Manufacturing processes

Introduction:-

The word manufacture is derived from two Latin words, manus (hand) and factus (make); the combination means made by hand. The English word manufacture is several centuries old, and ‘‘made by hand’’ accurately described the manual methods used when the word was first coined.1 Most modern manufacturing is accomplished by automated and computer-controlled machinery

As a field of study in the modern context, manufacturing can be defined two ways, one technologic and the other economic. Technologically, manufacturing is the application of physical and chemical processes to alter the geometry, properties, and/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 labor, as depicted in Figure(1)

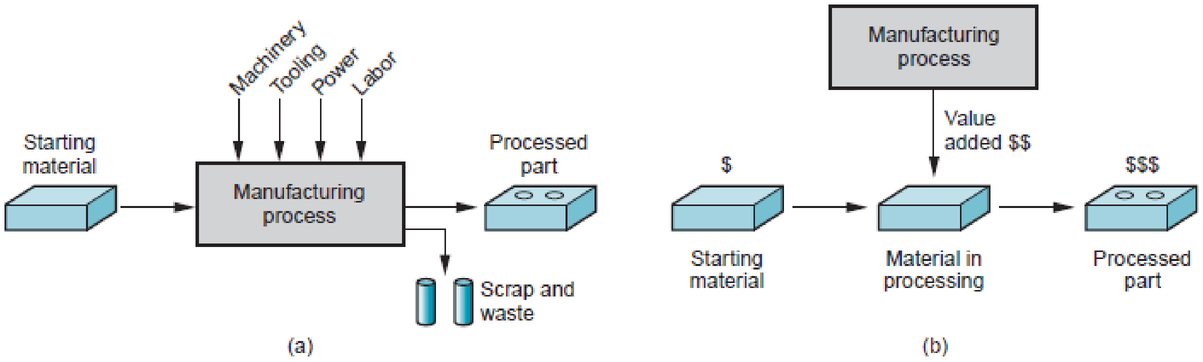


FIGURE 1 Two ways to define manufacturing: (a) as a technical process, and (b) as an economic process.

FUNDAMENTALS OF METAL FORMING:-

Metal forming includes a large group of manufacturing processes in which plastic deformation is used to change the shape of metal work pieces. Deformation results from these 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.

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. 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. 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. We examine all of these issues in this chapter, but first let us provide an overview of the metal forming processes.

Metal Forming:-

Metal forming processes can be classified into two basic categories: bulk deformation processes and sheet metalworking processes.. Each category includes several major classes of shaping operations as indicated in Figure (2)

Large group of manufacturing processes in which plastic deformation is used to change the shape of metal work pieces

•The tool, usually called a die, applies stresses that exceed yield strength of metal

•The metal takes a shape determined by the geometry of the die

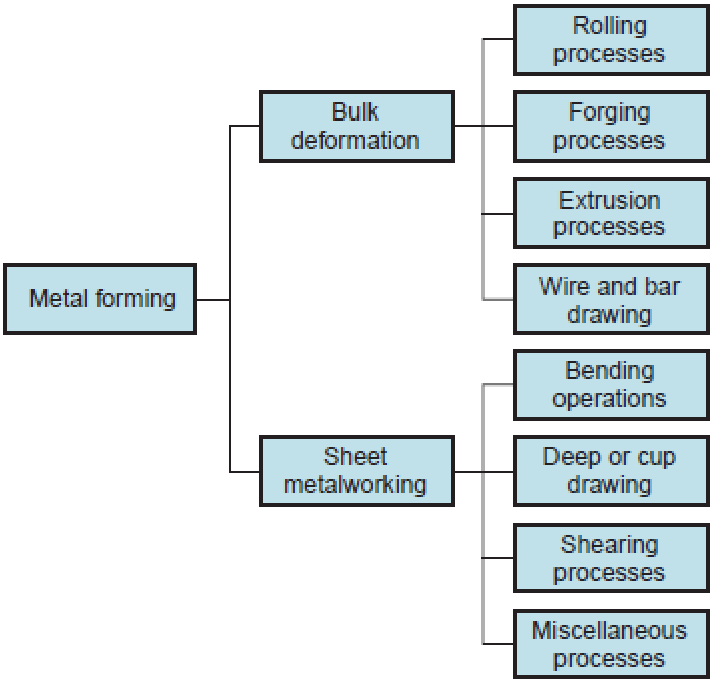
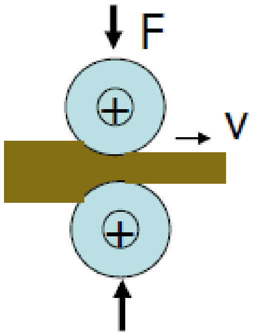
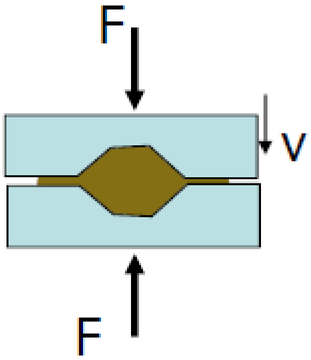


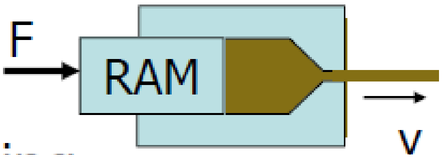
FIGURE 2 Classification of metal forming operations

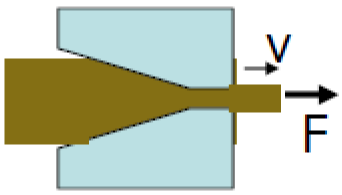
Classification of Metal forming

1- Bulk Deformation Process
   1) Rolling
   2) **Forging**
   3) Extrusion
   4) Drawing



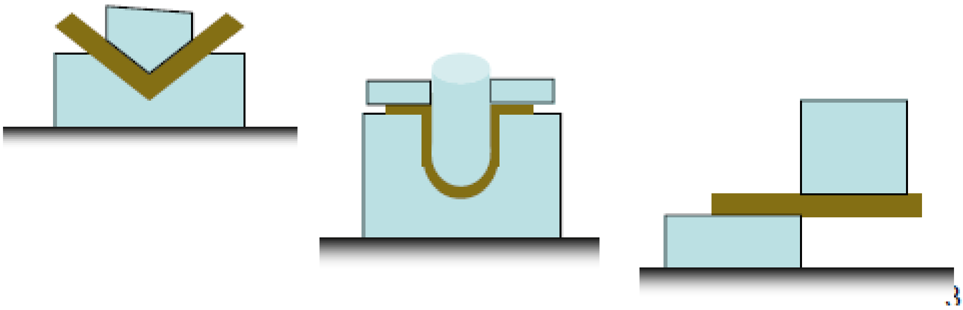






2- Sheet metal forming

1) Bending
2) Drawing
3) Shearing
4) Stamping



Temperature in Metal Forming:-

•Any deformation operation can be accomplished with lower forces and power at elevated temperature

•Three temperature ranges in metal forming:

1- Cold working
2- Warm working
3- Hot working

Cold Working

Cold working (also known as cold forming) is metal forming performed at room temperature or slightly above. Significant advantages of cold forming compared

- Performed at room temperature or slightly above

•Many cold forming processes are important mass production operations

•Minimum or no machining usually required

- These operations are near net shape or net shape processes

Advantages of Cold Forming vs. Hot Working

- Better accuracy, closer tolerances
- Better surface finish
- Strain hardening increases strength and hardness
- Grain flow during deformation can cause desirable directional properties in product
- No heating of work required

Disadvantages of Cold Forming

- Higher forces and power required
- Surfaces of starting workpiece must be free of scale and dirt
- Ductility and strain hardening limit the amount of forming that can be done
  - A- In some operations, metal must be annealed to allow further deformation
  - B- In other cases, metal is simply not ductile enough to be cold worked

Warm Working

Performed at temperatures above room temperature but below recrystallization temperature

- Dividing line between cold working and warm working often expressed in terms of melting point:

- 0.3Tm, where Tm = melting point (absolute temperature) for metal

Advantages of Warm Working

- Lower forces and power than in cold working
- More intricate work geometries possible
- Need for annealing may be reduced or eliminated

Hot Working

•Deformation at temperatures above recrystallization temperature

•Recrystallization temperature = about one-half of melting point on absolute scale

A- In practice, hot working usually performed somewhat above 0.5Tm

B- Metal continues to soften as temperature increases above 0.5Tm, enhancing advantage of hot working above this level .

Why Hot Working

Capability for substantial plastic deformation of the metal - far more than possible with cold working or warm working

•Why?

1- Strength coefficient is substantially less than at room temperature
2- Strain hardening exponent is zero (theoretically)
3- Ductility is significantly increased

Advantages of Hot Working vs. Cold Working

1- Workpart shape can be significantly altered
2- Lower forces and power required
3- Metals that usually fracture in cold working can be hot formed
4- Strength properties of product are generally isotropic
5- No strengthening of part occurs from work hardening
- Advantageous in cases when part is to be subsequently processed by cold forming

Disadvantages of Hot Working

•Lower dimensional accuracy

•Higher total energy required (due to the thermal energy to heat the workpiece)

•Work surface oxidation (scale), poorer surface finish

•Shorter tool life

Mechanical and mechanism of Metal Forming: -

Mechanical metal based on the analysis of stresses generated in the metal due to the problem and the fact that forces and deformations relatively complex so used several assumptions to simplify the solution and get acceptable results and the most important of which are: -

a. Neglect the elastic deformation and emotion take the plastic body (hardwood _ born) only.

b. neglect the work hardening values.

c. the metals with properties Isotropic and homogeneous .

Stresses analysis metals deformation;-

1- Strain in the plastic deformation: -

The analysis of stresses and Strain is to determine the Required of power and forces to get the desired shape in the various operations of plastic deformation, and these forces depends on several factors: -

a. Properties of metal

b. The temperature degree of deformation.

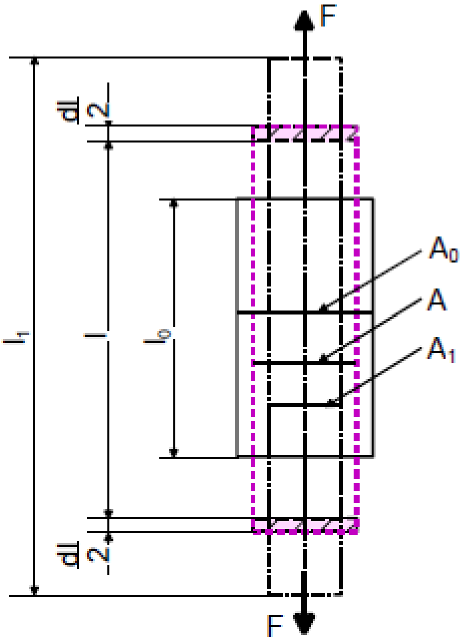
c. deformations method.

d. The design of deformations tools.

In the deformation the strain, stresses and pressure occur. If we assume that the metal have a certain size and mass of the original height (L_o) , the Strain axial is pivotal.

The logarithmic strain φ (true strain; degree of deformation) is a measure of the permanent (plastic) deformation

Because material dimensions changes under application of the load continuously, engineering stress and strain values are not the true indication of material deformation characteristics. Thus the need for measures of stress and strain based on instantaneous dimensions arises. Ludwik first proposed the concept of, and defined the true strain or natural strain (ε) as follows:



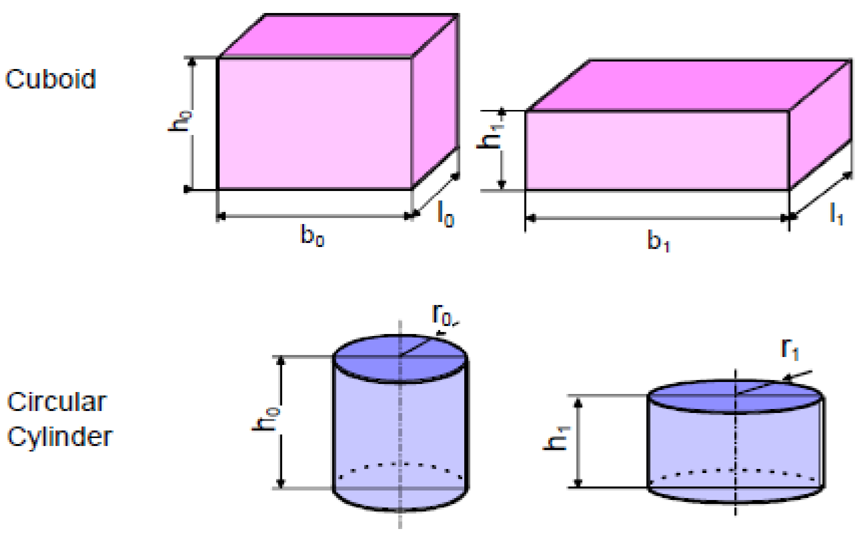
$$\varepsilon = \sum \frac{L_1 - L_0}{L_0} + \frac{L_2 - L_1}{L_1} + \frac{L_3 - L_2}{L_2} + \ldots$$

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

As material volume is expected to be constant i.e. $A_0L_0 = AL$, and thus

$$\varepsilon = \ln \frac{L}{L_0} = \ln \frac{A_0}{A} = \ln(e+1)$$

Logarithmic Strain in Upsetting



$$\varphi_h = \ln\left(\frac{h_1}{h_0}\right)$$

$$\varphi_b = \ln\left(\frac{b_1}{b_0}\right)$$

$$\varphi_l = \ln\left(\frac{l_1}{l_0}\right)$$

$$\varphi_h = \ln\left(\frac{h_1}{h_0}\right)$$

$$\varphi_r = \ln\left(\frac{r_1}{r_0}\right) = \varphi_t$$

The main expression in the formation processes is through a decrease in the values of the cross-section area of the blocks

$r=A_o-A_1/A_o$ ……………………….(1)
$V_o=V_1$ ………………………….(2)
$A_oL_o=A_1L_1$
$A_1/A_o= 1-r$ ……………………….(3)
$A_1/A_o= L_1//L_o$ …………………….(4)

$A_o/ A_1 = (1-r)$
$E=\ln L_1/L_o = LnA_o/A_1 = Ln 1/(1-r)$

Material Behavior in Metal Forming

•Plastic region of stress-strain curve is primary interest because material is plastically deformed

• In plastic region, metal's behavior is expressed by the flow curve:

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

Where:-

K = strength coefficient; and

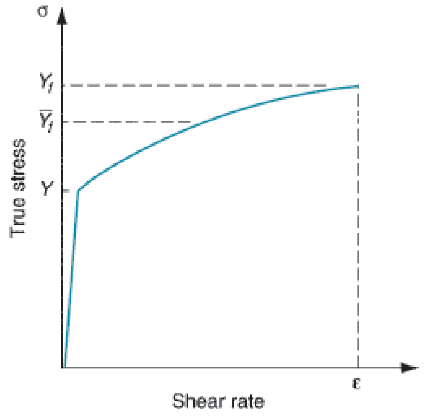
n = strain hardening exponent

•Stress and strain in flow curve are true stress and true strain.

