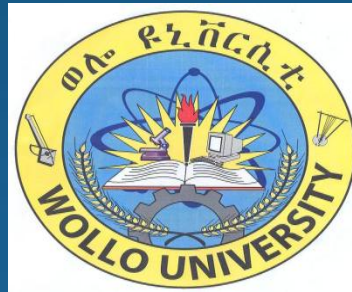


Wollo University
Institution of Technology
College Of Engineering
Department Of Mechanical Engineering



Course Title: **Production Engineering II**

Course Number: MEng 3222

Ects'5: 2 Lectures. 3 Tutorials

Credit: 3 Cr hr

Target group :- All Mechanical Engineering 3rd year.

Semester: II

Instructor Name; Wudu Y. (MSc in Manufacturing Engineering)

Chapter one

Fundamentals of metal forming

Outlines

- Introduction
 - ✓ Classification of metal forming processes
- Rolling of Metals
- forging of metals
- Extrusion of metals
- Drawing of metals
- Sheet-Metal Forming Processes
 - ✓ Shearing operation,
 - ✓ bending,
 - ✓ Deep drawing,
 - ✓ Spinning,
 - ✓ Stretch forming;

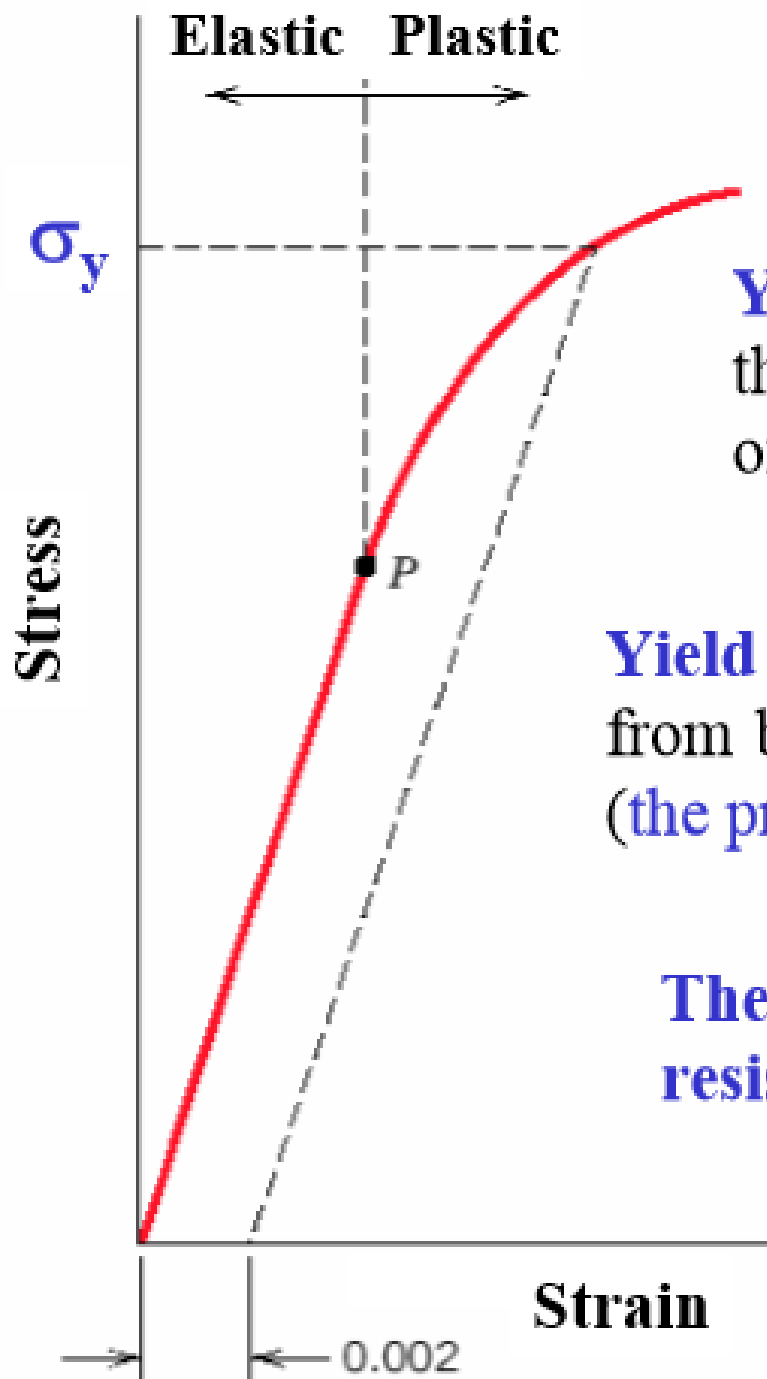
Chapter ONE

Ch.1.Fundamentals of metal forming

1.1 Introduction

- Metal forming processes, also known as mechanical working processes, are primary shaping processes in which a mass of metal or alloy is subjected to mechanical forces.

- Metal forming includes a large group of manufacturing processes in which plastic deformation is used to change the shape of metal to work pieces.
- The tools used for such deformation are called die, punch etc.
- 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.



Yield strength σ_y - is chosen as that causing a permanent strain of 0.002

Yield point P - the strain deviates from being proportional to the stress (the proportional limit)

The yield stress is a measure of resistance to plastic deformation

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

➤ Stresses to plastically deform the metal are usually *compressive*

Examples: **rolling, forging, extrusion**

However, some forming processes

✓ **Drawing** (*tensile* stresses)

✓ Others **bend** the metal (*tensile and compressive*)

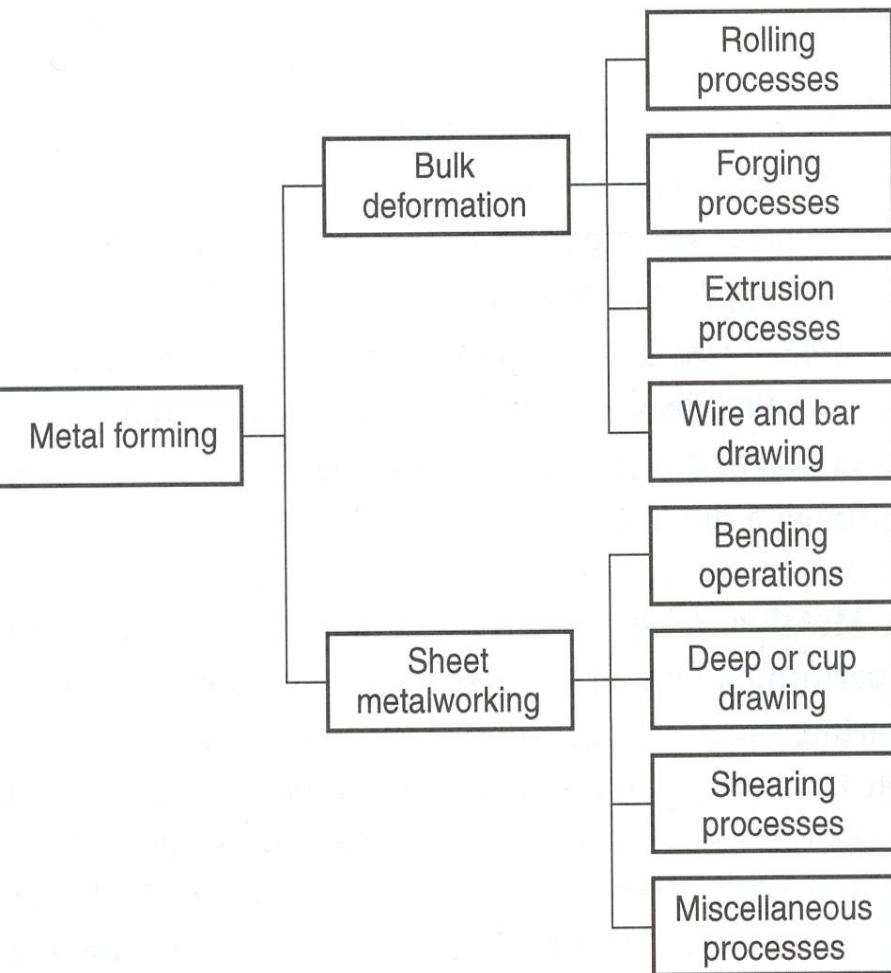
✓ Still others apply *shear* stresses e.g cutting process

- Plasticity, ductility and malleability are the properties of a material, which retains the deformation produced under applied forces permanently
- these metal properties are important for metal working processes.
- **Plasticity** is the ability of material to undergo some degree of permanent deformation without rupture or failure.

➤ **Ductility** is the property of a material enabling it to be drawn into wire with the application of tensile force.

➤ **Malleability** is the ability of the material to be flattened into thin sheets without cracking by hot or cold working with the application of compressive force..

1.2 Classification of metal forming processes



- It is a **severe deformation** process resulting in **massive shape change**.
- Sheet metal working or **press working** is the term often applied to **sheet metal operations** because the **press machines** used to perform these operations .

General classification of metal forming processes

Sheet Metal-working

- Also called “**Press-working**”.
- **Cold** working processes.
- Use set of **punch and die**.
- Performed **on metal sheets, strips and coils**.
- Generally **two-axial** stress states:
- **Shearing, bending, spinning, stretching.**

Bulk Deformation

- **Massive** shape changes.
- Starting work shapes include:
billets and rectangular bars.
- Generally **multi-axial compressive stress** states
- **Rolling, forging, extrusion, drawing.**

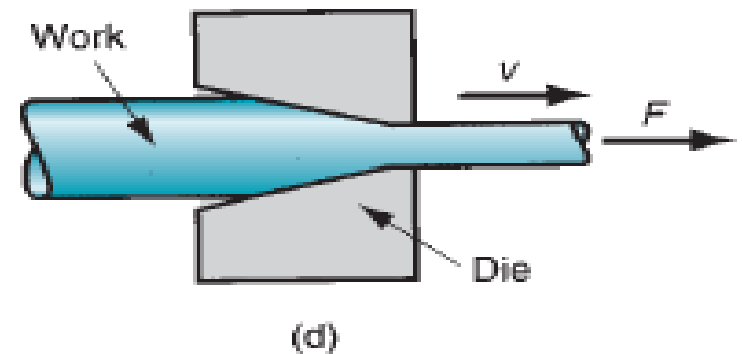
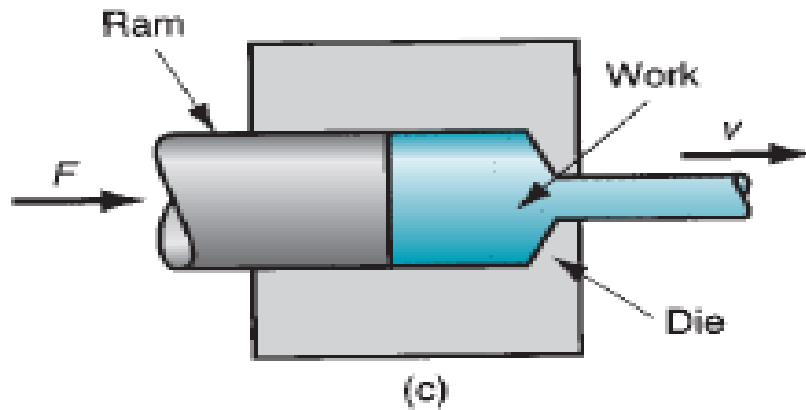
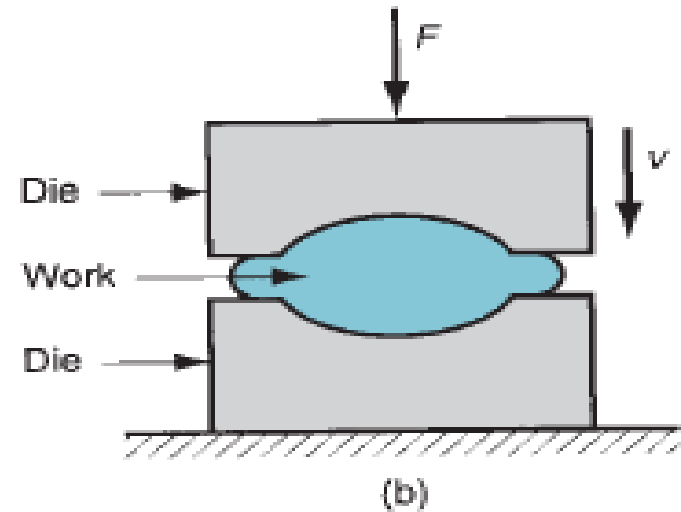
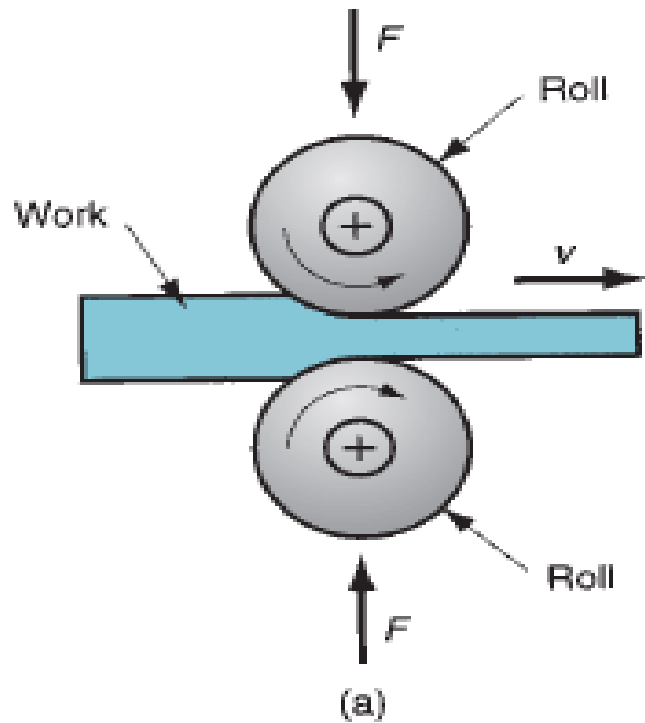


FIGURE 1.1 Basic bulk deformation processes: (a) rolling, (b) forging, (c) extrusion, and (d) drawing.

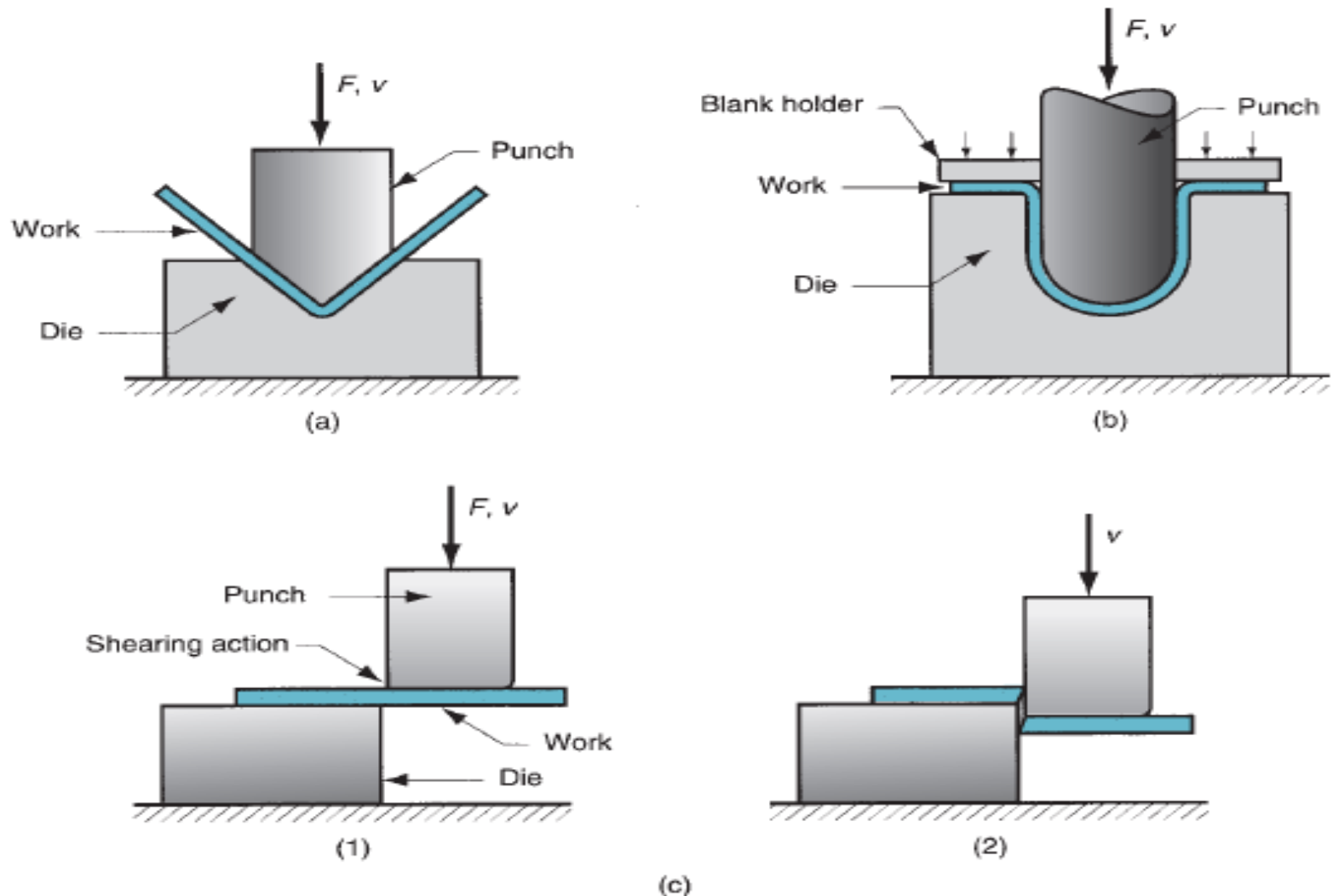
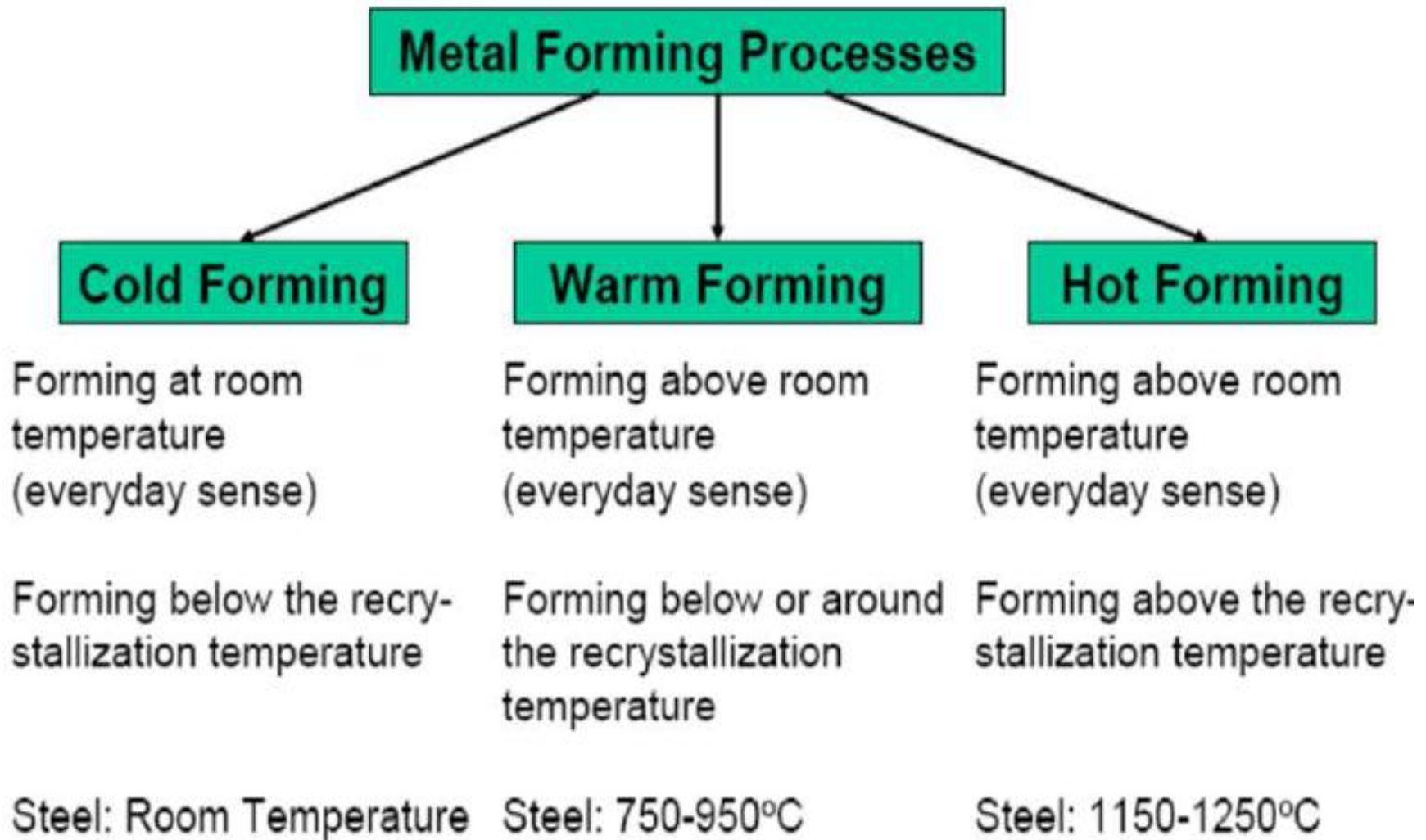


FIGURE 1.2 Basic sheet metalworking operations: (a) bending, (b) drawing, and (c) shearing: (1) as punch first contacts sheet, and (2) after cutting. Force and relative motion in these operations are indicated by F and v .

Classification of metal forming based on the operating temperature



Q. What is recrystallization Temperature of metal?

- Recrystallization temperature is a particular temperature point below the melting point of a metal (or material).
- At recrystallization temperature, you can easily succeed to change the size and shape of grains of metal(grain) and make the metal more ductile
- at this temperature, the metal behave in plastic manner, allowing them to deform greatly for very less force application.

Advantage of cold forming compared to hot forming:

- closer tolerances can be achieved;
- good surface finish;
- higher strength and hardness is seen in part;
- since no heating of the work is involved, furnace, fuel, electricity costs are minimized,
- Machining requirements are minimum resulting in possibility of near net shaped forming.

Disadvantages:

Cont....

- higher forces and power are required;
- strain hardening of the work metal limit the amount of forming that can be done,
- sometimes cold forming annealing-cold forming cycle should be followed,
- the work piece is not ductile enough to be cold worked.

Warm working: In this case, forming is performed at temperatures just above room temperature but below the recrystallization temperature.

➤ The working temperature is taken to be $0.3 T_m$ where T_m is the melting point of the work piece.

Advantages:

- lower forces required,
- intricate work geometries possible,
- annealing stages can be reduced

Hot working: Involves deformation above recrystallization temperature, between $0.5T_m$ to $0.75T_m$.

Advantages:

- significant plastic deformation can be given to the sample,
- significant change in work piece shape,
- lower forces are required,
- materials with premature failure can be not formed,

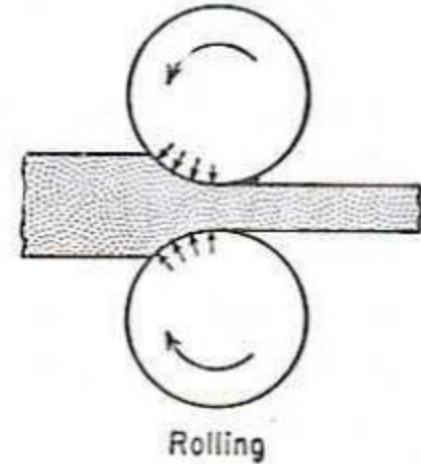
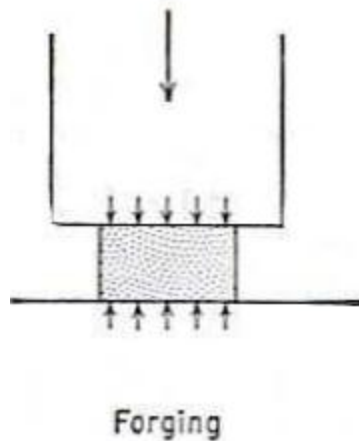
Disadvantages:

- shorter tool life,
- poor surface finish,
- lower dimensional accuracy,
- simple surface oxidation

❖ based on the type of force applied on to the work piece as it is formed into shape.

