(b)

Extrusion- Indirect

Limitations:

1. Length of the extruded part is limited due to the difficulty in supporting the ram and the extruded part.

2. Lower rigidity of the hollow ram.



Drawing (Wire and Bar Drawing)

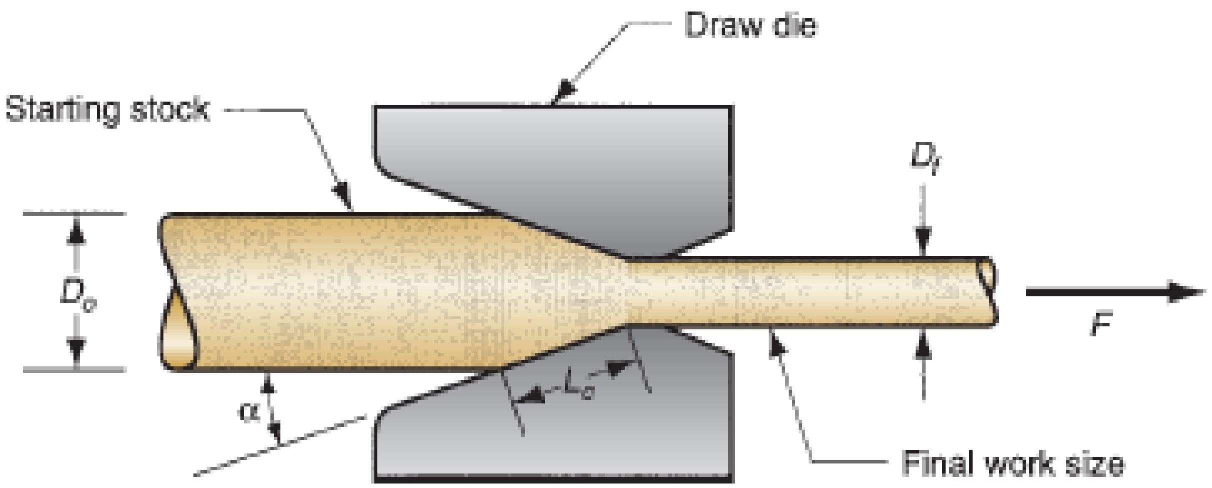
- In this forming process, the ***diameter of a round wire or bar is reduced by pulling it through a die opening***.

- The process is similar to extrusion except that work is pulled through the die opening.

- Drawing is a term also used in sheet metalworking. However, the term **wire and bar drawing** is used to distinguish the drawing process discussed here from the sheet metal process of the same name.

Drawing (Wire and Bar Drawing)

- The difference between bar drawing and wire drawing is the stock size that is processed. ***Bar drawing*** is the term used for large diameter bar and rod stock, while ***wire drawing*** applies to small diameter stock. Wire sizes down to 0.03 mm (0.001 in) are possible.



- Bar drawing is generally accomplished as a ***single-draft*** operation—the stock is pulled through one die opening. Wire drawing, however, is continuous. The wire coil passes through a number of dies.

Sheet Metalworking

- **Sheet Metalworking** operations performed on metal sheets, strips, and coils.

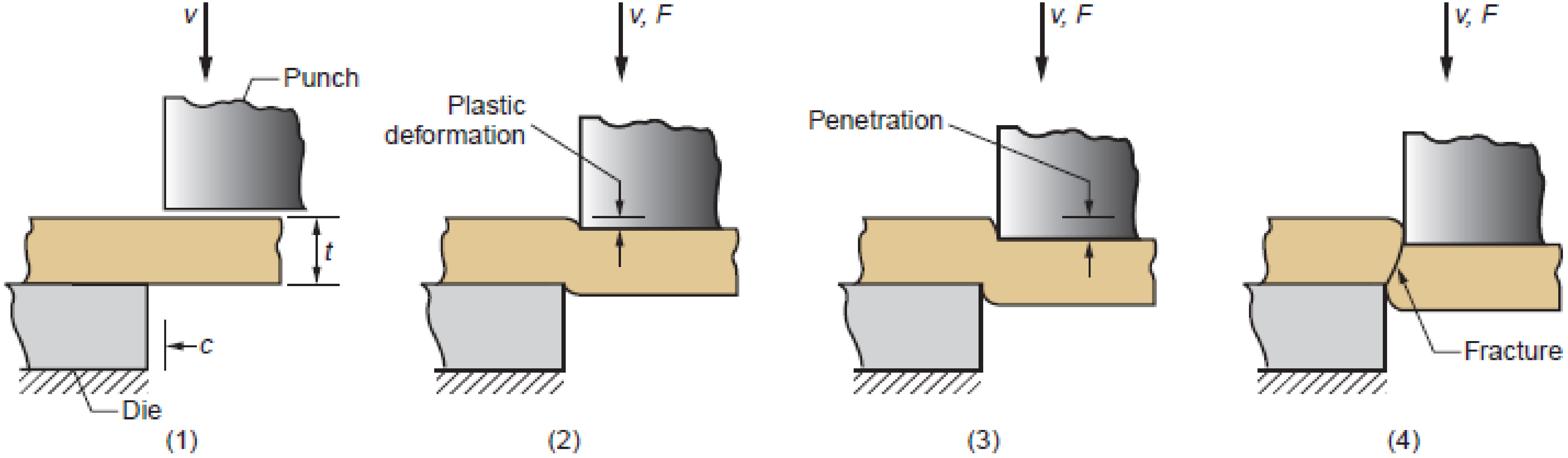
- The surface area–to–volume ratio of the starting metal is high; thus, this ratio is a useful means to distinguish bulk deformation from sheet metal processes.