Flow Stress

•For most metals at room temperature, strength increases when deformed due to strain hardening

•Flow stress = instantaneous value of stress required to continue deforming the material



$$Y_f = K\epsilon^n$$

Where

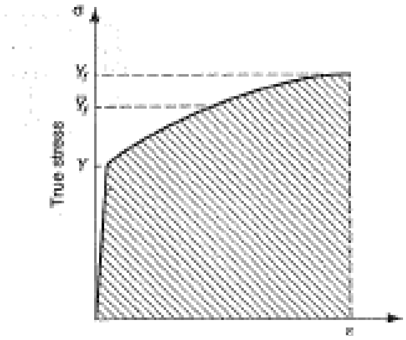
Yf = flow stress, that is, the yield strength as a function of strain

Average Flow Stress

Average Flow Stress The average flow stress (also called the mean flow stress) is the average value of stress over the stress–strain curve from the beginning of strain to the final (maximum) value that occurs during deformation. The value is illustrated in the stress–strain plot of Figure 18.4. The average flow stress is determined by integrating the flow curve equation,

, between zero and the final strain value defining the range of interest. This yields the equation**:**

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



where $\overline{Y}_f$ = average flow stress, MPa (lb/in^2); and ϵ = maximum strain value during the deformation process.

Strain Rate

What is Strain Rate.

- Strain rate in forming is directly related to speed of deformation *v*
- Deformation speed *v* = velocity of the ram or other movement of the equipment *Strain rate* is defined:

$$\dot{\epsilon} = \frac{v}{h}$$

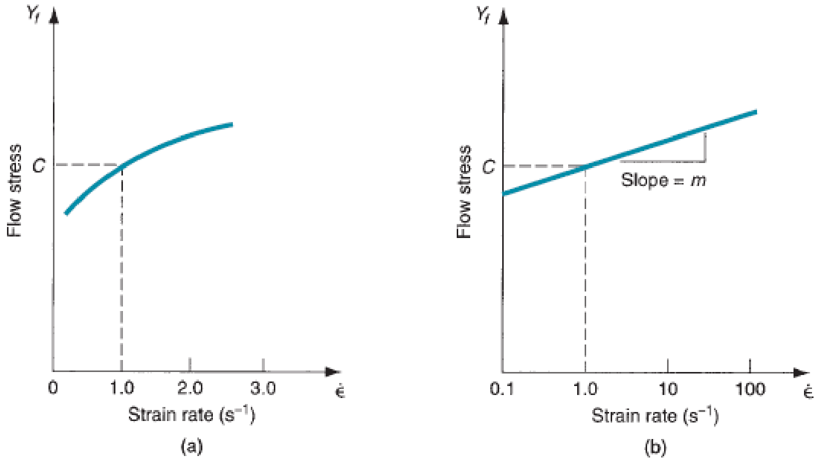
where $\dot{\epsilon}$ = true strain rate, m/s/m (in/sec/in), or simply s^{-1}; and h = instantaneous height of the workpiece being deformed, m (in). If deformation speed v is constant during the operation, strain rate will change as h changes. In most practical forming operations,

Effect of Strain Rate on Flow Stress

- Flow stress is a function of temperature
- At hot working temperatures, flow stress also depends on strain rate

-As strain rate increases, resistance to deformation increases

-This effect is known as strain-rate sensitivity



valuation of strain rate is complicated by the geometry of the workpart and variations in strain rate in different regions of the part. Strain rate can reach 1000 s–1 or more for some metal forming processes such as high-speed rolling and forging. We have already observed that the flow stress of a metal is a function of temperature. At the temperatures of hot working, flow stress depends on strain rate. The effect of strain rate on strength properties is known as strain rate sensitivity. The effect can be seen in Figure above As strain rate is increased, resistance to deformation increases. This usually plots approximately as a straight line on a log–log graph, thus leading to the relationship

$$Y_f = C\dot{\epsilon}^m$$

where C is the strength constant (similar but not equal to the strength coefficient in the flow curve equation), and m is the strain rate sensitivity exponent. The value of C is determined at a strain rate of 1.0, and m is the slope of the curve .

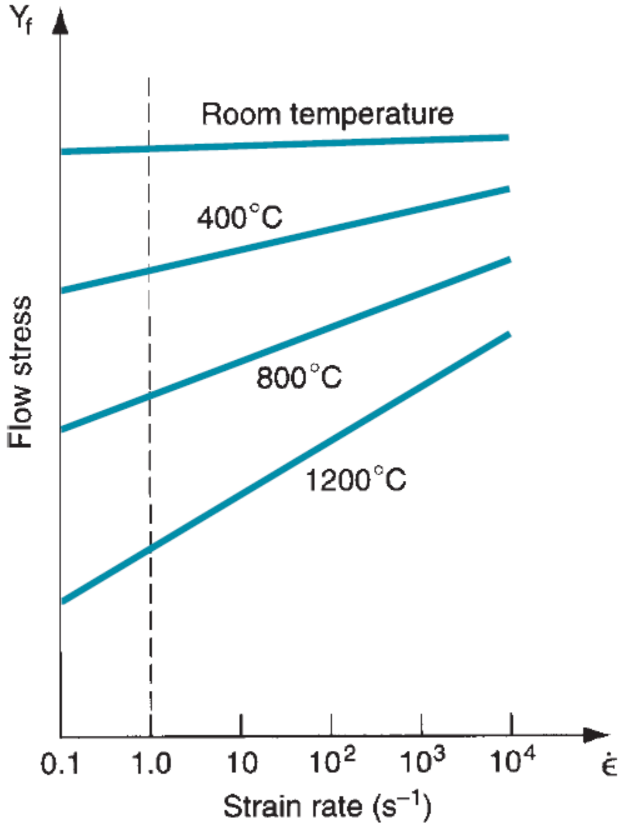


FIGURE the Effect of temperature on flow stress for a typical metal. The constant C in Eq.

$$Y_f = C\dot{\epsilon}^m$$

indicated by the intersection of each plot with the vertical dashed line at strain rate =1.0, decreases, and m (slope of each plot) increases with increasing temperature

Ex/ A metal has a flow curve with parameters: K = 850 MPa and strain hardening exponent n = 0.30. A tensile specimen of the metal with gage length = 100 mm is stretched to a length = 157 mm. Determine the flow stress at the new length and the average flow stress that the metal has been subjected to during the deformation.

Solution: ε = ln (157/100) = ln 1.57 = 0.451
Flow stress Yf = 850(0.451)0.30 = **669.4 MPa.**
Average flow stress Y_f = 850(0.451)0.30/1.30 = **514.9 MPa.**

Ex/ K = 35,000 lb/in2 and n = 0.40 for a metal used in a forming operation in which the workpart is reduced in cross-sectional area by stretching. If the average flow stress on the part is 20,000 lb/in2, determine the amount of reduction in cross-sectional area experienced by the part.

Solution: $Y_f = K\varepsilon n/(1+n)$
20,000 = 35,000 ε.4/(1.4)
1.4(20,000) = 35,000 ε.4
28,000/35,000 = 0.8 = ε.4
0.4 ln ε = ln (0.8) = -0.22314
ln ε = -0.22314/0.4 = -0.55786
ε = 0.5724
ε = ln(Ao/Af) = 0.5724
$A_o/A_f = 1.7726$
$\mathbf{A_f = A_o/1.7726 = 0.564A_o}$

EX/ The gage length of a tensile test specimen = 150 mm. It is subjected to a tensile test in which the grips holding the end of the test specimen are moved with a relative velocity = 0.1 m/s. Construct aplot of the strain rate as a function of length as the specimen is pulled to a length = 200 mm.

Solution: The following values are calculated for the plot:

At L = 150 mm, strain rate = 0.1/0.15 = 0.667 s^{-1}

At L = 160 mm, strain rate = 0.1/0.16 = 0.625 s^{-1}

At L = 170 mm, strain rate = 0.1/0.17 = 0.588 s^{-1}

At L = 180 mm, strain rate = 0.1/0.18 = 0.555 s^{-1}

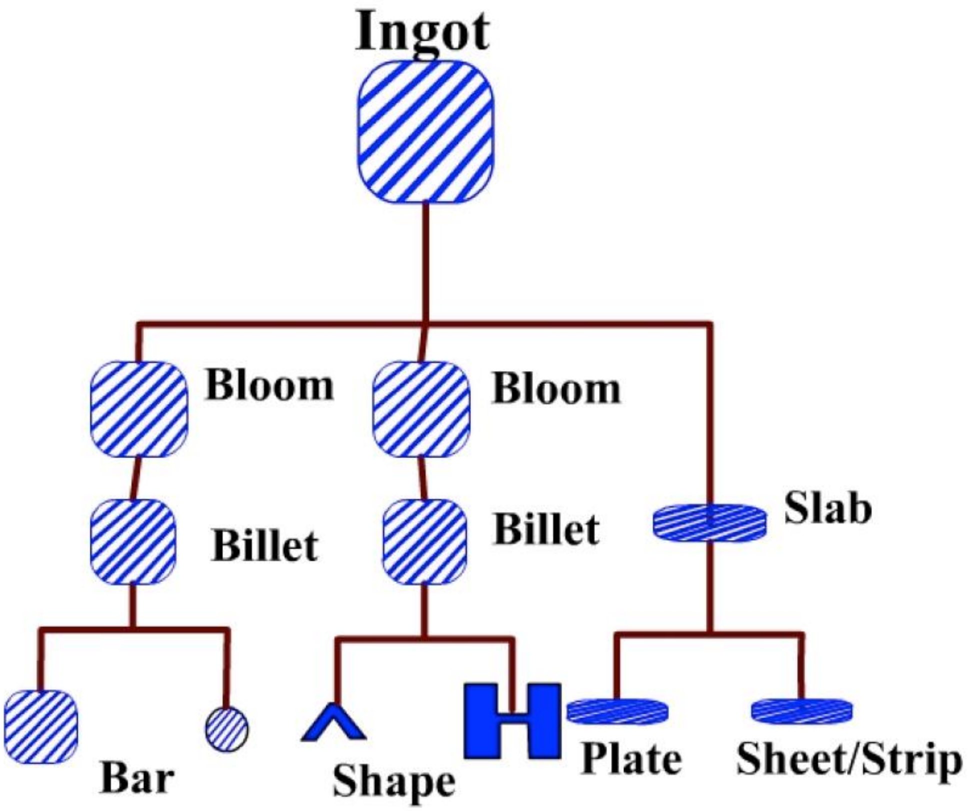
At L = 190 mm, strain rate = 0.1/0.19 = 0.526 s^{-1}

At L = 200 mm, strain rate = 0.1/0.20 = 0.500 s^{-1}

1. Rolling :-

1.1 Introduction Rolling is one of the most important industrial metal forming operations. Hot Rolling is employed for breaking the ingots down into wrought products such as into blooms and billets, which are subsequently rolled to other products like plates, sheets etc. Rolling is the plastic deformation of materials caused by compressive force applied through a set of rolls. The cross section of the work piece is reduced by the process. The material gets squeezed between a pair of rolls, as a result of which the thickness gets reduced and the length gets increased. Mostly, rolling is done at high temperature, called hot rolling because of requirement of large deformations. Hot rolling results in residual stress-free product. However, scaling is a major problem, due to which dimensional accuracy is not maintained. Cold rolling of sheets, foils etc is gaining importance, due to high accuracy and lack of oxide scaling. Cold rolling also strengthens the product due to work hardening. Steel ingot is the cast metal with porosity and blowholes. The ingot is soaked at the hot rolling temperature of 1200o C and then rolled into blooms or billets or slabs. Bloom is has a square cross section, with area more than 230 cm^2 .