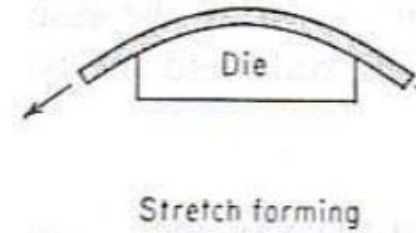
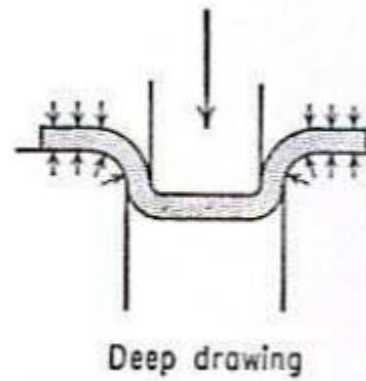
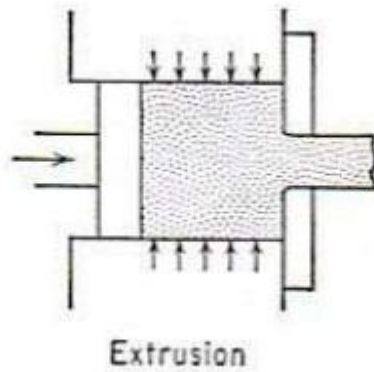
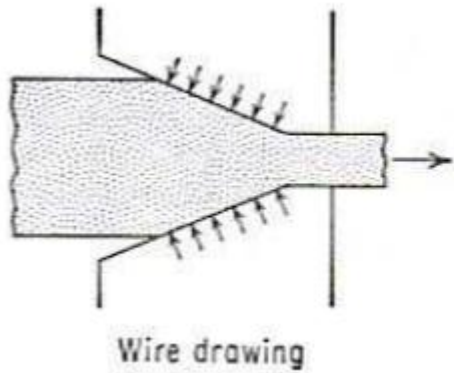
- Direct-compression-type processes
- Indirect-compression processes
- Tension type processes
- Bending processes
- Shearing processes

Direct-compression type processes: the applied force is normal to the direction of the metal flow in compression, e.g: **forging and rolling processes.**



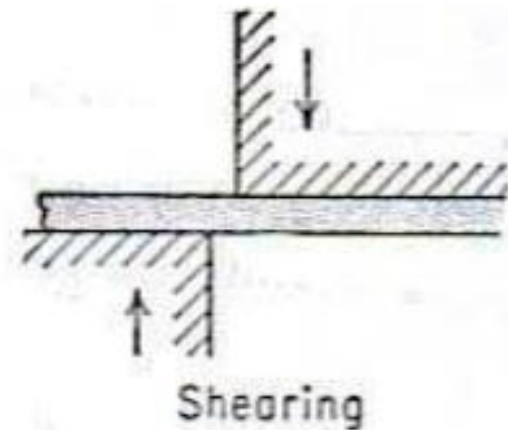
Indirect-compression type processes: the **primary forces** are frequently **tensile**, with **indirect compressive forces** developed by the reaction of the work piece.

- The metal flow is therefore under the **combined stress state**, e.g: **extrusion, wire drawing, tube drawing.**



Tension type processes: the applied force is **tensile**, i.e., stretching forming.

Shearing processes: the applied force involves the application of **shearing forces** of the metal in the plane of shear.



Importance of Metal Forming in Manufacturing(production) Engineering

- Close to net shape/close tolerance.
- High Production Rate.
- High Profit Margin.
- Low scrap Rate.
- Improving Material Properties.

Skills Needed for Metal Forming Engineering

- Mechanics.
- Material Science.
- Manufacturing Process.
- Design and Control.
- Machinery.
- Computer Skills.
- FEA.

Applications and Products of Metal forming in

- Automotive
- Aerospace
- Appliance
- Cookware etc.

End of week 1

N.B: The next topic is rolling
process

1.2 ROLLING

- Rolling is a deformation process in which the thickness of the work is reduced by compressive forces exerted by two opposing rolls.
- material gets pulled in by the friction between the surfaces of the rolls and the material.

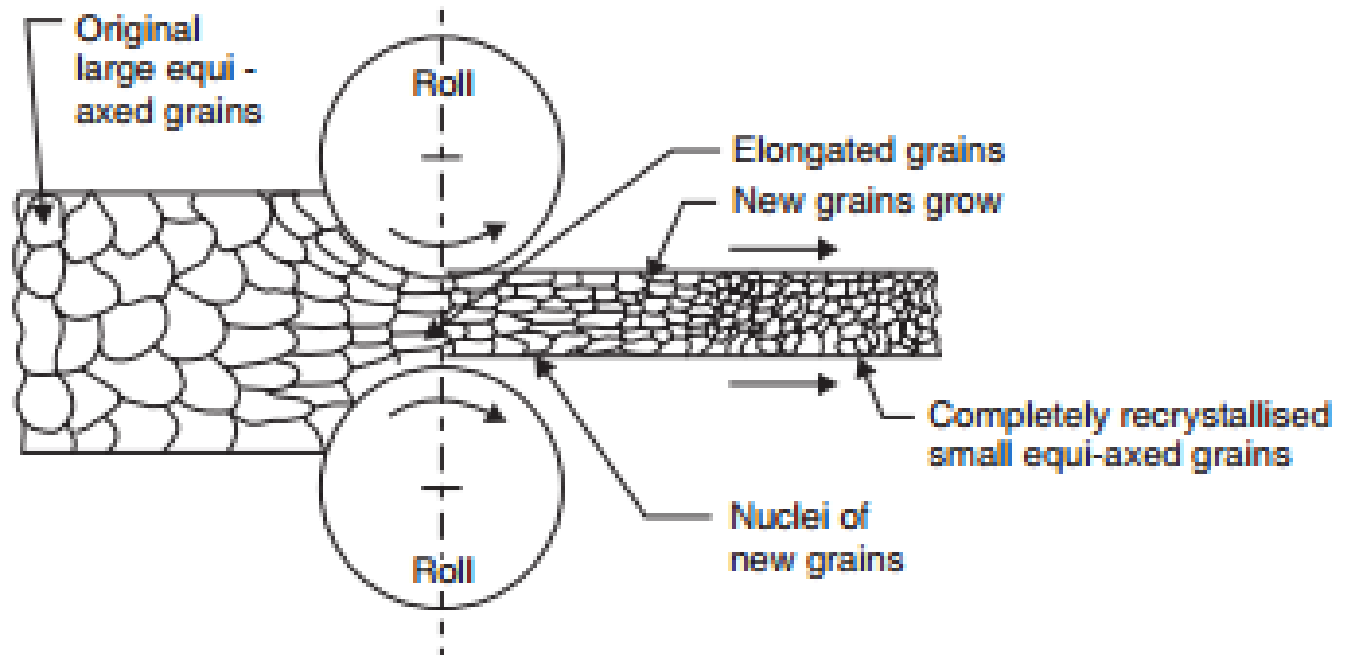


Fig.1.3
Rolling
Process

- The process of plastically deforming metal by passing it between rolls.
- The material is subjected to high compressive force as it is squeezed (and pulled along) by the rolls

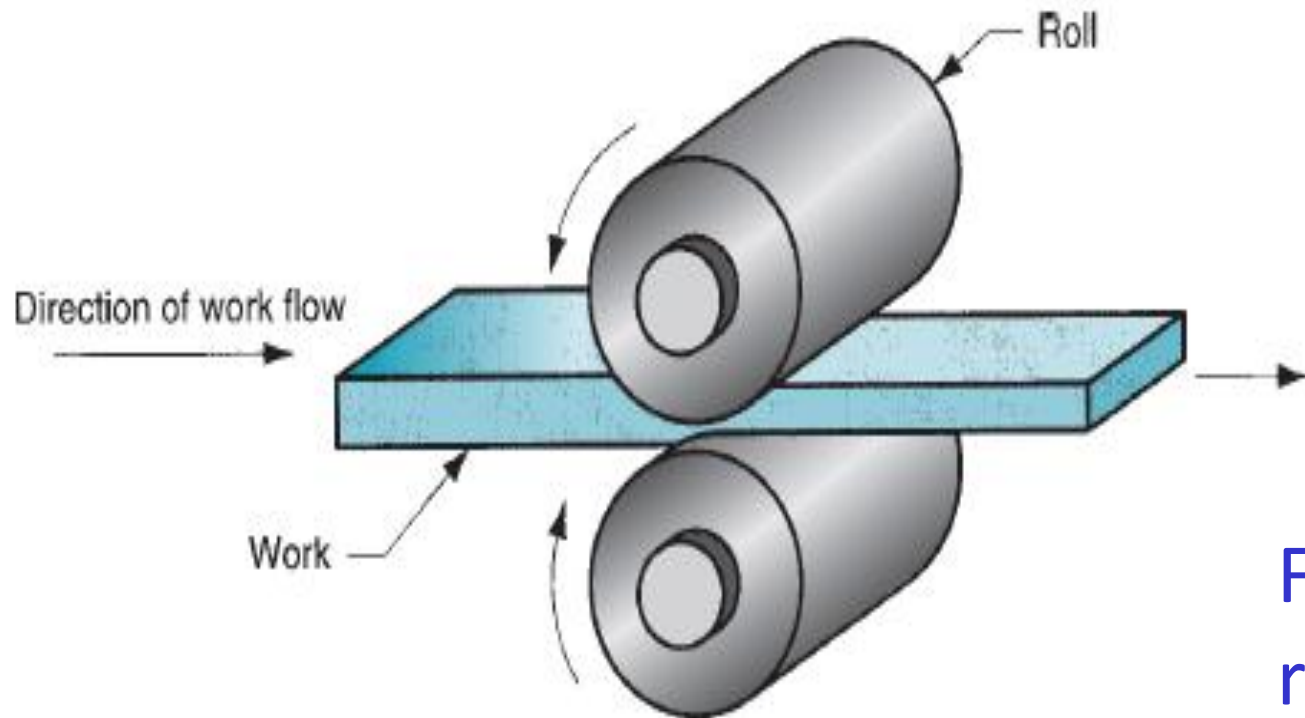


Fig 1.4.flat rolling process.

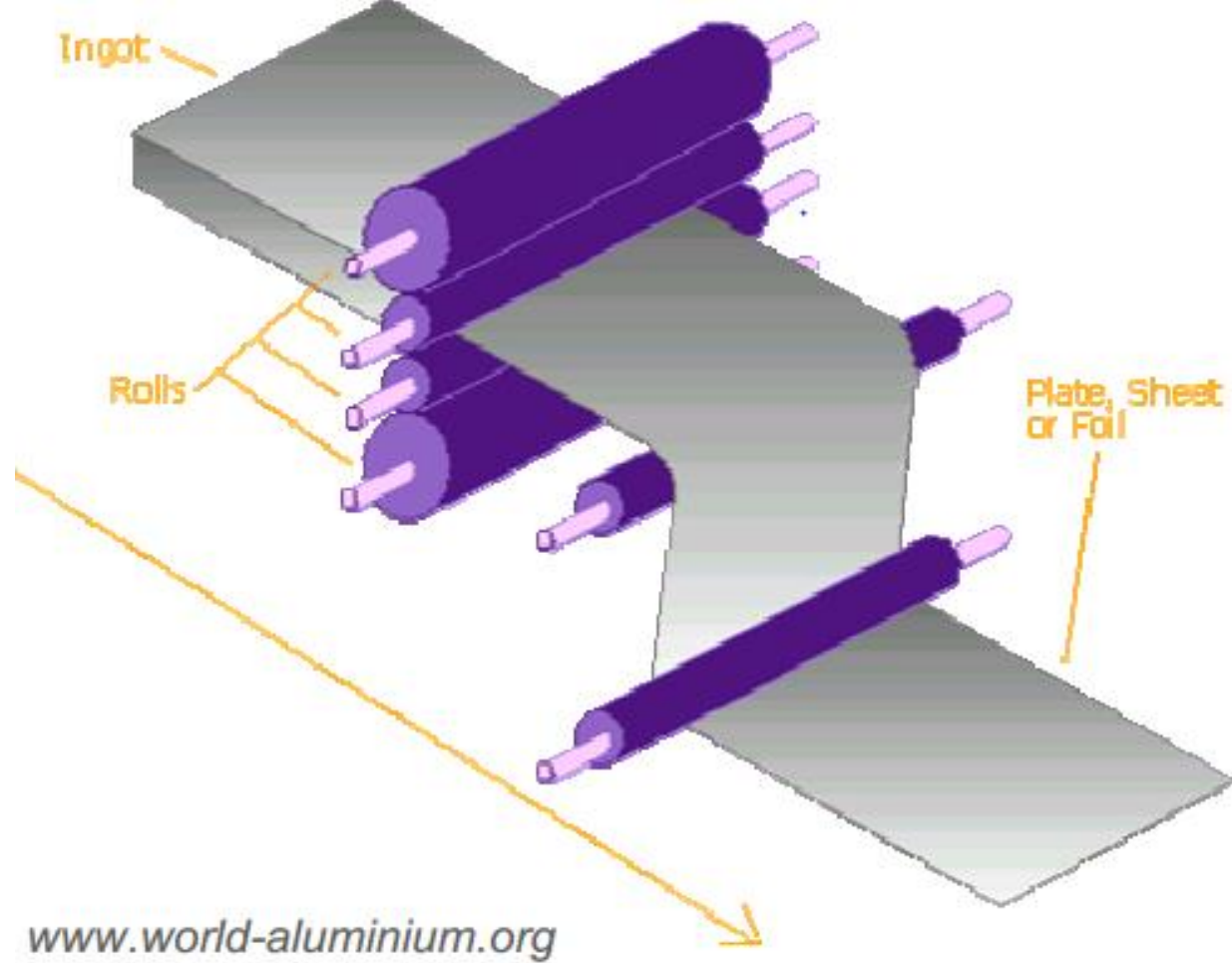


Fig 1.5 shows flat
rolling,

Rotating **rolls** perform two main functions:

✓ **Pull the work into the gap** between them by friction between work part and rolls then **squeeze the work to reduce its cross section.**

Types of Rolling

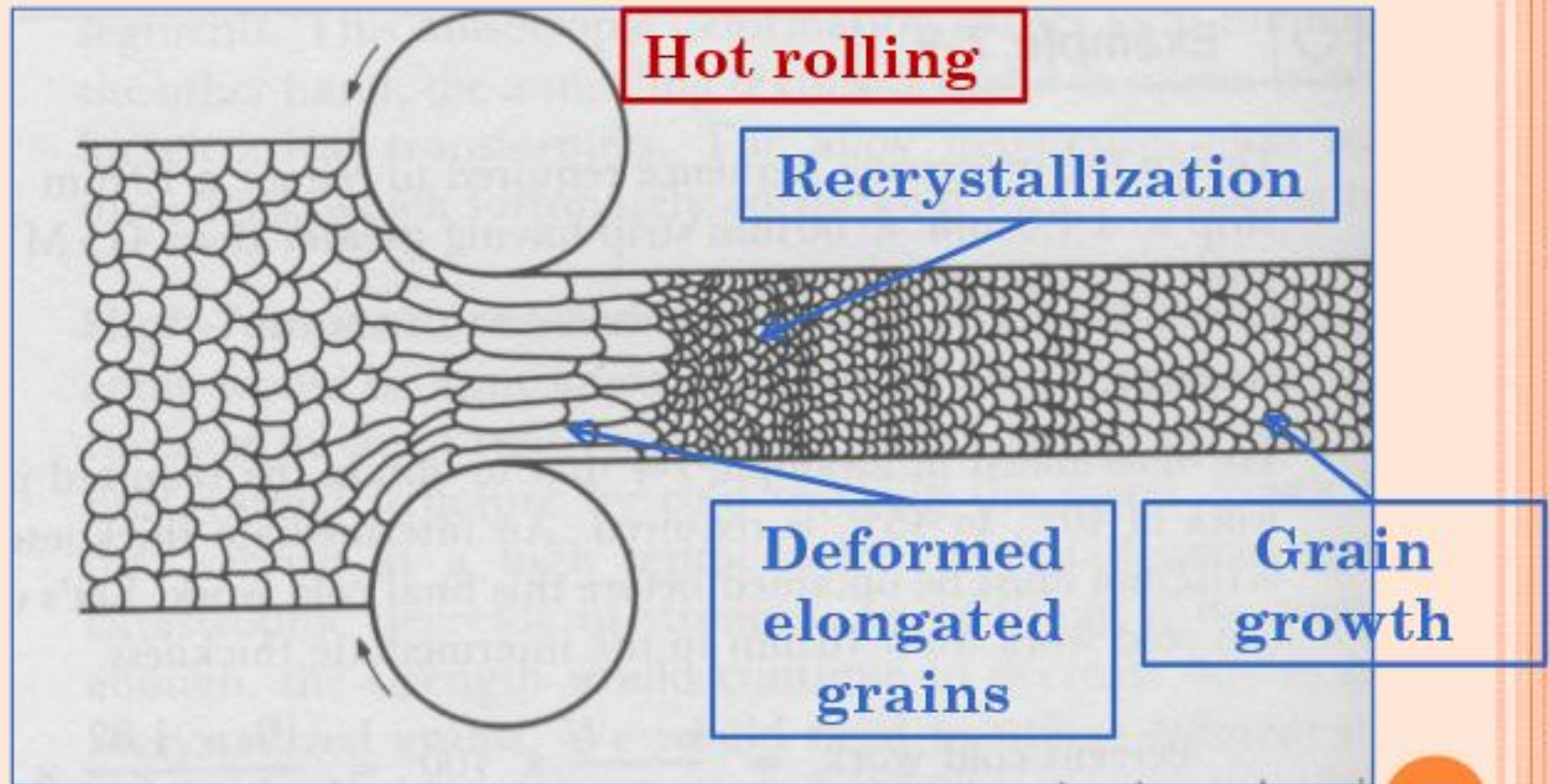
➤ Based on **work-piece geometry**:

- **Flat rolling** - used to **reduce thickness** of a rectangular cross section
- **Shape rolling** - square cross section **is formed into a shape** such as an **I-beam**

➤ Based on **work temperature**:

- **Hot Rolling** – most common due to the **large amount of deformation** required
- **Cold rolling** – produces **finished sheet** and plate stock

STRUCTURE OF HOT-WORKED MATERIAL



If the hot working T is properly controlled, the fine product will have fine grain sizes.

❖ hot rolling characterized by

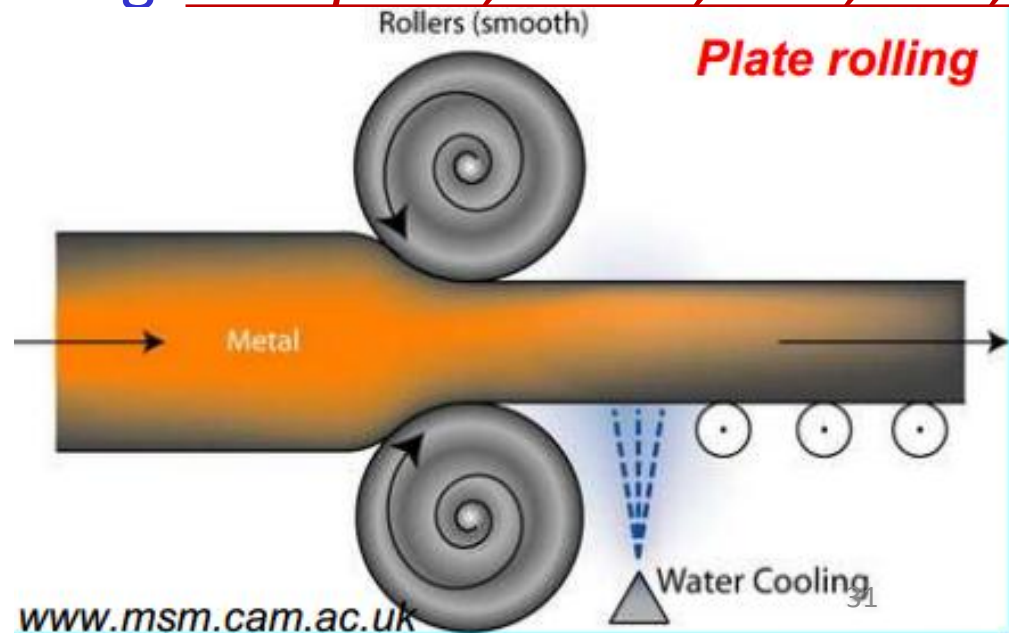
- No close tolerances,
- surface has a characteristic oxide scale.
- free of residual stresses.

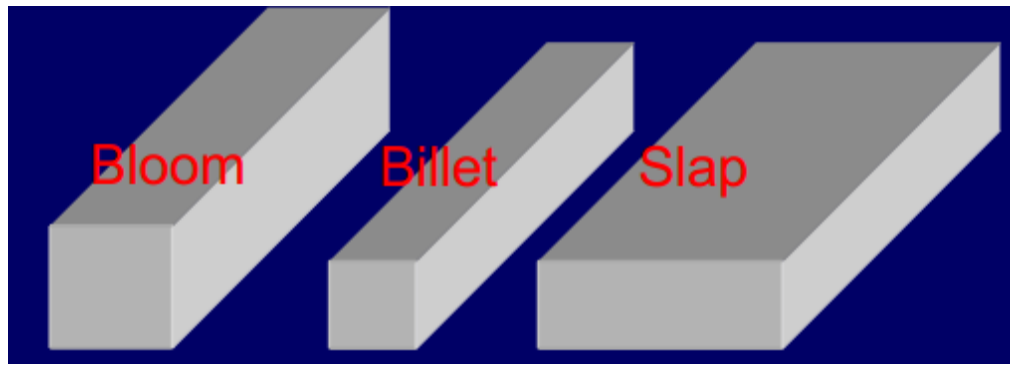
➤ Let us follow the sequence of steps in a steel rolling mill to illustrate the variety of products made.

Hot rolling

Most rolling is carried out by hot working (hot rolling), owing to The large amount of deformation required

- The initial breakdown of ingots into blooms, slab and billets (intermediate products) is done by hot-rolling. This is followed by further hot-rolling into plate, sheet, rod, bar, pipe, rail.





Bloom is the product of first breakdown of ingot (cross sectional area : 150*150mm to 150*300mm.)

➤ **Billet** is the product obtained from a further reduction of bloom by hot rolling

50X50 mm to 125X125 mm.

Slab is the hot rolled ingot

50 to 150 mm thick & 600 to 1500mm width.

➤ Bloom, Billet & Slabs are Semi-finished (intermediate) products, which are subsequently rolled into final product shapes.

➤ Blooms are rolled into structural shapes and rails for railroad tracks.

Slabs are rolled into plates, sheets, and strips

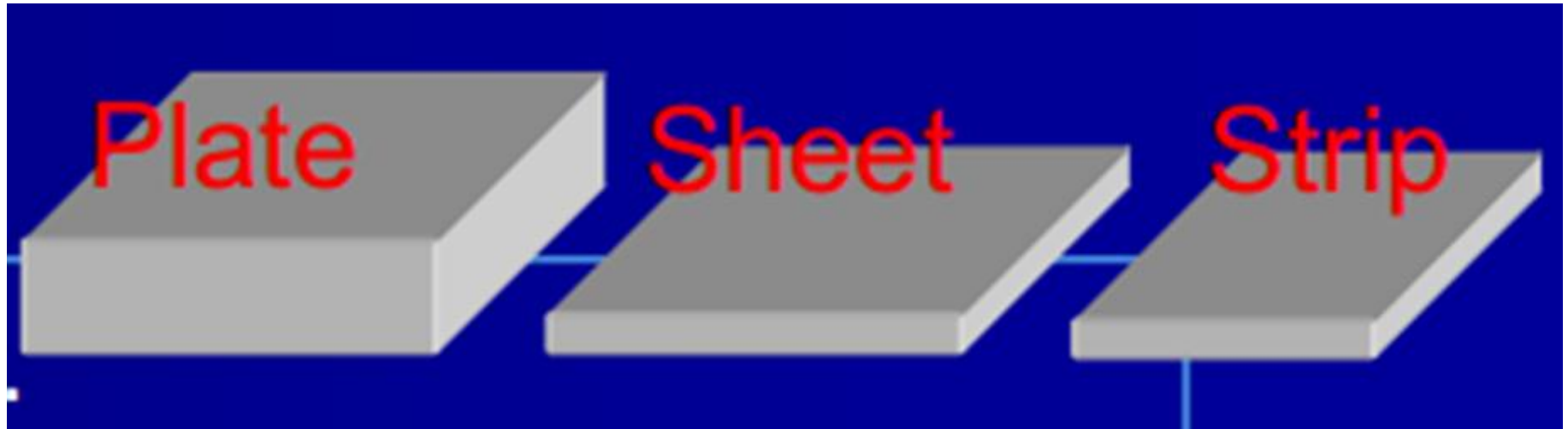
Plate is the product with a thickness > 6 mm.