- Typical sheet metal thicknesses are between 0.4 mm to 6 mm

- Sheet-metal operations are usually performed at room temperature (cold working)

Sheet Metalworking

- **The three major categories of operations include**
  - a) Cutting (Through shearing action)
  - b) Bending
  - c) Deep Drawing
- Stages of Shearing

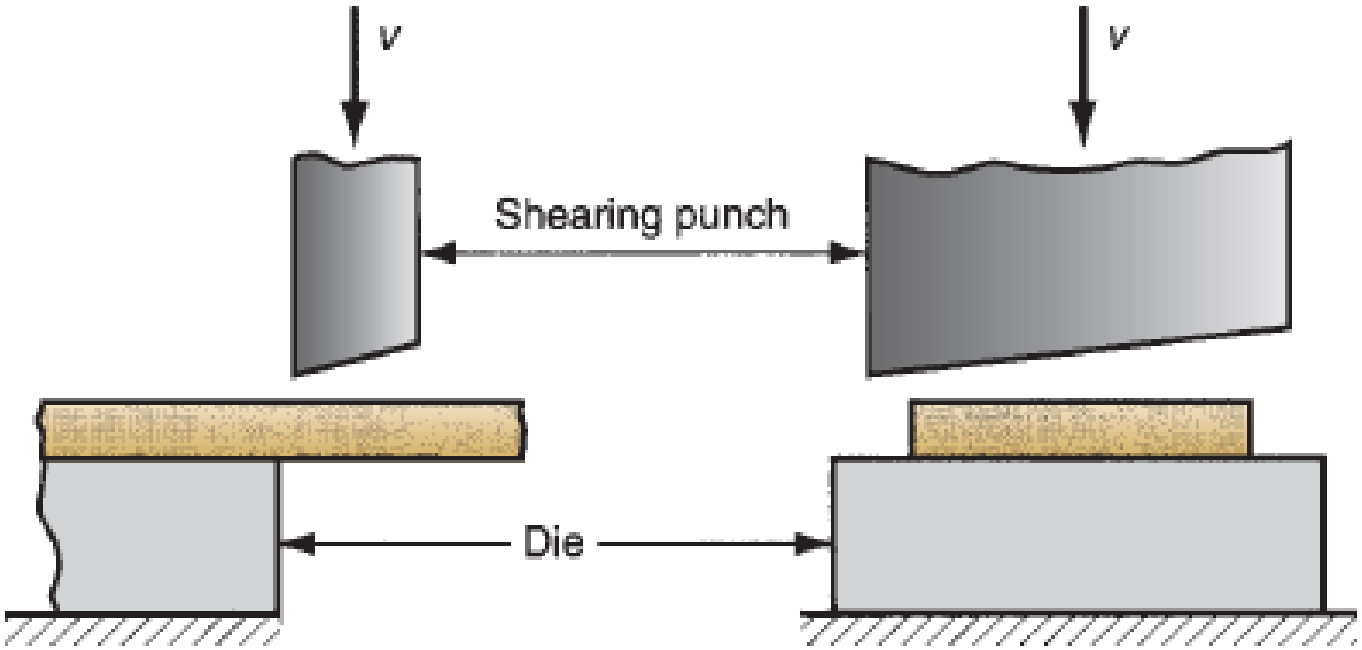


Sheet Metalworking – Cutting Operations

- ***Shearing, Blanking and Punching*** are major cutting operations

- Shearing is a sheet-metal cutting operation along a straight line between two cutting edges