A slab, also from ingot, has rectangular cross-section, with area of at least 100 cm^2 and width at least three times the thickness. A billet is rolled out of bloom, has at least 40 mm X 40 mm cross-section. Blooms are used for rolling structural products such as I-sections, channels, rails etc. Billets are rolled into bars, rods. Bars and rods are raw materials for extrusion, drawing, forging, machining etc. Slabs are meant for rolling sheets, strips, plates etc.



1.2 Rolling mills:

Rolling mill consists of rolls, bearings to support the rolls, gear box, motor, speed control devices, hydraulic systems etc. The basic type of rolling mill is two high rolling mill. In this mill, two opposing rolls are used. The direction of rotation of the rolls can be changed in case of reversing mills, so that the work can be fed into the rolls from either direction. Such mills increase the productivity. Non reversing mills have rolls rotating in same direction. Therefore, the work piece cannot be fed from the other side. Typical roll diameters may be 1.4 m.

A three high rolling mill has three rolls. First rolling in one direction takes place along one direction. Next the work is reversed in direction and fed through the next pair of roll. This improves the productivity. Rolling power is directly proportional to roll diameter. Smaller dia rolls can therefore reduce power input. Strength of small diameter rolls are poor. Therefore, rolls may bend. As a result, largerdia backup rolls are used for supporting the smaller rolls. Four high rolling mill is one such mill. Thin sections can be rolled using smaller diameter rolls. Cluster mill and Sendzimir mill are used for rolling thin strips of high strength materials and foils [0.0025 mm thick]. The work roll in these mills may be as small as 6 mm diameter – made of tungsten carbide. Several rolling mills arranged in succession so as to increase productivity is called rolling stand. In such arrangement, anuncoiler and windup reels are used. They help in exerting back tension and front tension.

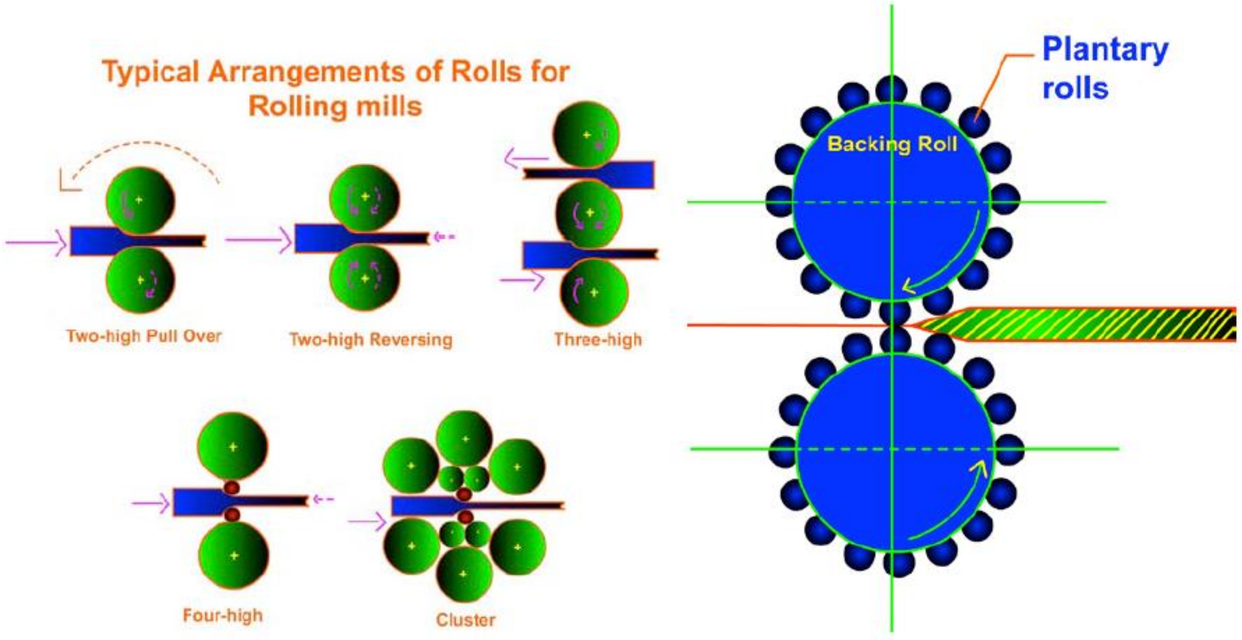


Fig. Rolling mills

Planetary mill has a pair of large heavy rolls, surrounded by a number of smaller rolls around their circumference. In this mill, a slab can be reduced to strip directly in one pass. Feeder rolls may be needed in order to feed the work piece into the rolls. Merchant mill is specifically used for rolling bars. Hot rolling is usually done with two high reversing mill in order to breakdown ingots into blooms and billets.

For increased productivity, universal mill has two vertical rolls which can control the width of the work simultaneously.

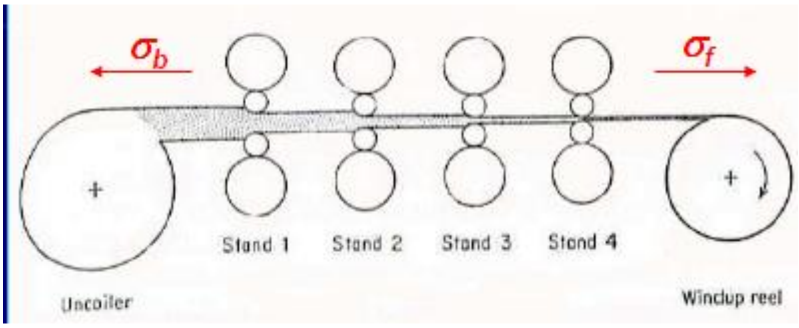
Different types of rolling processes:-

There are different types of rolling processes as listed below.

- Continuous rolling
- Transverse rolling
- Shaped rolling or section rolling
- Ring rolling
- Powder rolling
- Continuous casting and hot rolling
- Thread rolling

1. Continuous rolling

- Use a series of rolling mill and each set is called a stand.
- The strip will be moving at different velocities at each stage in the mill

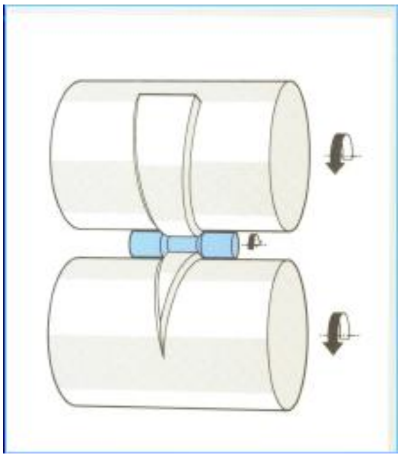


The speed of each set of rolls is synchronised so that the input speed of each stand is equal to the output speed of preceding stand.

The uncoiler and windup reel not only feed the stock into the rolls and coiling up the final product but also provide back tension and front tension to the strip.

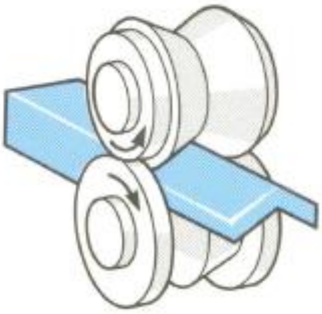
Transverse rolling:-

- Using circular wedge rolls.
- Heated bar is cropped to length and fed in transversely between rolls.
- Rolls are revolved in one direction



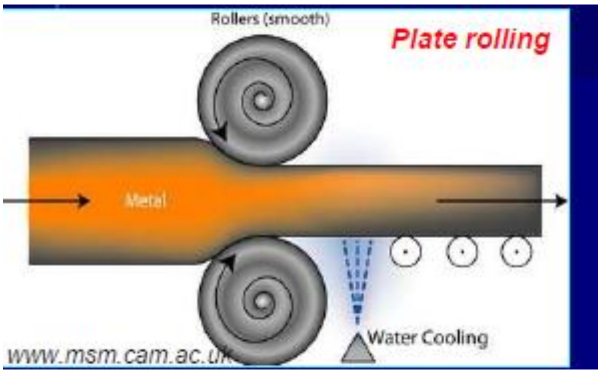
Shaped rolling or section rolling:-

- A special type of cold rolling in which flat slap 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.



Hot-rolling

- The first hot-working operation for most steel products is done on the primary roughing mill (blooming, slabbing or cogging mills).
- These mills are normally two-high reversing mills with 0.6-1.4 m diameter rolls (designated by size).



- The objective is to breakdown the cast ingot into blooms or slabs for subsequent finishing into bars, plate or sheet.

- In hot-rolling steel, the slabs are heated initially at 1100 -1300 °C. The temperature in the last finishing stand varies from 700 - 900 °C, but should be above the upper critical temperature to produce uniform equiaxed ferrite grains.

Cold-rolling:-

- Cold rolling is carried out under recrystallisation temperature and introduces work hardening.

- The starting material for cold-rolled steel sheet is pickled hot-rolled breakdown coil from the continuous hot-strip mill.

- Cold rolling provide products with superior surface finish (due to low temperature - no oxide scales)

- Better dimensional tolerances compared with hot-rolled products due to less thermal expansion.

- Cold-rolled nonferrous sheet may be produced from hot-rolled strip, or in the case of certain copper alloys it is cold-rolled directly from the cast state.

Cold rolled metals are rated as ‘temper

- Skin rolled : Metal undergoes the least rolling ~ 0.5-1% harden, still more workable.

- Quarter hard : Higher amount of deformation. Can be bent normal to rolling direction without fracturing

- Half hard : Can be bent up to 90o.

- Full hard : Metal is compressed by 50% with no cracking. Can be bent up to 45o.

Fundamental concept of metal rolling:-

1) The arc of contact between the rolls and the metal is a part of a circle.

2) The coefficient of friction, μ, is constant in theory, but in reality μ varies along the arc of contact.

3) The metal is considered to deform plastically during rolling.

4) The volume of metal is constant before and after rolling. In practical the volume might decrease a little bit due to close-up of pores.

5) The velocity of the rolls is assumed to be constant.

6) The metal only extends in the rolling direction and no extension in the width of the material.

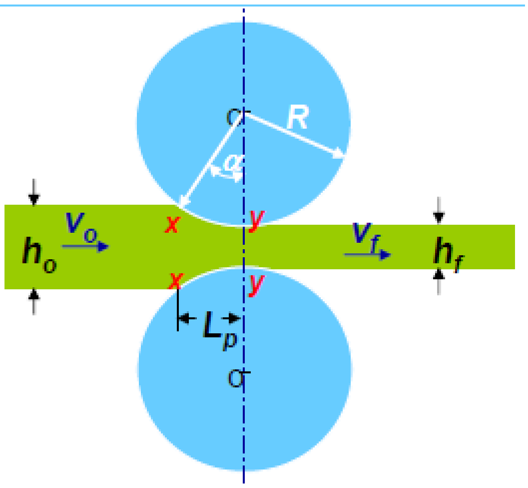
7) The cross sectional area normal to the rolling direction is not distorted.

Forces and geometrical relationships in rolling:-

- A metal sheet with a thickness ho enters the rolls at the entrance plane **xx** with a

velocity vo.

- It passes through the roll gap and leaves the exit plane **yy** with a reduced thickness h_f and at a velocity v_f.



- Given that there is no increase in width, the vertical compression of the metal is translated into an elongation in the rolling direction.
- Since there is no change in metal volume at a given point per unit time throughout the process, therefore

$$\boxed{bh_o v_o = bhv = bh_f v_f}$$

Where **b** is the width of the sheet
v is the velocity at any thickness **h** intermediate between h_o and h_f.

From the equation $bh_o v_o = bh_f v_f$

Given that $b_o = b_f$ $h_o \frac{L_o}{t} = h_f \frac{L_f}{t}$

Then we have $v_o h_o = v_f h_f$

When ho > hf , we then have vo < vf

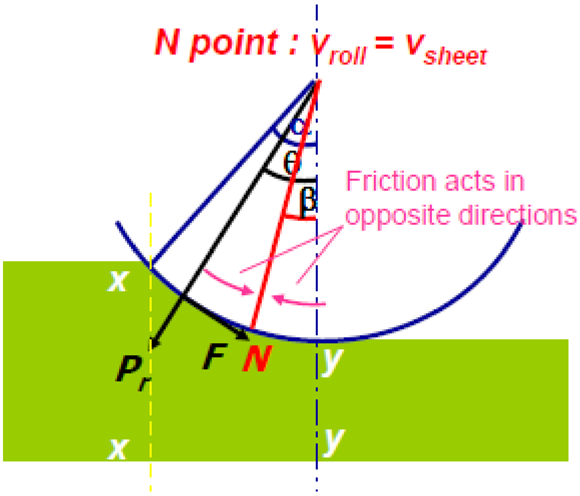
The velocity of the sheet must steadily increase from entrance to exit such that a vertical element in the sheet remain undistorted.

$$\frac{v_o}{v_f} = \frac{h_f}{h_o}$$

- At only one point along the surface of contact between the roll and the sheet, two forces act on the metal: 1) a radial force Pr and 2) a tangential frictional force F.