Sheet is the product with thickness < 6 mm and width > 600 mm.

Strip is the product with a thickness < 6 mm & width < 600 mm

Billets are rolled into bars and rods.

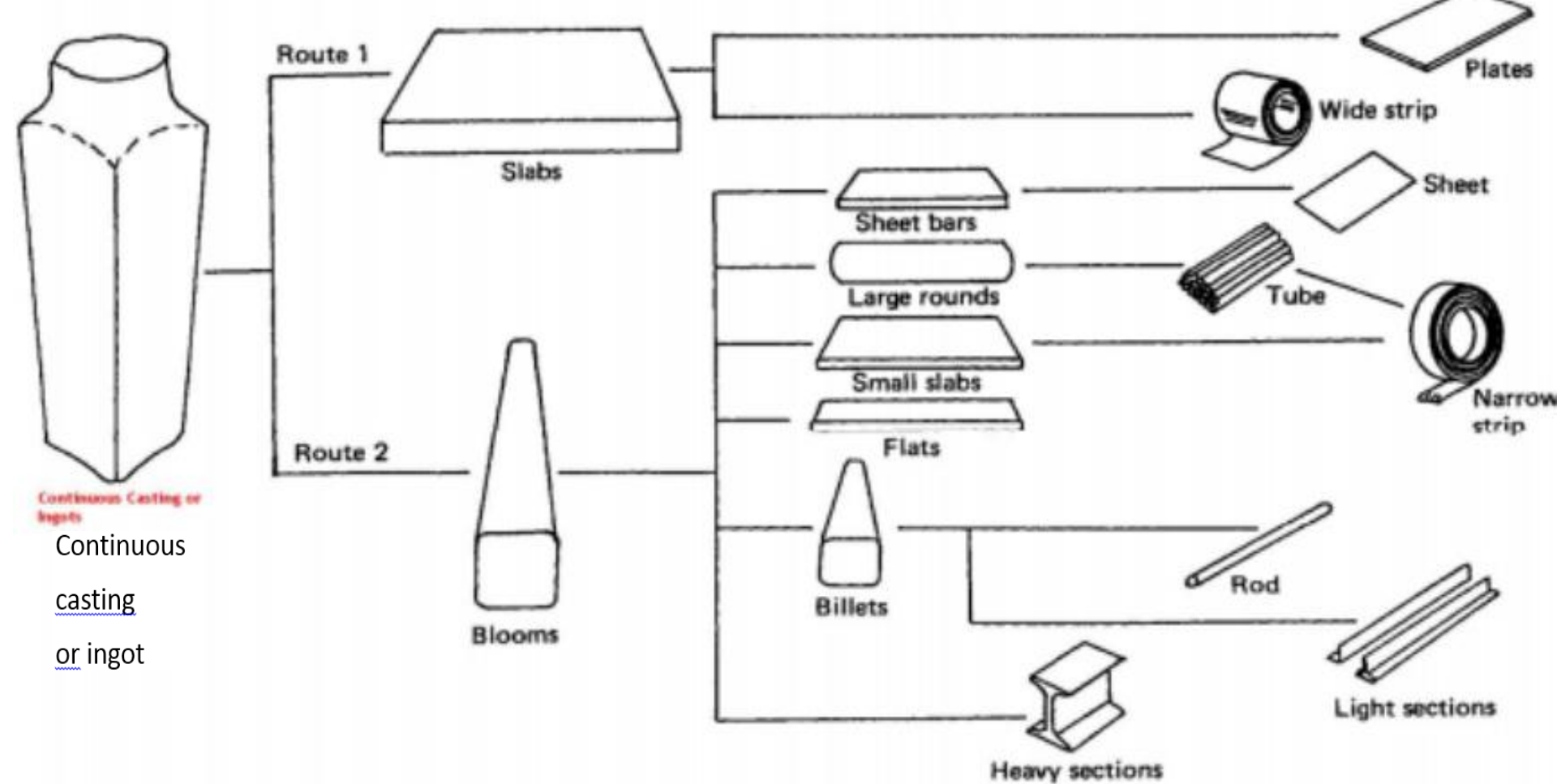
Bars & rods can be used as raw materials for a extrusion, wire drawing, forging, and other metalworking processes.



Cont....

➤ Hot-rolled plates are used in shipbuilding, bridges, boilers, welded structures for various heavy machines, tubes and pipes, and many other products



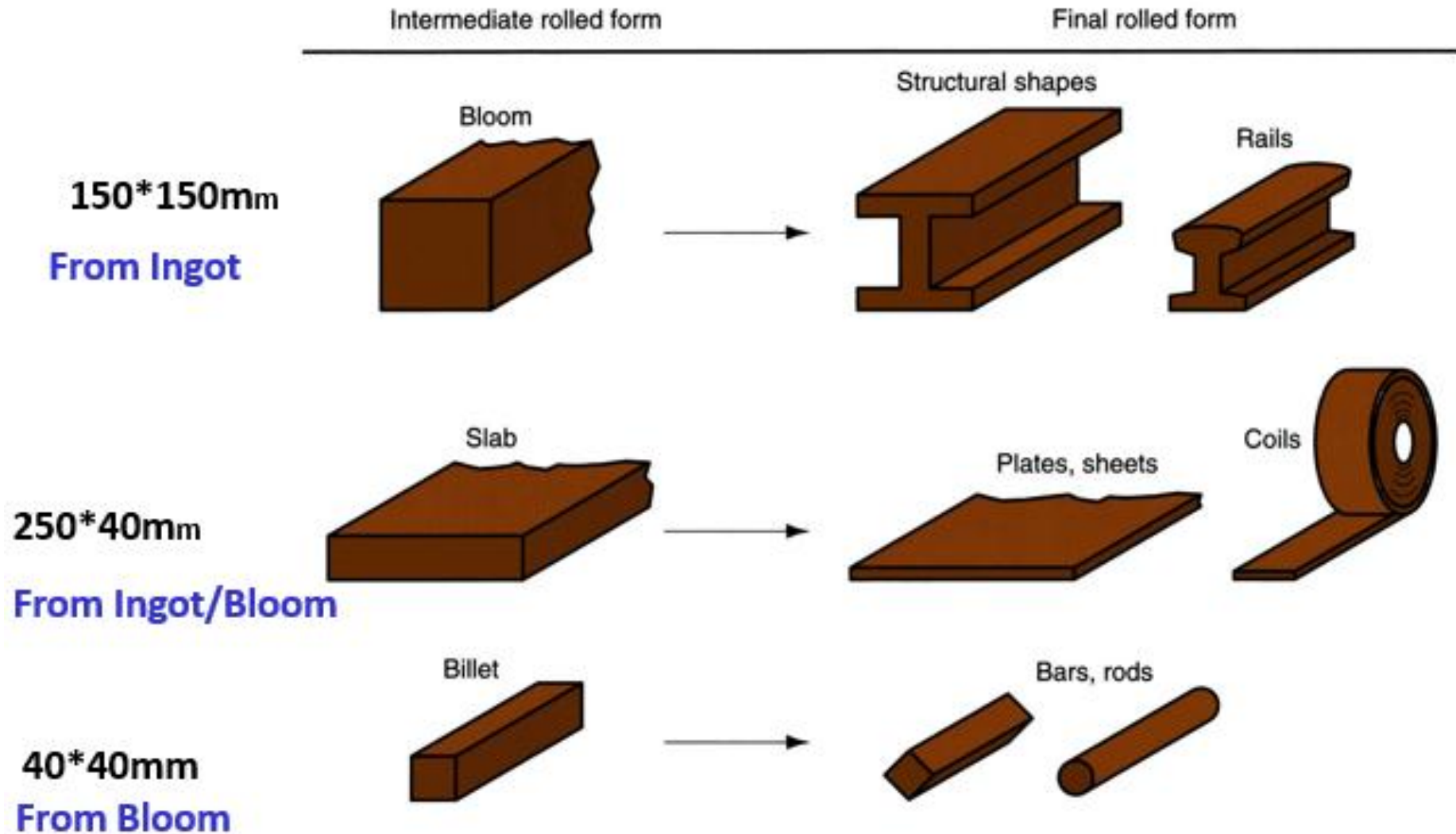


Schematic representation of the **sequences of basic rolling** processes.

➤ **Route 1** lead to production of plate and wide strip.

➤ **Route 2** results in sheet, narrow strip, tube and sections

Rolled Products Made of Steel



Some of the steel products made in a rolling mill. 36

Mechanics of metal forming processes:

- in this section ,we will perform the stress analysis in order to :
 - ✓ determine the force required to produce a given amount of deformation to obtain a product in a required geometry

Flat rolling and its analysis

✓ Flat rolling is illustrated in the Figures below.

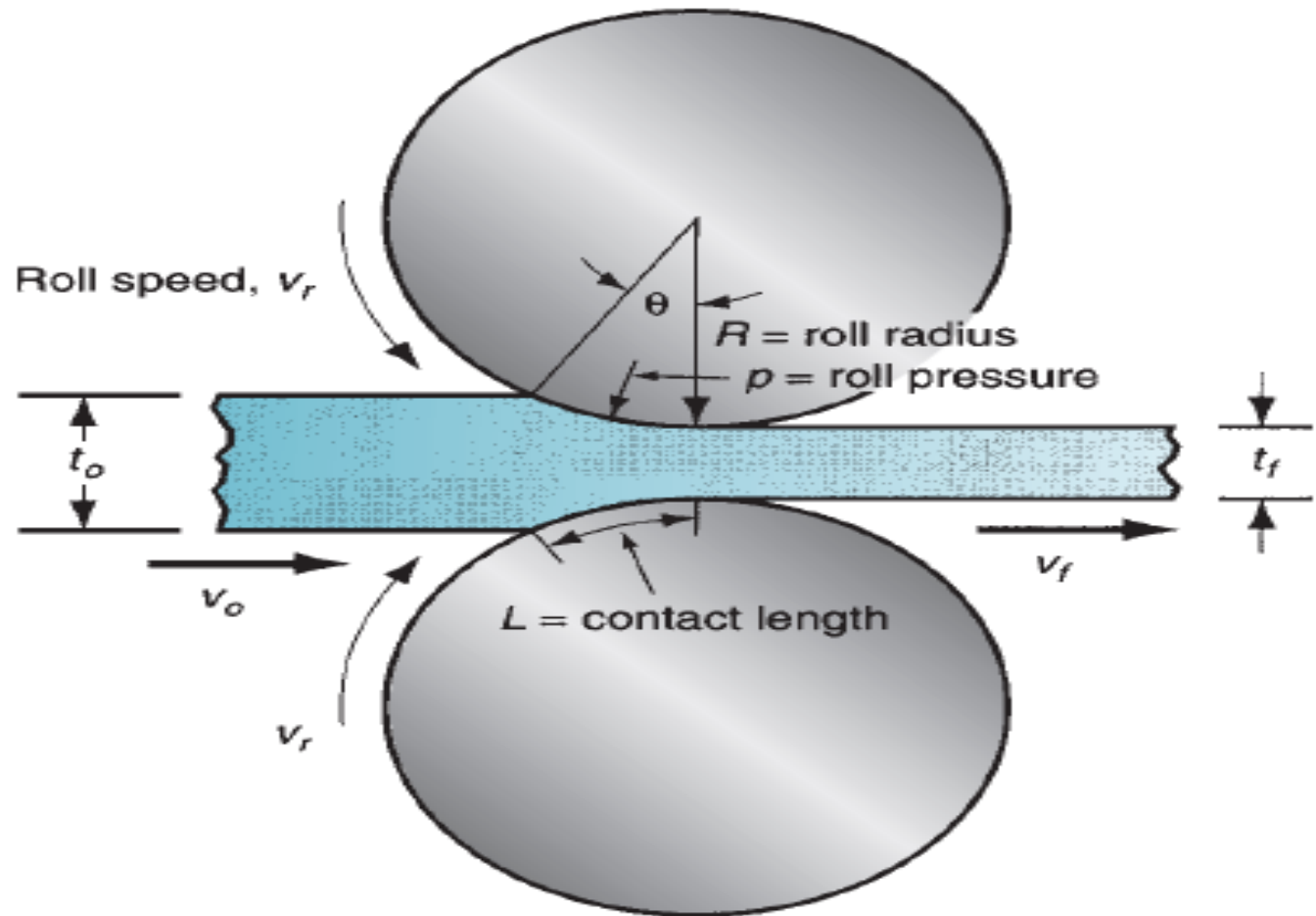


FIGURE shows flat rolling, indicating before and after thicknesses, work velocities, angle of contact with rolls, and other features.

➤ It involves the rolling of slabs, plates, strips, and sheets work part

➤ **In flat rolling**, the work is squeezed between two rolls so that its thickness is reduced by an amount called the draft:

$$d = t_o - t_f \quad (19.1)$$

Where d = draft, mm; t_o = starting thickness, mm; and t_f = final thickness, mm

➤ Draft is sometimes expressed as a fraction of the starting stock thickness, called the reduction r :

$$r = \frac{d}{t_o} \quad (19.2)$$

➤ When a series of rolling operations are used, reduction is taken as the sum of the drafts divided by the original thickness.

➤ In addition to thickness reduction, rolling usually increases **work width**. This is called spreading

➤ **Conservation of matter** is preserved, so the **volume of metal** exiting the rolls equals the volume entering

$$t_o w_o L_o = t_f w_f L_f \quad (19.3)$$

Where w_o and w_f are the before and after work widths, mm; and L_o and L_f are the before and after work lengths, mm.

➤ The true strain experienced by the work in rolling is based on before and after stock thicknesses. In equation form,

$$\epsilon = \ln \frac{t_o}{t_f} \quad (19.6)$$

- The true strain can be used to determine the average flow stress $\bar{Y}_f$ applied to the work material in flat rolling.

$$\bar{Y}_f = \frac{K\epsilon^n}{1+n} \quad (19.7)$$

- The average flow stress is used to compute estimates of force and power in rolling.
- Friction in rolling occurs with a certain coefficient of friction, and the compression force of the rolls, multiplied by this coefficient of friction, results in a friction force between the rolls and the work.

➤ There is a limit to the maximum possible draft that can be accomplished in flat rolling with a given coefficient of friction, defined by:

$$d_{\max} = m^2 R \quad (19.8)$$

Where $d_{\max}$ = maximum draft, mm; m = coefficient of friction; and R = roll radius mm.

➤ The equation indicates that if friction were zero, draft would be zero, and it would be impossible to accomplish the rolling operation.

- Coefficient of friction in rolling depends on lubrication, work material, and working temperature.
- In cold rolling, the value is around 0.1; in warm working, a typical value is around 0.2; and in hot rolling, μ is around 0.4.
- An approximation roll force can be calculated based on the **average flow stress experienced by the work material** in the roll gap. That is

$$F = \overline{Y}_f w L \quad (19.10)$$

Where $\overline{Y}_f$ = average flow stress from Eq. (19.7), MPa; and the product wL is the roll-work contact area, mm². Contact length can be approximated by:

$$L = \sqrt{R(t_o - t_f)} \quad (19.11)$$

➤ The torque in rolling can be estimated by assuming that the roll force is centered on the work as it passes between the rolls, and that it acts with a moment arm of one-half the contact length L

➤ Thus, torque for each roll is

$$T = 0.5 FL \quad (19.12)$$

➤ The power required to drive each roll is the product of torque and angular velocity.

➤ Angular velocity is $2\pi N$, where N = rotational speed of the roll.

➤ Thus, the power for each roll is $2\pi NT$.

➤ Substituting Eq. (19.12) for torque in this expression for power, and doubling the value to account for the fact that a rolling mill consists of two powered rolls, we get the following expression:

$$P = 2\pi NFL \quad (19.13)$$

Where P = power, J/s; N = rotational speed, rev/min; F = rolling force, N; and L = contact length, m.

Example 1

A 300-mm-wide strip 25-mm thick is fed through a rolling mill with two powered rolls each of radius = 250 mm. The work thickness is to be reduced to 22 mm in one pass at a roll speed of 50 rev/min. The work material has a flow curve defined by $K = 275$ MPa and $n = 0.15$, and the coefficient of friction between the rolls and the work is assumed to be 0.12. If the friction is sufficient to permit the rolling operation to be accomplished. Determine the roll force, torque, and power.

Solution:

The draft attempted in this rolling operation is

$$d = 25 - 22 = 3 \text{ mm}$$

The maximum possible draft for the given coefficient of friction is

$$d_{\max} = (0.12)^2(250) = 3.6 \text{ mm}$$

Since the maximum allowable draft exceeds the attempted reduction, the rolling operation is feasible. To compute rolling force, we need the contact length L and the average flow stress Y_f . The contact length is

$$L = \sqrt{250(25 - 22)} = 27.4 \text{ mm}$$

Y_f is determined from the true strain:

$$\epsilon = \ln \frac{25}{22} = 0.128$$

$$\bar{Y}_f = \frac{275(0.128)^{0.15}}{1.15} = 175.7 \text{ MPa}$$

Rolling force is determined by

$$F = 175.7(300)(27.4) = 1,444,786 \text{ N}$$

Torque required to drive each roll is

$$T = 0.5(1,444,786)(27.4)(10^{-3}) = 19,786 \text{ N-m}$$

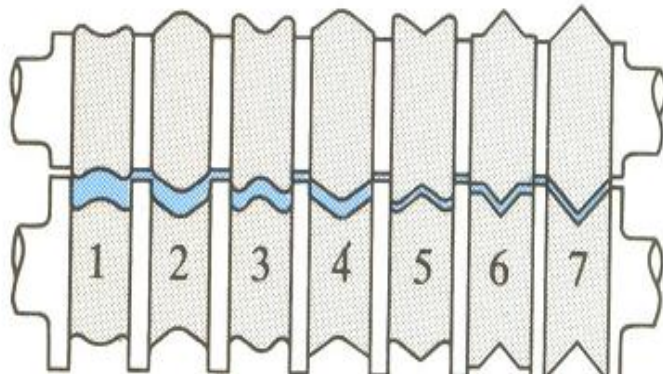
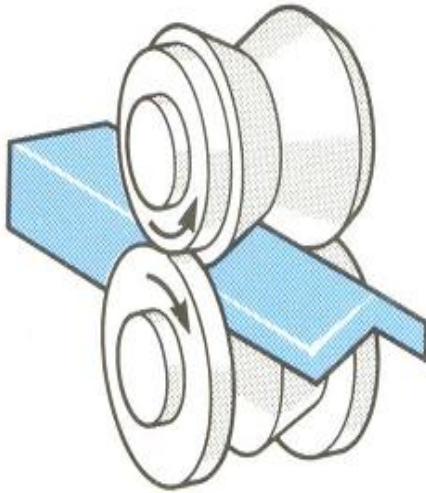
And the power is obtained as

$$P = 2\pi(50)(1,444,786)(27.4)(10^{-3}) = 12,432,086 \text{ N-m/min} = 207,201 \text{ N-m/s(W)}$$

Shape(section) Rolling

- Work is deformed into a contoured cross section rather than flat (rectangular)
- Accomplished by passing work through rolls
e.g. production of an I-beam.
- Most rolling processes requiring equipment, called rolling mills, to perform them.
- Shaping rolls are more complicated; and the work, usually starting as a square shape, requires a gradual transformation through several rolls in order to achieve the final cross section.

Shaped rolling or section rolling



- A special type of cold rolling in which flat slab is progressively bent into **complex shapes** by passing it through a series of **driven rolls**.

- No appreciable change in the thickness of the metal during this process.

- Suitable for producing moulded sections such as irregular shaped channels and trim.



Shaped rolling or section rolling

A variety of sections can be produced by roll forming process using a series of forming rollers in a continuous method to roll the metal sheet to a specific shape

Applications:

- construction materials,
- partition beam
- ceiling panel
- roofing panels.
- steel pipe
- automotive parts
- household appliances
- metal furniture,
- door and window frames
- other metal products.

- Further flattening of hot-rolled plates and sheets is often accomplished by cold rolling, Cold rolling
 - will strengthen the metal and permits a tighter tolerance on thickness and
 - absent of scale in cold rolling
- These characteristics make cold-rolled sheets, strips, and coils ideal for parts of products ranging from automobiles bodies to office

cold-rolling: Characterized by

- introduces **work hardening**
- providing sheet, strip, foil with **good surface finishes**(due to **low temperature** **no oxide scales**), and
- increased **mechanical strength**
- Better **dimensional tolerances** compared with hot-rolled products due to **less thermal expansion**.



Rolled strips

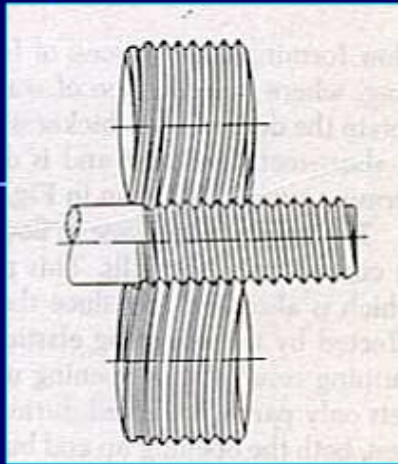


Figure. Sheet rolling machines rolled strip

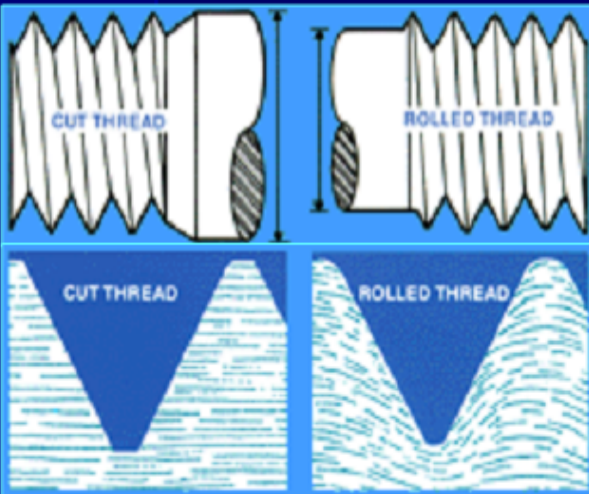
Reading assignment

- Ring rolling
- Thread Rolling
- Tube Rolling

Thread rolling



- **Dies** are pressed against the surface of cylindrical blank. As the blank rolls against the in-feeding die faces, the material is displaced to form the **roots** of the thread, and the displaced material flows **radially outward** to form the **thread's crest**.
- A blank is fed between **two grooved die plates** to form the threads.
- The thread is formed by the **axial flow** of material in the work piece. The grain structure of the material is not cut, but is **distorted** to follow the thread form.
- Rolled threads are produced in a **single pass** at speeds far in excess of those used to cut threads.
- The resultant thread is very much **stronger** than a cut thread. It has a greater resistance to mechanical stress and an increase in fatigue strength. Also the surface is burnished and **work hardened**.