- It is used to cut large sheets into smaller sections



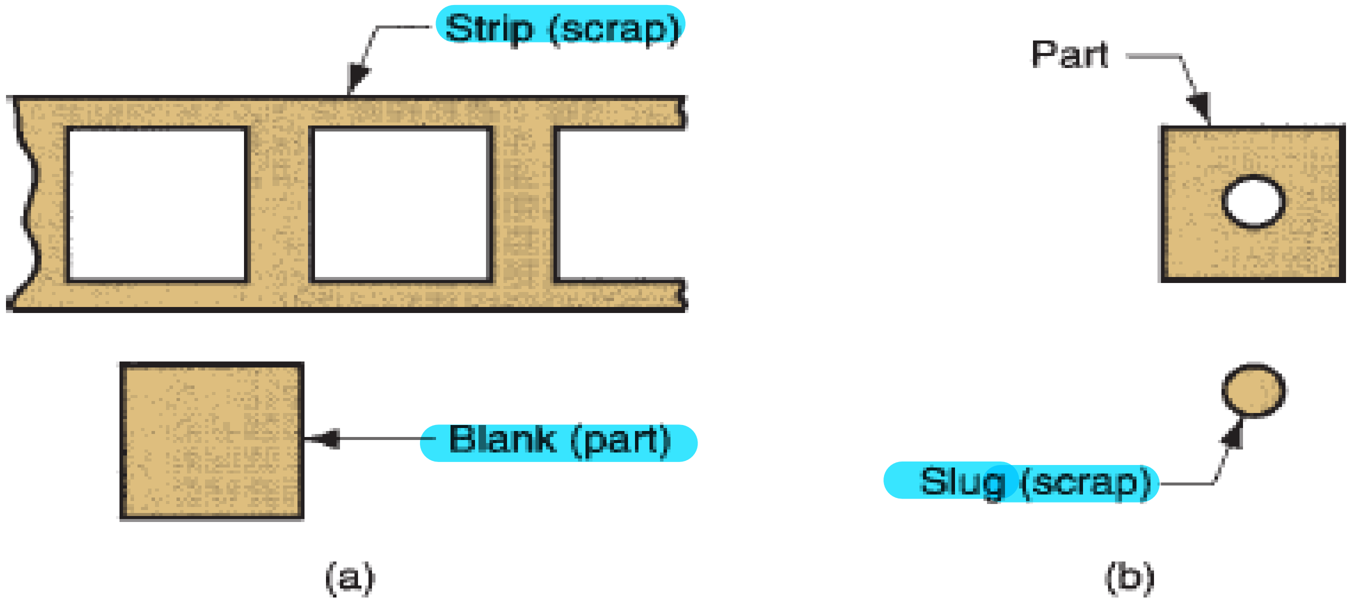
(a) Side View

(b) Front view

Cutting Operations-Blanking and Punching

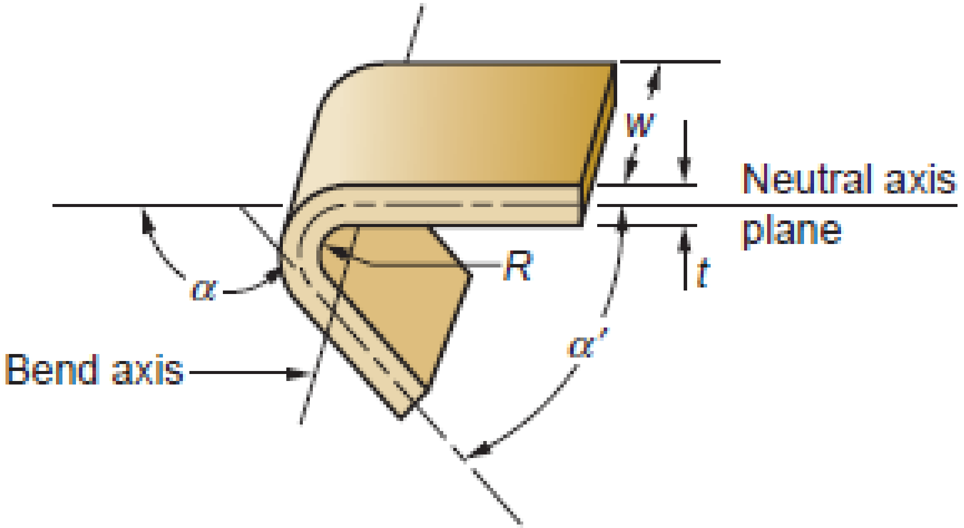
(a) Blanking involves cutting of the sheet metal along a closed outline in a single step to separate a piece from the surrounding stock. The part that is cut out is the desired product known as the blank.