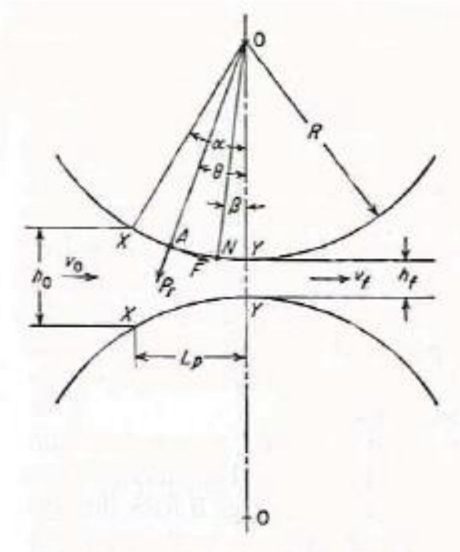
- If the surface velocity of the roll vr equal to the velocity of the sheet, this point is called neutral point or no-slip point. For example, point N.

- Between the entrance plane (xx) and the neutral point the sheet is moving slower than the roll surface, and the tangential frictional force, F, act in the direction (see Fig) to draw the metal into the roll.



- On the exit side (yy) of the neutral point, the sheet moves faster than the roll surface. The direction of the frictional fore is then reversed and oppose the delivery of the sheet from the rolls.

Pr is the radial force, with a vertical component P (rolling load - the load with which the rolls press against the metal). The specific roll pressure, p, is the rolling load divided by the contact area.



$$p = \frac{P}{bL_p}$$

Where **b** is the width of the sheet.
L_p is the projected length of the arc of contact.

$$L_p = \left[R(h_o - h_f) - \frac{(h_o - h_f)^2}{4} \right]^{1/2} \approx [R(h_o - h_f)]^{1/2}$$

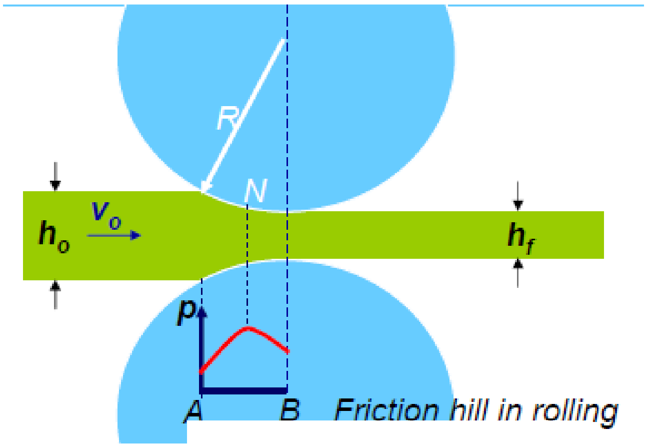
$$L_p \approx \sqrt{R\Delta h}$$

Roll pressure:-

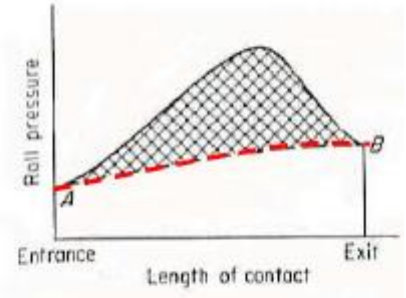
- The distribution of roll pressure along the arc of contact shows that the pressure rises to a maximum at the neutral point and then falls off.

- The pressure distribution does not come to a sharp peak at the neutral point, which indicates that the neutral point is not really a line on the roll surface but an area. Friction hill in rolling

- The area under the curve is proportional to the rolling load. • The area in shade represents the force required to overcome frictional forces between the roll and the sheet.



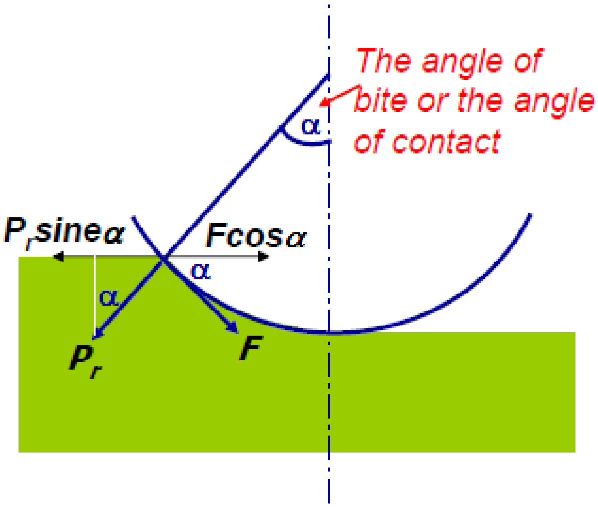
Friction hill in rolling



- The area under the dashed line AB represents the force required to deform the metal in plane homogeneous compression.

Roll bite condition

For the work piece to enter the throat of the roll, the component of the friction force must be equal to or greater than the horizontal component of the normal force.



$$\boxed{F\cos\alpha \geq P_r \sin\alpha}$$

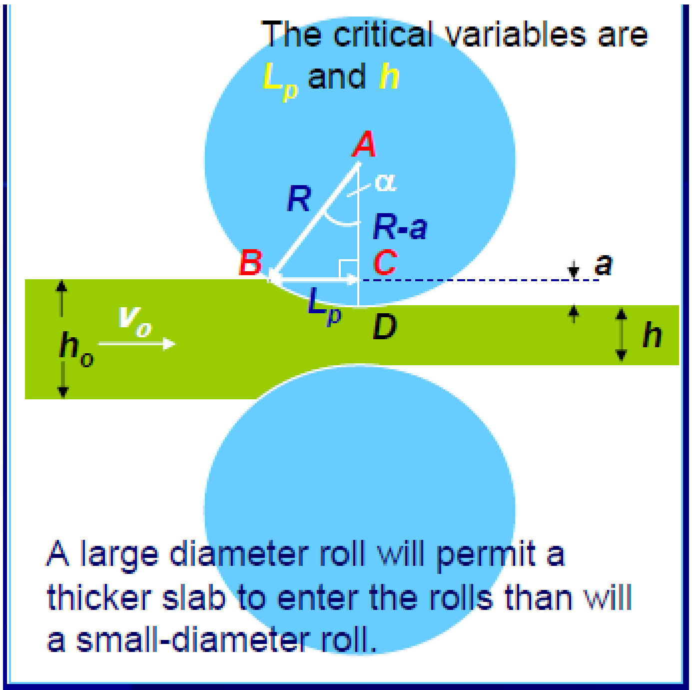
$$\frac{F}{P_r} \geq \frac{\sin\alpha}{\cos\alpha} \geq \tan\alpha$$

and

$$F = \mu P_r$$

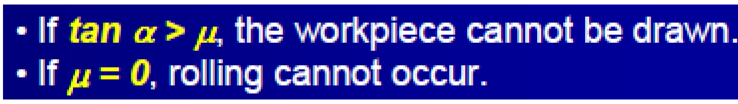
$$\boxed{\mu = \tan\alpha}$$

F is a tangential friction force


The critical variables are L_p and h

A large diameter roll will permit a thicker slab to enter the rolls than will a small-diameter roll.

P_r is radial force


- If $\tan\alpha > \mu$, the workpiece cannot be drawn.
- If $\mu = 0$, rolling cannot occur.

The maximum reduction

From triangle ABC, we have

$$R^2 = L_p^2 + (R-a)^2$$
$$L_p^2 = R^2 - (R^2 - 2Ra + a^2)$$
$$L_p^2 = 2Ra - a^2$$

As a is much smaller than R, we

can then ignore a^2.

$$L_p \approx \sqrt{2Ra} \approx \sqrt{R\Delta h}$$

Where $\Delta h = h_o - h_f = 2a$

$$\mu = \tan\alpha = \frac{L_p}{R - \Delta h/2} \approx \frac{\sqrt{R\Delta h}}{R - \Delta h/2} \approx \sqrt{\frac{\Delta h}{R}} \Rightarrow \boxed{(\Delta h)_{\max} = \mu^2 R}$$

Power and force of rolling

On either side of this point, slipping and friction occur between roll and work. The amount of slip between the rolls and the work can be measured by means of the forward slip, a term used in rolling that is defined:

$$s = \frac{v_f - v_r}{v_r}$$

where s ¼ forward slip; vf ¼ final (exiting) work velocity, m/s (ft/sec); and vr ¼ roll speed, m/s (ft/sec).

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

$$\epsilon = \ln\frac{t_o}{t_f}$$

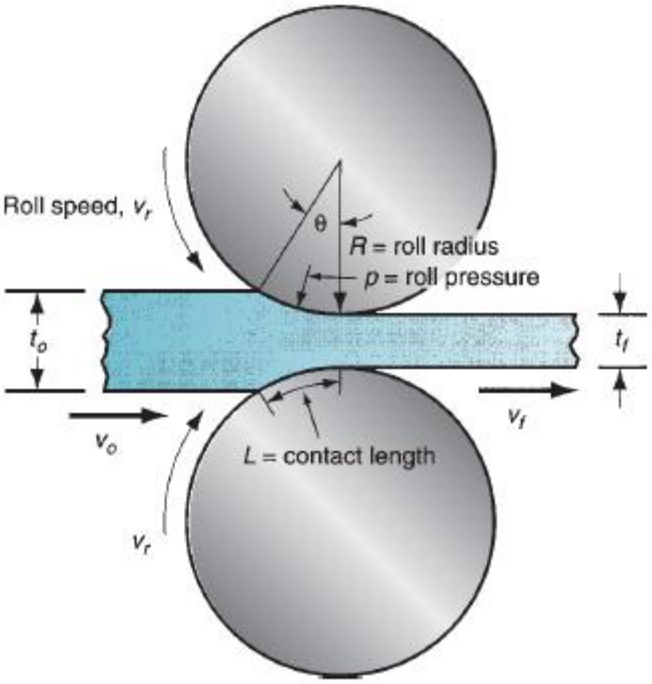
Given a coefficient of friction sufficient to perform rolling, roll force F required to maintain separation between the two rolls can be computed by integrating the unit roll pressure (shown as p in Figure) over the roll-work contact area. This can be expressed:

$$F = w \int_{0}^{L} p \, d L$$

An approximation of the results obtained by Eq. can be calculated based on the average flow stress experienced by the work material in the roll gap. That is

$$F = \overline{Y}_f w L$$

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



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

$$T = 0.5\,FL$$

The power required to drive each roll is the product of torque and angular velocity. Angular velocity is 2pN, where N ¼ rotational speed of the roll. Thus, the power for each roll is 2pNT. Substituting for torque Eq 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:

$$P = 2\pi NFL$$

where P = power, J/s or W (in-lb/min); N = rotational speed, 1/s (rev/min); F = rolling force, N (lb); and L = contact length, m (in).

Example 1/ A 300-mm-wide strip 25-mm thick is fed through a rolling mill with two powered rolls each of radius ¼ 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 ¼ 275 MPa and n ¼ 0.15, and the coefficient of friction between the rolls and the work is assumed to be 0.12. Determine if the friction is sufficient to permit the rolling operation to be accomplished. If so, calculate the roll force, torque, and horsepower.

Solution: The draft attempted in this rolling operation is
d = 25 - 22 = 3mm

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

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 $\overline{Y}_f$. The contact length is given by Eq. (19.11):

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

$\overline{Y}_f$ is determined from the true strain:

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

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

Rolling force is determined from Eq. (19.10):

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

Torque required to drive each roll is given by Eq. (19.12):

$$T = 0.5(1,444,786)(27,4)(10^{-3}) = 19,786\,\text{N-m}$$

and the power is obtained from Eq. (19.13):

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

For comparison, let us convert this to horsepower (we note that one horsepower = 745.7 W):

$$HP = \frac{207,201}{745.7} = 278\,\text{hp}$$

Q1/ A 42.0-mm-thick plate made of low carbon steel is to be reduced to 34.0 mm in one pass in a rolling operation. As the thickness is reduced, the plate widens by 4%. The yield strength of the steel plate is 174 MPa and the tensile strength is 290 MPa. The entrance speed of the plate is 15.0 m/min. The roll radius is 325 mm and the rotational speed is 49.0 rev/min. Determine (a) the minimum required coefficient of friction that would make this rolling operation possible, (b) exit velocity of the plate,
and (c) forward slip.

Q2/ A series of cold rolling operations are to be used to reduce the thickness of a plate from 50mmdown to 25 mm in a reversing two-high mill. Roll diameter ¼ 700 mm and coefficient of friction between rolls and work ¼ 0.15. The specification is that the draft is to be equal on each pass. Determine (a) minimum number of passes required, and (b) draft for each pass?

Q3/ A continuous hot rolling mill has eight stands. The dimensions of the starting slab are: thickness = 3.0 in, width = 15.0 in, and length = 10 ft. The final thickness is to be 0.3 in. Roll diameter at each stand ¼ 36 in, and rotational speed at stand number 1 = 30 rev/min. It is observed that the speed of the slab entering stand 1 = 240 ft/min. Assume that no widening of the slab occurs during the rolling sequence. Percent reduction in thickness is to be equal at all stands, and it is assumed that the forward slip will be equal at each stand. Determine (a) percentage reduction at each stand, (b) rotational speed of the rolls at stands 2 through 8, and (c) forward slip. (d) What is the draft at stands 1 and 8? (e) What is the length and exit speed of the final strip exiting stand 8?