Cut thread and rolled thread

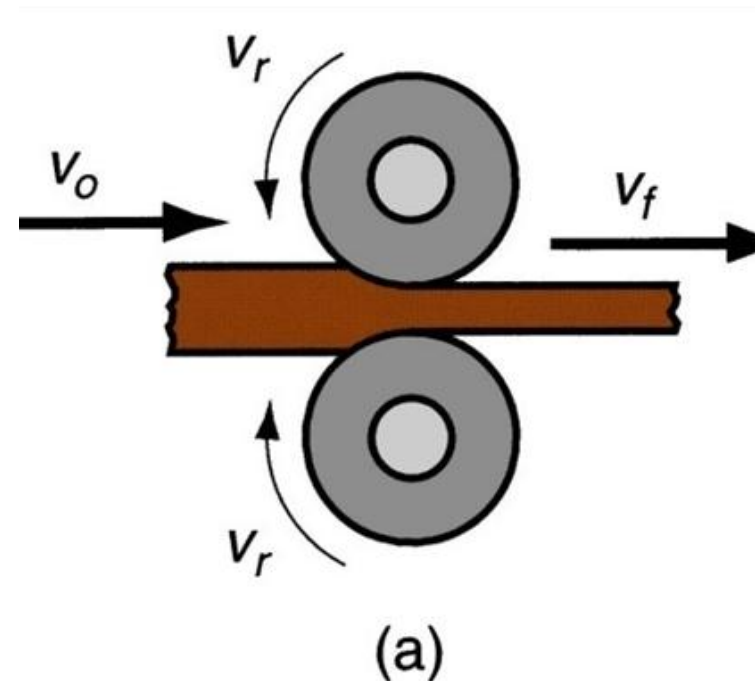


Rolling Mills

Mills are designed in different types of configurations

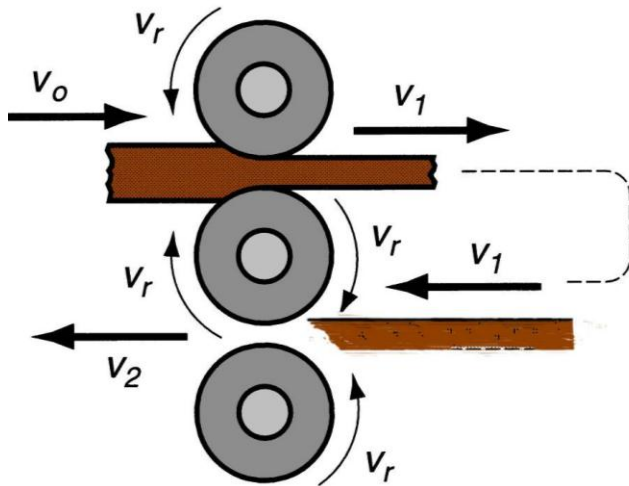
Rolling mill configurations:

I. **Two-high** – two opposing rolls.



II. Three-High Rolling Mill

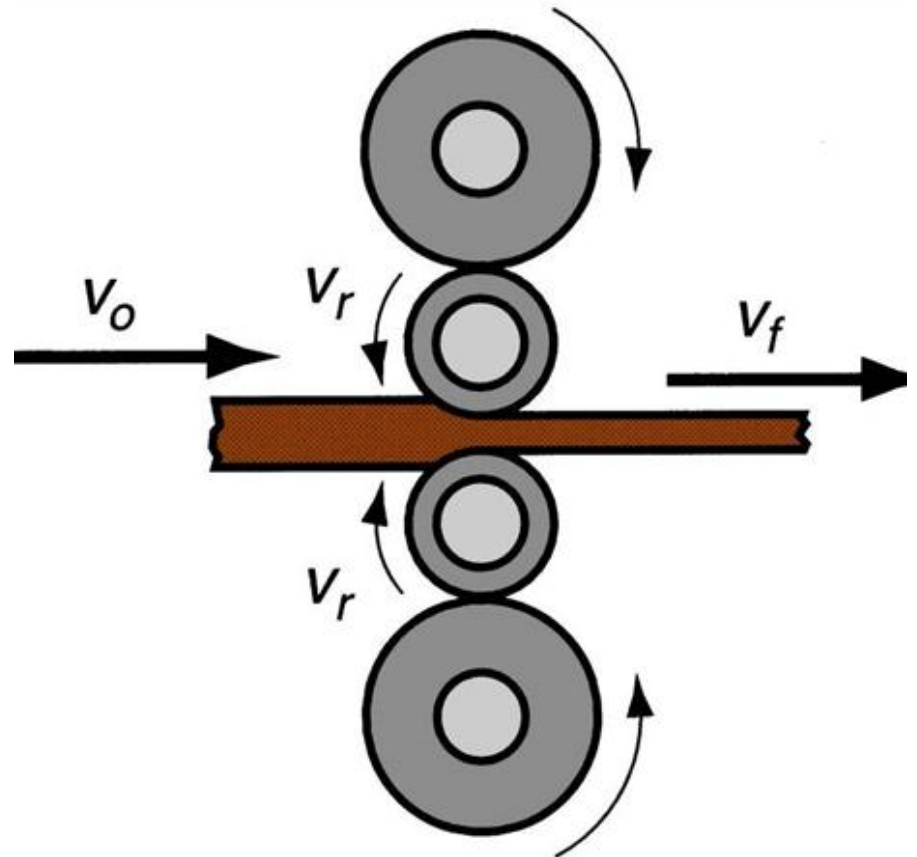
- There are three rolls one above the other that rotate in one direction.
- The **top two rolls** will be used for **first reduction** and the sheet is shifted to the **bottom two rolls** and further reduction is done.
- All of these mills are usually used for **primary rolling** and the roll diameters range from 60 to 140 cm



Disadvantage: automated mechanism is required to shift the slab

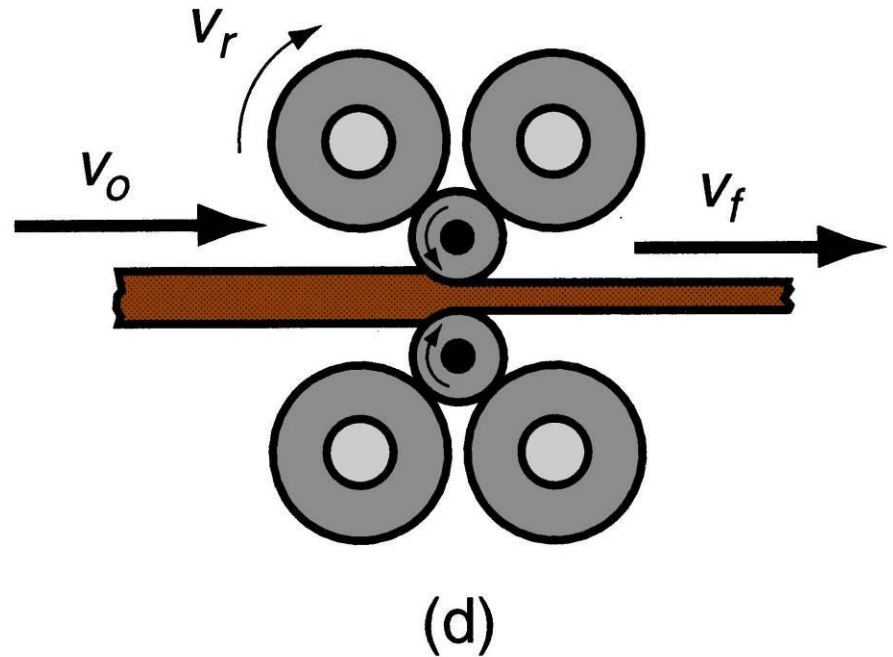
III. Four-high – backing rolls support smaller work rolls.

- A small roll diameter is advantageous because less roll is in contact with the material, which results in a lower force and energy requirement.



IV. Cluster Mill

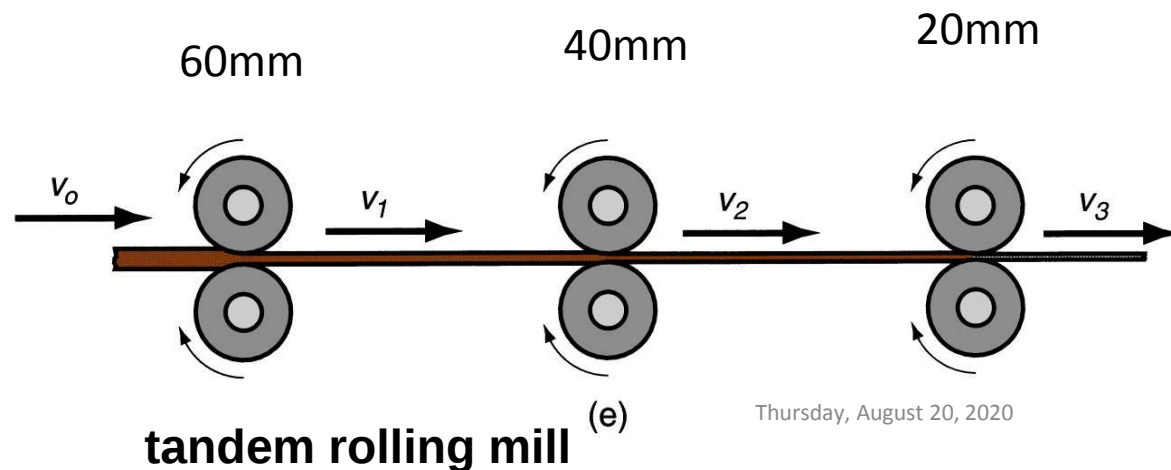
➤ These types of mills are commonly used to hot roll wide plates, most cold rolling applications, and to roll foils



cluster mill

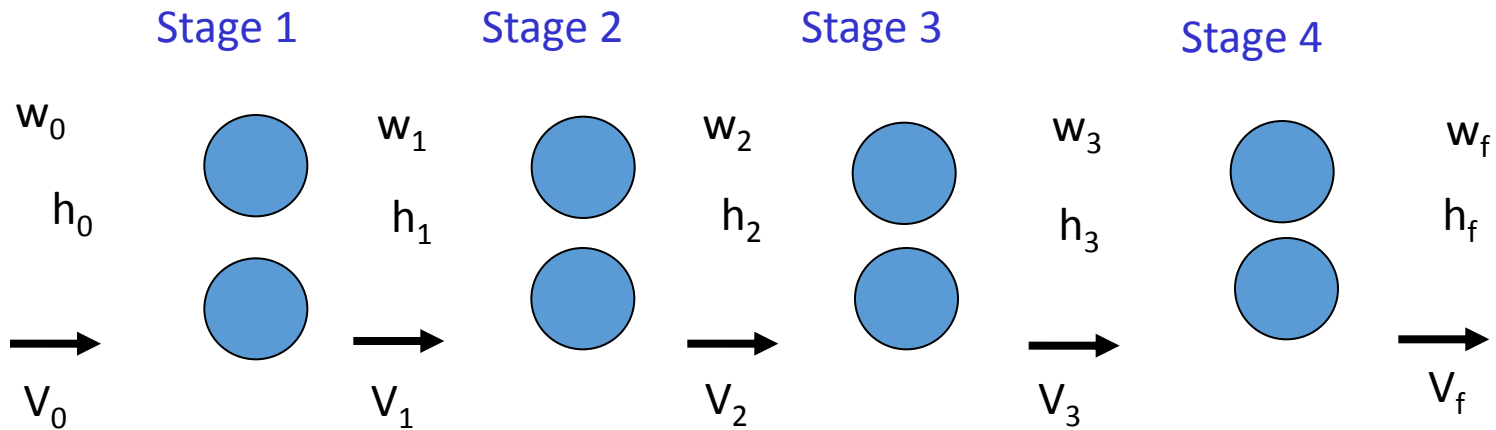
Tandem Rolling Mill

- A **tandem mill** is a special type of modern rolling mill where rolling is done in **one pass**.
- In a **traditional rolling** mill rolling is done in **several passes**, but in **tandem mill** there are several *stands* and **reductions take place successively**.
- The number of stands ranges from 2 to 18.
- Tandem mill can be either hot or cold rolling mill type



A series of rolling
stands in
sequence

Tandem Rolling



Volume conserved

$$h_0 V_0 w_0 = h_1 V_1 w_1 = h_2 V_2 w_2 = h_3 V_3 w_3 = h_f V_f w_f$$

Rolling schedules

Equal drafts

$$h_0 - h_1 = h_1 - h_2 = h_2 - h_3 = h_3 - h_f$$

Equal strains

$$\ln \frac{h_0}{h_1} = \ln \frac{h_1}{h_2} = \ln \frac{h_2}{h_3} = \ln \frac{h_3}{h_f}$$

Problems and defects in rolled products

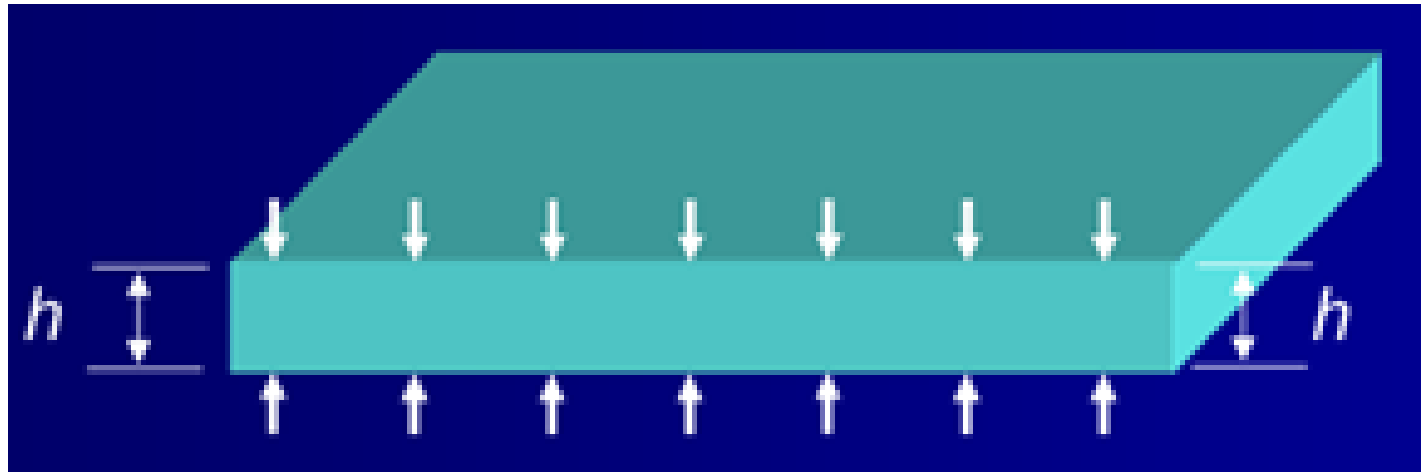
I. Defects *from cast ingot before rolling* i.e during the *in got stage of production*.

- *e.g. Porosity, cavity, blow hole* occurred in the cast ingot will be closed up during the rolling process.
- ✓ *non-metallic inclusions* related to melting and solidification practices., these defects can reduce the strength in the thickness direction.

II. Defects during rolling

There are *two aspects to the problem* of the shape of a sheet.

1) Uniform thickness over the width and thickness — can be precisely controlled with modern gage control system.



2) Flatness — difficult to measure accurately.



End of Rolling process!

N.B: The next topic is Forging
process

1.3 Forging

➤ Contents to be discussed

➤ Definition

- ✓ Classification of forging processes

- ✓ difference b/n open-die, closed die and flash less forging

- ✓ Forging equipment (hammers, presses, and dies)

- ✓ Terminologies for a conventional impression (closed)die forging setups.

- ✓ Analysis of Open-Die Forging

Forging is the working of metal into a useful shape by

hammering or pressing

➤ it is a deformation process in which the **work is** compressed between two dies, using either impact or gradual pressure

➤ Useful industrial process used to make a variety of high-strength components for automotive, aerospace, and other applications.

➤ Forging can be classified in to many different ways.

➤ We can classify forging operations is by working temperature, type of equipment and process.

❖ Most forging operations are performed hot or warm, owing to reduce strength and increase ductility of the work metal.

➤ by working temperature

1) Hot forging

2) Warm forging

3) Cold forging

Classification of forging processes

➤ By equipment

1) **Forging hammer** or drop hammer

2) **Press forging**

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

➤ by Type of process-degree to which the flow of the work metal is constrained by the dies.

✓ By this classification, there are three types of forging operations, shown in Figure below

- (a) open-die forging,
- (b) impression-die forging, and
- (c) flash less forging.

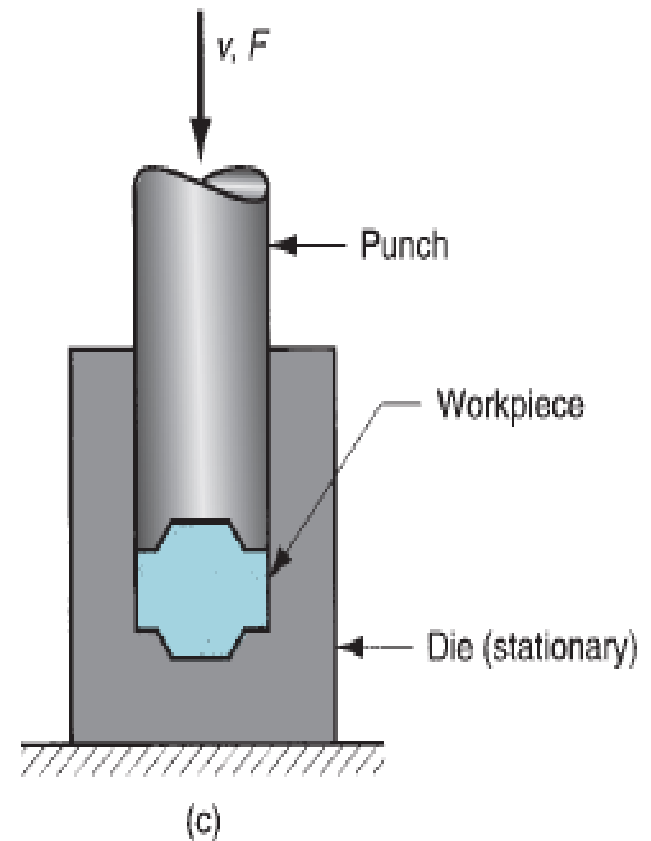
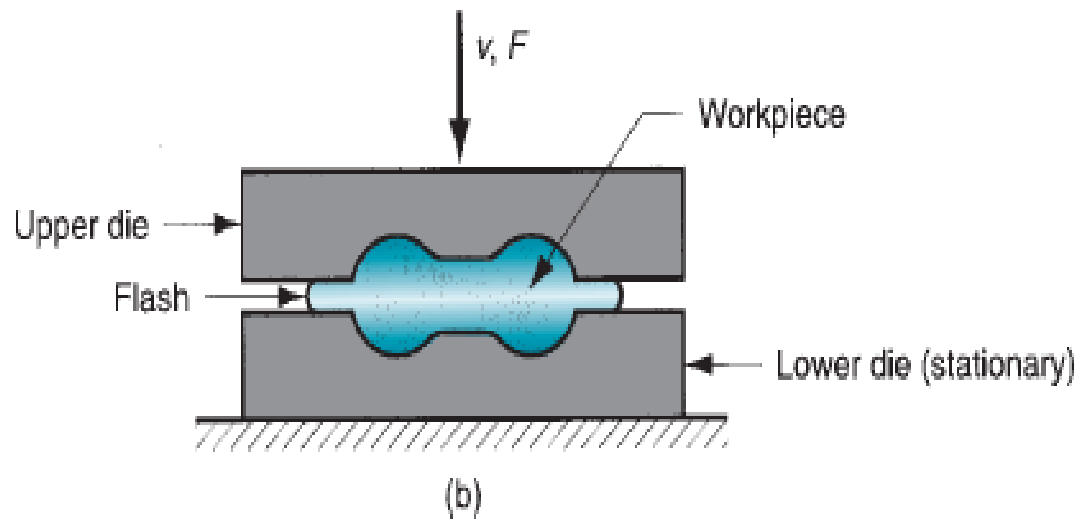
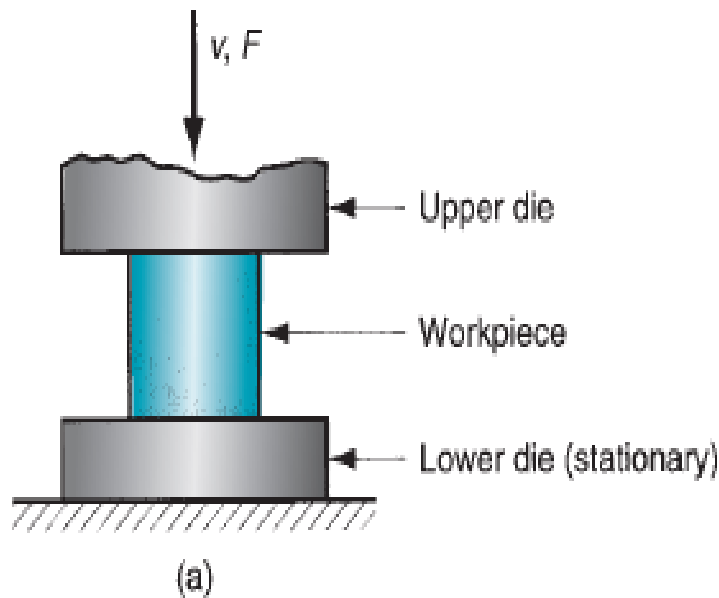
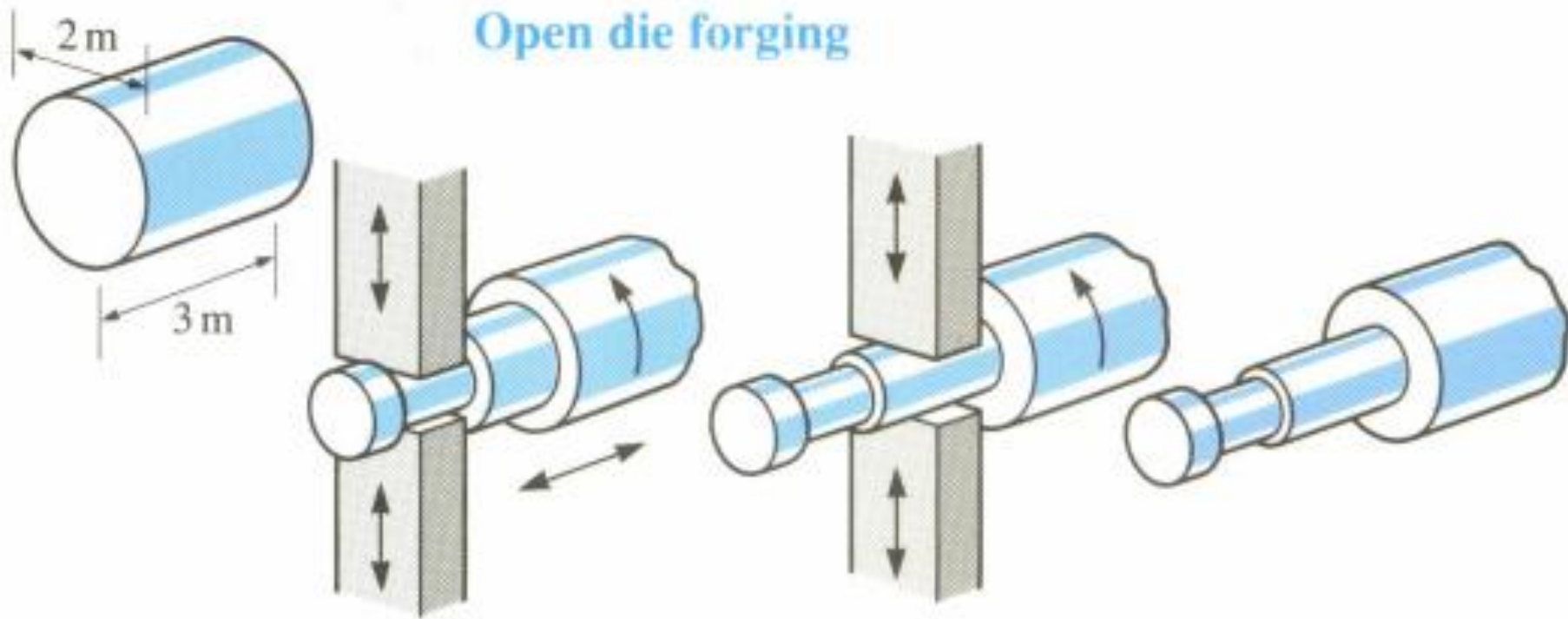


Figure: forging operation illustration (a) **open-die** forging, (b) **impression-die** forging, and (c) **flash less** forging.

I. Open-die forging

- In open-die forging, the work is compressed **between two flat** (or almost flat) dies, thus allowing the **metal to flow** without constraint **in a lateral direction** relative to the die surfaces.
- This forging operation, known as **upset forging** that **reduces the height of the work and increases its diameter**.
- **Shapes generated** by open-die operations include: **shafts, disks, and rings**(shapes with **round cross section**) .