(b)Punching is similar to blanking except that it produces a hole, and the separated piece is scrap called the slug.

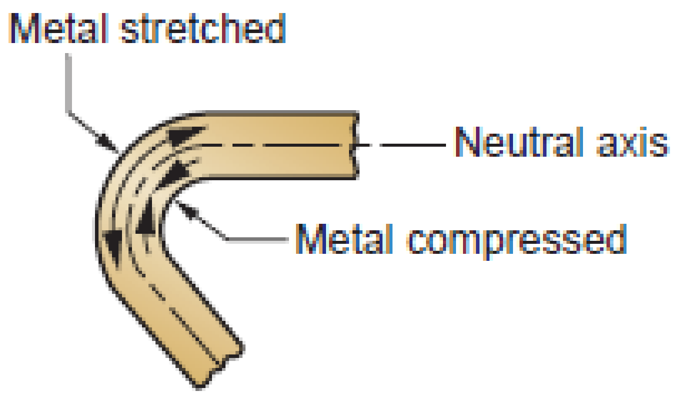


Sheet Metalworking – Bending Operations

- Bending is sheet metal is defined as the straining the metal around the straight axis. (see figure (a))
- During this operation, the metal above and below the neutral plane is compressed or stretched depending upon the sense of the bending moment. (see figure (b))



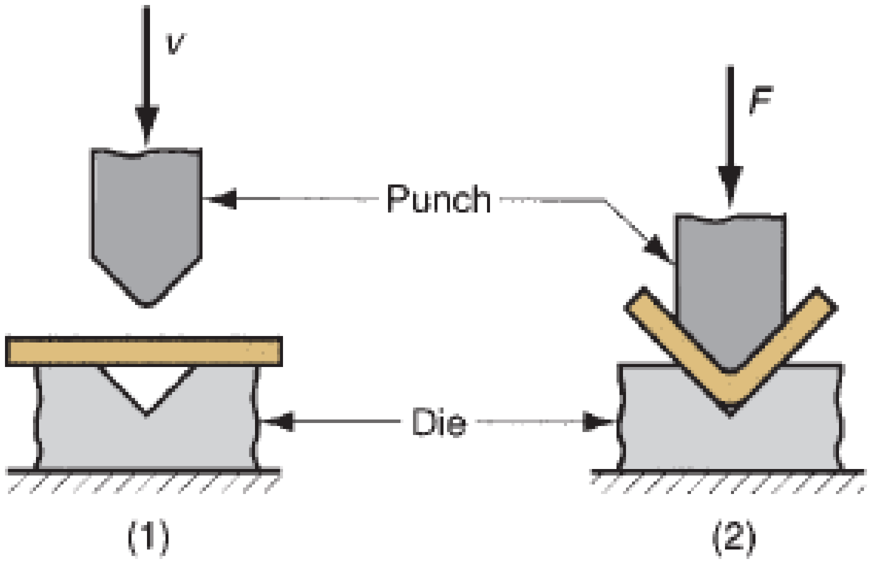
(a)