Q4/ A hot rolling mill has rolls of diameter = 24 in. It can exert a maximum force = 400,000 lb. The mill has a maximum horsepower = 100 hp. It is desired to reduce a 1.5-in thick plate by the maximum possible draft in one pass. The starting plate is
10 in wide. In the heated condition, the work material has a strength coefficient = 20,000 lb/in^2 and a strain-hardening exponent ¼ zero. Determine (a) maximum possible draft, (b) associated true strain, and (c) maximum speed of the rolls for the operation.

Forging

Forging is the term for shaping metal by using localized compressive forces. **Cold forging** is done at room temperature or near room temperature. **Hot forging** is done at a high temperature, which makes metal easier to shape and less likely to fracture. **Warm forging** is done at intermediate temperature between room temperature and hot forging temperatures.

- Forging is the working of metal into a useful shape by hammering or pressing.
- The oldest of the metalworking arts (primitive blacksmith).
- Replacement of machinery occurred during early the Industrial revolution.
- Forging machines are now capable of making parts ranging in size of a bolt to a turbine rotor.
- Most forging operations are carried out hot, although certain metals may be cold-forged.

Classification of forging processes:-

By equipment or mechanism

1) Forging hammer or drop hammer
   It is the process that change the shape of the product by continual hammering in several directions to get to the final form or ship.

2) Press forging
   It is scientific, which is done by changing the shape of the product by shedding constant pressure on the product at a fixed strain rate to get to the final form

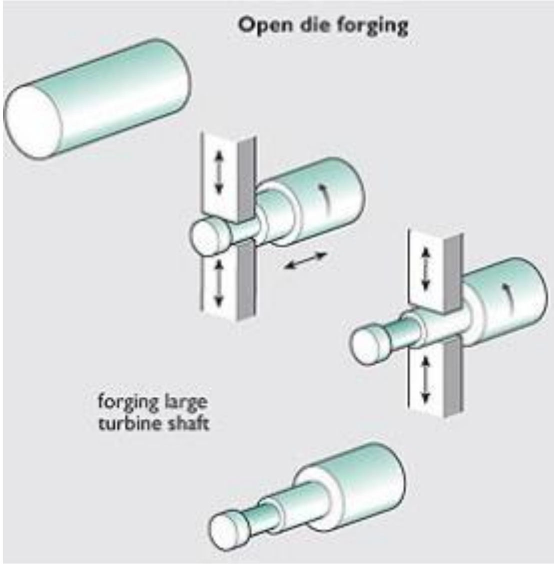
By process

1) Open - die forging
2) Closed - die forging

Open-Die Forging

Most forging processes begin with open die forging. Open die forging is hot mechanical forming between flat or shaped dies in which the metal flow is not completely restricted. The stock is laid on a flat anvil while the flat face of the forging hammer is struck against the stock. The equipment may range from the anvil and hammer to giant hydraulic presses

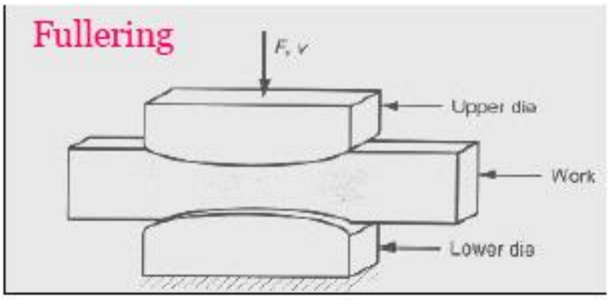
Open-die hot forging is an important industrial process. Shapes generated by open-die operations are simple; examples include shafts, disks, and rings. In some applications, the work must often be manipulated (for example, rotating in steps) to effect the desired shape change. Open-die forging process is shown in the following Figure.



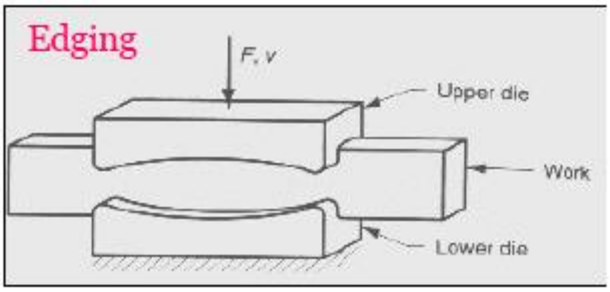
Open-Die Forging

The skill of the human operator is a factor in the success of these operations. An example of open-die forging in the steel industry is the shaping of a large, square cast ingot into a round cross section. Open-die forging operations produce rough forms, and subsequent operations are required to refine the parts to final geometry and dimensions

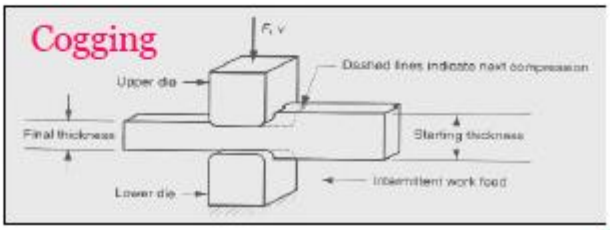
- An important contribution of open-die hot forging is that it creates favorable grain low and metallurgical structure in the metal. Operations classified as open-die forging or related operations include fullering, edging, and cogging, as shown in the next diagrams. Open-die hot forging is an important industrial process. Shapes generated by open-die operations are simple; examples include shafts, disks, and rings. In some applications, the work must often be manipulated (for example, rotating in steps) to effect the desired shape change.



Fullering is a forging operation performed to reduce the cross section and redistribute the metal in a work part in preparation for subsequent shape forging. It is accomplished by dies with convex surfaces. Fullering die cavities are often used designed into multicavity impression dies so that the starting bar can be rough formed before final shaping.



Edging is similar to fullering, except that the dies have concave surfaces.



Cogging operation consists of a sequence of forging compressions along the length of a workpiece to reduce cross section and increase length. It is used in the steel industry to produce blooms and slabs from cast ingots. It is accomplished using open dies with flat or slightly contoured surfaces. The term *incremental forging* is sometimes used for this process.

Advantages and Limitations

Advantages

1-Simplest type of forging

2-Dies are inexpensive

3-Wide range of part sizes, ranging from 30-1000lbs

4-Good strength qualities

5-Generally good for small quantities

Limitations

1-Simple shapes only

2-difficult to hold close tolerances

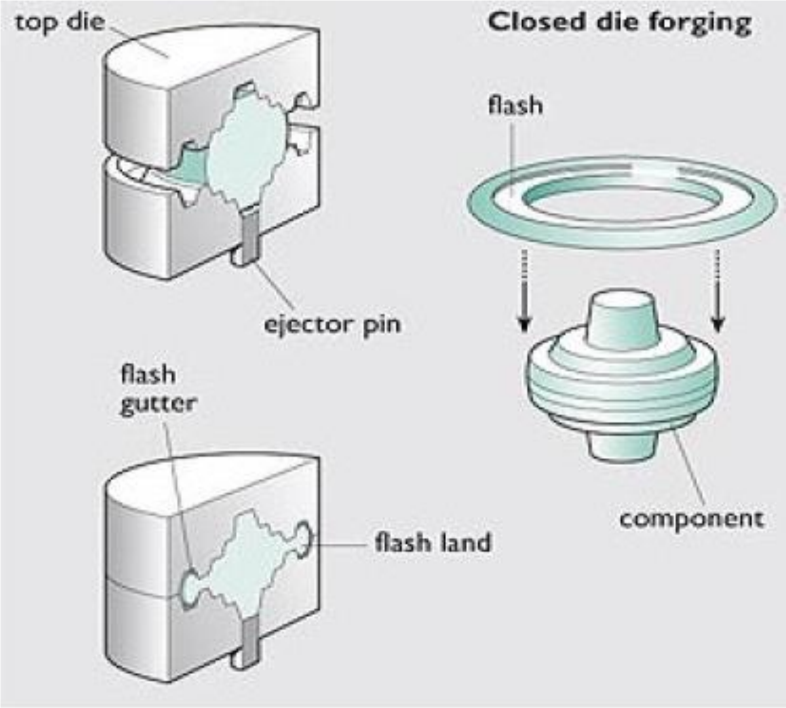
3-machining necessary

4-low production rate

5-poor utilization of material

6-high skill required

Impression or Close Die Forging



Impression die forging

In impression-die forging, so0metimes called closed die forging, the die surfaces contain a shape or impression that is imparted to the work during compression, thus

constraining metal flow to a significant degree as shown in following Figure. In this type of operation, a portion of the work metal flows beyond the die impression to form flash and must be trimmed off later. The process is shown in the following Figure as a three step sequence. The raw work piece is shown as a cylindrical part similar to that used in the previous open-die operation.

Advantages and Limitations

Advantages

1-Good utilization of material

2-Better properties than Open Die Forgings

3-Dies can be made of several pieces and inserts to create more advanced parts

4-Presses can go up to 50,000 ton capacities

5-Good dimensional accuracy

6-High production rates

7-Good reproducibility

Limitations

1-High die cost

2-Machining is often necessary

3-Economical for large quantities, but not for small quantities

Forging Machines

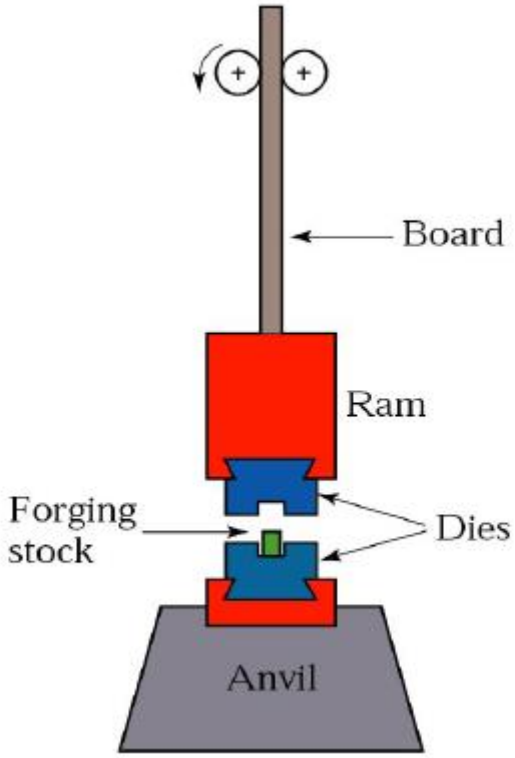
Equipment used in forging consists of forging machines, classified as **forging hammers** and **presses**, and **forging dies**, which are the special tooling used in these machines. In addition, auxiliary equipment is needed, such as furnaces to heat the work, mechanical devices to load and unload the work, and trimming stations to cut away the flash in impression-die forging

Forging Hammers: Forging hammers operate by applying an impact load against the work. The term drop hammer is often used for these machines, owing to the means of delivering impact energy. Drop hammers are most frequently used or impression-die forging. The upper portion of the forging die is attached to the ram, and the lower portion to the anvil. In the operation, the work is placed on the lower die, and the ram is lifted and then dropped. When the upper die strikes the work, the impact energy causes the part to assume the form of the die cavity.

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. The force of the blow is determined by the height of the drop and the weight of the ram.

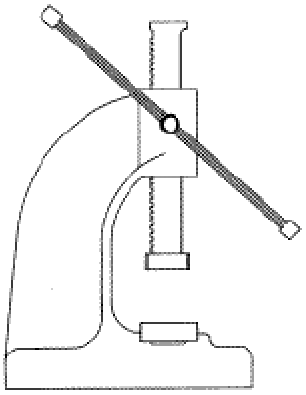
Power drop hammers accelerate the ram by pressurized air or steam. One disadvantage of the drop hammers is that a large amount of the impact energy is transmitted through the anvil and into the floor of the building. This results in a great deal of vibration for the surrounding area.



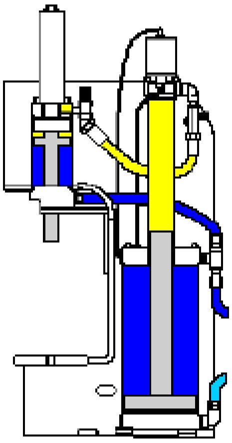
Forging Presses: Presses apply gradual pressure, rather than sudden impact, to accomplish the forging operation. Forging presses include **mechanical presses, hydraulic presses, and screw presses.**

Mechanical presses typically operate by means of eccentrics, cranks, or knuckle joints, which convert the rotating motion of a drive motor into the translational motion of the ram. These mechanisms are very similar to those used in stamping presses. Mechanical presses typically achieve very high forces at the bottom of the forging stroke.

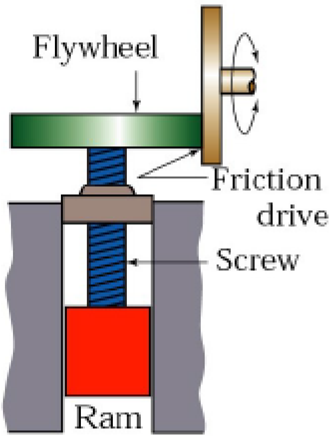
Hydraulic presses use a hydraulically driven piston to actuate the ram. **Screw presses** apply force by a screw mechanism that drives the vertical ram. Both screw drive and hydraulic drive operate at relatively low ram speeds and can provide a constant force throughout the stroke. These machines are therefore suitable for forging (and other forming) operations that require a long stroke.