Open-die forging is often used to preform the work piece for closed-die forging. [extreme for.mp4](#)



II. Impression-die (closed die)forging

- The work piece is deformed under high pressure in a closed cavity. thus constraining metal flow to a significant degree.
- In this type of operation a portion of the work metal flows beyond the die impression to form flash.
- Flash is excess metal that must be trimmed off later

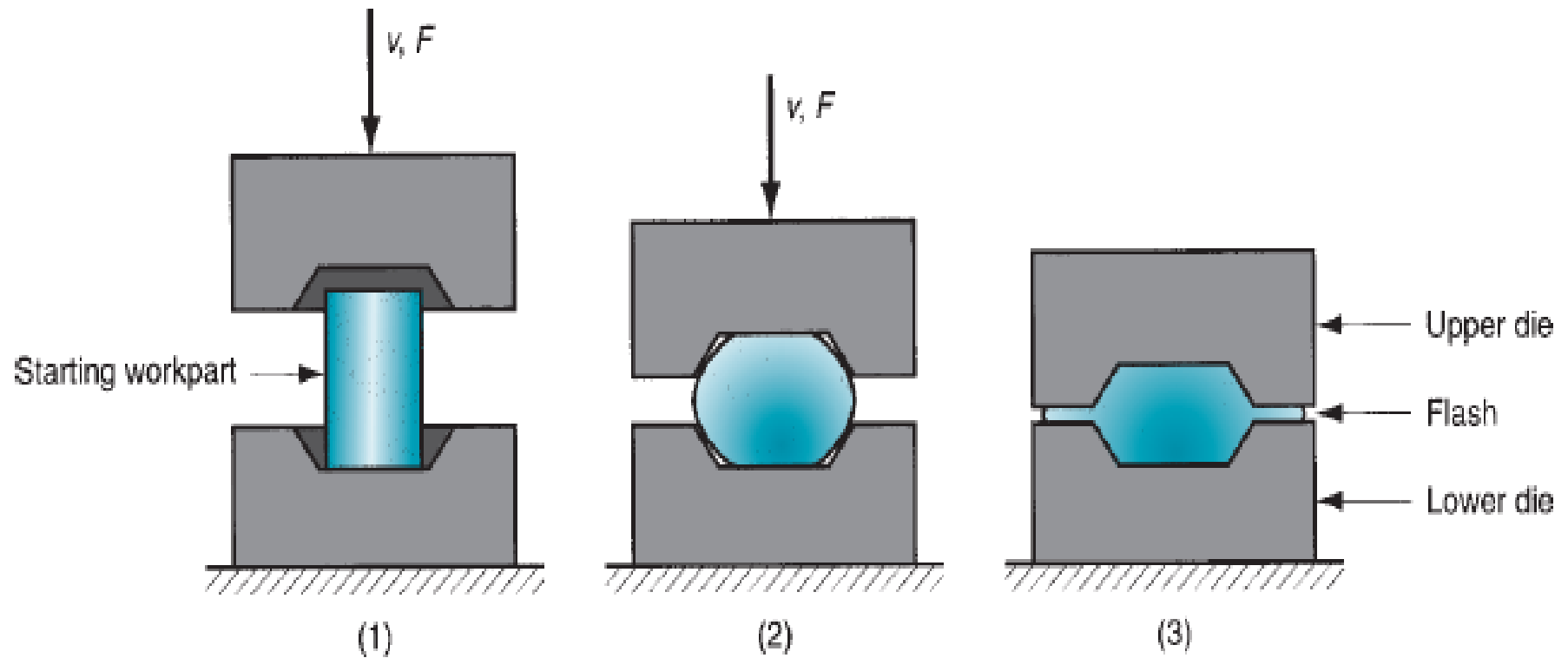


Figure: Sequence in impression-die forging: (1) just prior to initial contact with raw work piece, (2) partial compression, and (3) final die closure, **causing flash to form in gap between die plates.**

❖ flash has **important function** during impression-die forging.

➤ thin flash cools & **constraining the bulk of the work material** to remain in the die cavity.
as a 'safety value' for excess metal.

➤ **Builds up high** compression pressures **forcing the material to fill all recesses of die cavity to ensure high-quality product.**

III. Flash less forging

- In flash less forging, the work is completely constrained within the die and no excess flash is produced.
- the work volume must equal the space in the die cavity within a very close tolerance.
- If the starting blank is too large, excessive pressures may cause damage to the die or press.

➤ If the blank is too small, the cavity will not be filled.

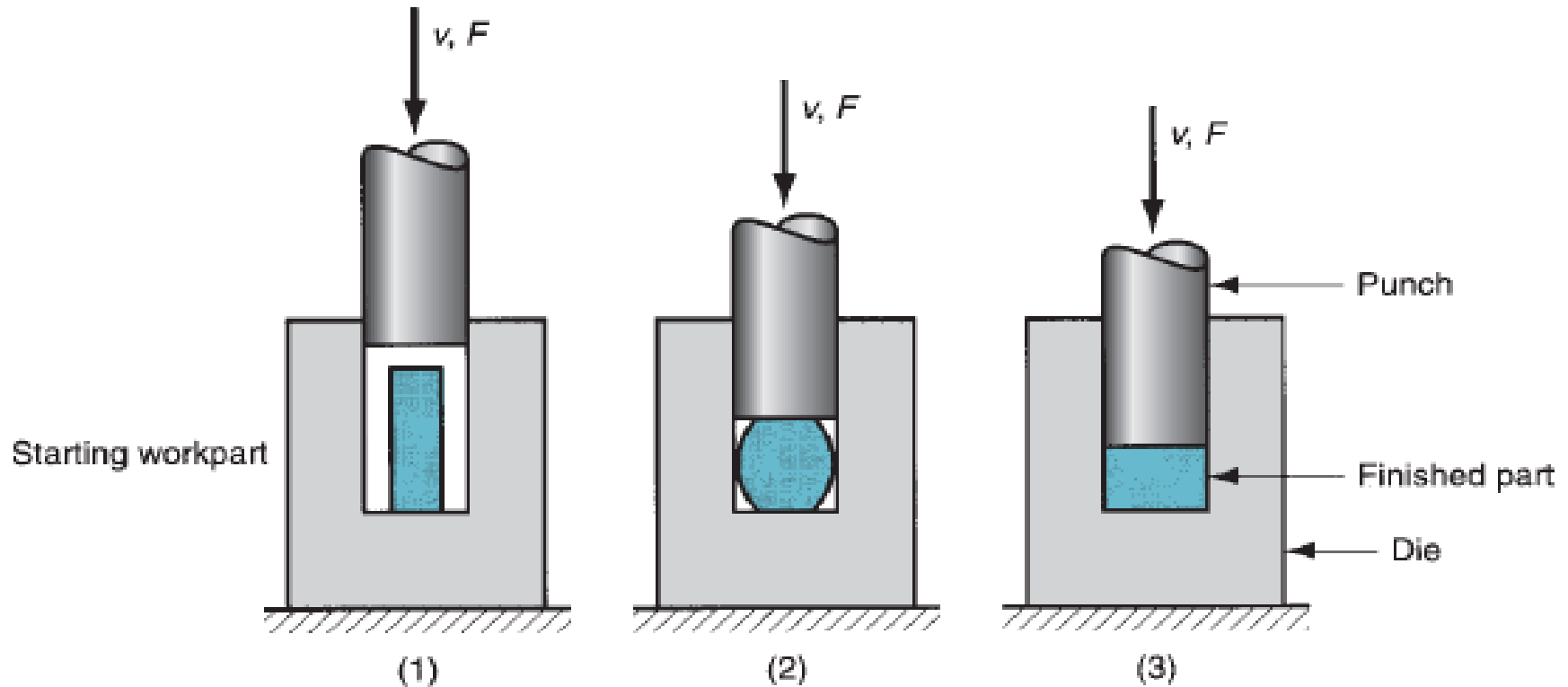


Figure: Flash less forging: (1) just before initial contact with work piece, (2) partial compression, and (3) final punch and die closure. (v = velocity) and applied force, respectively.

➤ Flash less forging is often classified as a **precision forging process**. The process is also used to **provide good surface finish and dimensional accuracy** on work parts. A common application of coining is **minting of coins**

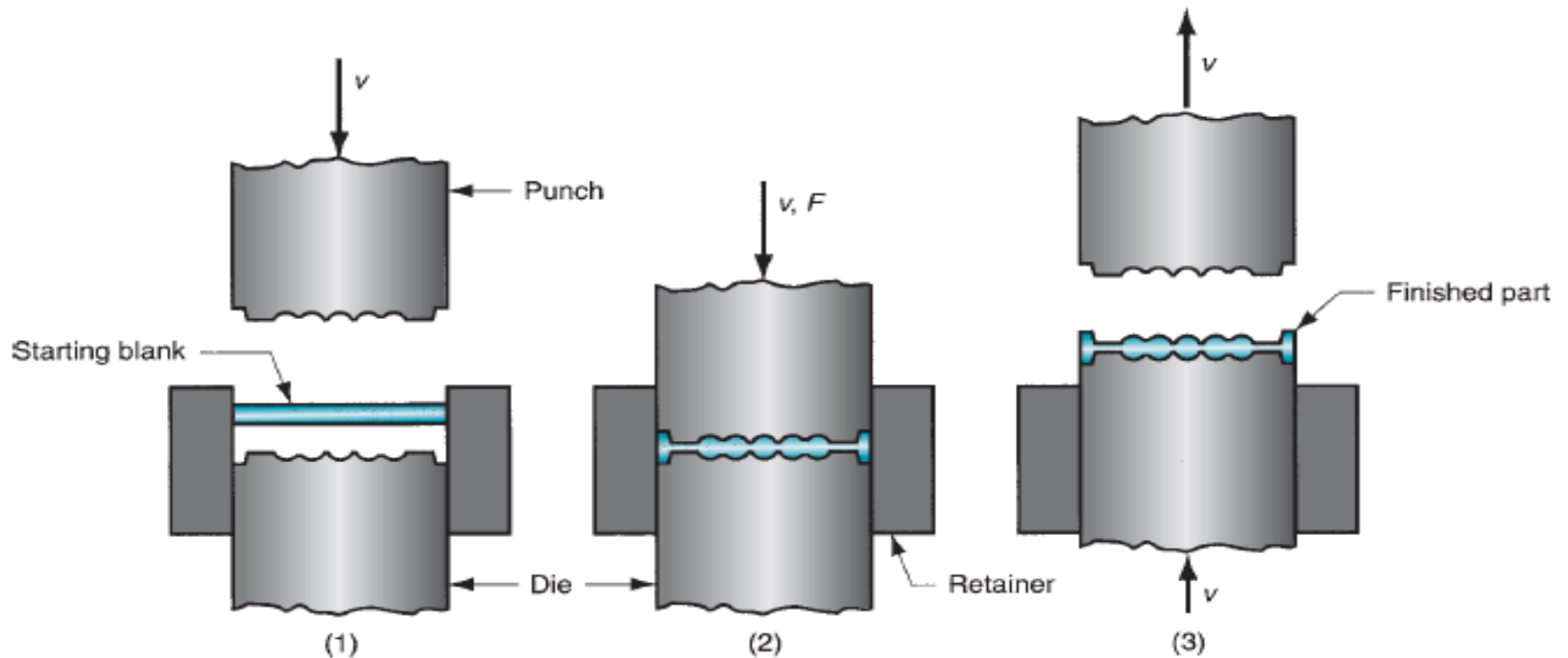


Fig **Coining operations**: (1) **start of cycle**, (2) **compression stroke**, and (3) **ejection of finished part**.



Forged parts

Examples of **coined parts** including **coins**, **medals**, **cutlery** and **hand tools**



Sequence of manufacturing wrenches



Forging hammers, presses, and dies

- **Equipment** used in forging consists of **hammers or presses, and forging dies**
- In addition, **auxiliary equipment** like : **furnaces** to heat the work, **mechanical devices** to load and unload the work, **and trimming stations** to cut away the flash in impression-die forging **piercing stations** to produce hole.

Forging Hammers:-operate by applying an **impact loading** against the work.

Example: Forging hammer or drop hammer



Forging machine

Figure: Drop forging hammer

$$\text{Potential energy} = mgh$$

- The energy supplied by the blow is equal to the potential energy due to the weight of the ram and the height of the fall.

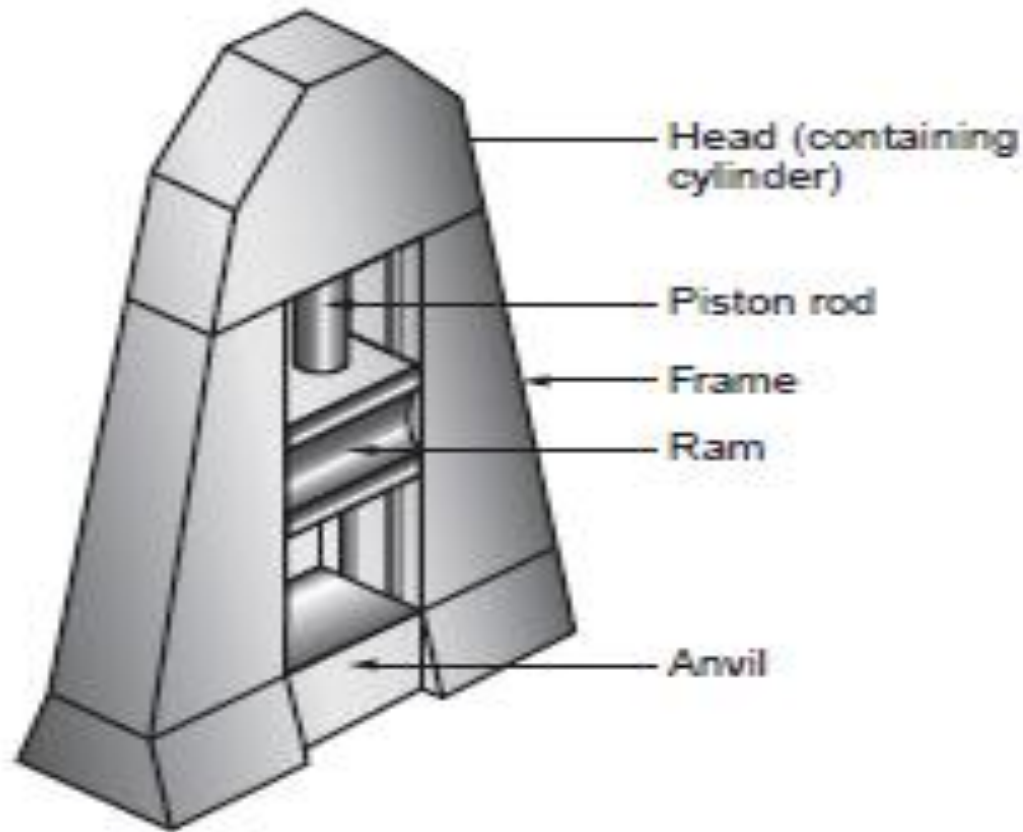


Figure: Diagram showing details of a drop hammer for impression-die forging.

- The **upper portion** of the forging die is attached **to the ram**, and the **lower portion** is attached to the **anvil**.

➤ Several blows of the hammer are often required to achieve the desired change in shape.

A. Drop hammers can be classified as gravity drop hammers and power drop hammers.

➤ **Gravity drop hammers** achieve their energy by the falling weight of a heavy ram.

➤ **Power drop hammers** accelerate the ram by pressurized air or steam. .

B. Forging Presses

➤ Presses **apply** gradual pressure, to accomplish the forging operation.

Forging presses **include** mechanical presses, hydraulic presses, and screw presses.

C. Forging Dies

➤ Proper die design is important in the success of a forging operation.

➤ Parts to be forged must be designed based on knowledge of the principles and limitations of this process.

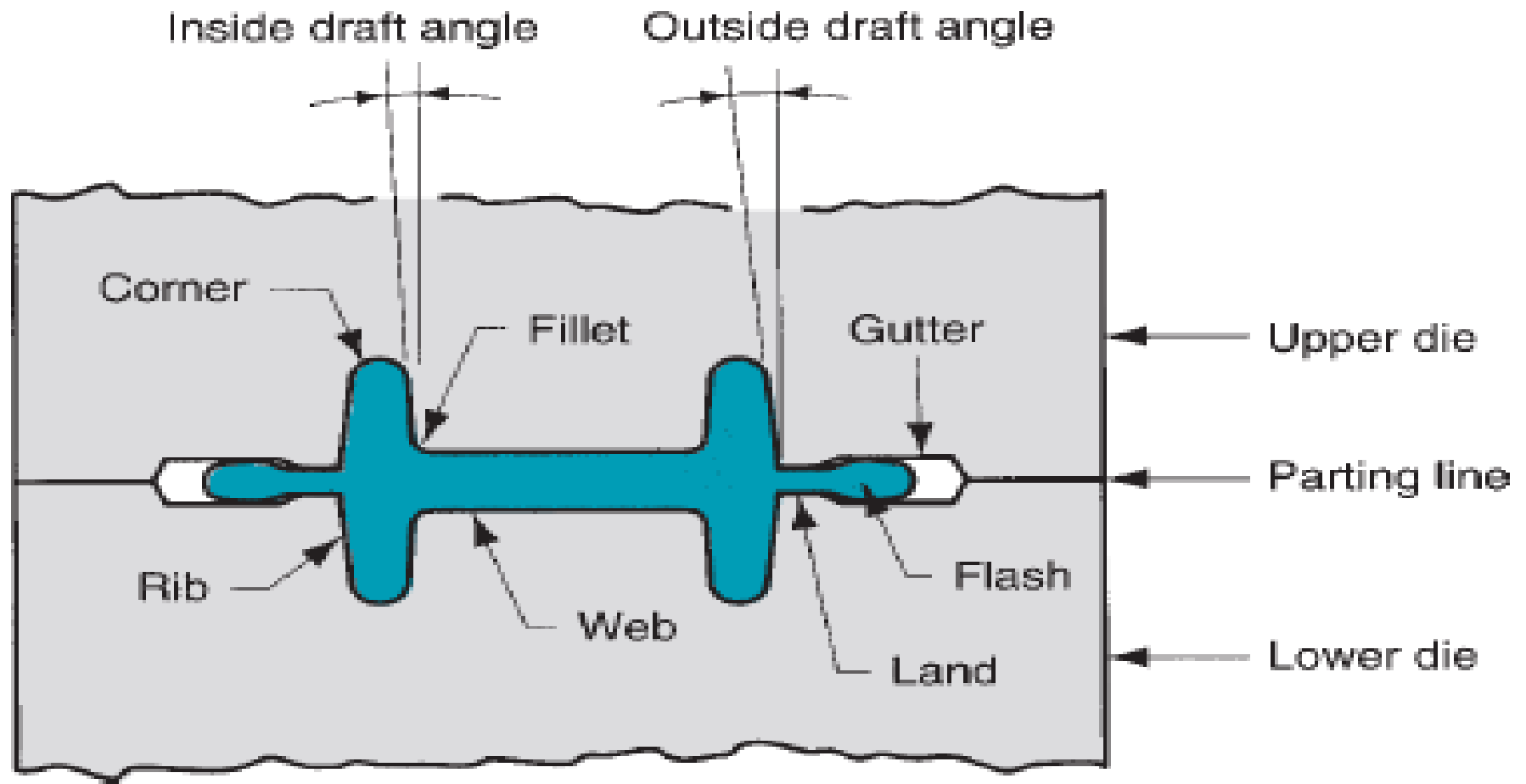


Figure: Terminology for a conventional impression die in forging.

a. Parting line: The parting line is the plane that divides the upper die from the lower die., Called the flash line in impression-die forging.

b. Webs and ribs: A web is a thin portion of the forging that is parallel to the parting line, while a rib is a thin portion perpendicular to the parting line.

➤ These part features cause difficulty in metal flow as well as the life of the die.

c. Fillet and corner radii: Fillets and corners are curved surface connecting ribs, bosses and webs, and are defined by their transverse section.

d. A corner is a **convex arc**, which joins two intersecting sides at an external angle of **more than 180°** , whereas

e. fillet is a **concave arc**, which **joins two intersecting sides** at an external angle of **less than 180°** .

➤ **Design of fillet and corner affect grain flow, forging pressure requirement, die wear, amount of metal to be removed during machining, and cost of dies and forgings.**

Analysis of Open-Die Forging

➤ If open-die forging is carried out under ideal conditions of no friction between works and die surfaces, then homogeneous deformation occurs,

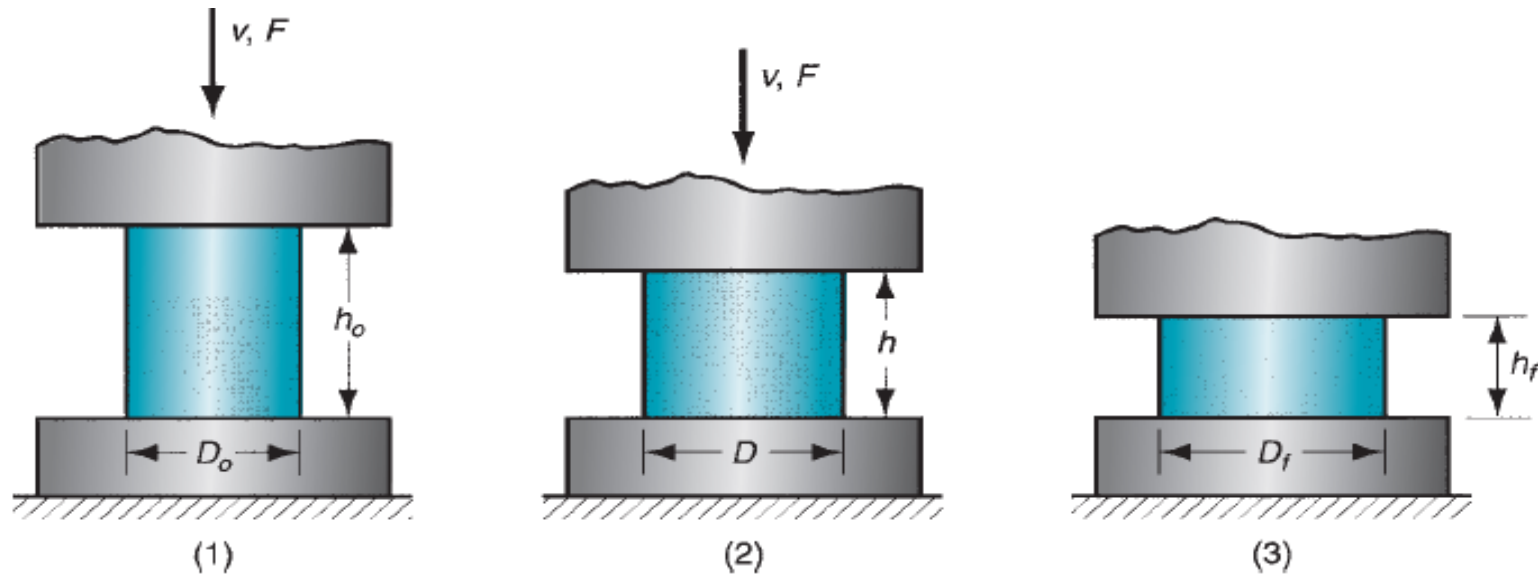


FIG. Homogeneous deformation of a cylindrical work part :
(1) start of process with work piece at its original length and diameter,
(2) partial compression, and
(3) final size

➤ Under these ideal conditions, the true strain experienced by the work during the process can be determined by
$$\epsilon = \ln \frac{h_o}{h} \quad (19.14)$$

Where h_o = starting height of the work, mm; and h = the height at some intermediate point in the process, mm.

➤ At the end of the compression stroke, h = its final value h_f , and the true strain reaches its maximum value.

➤ The true strain can be used to determine the average flow stress Y_f as follow

$$Y_f = K\epsilon^n$$

➤ The force required to continue the compression at any given height h during the process can be obtained by multiplying the corresponding cross-sectional area by the flow stress:

$$F = Y_f A \quad (19.15)$$

Where F =force, (N); A = cross-sectional area of the part, mm^2 ; and Y_f = flow stress corresponding to the strain given by Eq. (19.14), MPa.

➤ As an approximation, we can apply a shape factor to Eq.

(19.15) to account for effects of the D/h ratio and friction:

$$F = K_f Y_f A \quad (19.16)$$

Where F , Y_f , and A have the same definitions as in the previous equation; and K_f is the forging shape factor, defined as

$$K_f = 1 + \frac{0.4 \mu D}{h} \quad (19.17)$$

Where μ = coefficient of friction; D = work part diameter, mm; and h = work part height, mm.

Example 1

A cylindrical work piece is subjected to a cold upset forging operation. The starting piece is 75 mm in height and 50 mm in diameter. It is reduced in the operation to a height of 36 mm. The work material has a flow curve defined by $K = 350 \text{ MPa}$ and $n = 0.17$. Assume a coefficient of friction of 0.1 and assume strain at the start of the process = 0.002. Determine the force as the process begins, at intermediate heights of 62 mm, 49 mm, and at the final height of 36 mm.