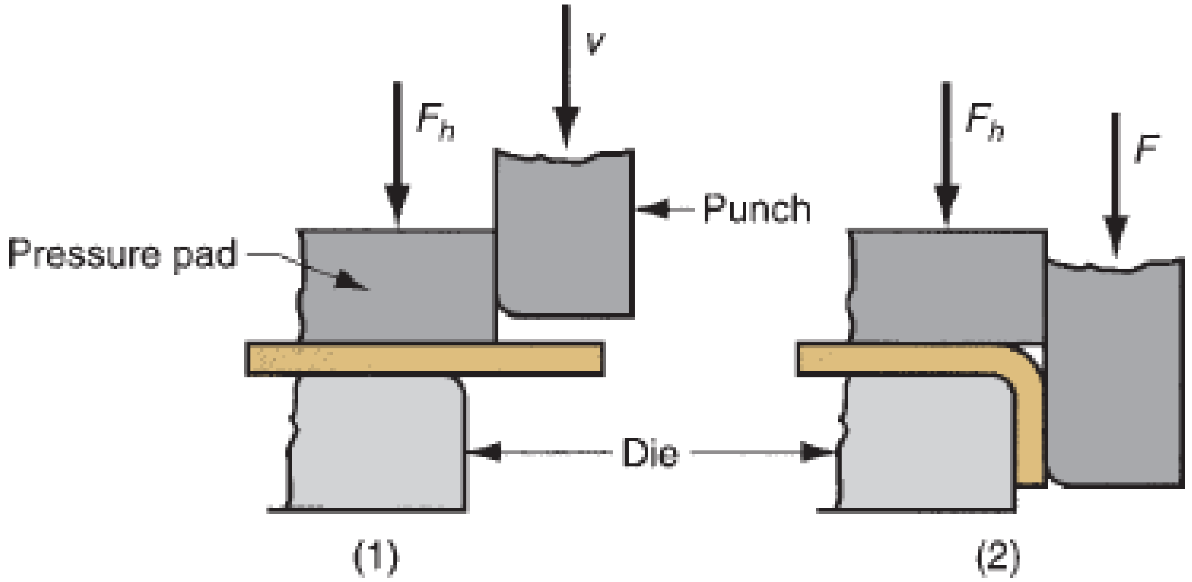
(b)

V-Bending and Edge Bending Operations

- V Bending is done using a V-shaped punch and die. A wide range of included angle can be provided by designing the punch and die.