Mechanical Press



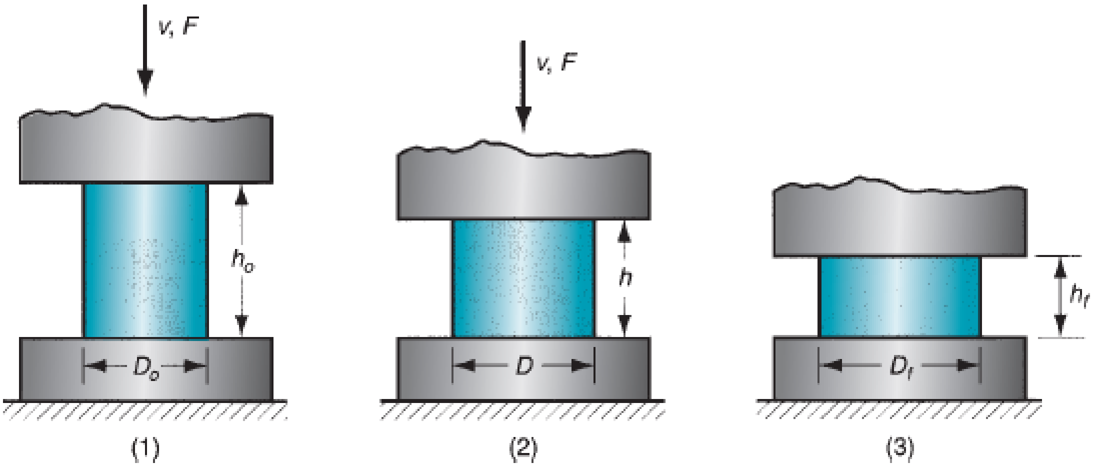
Hydraulic Press

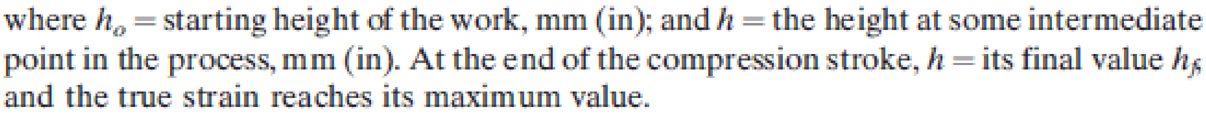


Screw Press

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, and the radial flow of the material is uniform throughout its height, as pictured in Figure. Under these ideal conditions, the true strain experienced by the work during the process can be determined by

$$\epsilon = \ln \frac{h_o}{h}$$




where h_o = starting height of the work, mm (in); and h = the height at some intermediate point in the process, mm (in). At the end of the compression stroke, h = its final value h_f, and the true strain reaches its maximum value.

the true strain reaches its maximum value. Estimates of force to perform upsetting can be calculated. The force required to continue the compression at any given height h during the process can be obtained by multiplying the corresponding cross- ectional area by the flow stress

All of these factors cause the actual upsetting force to be greater than what is predicted by. As an approximation, we can apply a shape factor to to account for effects of the D/h ratio and friction:

$$F = K_f Y_f A$$

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

$$K_f = 1 + \frac{0.4\,\mu D}{h}$$

where μ=coefficient of friction; D =work part diameter or other dimension representing contact length with die surface, mm (in); and h = work part height, mm (in).

Example/ A cylindrical work piece is subjected to a cold upset forging operation. The starting piece is 75 mm in height and 50mmin diameter. It is reduced in the operation to a height of 36mm.The work material has a flow curve defined by K=350MPaand n=0.17.Assume a coefficient of friction of 0.1.Determine the force as the process begins, at intermediate heights of 62mm, 49 mm, and at the final height of 36 mm.

Solution: Workpiece volume $V = 75\pi(50^2/4) = 147{,}262$ mm^3. At the moment contact is made by the upper die, $h = 75$ 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 $D = 50$ mm and area $A = \pi(50^2/4) = 1963.5$ 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 $h = 62$ mm,

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

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

Assuming constant volume, and neglecting barreling,

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

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

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

Similarly, at $h = 49$ mm, $F = 955{,}642$ N; and at $h = 36$ mm, $F = 1{,}467{,}422$ N. The load-stroke curve in Figure 19.12 was developed from the values in this example. ■

Q1/ A cylindrical part is warm upset forged in an open die. *Do* = 50 mm and *ho* = 40 mm. Final height = 20 mm. Coefficient of friction at the die -work interface = 0.20. The work material has a flow curve defined by: K = 600 MPa and n = 0.12. Determine the force in the operation (a) just as the yield point is reached (yield at strain = 0.002), (b) at h = 30 mm, and (c) at h = 20 mm.

Q2/ A cylindrical work part with D = 2.5 in and h = 2.5 in is upset forged in an open die to a height = 1.5 in. Coefficient of friction at the die -work interface = 0.10. The work material has a flow curve defined by: K = 40,000 lb/in2 and n = 0.15. Determine the instantaneous force in the operation (a) just as the yield point is reached (yield at strain = 0.002), (b) at height h = 2.3 in, (c) h = 1.9 in, and (d) h = 1.5 in.

Q3/ A hydraulic forging press is capable of exerting a maximum force = 1,000,000 N. A cylindrical workpart is to be cold upset forged. The starting part has diameter = 30 mm and height = 30 mm. The flow curve of the metal is defined by K = 400 MPa and n = 0.2. Determine the maximum reduction in height to which the part can be compressed with this forging press, if the coefficient of friction = 0.1.

Q4/A hot upset forging operation is performed in an open die. The initial size of the work part is: Do = 25 mm, and ho = 50 mm. The part is upset to a diameter = 50 mm. The work metal at this elevated temperature yields at 85 MPa (n = 0). Coefficient of friction at the die -work interface = 0.40. Determine: (a) final height of the part, and (b) maximum force in the operation

EXTRUSION:-

Extrusion is a process that forces metal or plastic to flow through a shaped opening die. The material is plastically deformed under the compression in the die cavity. The process can be carried out hot or cold depending on the ductility of the material.

The **tooling cost** and **setup** is expensive for the extrusion process, but the actual manufactured part cost is inexpensive when produced in significant quantities.

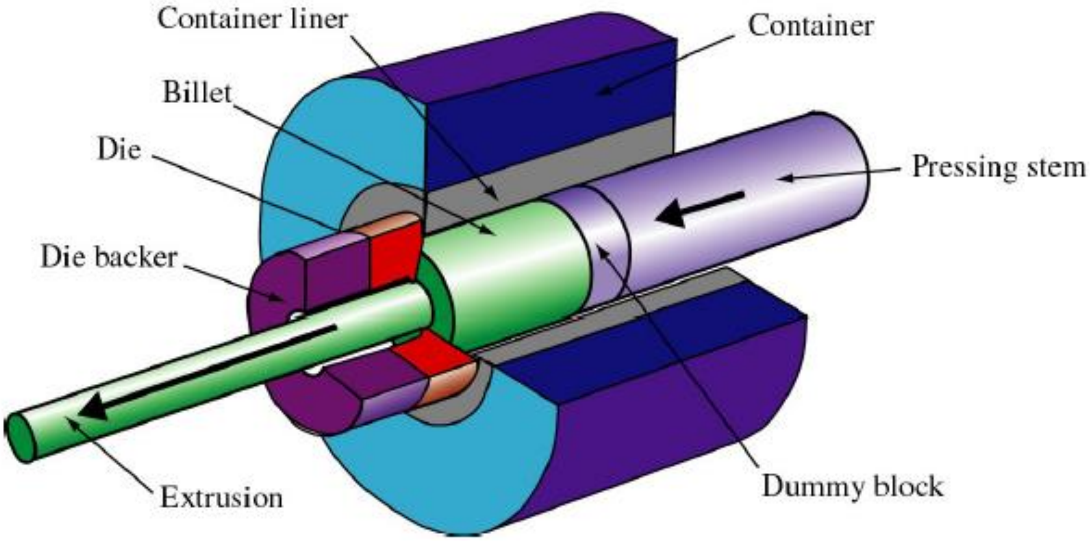
Materials that can be extrudes are aluminum, copper, steel, magnesium, and plastics. Aluminum, copper and plastics are most suitable for extrusion.

Classification of extrusion processes:-

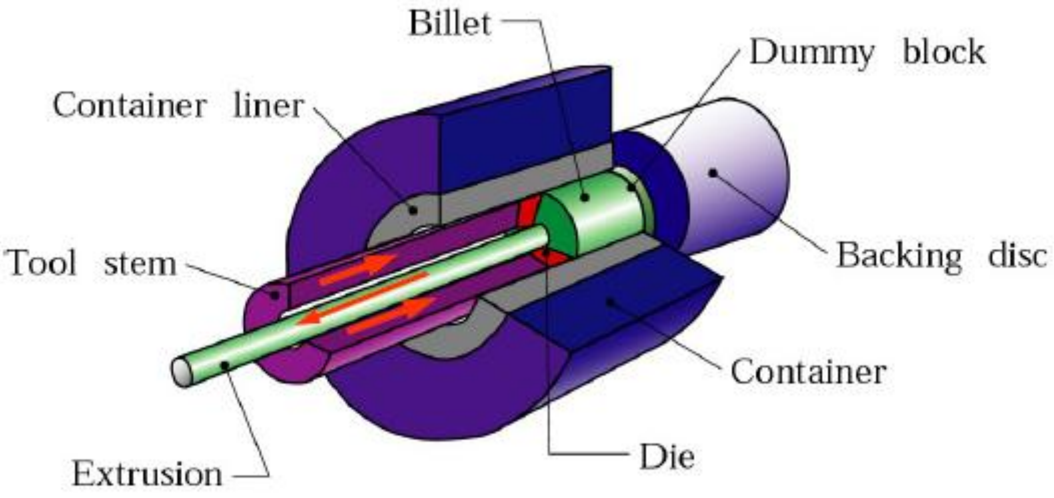
There are several ways to classify metal extrusion processes

1- By direction • Direct / Indirect extrusion
2- By operating temperature • Hot / cold extrusion
3- By equipment • Horizontal and vertical extrusion
4- Hydrostatic Extrusion: Pressure is applied by a piston through incompressible fluid medium surrounding the billet

Direct Extrusion: In this extrusion process, the heated billet is placed in the container. A ram towards the die pushes it. The metal is subjected to plastic deformation, slides along the walls of the container and is forced to flow through the Die opening. At the end of the extruding operation, a small piece of metal, called Butt-end scrap, remains in the container and cannot be extruded. Direct extrusion Process is shown in the following Figure



Indirect Extrusion: For the production of solid part, the die is mounted on the end of a hollow ram and enters the container as shown in the following Figure, the outer end of container being closed by a closure plate. As the ram travels, the die applies pressure on the billet and the deformed metal flows through the die opening in the direction opposite to the ram motions and the product is extruded through the hollow ram. In indirect extrusion, there is practically no slip of billet with respect to the container walls.



Cold extrusion

Cold extrusion is the process done at room temperature or slightly elevated temperatures. This process can be used for most materials-subject to designing robust enough tooling that can withstand the stresses created by extrusion.

Advantages

- No oxidation takes place.
- Good mechanical properties due to severe cold working as long as the temperatures created are below the recrystallization temperature.
- Good surface finish with the use of proper lubricants.

Hot 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 (5076 - 101,525 psi). • The most commonly used extrusion process is the hot direct process. The cross-sectional shape of the extrusion is defined by the shape of the die. • Due to the high temperatures and pressures and its detrimental effect on the die life as well as other components, good lubrication is necessary. Oil and graphite work at lower temperatures, whereas at higher temperatures glass powder is used.

Horizontal extrusion presses

(15- 50 MN capacity or up to 140 MN)

- Used for most commercial extrusion of bars and shapes. Disadvantages:
- Deformation is non-uniform due to different temperatures between top and bottom parts of the billet.

Vertical extrusion presses

(3- 20 MN capacity)

Chiefly used in the production of thin-wall tubing.

Advantages:

- Easier alignment between the press ram and tools.
- Higher rate of production.
- Require less floor space than horizontal presses.
- uniform deformation, due to uniform cooling of the billet in the container.

Vertical extrusion machine

Requirements:

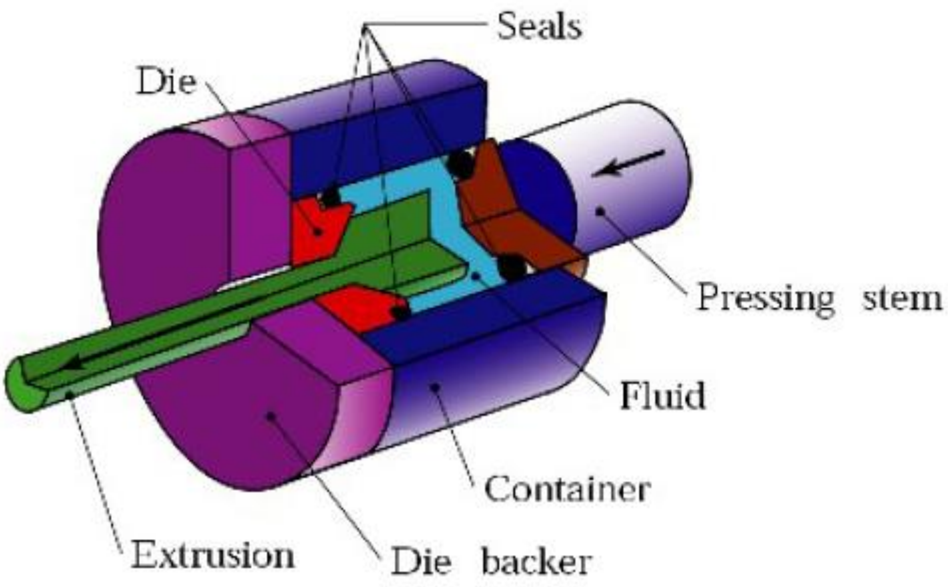
- Need considerable headroom to make extrusions of appreciable length.
- A floor pit is necessary.