Solution:

Work piece volume $V = 75\pi (50^2/4) = 147,262 \text{ mm}^3$. At the moment contact is made by the upper die, $h = 75\text{mm}$ and the force $F = 0$. At the start of yielding, h is slightly less than 75 mm, and we assume that strain = 0.002, at which the flow stress is

$$Y_f = K\epsilon^n = 350(0.002)^{0.17} = 121.7 \text{ MPa}$$

The diameter is still approximately $D = 50 \text{ mm}$ and area $A = \pi (50^2/4) = 1963.5\text{mm}^2$. For these conditions, the adjustment factor K_f is computed as

$$K_f = 1 + \frac{0.4(0.1)(50)}{75} = 1.027$$

The forging force is

$$F = 1.027(121.7)(1963.5) = 245,410 \text{ MPa}$$

At $h = 62 \text{ mm}$,

$$\epsilon = \ln \frac{75}{62} = \ln(1.21) = 0.1904$$

$$Y_f = 350(0.1904)^{17} = 264.0 \text{ MPa}$$

Assuming constant volume,

$$A = 147,262/62 = 2375.2 \text{ mm}^2 \text{ and } D = \sqrt{\frac{4(2375.2)}{\pi}} = 55.0 \text{ mm}$$

$$K_f = 1 + \frac{0.4(0.1)(55)}{62} = 1.035$$

$$F = 1.035(264)(2375.2) = 649,303 \text{ N}$$

Similarly, at $h = 49 \text{ mm}$, $F = 955,642 \text{ N}$; and at $h = 36 \text{ mm}$, $F = 1,467,422 \text{ N}$.

Work done in forging given by:

$W = \text{Force} \times \text{displacement} = \text{Force} \times \text{Height}$, but $F = k_f Y_f A$

$W = FH = k_f Y_f A H = k_f Y_f V$ because Volume $= AH$ in

joule

on other hand;

$\text{power} = \frac{\text{work done}}{\text{time}} = \frac{FH}{t}$ but $\frac{H}{t} = V$ where $V = \text{velocity of}$

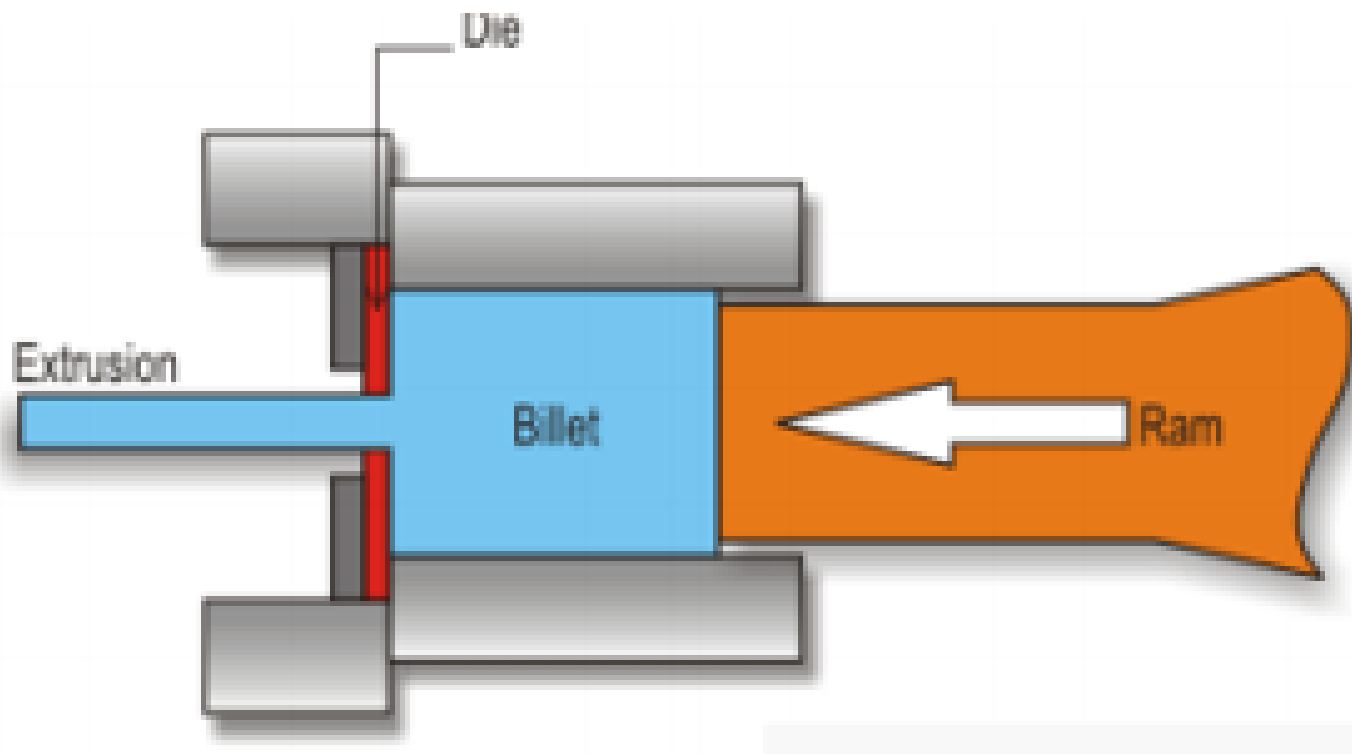
punch ,so that $P = FV$ in watt

End of Forging process!

N.B: The next topic is Extrusion
process

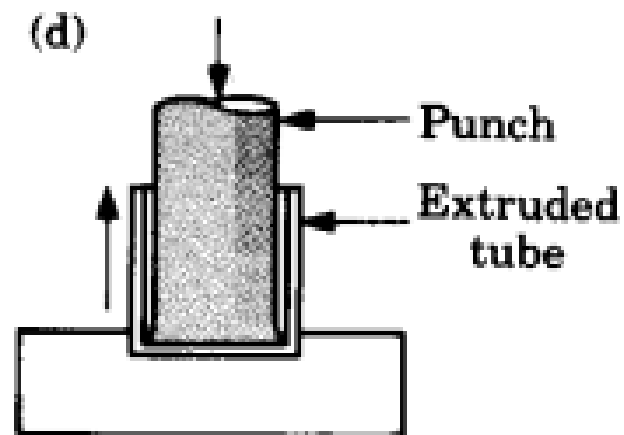
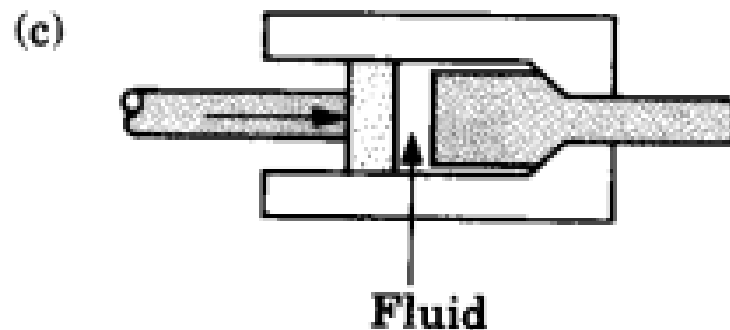
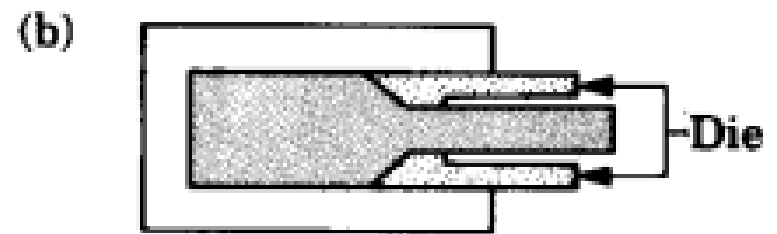
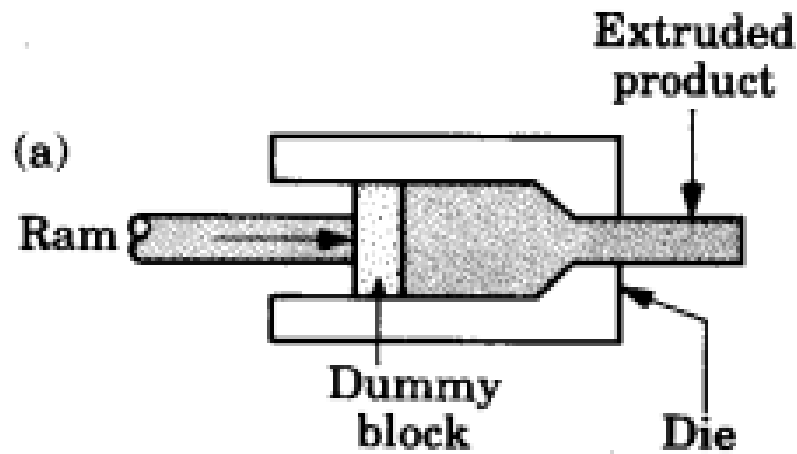
1.3 EXTRUSION

- Extrusion is the process by which a **block/billet of metal** is reduced in cross sectional shape by forcing it to flow through a die opening (orifice) under high pressure.
- it is a compression process in which the work **metal is forced to flow through a die opening to produce a desired cross-sectional shape.**



- ❖ extrusion is used **to**
- **produce cylindrical bars or hollow tubes or**
- **for the starting stock for drawn rod, cold extrusion or forged products.**

Types of Extrusion



(a) Direct

(b) indirect

(c) hydrostatic (d) impact

Types of Extrusion

- distinction between direct (forward) extrusion and indirect(backward) extrusion is based on direction
- Another classification is by working temperature: cold, or hot extrusion.
- In **Direct** extrusion , 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**

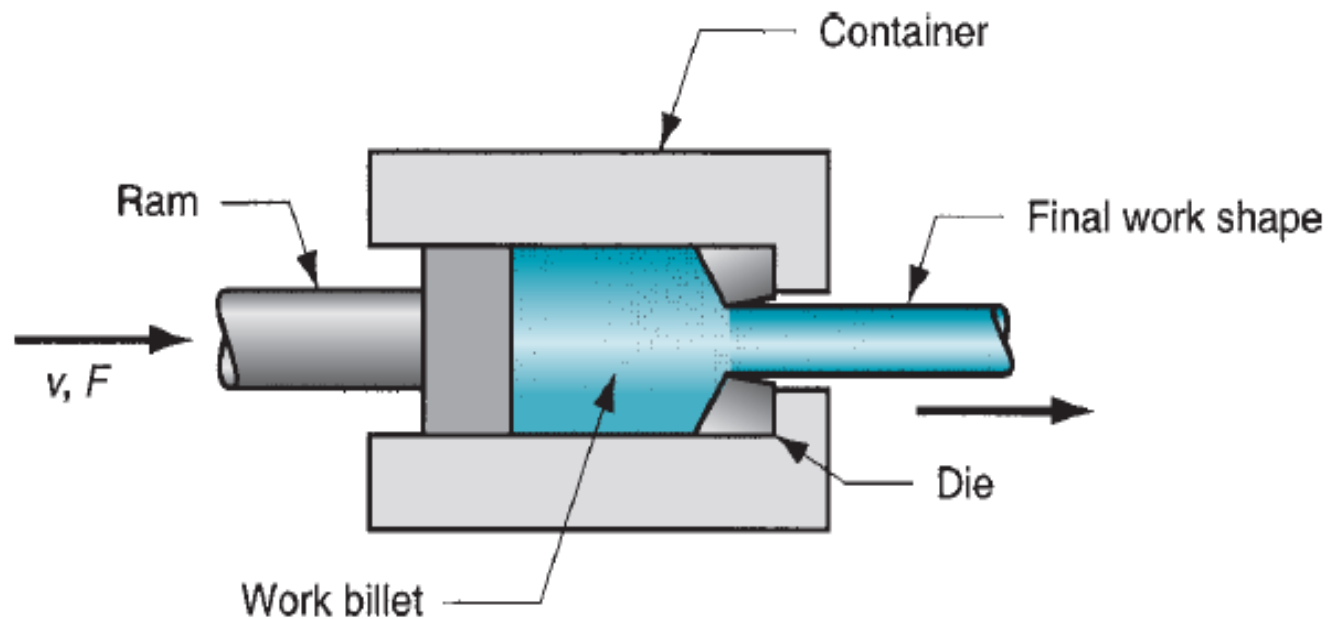
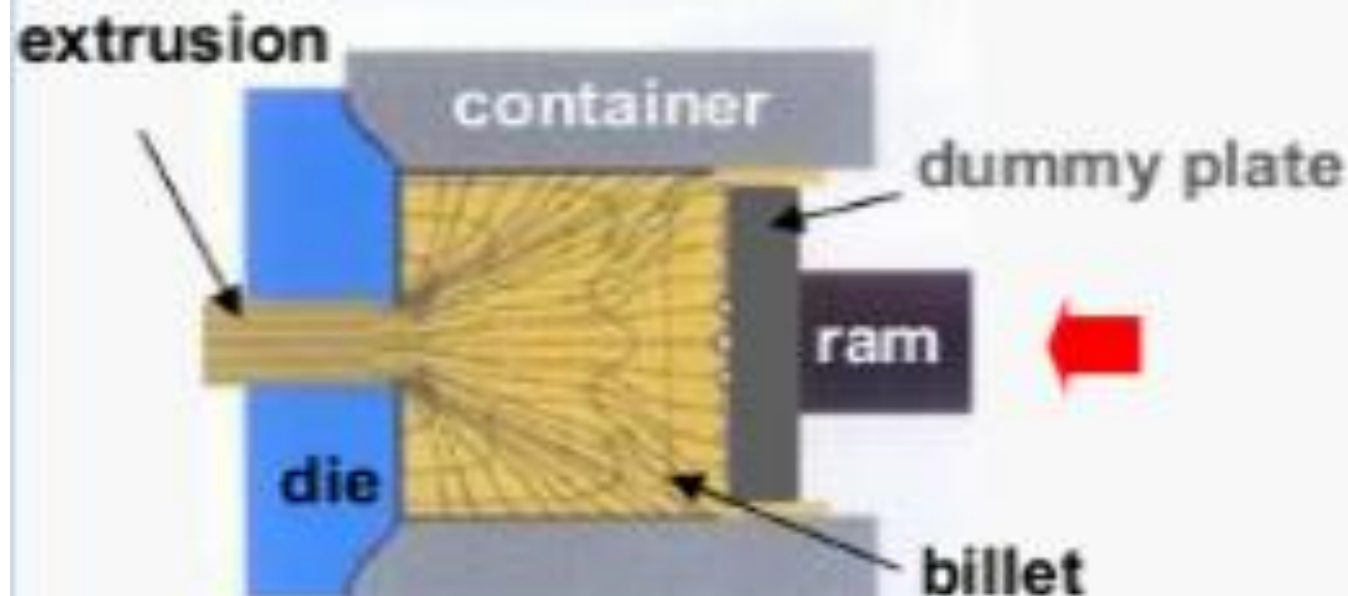


Fig .Direct extrusions.

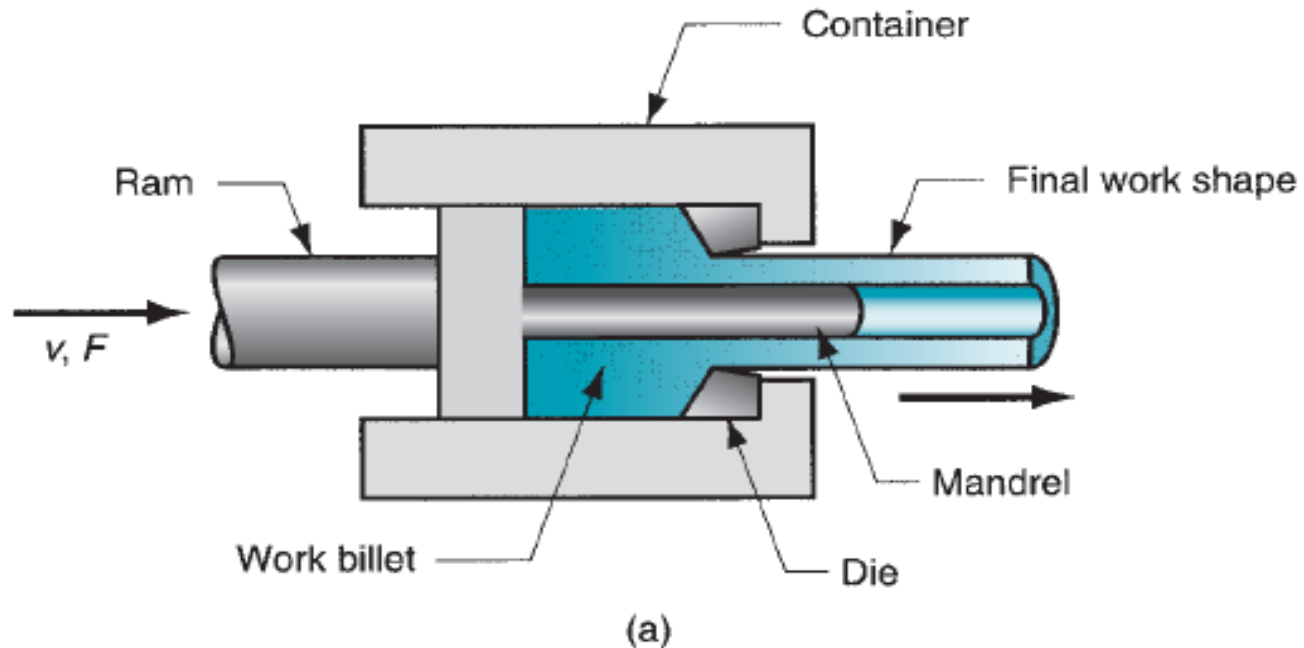
➤ One of the **problems in direct extrusion** is the significant **friction** that exists **between the work** surface and the **walls of the container** as the billet is forced to slide toward the die opening.

- In hot extrusion, the **friction form oxide layer on the surface of the billet**. This oxide layer can cause **defects in the extruded product**.
- To address these problems, **a dummy block is often used between the ram and the billet**.
- The diameter of the **dummy block** is slightly **smaller than the billet diameter**, so that a narrow ring of work metal (mostly the oxide layer) is left in the **container**, leaving the final product free of oxides.

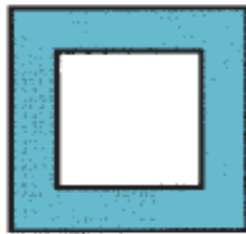


- The metal billet is placed in a container and driven through the die by the *ram*.
- The *dummy block* or pressure plate, is placed at the end of the ram in contact with the billet.
- Friction is at the die and container wall → requires higher pressure than indirect extrusion.

➤ Setup for extrusion of Hollow sections (e.g., tubes)



(b)



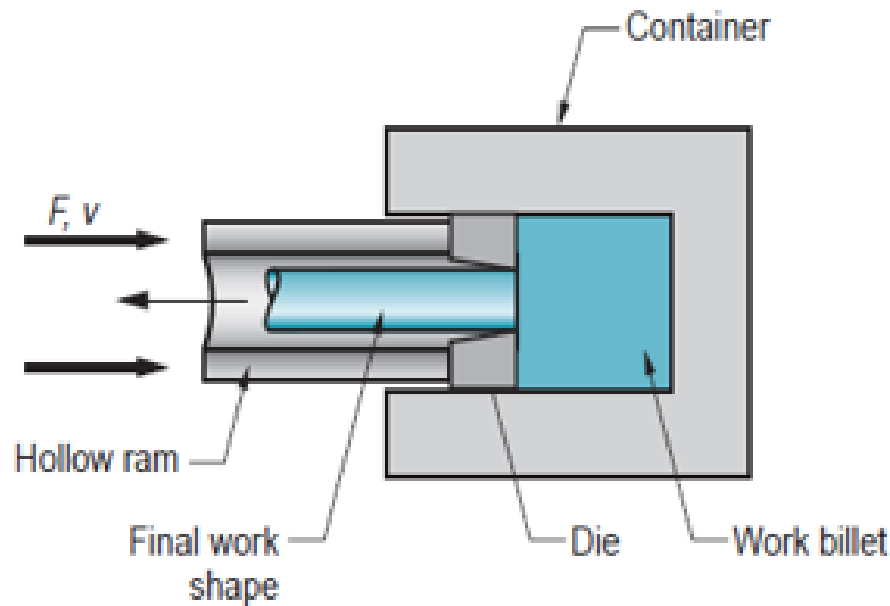
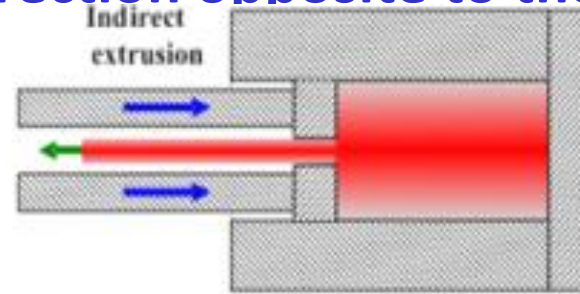
(c)



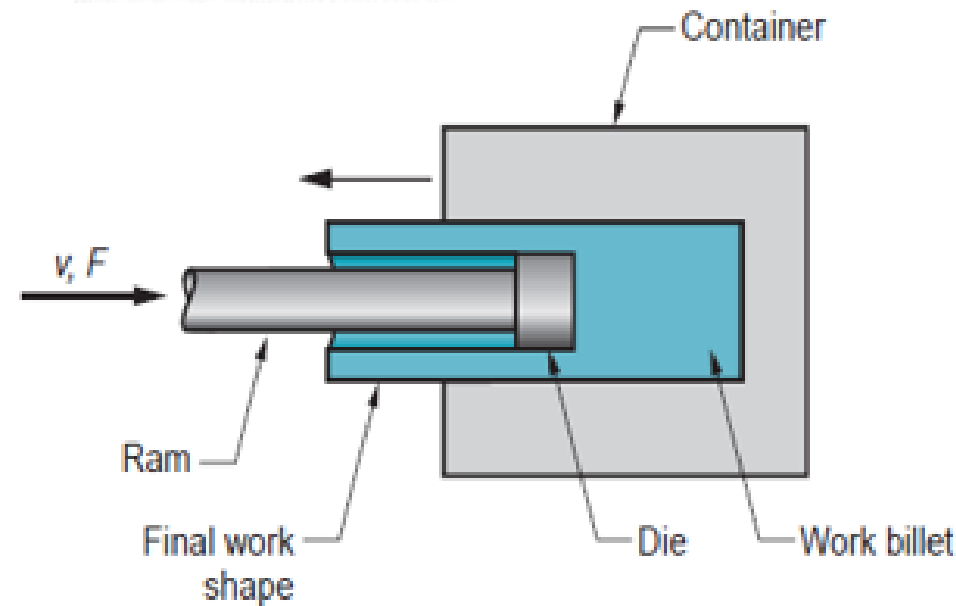
(a) Direct extrusion to produce a hollow or semi-hollow cross section; (b) hollow and (c) semi-hollow cross sections.

- The starting **billet is prepared with a hole** to allow 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 starting billet in direct extrusion is usually round in cross section, but the **final shape is determined by the shape of the die opening**.
- The largest dimension of the **die opening** must be **smaller than the diameter of the billet**.

- In **indirect extrusion** (backward extrusion/ **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**.



(a)



(b)

Indirect extrusion to produce (a) a solid cross section and (b) a hollow cross section.

❖ **Limitations** of indirect extrusion are imposed by the

➤ **lower rigidity of the hollow ram** and

➤ **difficulty in supporting the extruded product** as it exits the die.

❖ **Support of the ram** becomes **a problem** as work length increases

Hot versus Cold Extrusion

➤ Hot extrusion is done at fairly high temperatures, approximately **50 to 75 % of the melting point of the metal**.

➤ The pressures can range from 35-700 MPa

➤ Hot extrusion involves **prior heating of the billet** to a temperature **above its recrystallization temperature**.