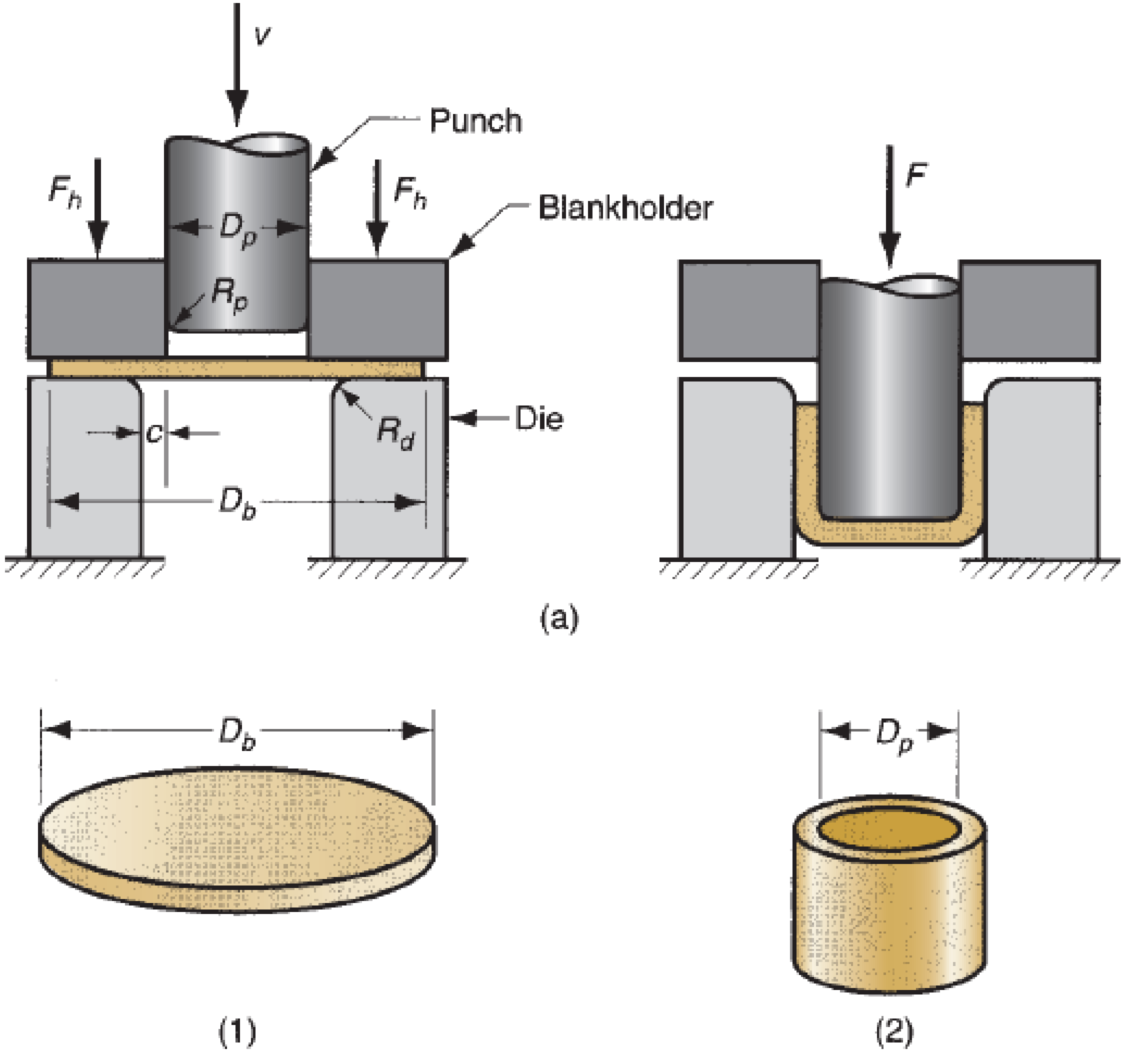


- Edge bending involves cantilever loading of the sheet metal. A pressure pad is used to hold the base part against the die. Edge bending is limited to 90 degree bends.



Deep Drawing Operations

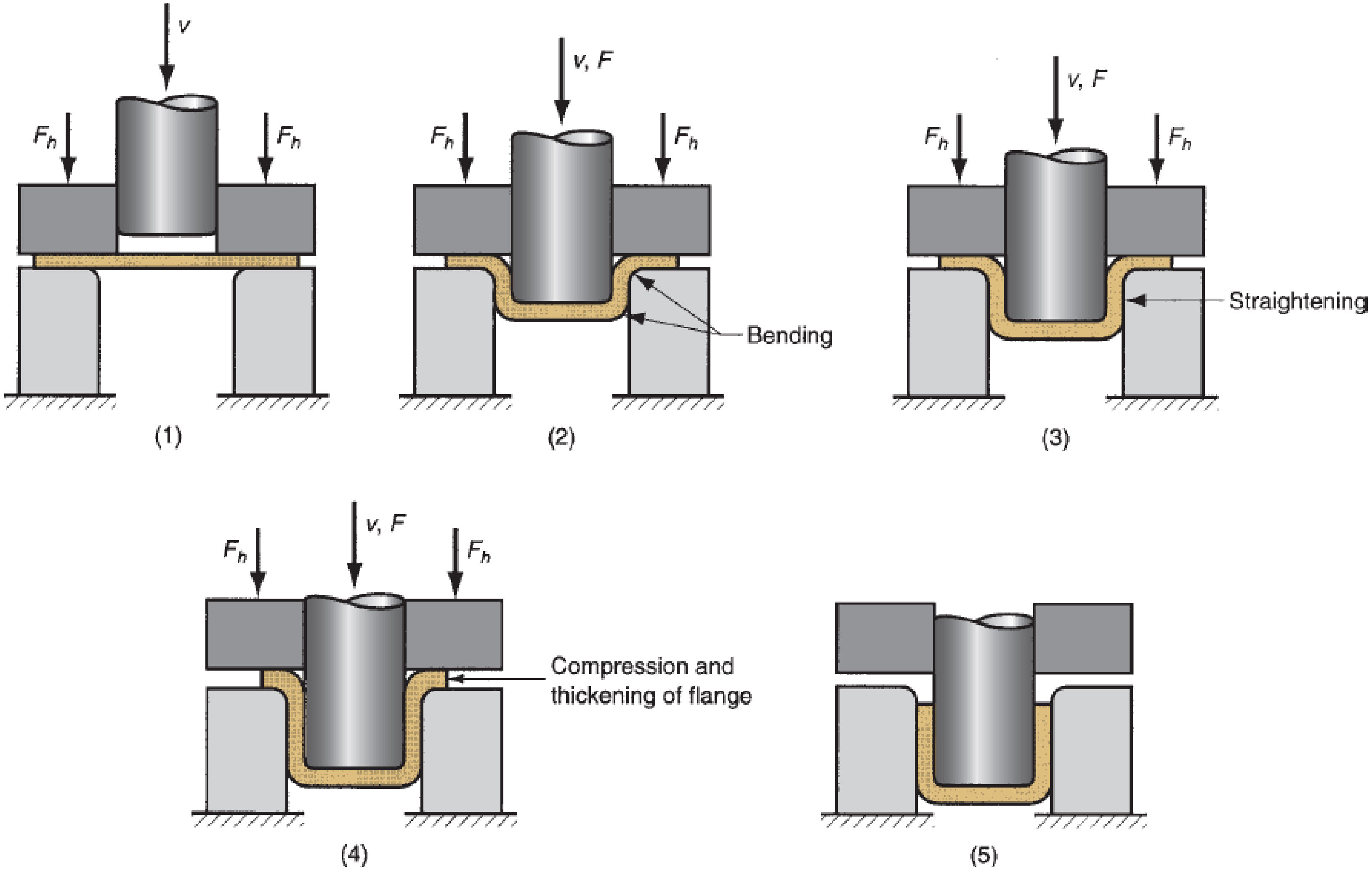
- Drawing is a sheet-metal-forming operation used to make cup-shaped, box-shaped, or other complex-curved and concave parts. It is performed by placing a piece of sheet metal over a die cavity and then pushing the metal into the opening with a punch.
- The blank must be usually held down flat against the die by blankholder.
- Beer-Cans, sinks and cooking pots are made by this operation.