Hydrostatic Extrusion

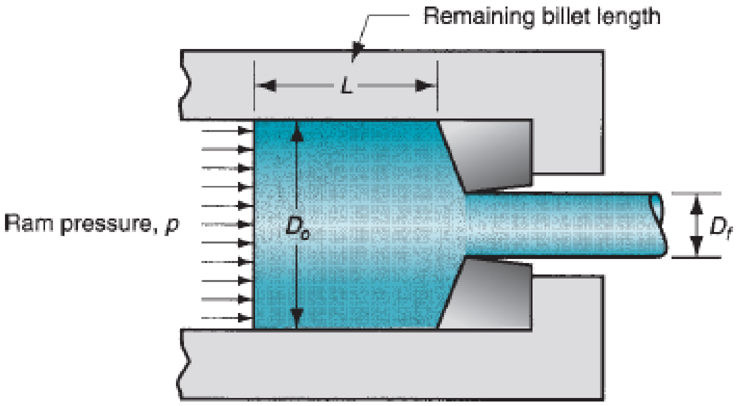
A Billet that is smaller than the chamber is used.

The Chamber is filled with a fluid. Pressure is then applied to the pressing stem

There is no friction to overcome



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

$$r_x = \frac{A_o}{A_f}$$

where r_x=extrusion ratio ; A_o=cross-sectional area of the starting billet,mm^2 (in^2); and A_f= final cross-sectional area of the extruded section,mm^2 (in^2). The ratio applies for

$$\epsilon = \ln r_x = \ln \frac{A_o}{A_f}$$

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

Under the assumption of ideal deformation (no friction and no redundant work), the Pressure applied by the ram to compress the billet through the die opening depicted in our figure can be computed as follows

$$p = \overline{Y}_f \ln r_x$$

where Y_f = average flow stress during deformation, MPa (lb/in^2). For convenience, we restate

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

In fact, extrusion is not a frictionless process, and the previous equations grossly underestimate the strain and pressure in an extrusion operation. Friction exists between the die and the work as the billet squeezes down and passes through the die opening. 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. which assumes no friction. for estimating extrusion strain has gained considerable recognition

$$\epsilon_x = a + b \ln r_x$$

Where e_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 indirect extrusion can be estimated based on Johnson's extrusion strain formula as follows

$$p = \overline{Y}_f \epsilon_x$$

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. We can write the following expression which isolates the friction force in the direct extrusion container

$$\frac{p_f \pi D_o^2}{4} = \mu p_c \pi D_o L$$

Where pf ¼ additional pressure required to overcome friction, MPa (lb/in^2); $\pi D_o{}^2/4$ = billet cross-sectional area,mm^2 (in^2); m = coefficient of friction at the container wall; p_c= pressure of the billet against the container wall, MPa (lb/in^2); and $\pi D_o L$ = area of the interface between billet and container wall,mm^2 (in^2).The right-hand side of this equation indicates the billet-container friction force, and the left-hand side gives the additional ram force to overcome that friction. In the worst case, sticking occurs at the container wall so that friction stress equals shear yield strength of the work metal:

$$\mu p_s \pi D_o L = Y_s \pi D_o L$$

where Y_s = shear yield strength, MPa (lb/in^2). If we assume that $Y_s = \overline{Y}_f/2$, then p_f reduces to the following:

Based on this reasoning, the following formula can be used to compute ram pressure in direct extrusion

$$p = \overline{Y}_f\left(\epsilon_x + \frac{2L}{D_o}\right)$$

Example/ A billet 75mmlong and 25mm in diameter is to be extruded in a direct extrusion operation with extrusion ratio rx = 4.0. The extrudate has a round cross section. The die angle (halfangle) = 90°. 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=75mm(starting value), L=50 mm, L=25 mm, and L=0.We compute the ideal true strain, extrusion strain using Johnson's formula, and average flow stress:

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

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

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

L=75mm:With a die angle of 90°, the billet metal is assumed to be forced through the die opening almost immediately; thus, our calculation assumes that maximum pressure is reached at the billet length of 75mm. For die angles less than 90°, the pressure would build to a maximum as the starting billet is squeezed into the cone-shaped portion of the extrusion die.

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

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

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

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

Q1/ in diameter is reduced by indirect (backward) extrusion to a 20 mm diameter. The die angle is 90°. The Johnson equation has a = 0.8 and b = 1.4, and the flow curve for the work metal has a strength coefficient of 800 MPa and strain-hardening exponent of 0.13. Determine (a) extrusion ratio, (b) true strain (homogeneous deformation), (c) extrusion strain, (d) ram pressure, and (e) ram force.

Q2/ A billet that is 75 mm long with diameter = 35 mm is direct extruded to a diameter of 20 mm. The extrusion die has a die angle = 75^o. For the work metal, K = 600 MPa and n = 0.25. In the Johnson extrusion strain equation, a = 0.8 and b = 1.4. Determine (a) extrusion ratio, (b) true strain (homogeneous deformation), (c) extrusion strain, and (d) ram pressure and force at L = 70, 60, 50, 40, 30, 20, and 10 mm. Use of a spreadsheet calculator is recommended for part (d)

Q3/ A direct extrusion operation is performed on a cylindrical billet with an initial diameter of 2.0 in and an initial length of 4.0 in. The die angle ¼ 60^o and orifice diameter is 0.50 in. In the Johnson extrusion strain equation, a = 0.8 and b =1.5. The operation is carried out hot and the hot metal yields at 13,000 lb/in2 and does not strain harden when hot. (a) What is the extrusion ratio? (b) Determine the ram position at the point when the metal has been compressed into the cone of the die and starts to extrude through the die opening. (c) What is the ram pressure corresponding to this position? (d) Also determine the length of the final part if the ram stops its forward movement at the start of the die cone

Q4/ An indirect extrusion process starts with an aluminum billet with diameter = 2.0 in and length = 3.0 in. Final cross section after extrusion is a square with 1.0 in on a side. The die angle = 90^o. The operation is performed cold and the strength coefficient of the metal K = 26,000 lb/in^2 and strain hardening exponent n=0.20. In the Johnson extrusion strain equation, a=0.8 and b= 1.2. (a) Compute the extrusion ratio, true strain, and extrusion strain. (b)What is the shape factor of the product? (c) If the butt left in the container at the end of the stroke is 0.5 in thick, what is the length of the extruded section? (d) Determine the ram pressure in the process.

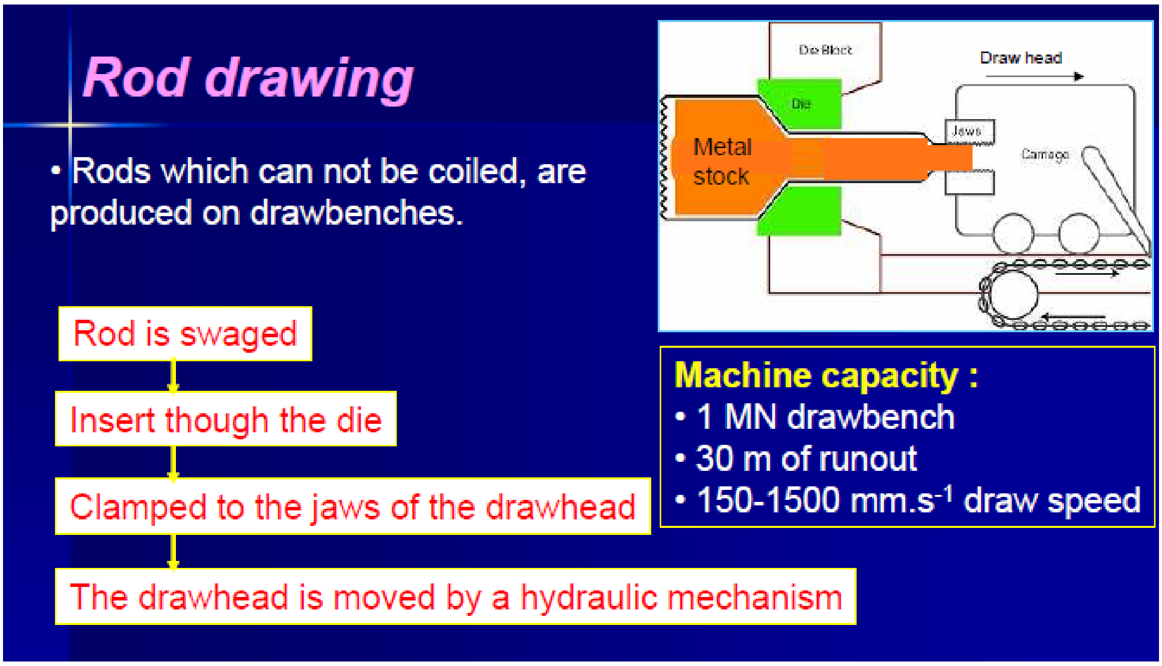
Drawing of rods, wires and tubes:-

Introduction

- Drawing operations involve pulling metal through a die by means of a tensile force applied to the exit side of the die.
- The plastic flow is caused by compression force, arising from the reaction of the metal with the die.
- Starting materials: hot rolled stock (ferrous) and extruded (nonferrous).
- Material should have **high ductility** and **good tensile strength**.
  - Ba r wire and tube drawing are usually carried out at room temperature, except for large deformation, which leads to considerable rise in temperature during drawing.
- The metal usually has a circular symmetry (but not always, depending on requirements).

Rod and wire drawing:-

- Reducing the diameter through plastic deformation while the volume remains the same.
- Same principals for drawing bars, rods, and wire but equipment is different in sizes depending on products.



Rod drawing

- Rods which can not be coiled, are produced on drawbenches.

Rod is swaged
↓
Insert though the die
↓
Clamped to the jaws of the drawhead
↓
The drawhead is moved by a hydraulic mechanism

Machine capacity :
- 1 MN drawbench
- 30 m of runout
- 150-1500 $mm.s^{-1}$ draw speed

Wire drawing die

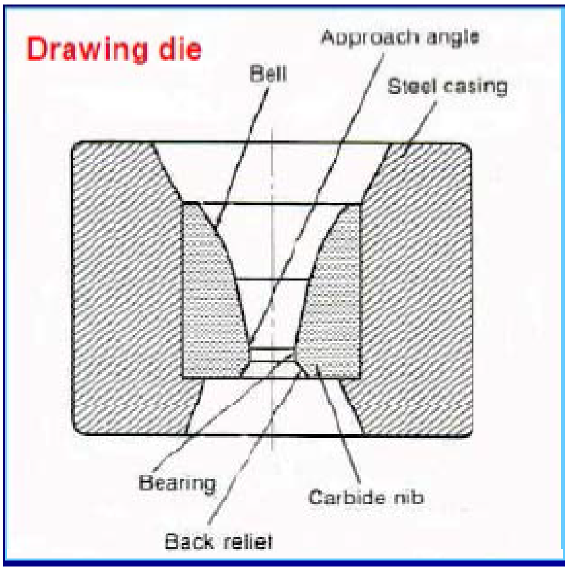
Conical drawing die

- **Shape of the bell** causes hydrostatic pressure to increase and promotes the flow of lubricant into the die.

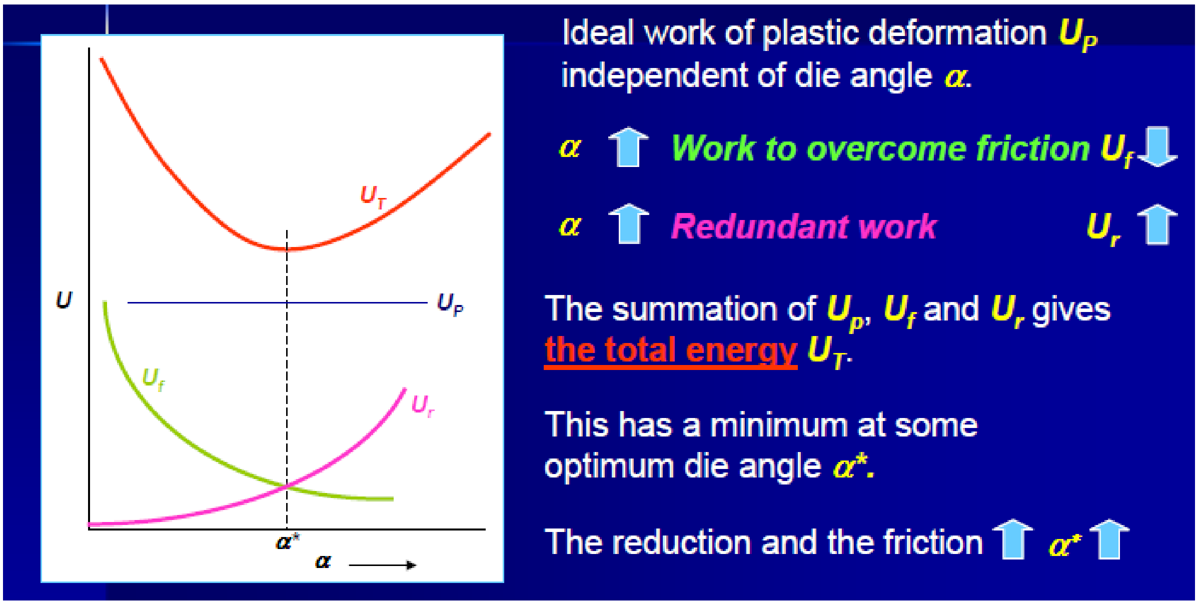
- **The approach angle** – where the actual reduction in diameter occurs, giving the half die angle α.