HOT EXTRUSION



- This reduces **strength** and increases **ductility** of the metal, permitting more extreme **size reductions and more complex shapes** to be achieved in the process.
- **Additional advantages** include **reduction of ram force, increased ram speed, and reduction of grain flow characteristics in the final product**

- **Lubrication is critical in hot extrusion** for certain metals (**e.g. steels**), and special **lubricants** have been developed that are effective under the harsh conditions in hot extrusion.
- **Oil and graphite** used as lubricant at **lower** temperatures, whereas at **higher** temperatures **glass powder is used**.
- **Metals that are typically extruded hot include** aluminum, copper, magnesium, zinc, tin, and their alloys.
- **Aluminum** is probably the most ideal metal for extrusion (**hot and cold**), and many **commercial aluminum products** are made by this process (**structural shapes, door and window frames,**

Cold Extrusion

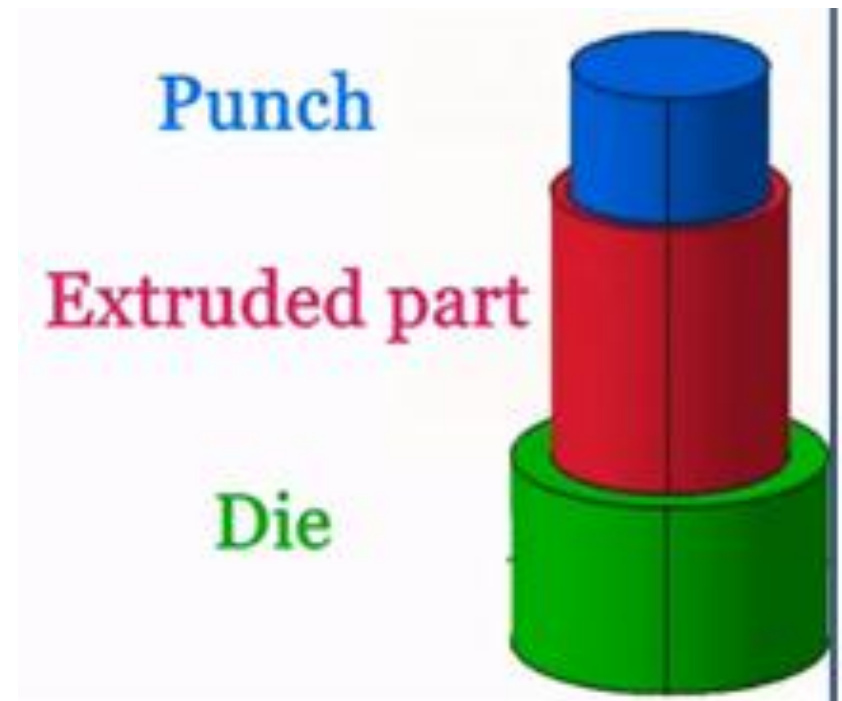
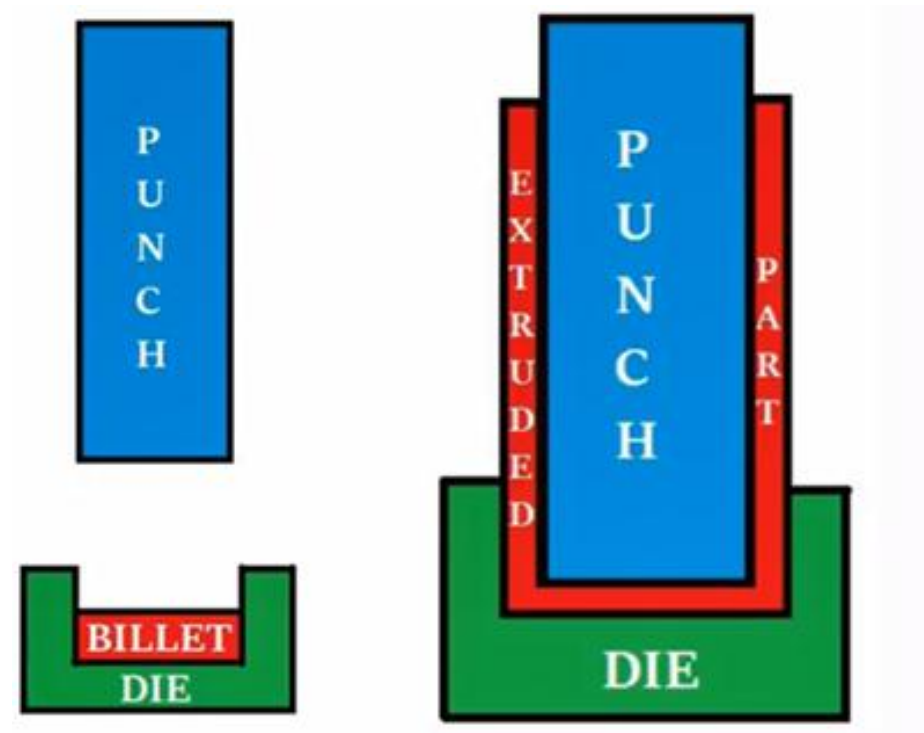
Cold extrusion generally used to produce **discrete parts**, often in finished (or near finished) form. Some important **advantages of cold** extrusion include increased **strength** due to strain hardening, **close tolerances**, **improved surface finish**, and **absence of oxide layers**.

Impact extrusion : In this process, **the punch** descends **with high velocity** and **strikes in the centre of the blank** which is placed in a die.

The material **deforms and fills up the annular space between the die and the punch** flowing upwards.

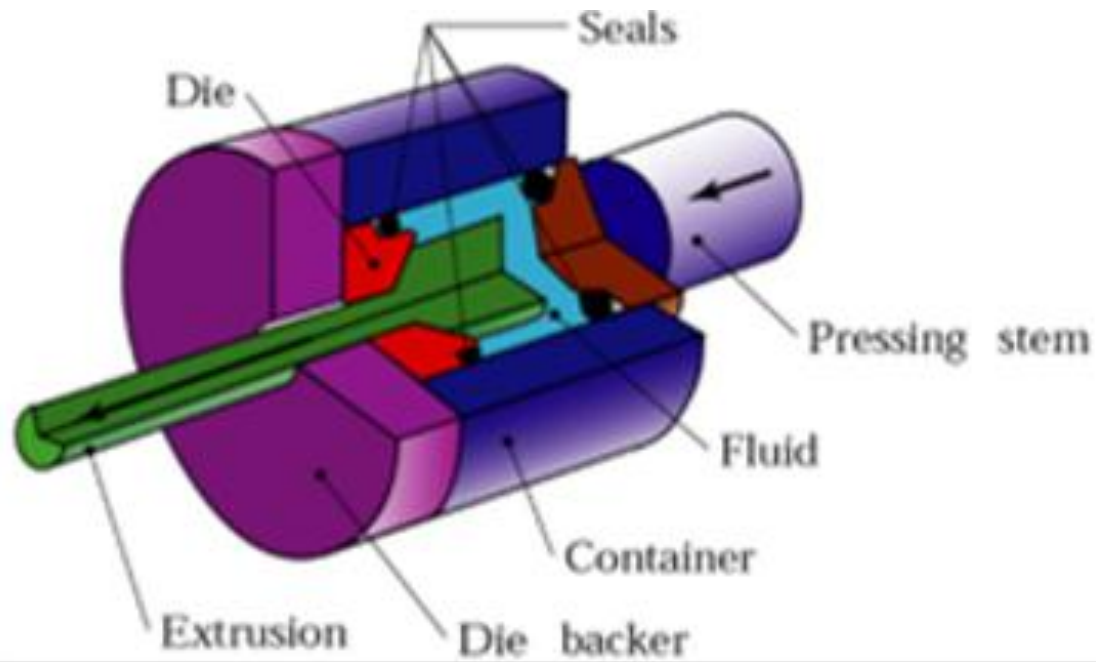
➤ Before the use of laminated plastic for manufacturing tooth paste, shaving cream tubes etc., these **collapsible tubes containing paste** were and are still made by this process.

➤ This process is actually a **backward extrusion process**.



Hydrostatic extrusion: The billet in the container is surrounded with fluid media, is also called hydrostatic fluid. The billet is forced through the die by a high hydrostatic fluid pressure. – 1000 to 3000 MPa

➤ The fluids commonly used are glycerin, ethyl glycol, mineral oils, castor oil mixed with alcohol etc. Relatively brittle materials can also be successfully extruded by this method.



Extrusion products

Typical parts produced by extrusion are trim parts used in automotive and construction applications, window frame members, railings, aircraft structural parts.

Example: Aluminium extrusions are used in commercial and domestic buildings for window and door frame systems, prefabricated houses/building structures, roofing and exterior cladding, curtain walling, shop fronts, etc. Furthermore, extrusions are also used in transport for airframes, road and rail vehicles and in marine applications.



Brass parts

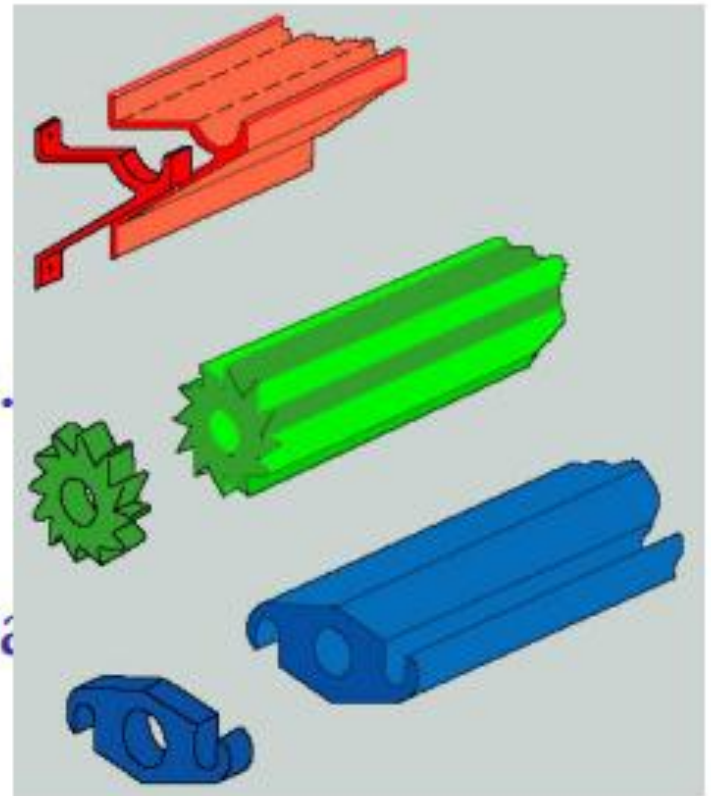


Aluminium extrusions



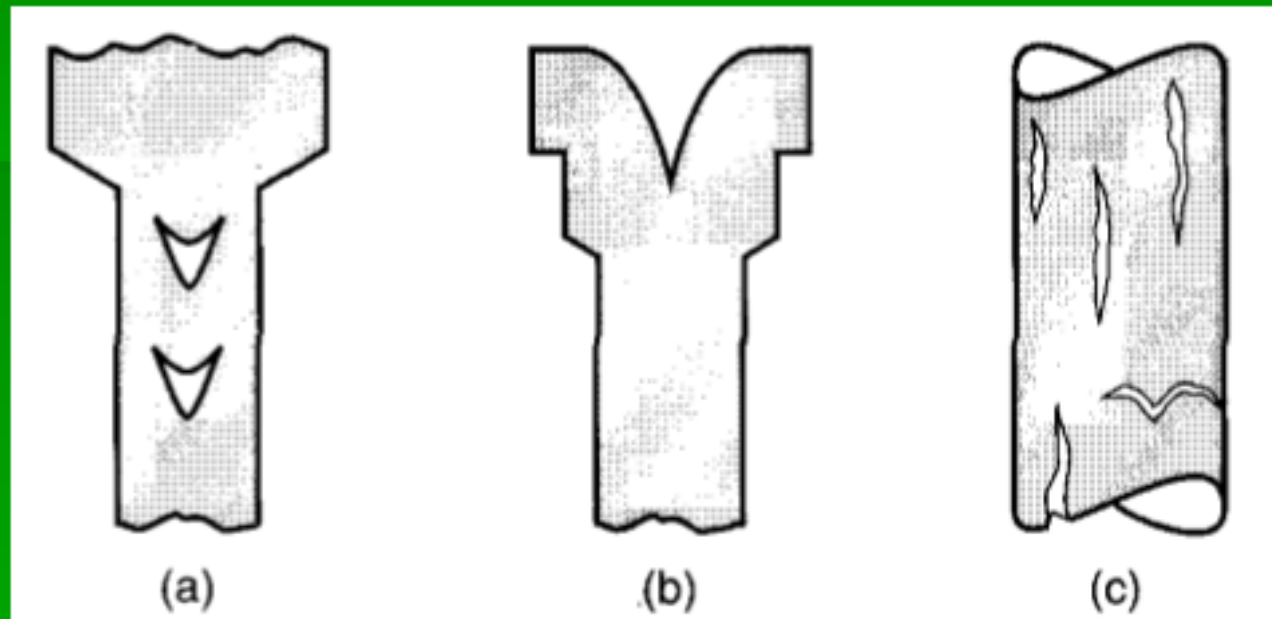
Examples

- Door & Window Frames.
- Aircraft body components.
- Structural and Architectural shapes.



Extrusion and examples of products made by sectioning off extrusions. *Source: Kaiser Aluminum.*

Extrusion Defects



- a) Centre-burst: internal crack due to excessive tensile stress at the centre possibly because of high die angle, low extrusion ratio.
- b) Piping: sink hole at the end of billet under direct extrusion.
- c) Surface cracking: High part temperature due to low extrusion speed and high strain rates.

ANALYSIS OF EXTRUSION

- Let us use Figure as a reference in discussing some of the parameters in extrusion.
- The diagram assumes that both billet and extrudate are round in cross section.

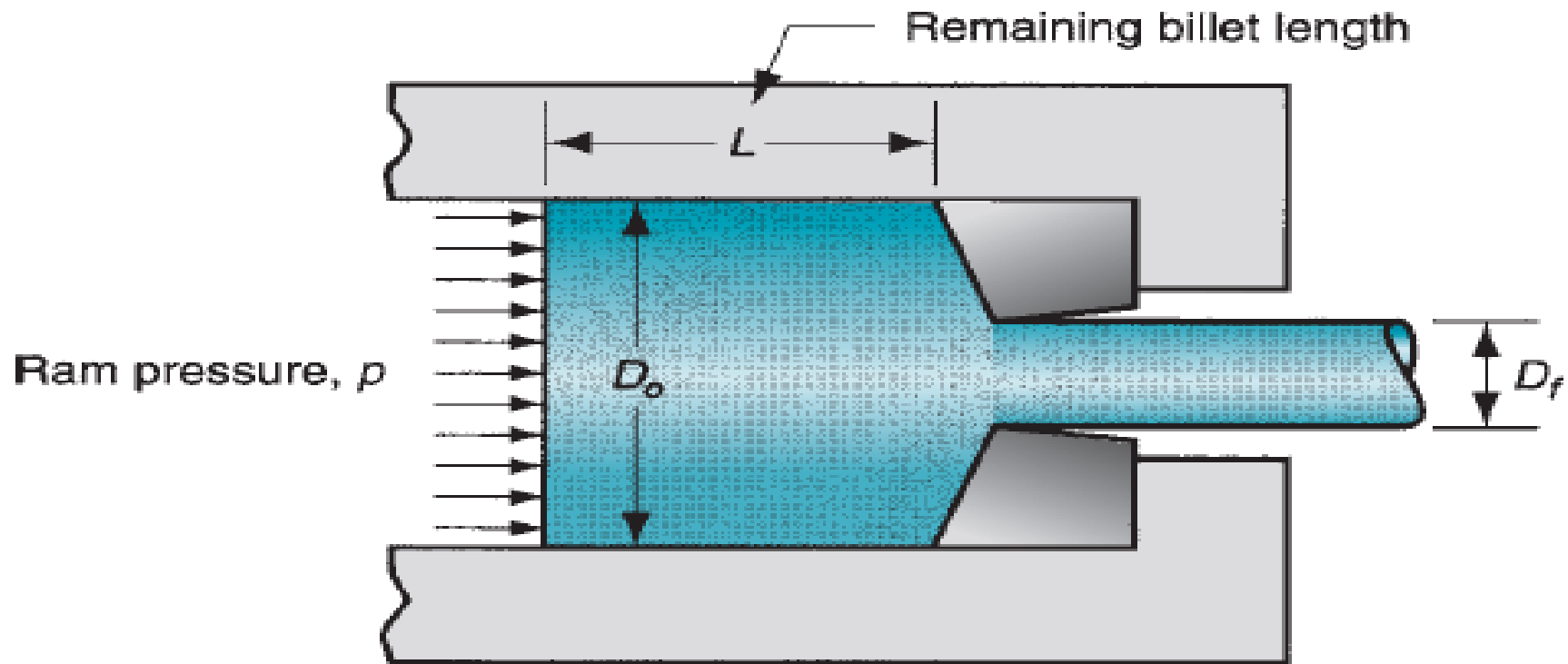


Fig. Pressure and other variables in direct extrusion.

- One important parameter is **the extrusion ratio**, also called the reduction ratio. The ratio is defined:

$$r_x = \frac{A_o}{A_f} \quad (19.19)$$

Where r_x = extrusion ratio; A_o = cross-sectional area of the starting billet, mm²; and A_f = final cross-sectional area of the extruded section, mm².

- The ratio applies for both direct and indirect extrusion.
- The value of r_x can be used to determine **true strain in extrusion**, given that ideal deformation occurs with no friction and no redundant work:

$$\epsilon = \ln r_x = \ln \frac{A_o}{A_f} \quad (19.20)$$

- In direct extrusion, friction also exists between the container wall and the billet surface.
- The effect of friction is to increase the strain experienced by the metal.
- Thus, the actual pressure is greater than that given by Eq. (19.21), which assumes no friction.
- Various methods have been suggested to calculate the actual true strain and associated ram pressure
- The following **empirical equation proposed by Johnson for estimating extrusion strain**:

$$\epsilon_x = a + b \ln r_x \quad (19.22)$$

Where ϵ_x = extrusion strain; and a and b are empirical constants for a given die angle.

- Typical values of these constants are: $a = 0.8$ and $b = 1.2$ to 1.5 .
- Values of a and b tend to increase with increasing die angle.
- The **ram pressure** to perform in direct extrusion can be estimated based on Johnson's extrusion strain formula as follows:

$$p = \bar{Y}_f \epsilon_x \quad (19.23a)$$

Where Y_f is calculated based on ideal strain from Eq. (19.20), rather than extrusion strain in Eq. (19.22).

$$Y_f = \frac{k \epsilon^n}{1+n}$$

- In direct extrusion, the effect of friction between the container walls and the billet causes the ram pressure to be greater than for indirect extrusion.
- The following formula can be used to compute **ram pressure in direct extrusion**:

$$p = \bar{Y}_f \left(\epsilon_x + \frac{2L}{D_o} \right) \quad (19.23b)$$

Where the term **$2L/D_o$** accounts for the **additional pressure due to friction** at the container-billet interface. **L** is the portion of the billet length remaining to be extruded, and **D_o** is the original diameter of the billet.

- Note that p is reduced as the remaining billet length decreases during the process.

➤ **Ram force** in indirect or direct extrusion is simply pressure p from Eqs. (19.23a) or (19.23b), respectively, multiplied by billet area A_o :

$$F = pA_o \quad (19.24)$$

Where F = ram force in extrusion, N (lb).

➤ **Power required** to carry out the extrusion operation is simply

$$P = Fv \quad (19.25)$$

Where P = power, J/s; F = ram force, N; and v = ram velocity, m/s.

Example 1

A billet 75mm long and 25mm in diameter is to be extruded in a direct extrusion operation with extrusion ratio $r_x = 4.0$. The extrudate has a round cross section. The work metal has a strength coefficient = 415 MPa, and strain-hardening exponent = 0.18. Use the Johnson formula with $a = 0.8$ and $b = 1.5$ to estimate extrusion strain. Determine the pressure applied to the end of the billet as the ram moves forward.

Solution

Let us examine the ram pressure at billet lengths of $L = 75\text{mm}$ (starting value), $L = 50\text{ mm}$, $L = 25\text{ mm}$, and $L = 0$. We compute the ideal **true strain**, **extrusion strain** using Johnson's formula, and average **flow stress**:

$$\epsilon = \ln r_x = \ln 4.0 = 1.3863$$

$$\epsilon_x = 0.8 + 1.5(1.3863) = 2.8795$$

$$\bar{Y}_f = \frac{415(1.3863)^{0.18}}{1.18} = 373 \text{ MPa}$$

$$p = 373 \left(2.8795 + 2 \frac{75}{25} \right) = 3312 \text{ MPa}$$

$$L = 50 \text{ mm: } p = 373 \left(2.8795 + 2 \frac{50}{25} \right) = 2566 \text{ MPa}$$

$$L = 25 \text{ mm: } p = 373 \left(2.8795 + 2 \frac{25}{25} \right) = 1820 \text{ MPa}$$

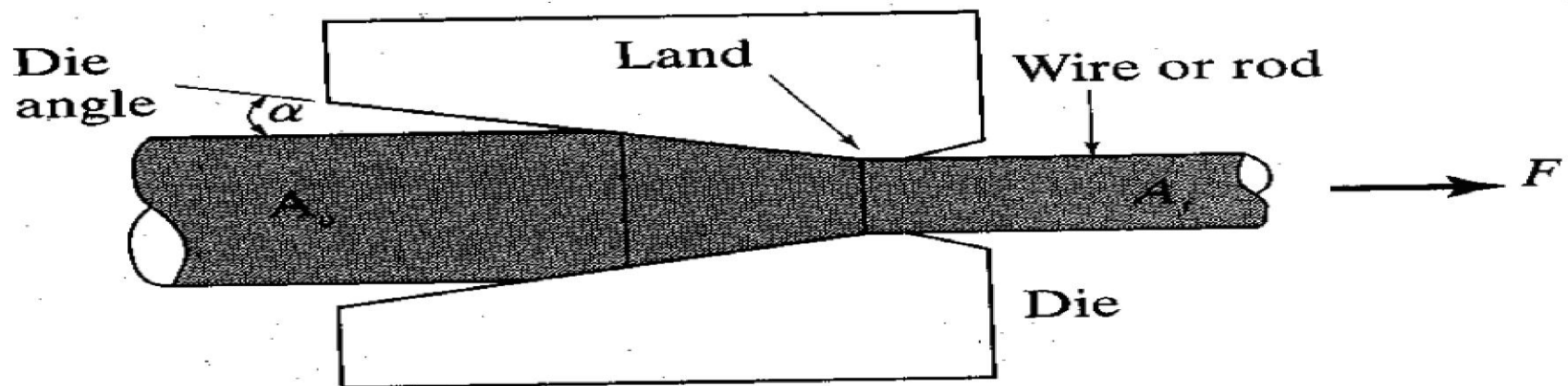
$L = 0$: Zero length is a hypothetical value in direct extrusion. In reality, it is impossible to squeeze all of the metal through the die opening. Calculated below is the hypothetical minimum value of ram pressure that would result at $L = 0$.

$$p = 373 \left(2.8795 + 2 \frac{0}{25} \right) = 1074 \text{ MPa}$$

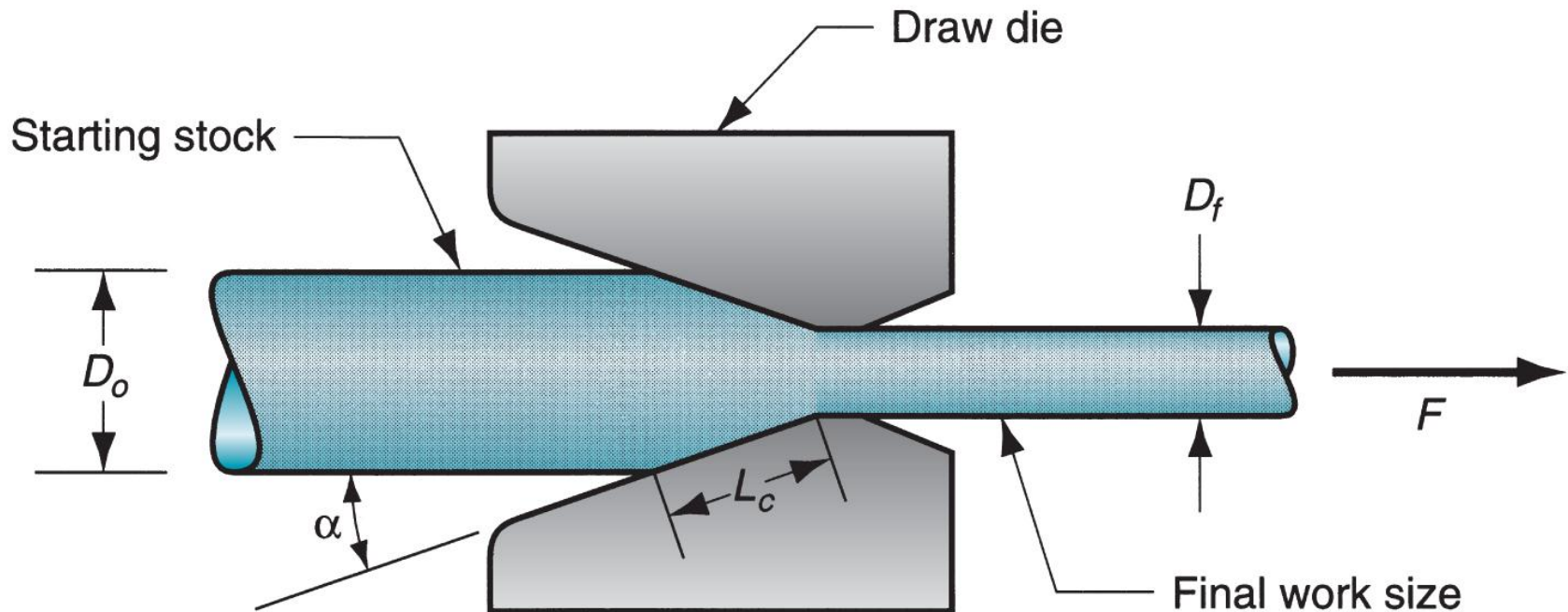
WHAT is DRAWING?