Deep Drawing Operation- Stages

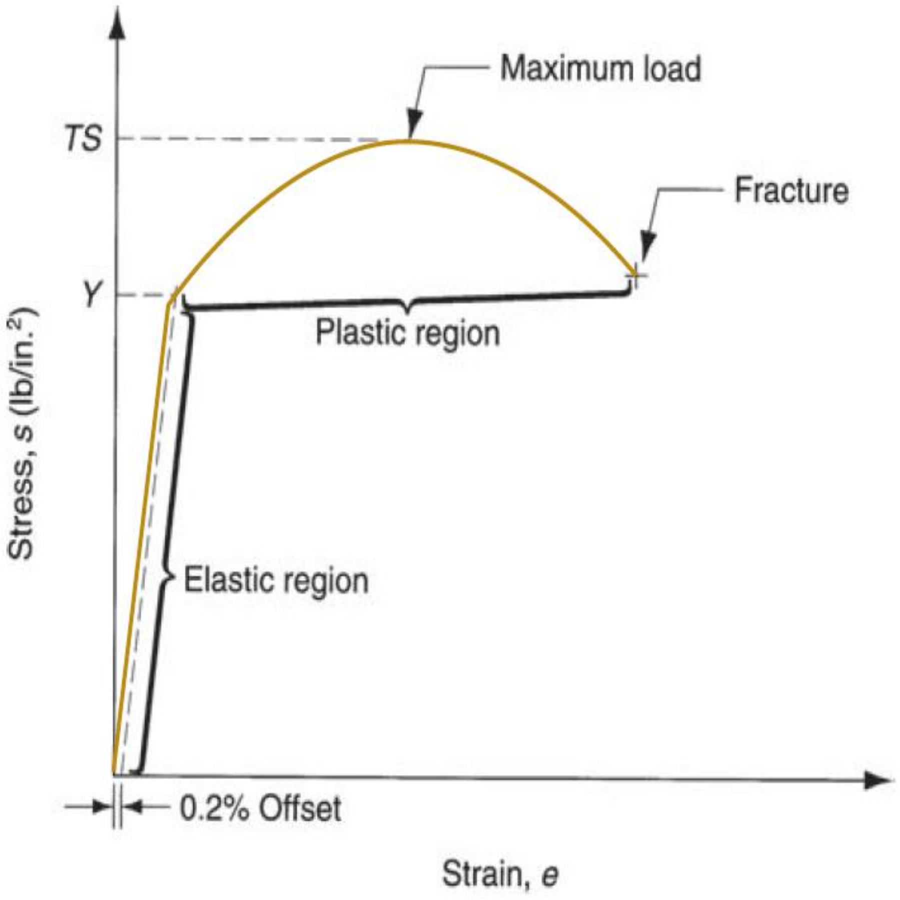
The Deep drawing operations goes through five basic stages:

1. Punch contacts the work piece.
2. Bending of the work piece.
3. Straightening of the work piece.
4. Compression and thickening of the flange
5. Final Shape



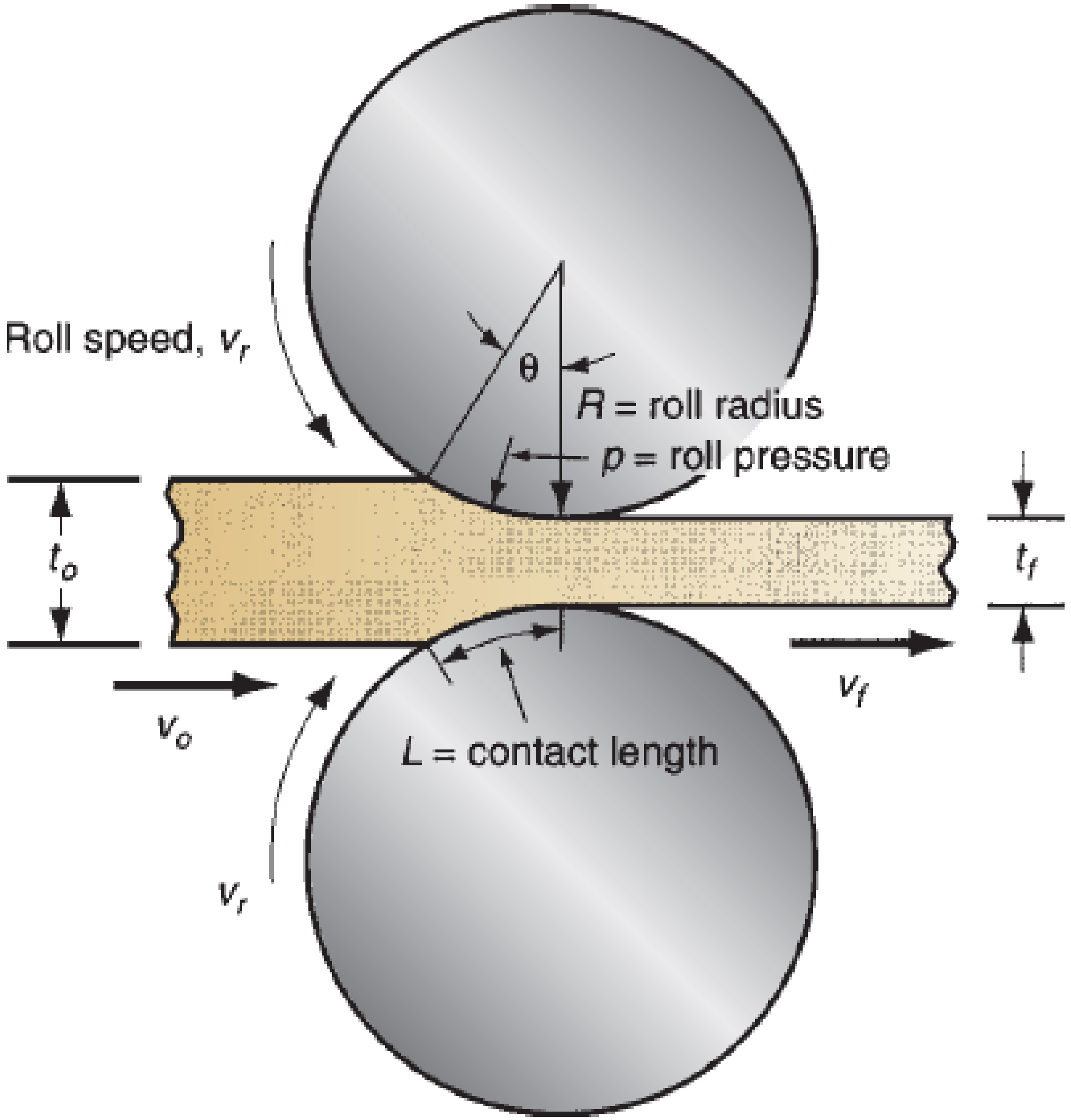
Problem 1

A Tensile test specimen has a starting gage length =100 mm and a cross-sectional area= 500mm^2. During the test, the specimen yields under a load of 40,000 N (this is the 0.2% offset) at a gage length of 100.4 mm. The maximum load of 80,000 N is reached at a gage length of 107.7 mm just before necking begins. Final fracture occurs at a gage length of 110.5 mm. Determine (a) yield strength, (b) modulus of elasticity, (c) tensile strength, (d) engineering and true strain at maximum load, and (e) percentage elongation.



Problem 2

A 500 mm wide strip 30 mm thick is fed through a rolling mill each of radius 250 mm. The work thickness is to be reduced to 27 mm in one pass. Assume the coefficient of friction to be 0.12 . Is this operation possible. If the strip is fed to the rollers at $v_0 = 2$ m/s and the work metal emerges with 510 mm width, calculate v_f. Assume that the density change in work metal is negligible.



Thank You!