Drawing is an operation in which the cross-section of solid rod, wire or tubing is reduced or changed in shape by pulling it through a die.

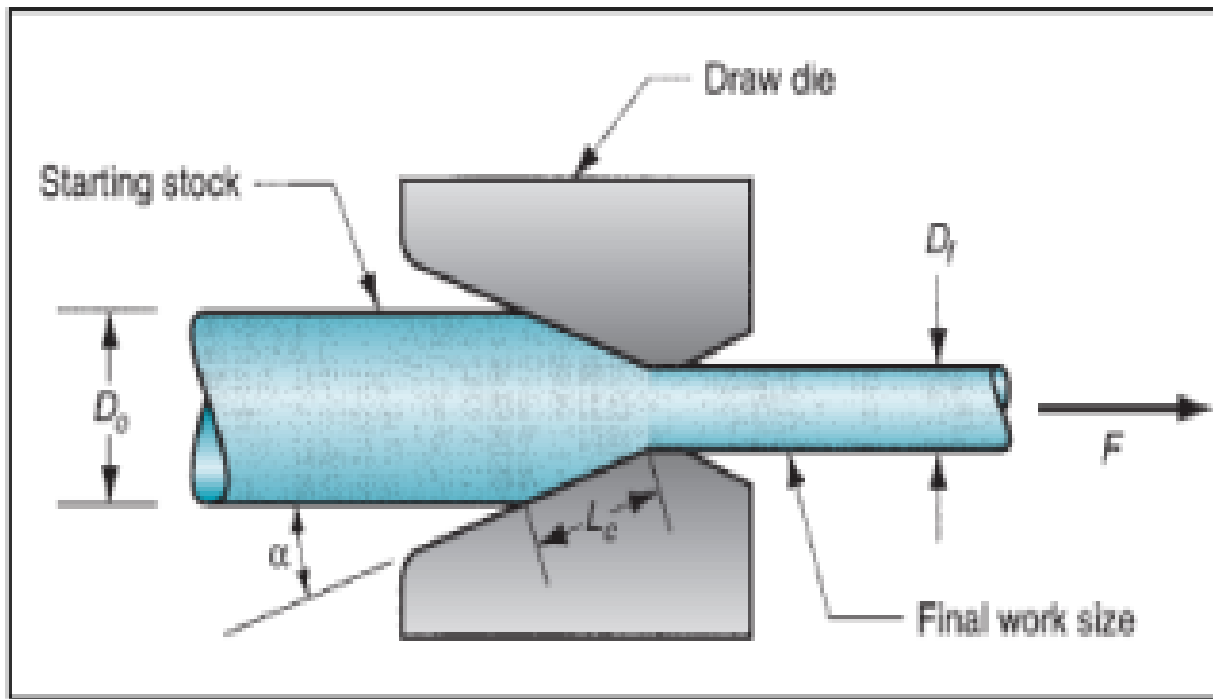
The principle of this procedure consist of reducing the thickness of a pointed ,tapered wire by drawing it through a conical opening in a tool made of a hard material.The wire will take shape of the hole.



- Wire and Bar Drawing
- Similar to extrusion *except work is pulled* through die in drawing
 - It is *pushed* through in extrusion
- Although drawing applies tensile stress, compression also plays a significant role since metal is squeezed as it passes through die opening



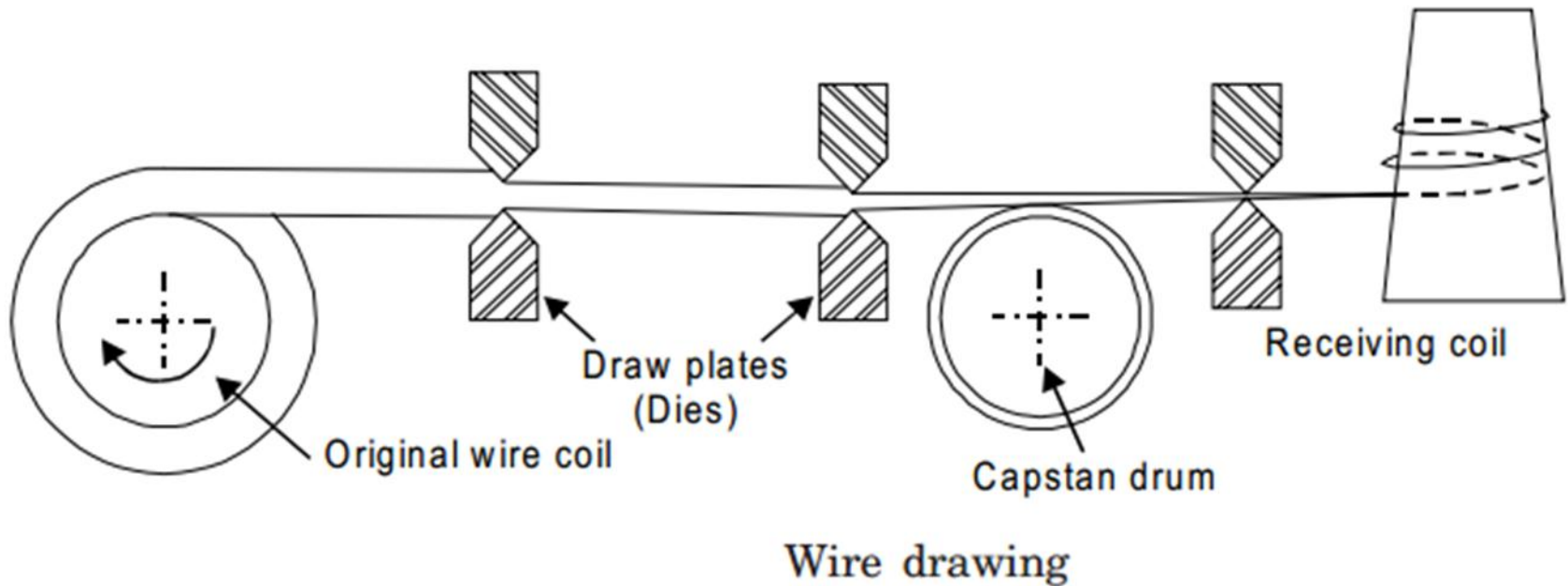
➤ In the context of bulk deformation, **drawing is an operation in which the cross section of a bar, rod, or wire is reduced by pulling it through a die opening, as in Figure**



Wire, rod, bar drawing

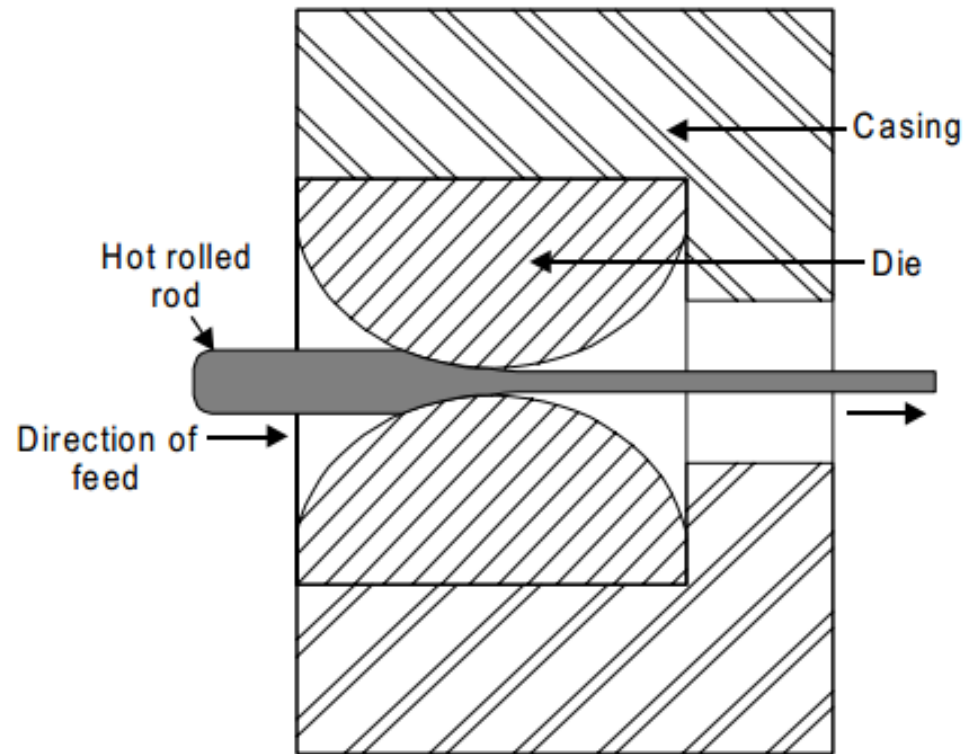
Fig. Drawing of bar, rod, or wire.

- The basic 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.



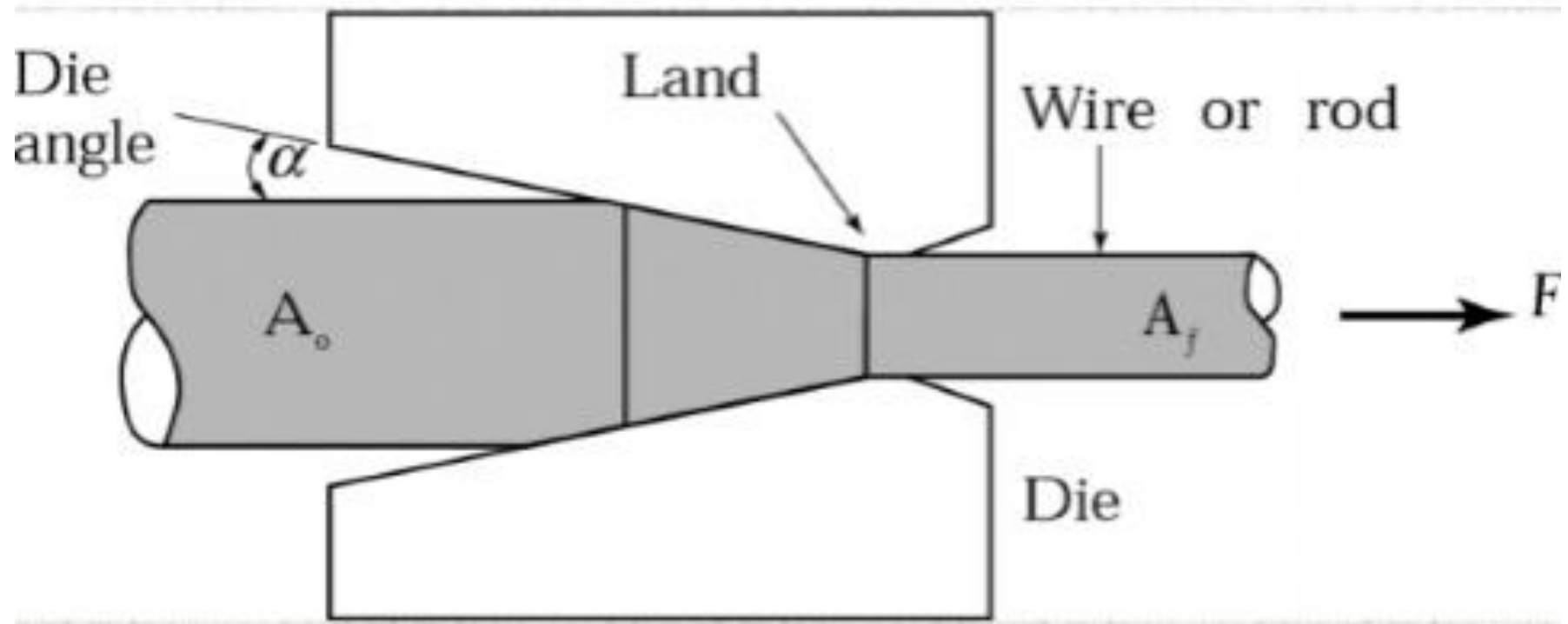
WIRE DRAWING

The process of producing **the wires of different diameters** is accomplished **by pulling a wire** through a hardened die usually made up carbide



Wire drawing

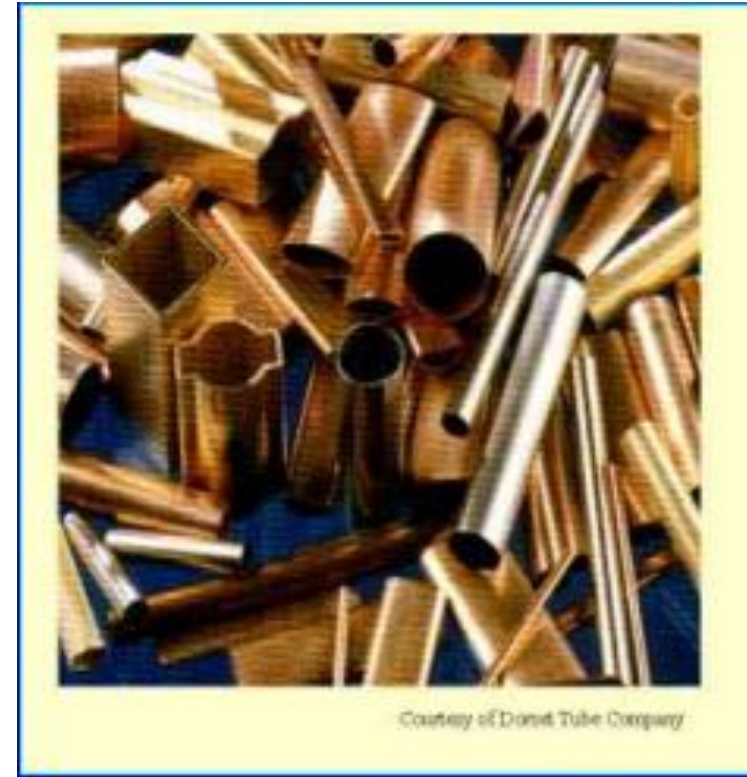
Process Variables in Wire Drawing



Process variables in wire drawing

- The die angle, the reduction in cross-sectional area per pass, the speed of drawing, the temperature, and the lubrication all affect the drawing force, F

Tube drawing :Tube drawing involves reducing the cross section and wall thickness through a draw die.

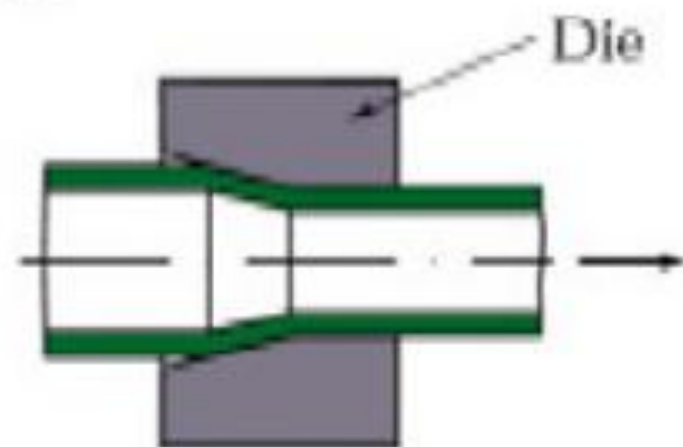


The cross section can be circular, square hexagonal or in any shapes

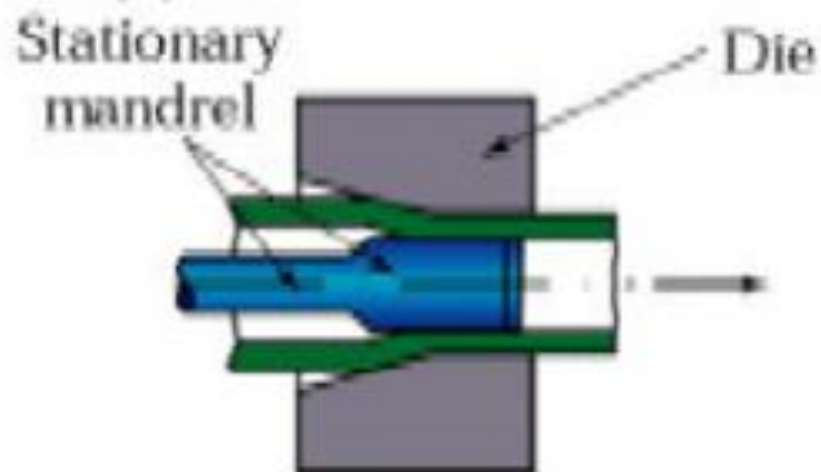
brass tubes for heat exchanger –cheap, strong, good corrosion resistant¹³³

Tube Drawing Operations

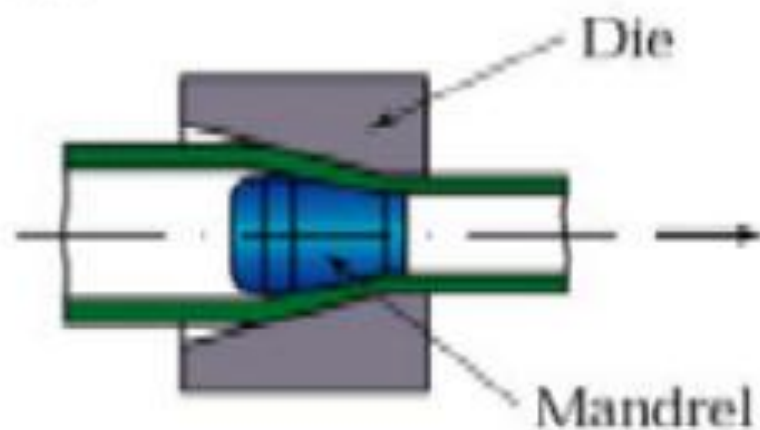
(a)



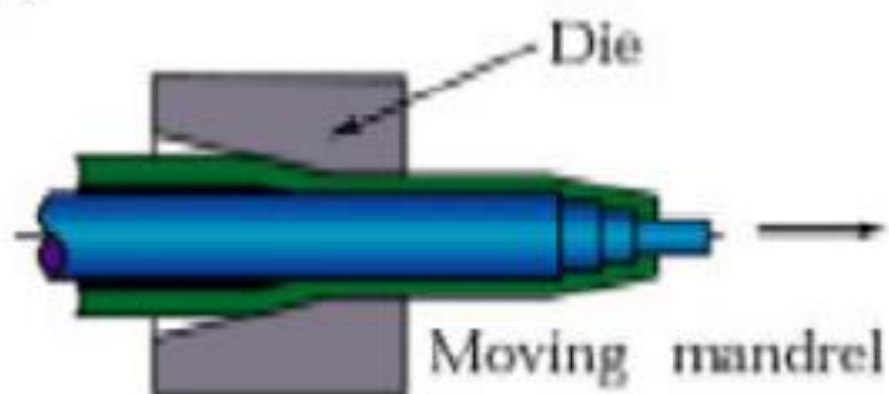
(b)



(c)



(d)



Defects in rod and wire drawing

- Defects in the starting rod (seams, slivers and pipe).
- Defects from the deformation process, i.e., **centre burst** or **chevron cracking (cupping)**.



Centre burst or chevron cracks

- This defect will occur for **low die angles** at low reductions.
- For a given reduction and die angle, the critical reduction to prevent fracture increases with the friction.

ANALYSIS OF DRAWING

- In a drawing operation, the change in size of the work is usually given by the **area reduction**, defined as follows:

$$r = \frac{A_o - A_f}{A_o} \quad (19.28)$$

Where r = area reduction in drawing; A_o = original area of work, mm² and A_f = final area, mm².

- Area reduction is often expressed **as a percentage**.
- In bar drawing and rod drawing the term **draft** is used to denote the **before and after difference in size** of the processed work.

- The draft is simply the **difference between** original and final diameter , $d=D_o-D_f$

➤ If no friction or redundant work occurred in drawing, true strain could be determined as follows:

$$\epsilon = \ln \frac{A_o}{A_f} = \ln \frac{1}{1-r} \quad (19.30)$$

where A_o and A_f are the original and final cross-sectional areas of the work, as previously defined; and r = drawing reduction as given by Eq. (19.28).

➤ The stress that results from this ideal deformation is given by

$$\sigma = \bar{Y}_f \epsilon = \bar{Y}_f \ln \frac{A_o}{A_f} \quad (19.31)$$

where

$$\bar{Y}_f = \frac{K\epsilon^n}{1+n}$$

- In addition to the ratio A_o/A_f , other variables that **influence draw stress are die angle and coefficient of friction** at the work–die interface.
- A number of methods have been proposed for predicting draw stress based on values of these parameters
- We present the **equation suggested by Schey:**

$$\sigma_d = \bar{Y}_f \left(1 + \frac{\mu}{\tan \alpha} \right) \phi \ln \frac{A_o}{A_f} \quad (19.32)$$

where σ_d = draw stress, Mpa; μ = die-work coefficient of friction; α = die angle as defined in Figure 19.40; and ϕ is a factor that accounts for inhomogeneous deformation which is determined as follows for a round cross section:

$$\phi = 0.88 + 1.2 \frac{D}{L_c} \quad (19.33)$$

Where D = average diameter of work during drawing, mm(in); and L_c = contact length of the work with the draw die in Figure 19.40, mm. Values of D and L_c can be determined from the following:

$$D = \frac{D_o + D_f}{2} \quad (19.34a)$$

$$L_c = \frac{D_o - D_f}{2 \sin \alpha} \quad (19.34b)$$

➤ The corresponding **draw force** is then the area of the drawn cross section multiplied by the draw stress:

$$F = A_f \sigma_d = A_f \bar{Y}_f \left(1 + \frac{\mu}{\tan \alpha} \right) \phi \ln \frac{A_o}{A_f} \quad (19.35)$$

where F = draw force, N; and the other terms are defined above.

The power required in a drawing operation is the draw force multiplied by exit velocity of the work.

Example 1

Wire is drawn through a draw die with entrance angle = 15° . Starting diameter is 2.5mm and final diameter = 2.0 mm. The coefficient of friction at the work-die interface = 0.07. The metal has a strength coefficient $K = 205$ MPa and a strain-hardening exponent $n = 0.20$. Determine the draw stress and draw force in this operation

Solution:

$D = 2.25$ mm and $L_c = 0.966$ mm. Thus,

$$\phi = 0.88 + 0.12 \frac{2.25}{0.966} = 1.16$$

The areas before and after drawing are computed as $A_o = 4.91\text{mm}^2$ and $A_f = 3.14\text{mm}^2$. The resulting true strain $e = \ln(4.91/3.14) = 0.446$, and the average flow stress in the operation is computed:

$$\bar{Y}_f = \frac{205(0.446)^{0.20}}{1.20} = 145.4 \text{ MPa}$$

Draw stress is given by:

$$\sigma_d = (145.4) \left(1 + \frac{0.07}{\tan 15} \right) (1.16)(0.446) = 94.1 \text{ MPa}$$

Finally, the draw force is this stress multiplied by the cross-sectional area of the exiting wire:

$$F = 94.1(3.14) = 295.5 \text{ N}$$

Drawing Practice and Products

❖ Drawing practice:

usually performed as **cold working**

Most frequently used **for round cross sections**

❖ Products:

Wire: electrical wire; wire stock for fences,

Rod stock for nails, screws, rivets, and springs

Bar stock: metal bars for machining, forging, and other processes

End of Drawing process!

N.B: The next topic is Sheet
metal working process

**Thank you for
your attention**