- The **bearing region** produces a frictional drag on the wire and also remove surface damage due to die wear, without changing dimensions.

- The **back relief** allows the metal to expand slightly as the wire leaves the die and also minimises abrasion if the drawing stops or the die is out of alignment.



The effect of die angle on the total energy required to cause deformation



Ideal work of plastic deformation U_P independent of die angle α.

α ↑ *Work to overcome friction* U_f ↓

α ↑ *Redundant work* U_r ↑

The summation of U_p, U_f and U_r gives the total energy U_T.

This has a minimum at some optimum die angle α^*.

The reduction and the friction ↑ α^* ↑

ANALYSIS OF DRAWING

The term continuous drawing is used to describe this type of operation because of the long production runs that are achieved with the wire coils, which can be butt-welded each to the next to make the operation truly continuous.

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

$$r = \frac{A_o - A_f}{A_o}$$

where r=area reduction in drawing; A_o=original area of work,mm^2 (in^2); and A_f =final area, mm^2 (in^2). Area reduction is often expressed as a percentage. In bar drawing, rod drawing, and in drawing of large diameter wire for upsetting and heading operations, 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 stock diameters

$$d = D_o - D_f$$

where d = draft, mm (in); D_o = original diameter of work, mm (in); and D_f = final work diameter, mm (in).

In this section, we consider the mechanics of wire and bar drawing. How are stresses and forces computed in the process? We also consider how large a reduction is possible in a drawing operation.

Mechanics of Drawing If no friction or redundant work occurred in drawing, true strain could be determined as follows

$$\epsilon = \ln \frac{A_o}{A_f} = \ln \frac{1}{1 - r}$$

where A_o and A_f are the original and final cross-sectional areas of the work, as previously defined; and r = drawing reduction .The stress that results from this ideal deformation is given by

$$\sigma = \overline{Y}_f \epsilon = \overline{Y}_f \ln \frac{A_o}{A_f}$$

Where $\overline{Y}_f = \frac{K\epsilon^n}{1+n}$ = average flow stress based on the value of strain. Because friction is present in drawing and the work metal experiences inhomogeneous deformation, the actual stress is larger than. 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 [1], [3], and [19].

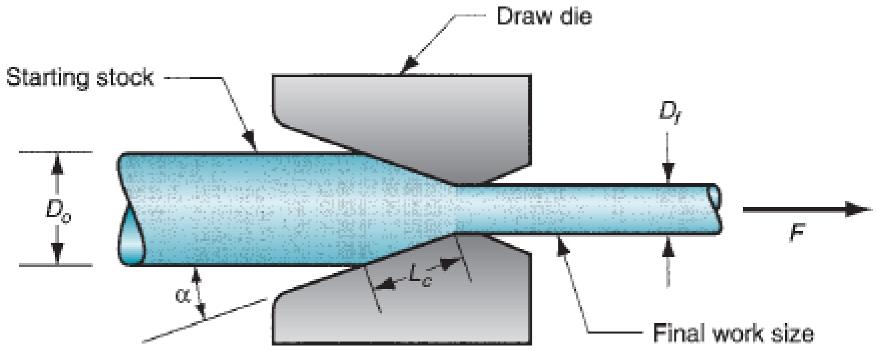
$$\sigma_d = \overline{Y}_f \left(1 + \frac{\mu}{\tan\alpha}\right) \phi \ln \frac{A_o}{A_f}$$

Where σ_d = draw stress, MPa (lb/in^2); μ = die-work coefficient of friction; α = die angle (half-angle) . and f is a factor that accounts for inhomogeneous

Deformation which is determined as follows for a round cross section

$$\phi = 0.88 \pm 0.12 \frac{D}{L_c}$$

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



$$D = \frac{D_o + D_f}{2}$$

$$L_c = \frac{D_o - D_f}{2\sin\alpha}$$

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

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

where F = draw force, N (lb); 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

Wire is drawn through a draw die with entrance angle = 15°. Starting diameter is 2.5 mm 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: The values of D and L_c for Eq. (19.33) can be determined using Eqs. (19.34). $D = 2.25$ 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 $A_o = 4.91$ mm^2 and $A_f = 3.14$ mm^2. The resulting true strain $\epsilon = \ln(4.91/3.14) = 0.446$, and the average flow stress in the operation is computed:

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

Draw stress

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

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

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

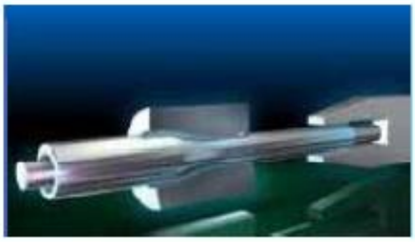
Tube-drawing processes:-

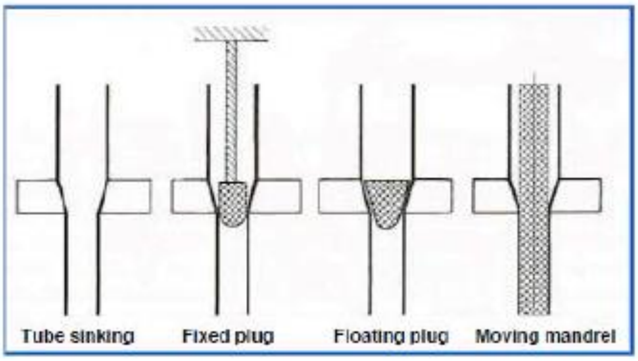
- Following the hot forming process, tubes are cold drawn using dies, plugs or mandrels to the required shape, size, tolerances and mechanical strength.
- provides good surface finishes.
- increase mechanical properties by strain hardening.
- can produce tubes with thinner walls or smaller diameters than can be obtained from other hot forming methods.
- can produce more irregular shapes.

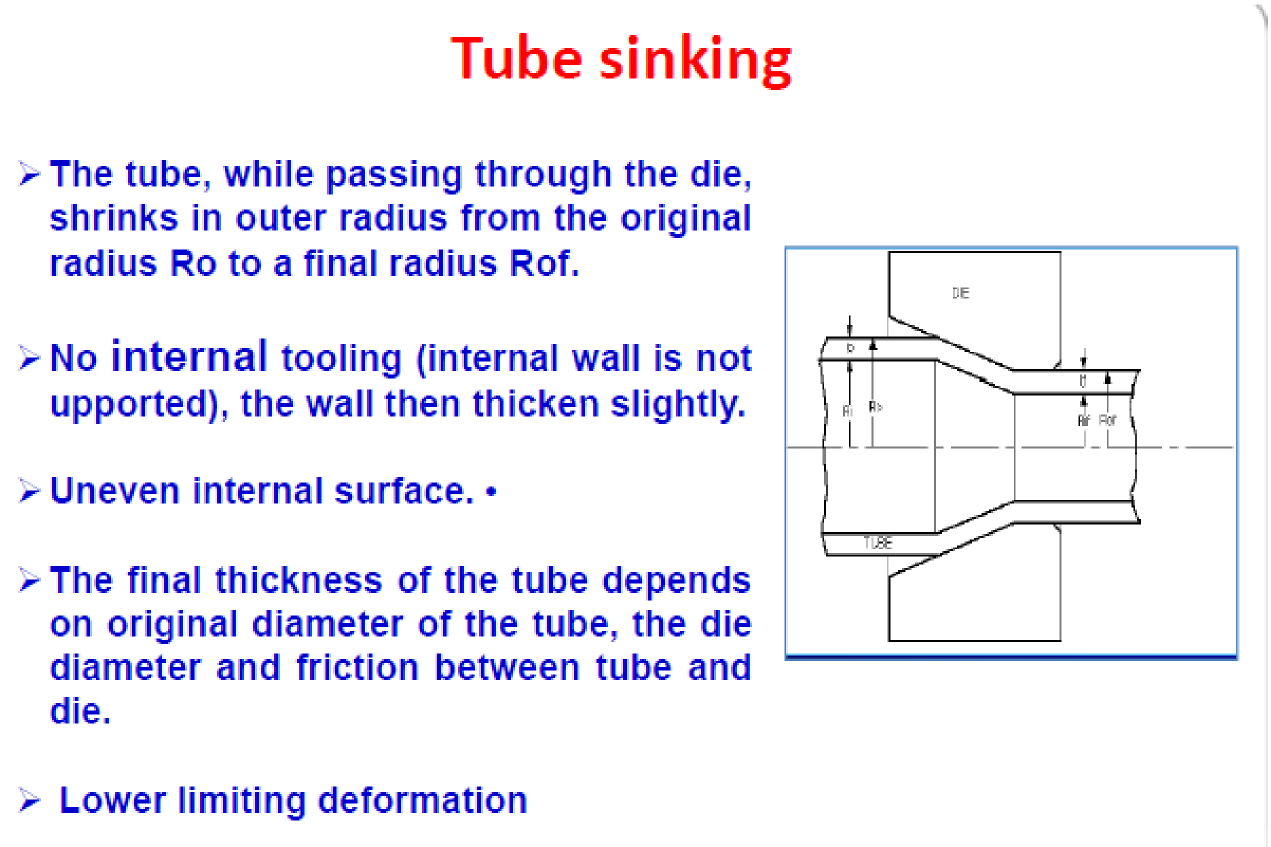
Classification of tube drawing processes

There are three basic types of tube-drawing processes

➢Sinking
  ▪ Plug drawing
  ▪ Fixed plug
➢- Floating plug
➢• Mandrel drawing.



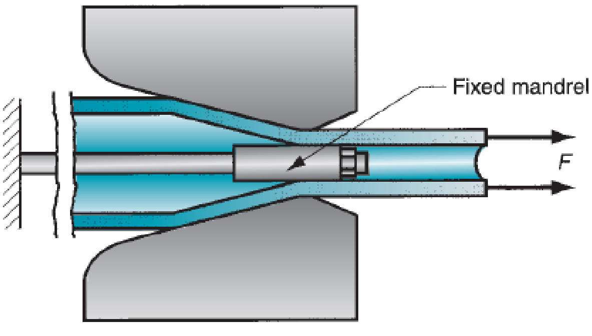




Tube sinking

- The tube, while passing through the die, shrinks in outer radius from the original radius Ro to a final radius Rof.
- No internal tooling (internal wall is not upported), the wall then thicken slightly.
- Uneven internal surface. •
- The final thickness of the tube depends on original diameter of the tube, the die diameter and friction between tube and die.
- Lower limiting deformation

Fixed plug drawing

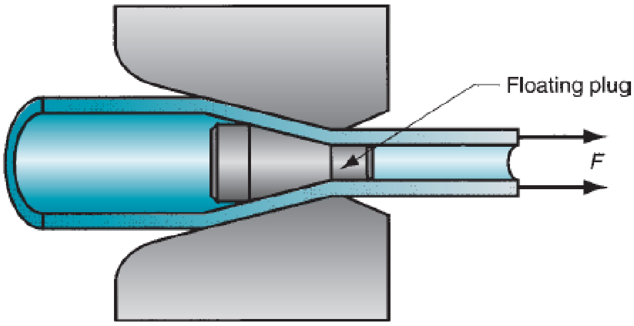


(a)

- **Use cylindrical / conical plug to control size/shape of inside diameter.**
- **Use higher drawing loads than floating plug drawing.**
- **Greater dimensional accuracy than tube sinking.**
- **Increased friction from the plug limit the reduction in area (seldom > 30%).**

- **can draw and coil long lengths of tubing.**

Floating plug drawing



(b)

- A tapered plug is placed inside the tube.

- As the tube is drawn the plug and the die act together to

reduce both the outside/inside diameters of the tube.

- Improved reduction in area than tube sinking (~ 45%).

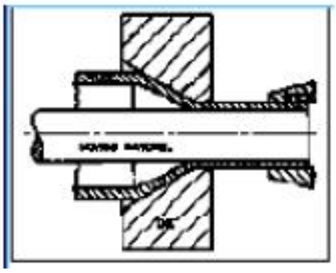
- Lower drawing load than fixed plug drawing.

- Long lengths of tubing is possible.

- Tool design and lubrication can be very critical

Moving mandrel drawing

- Draw force is transmitted to the metal by the pull on the exit section and by the friction forces acting along the tube –mandrel interface.



- minimised friction.
- Vmandrel = Vtube
- The mandrel also imparts a smooth inside finish surface of the tube.
- mandrel removal disturbs dimensional tolerance.

Q1/ Wire of starting diameter = 3.0 mm is drawn to 2.5 mm in a die with entrance angle = 15° degrees. Coefficient of friction at the work-die interface = 0.07. For the work metal, $K = 500$ MPa and $n = 0.30$. Determine: (a) area reduction, (b) draw stress, and (c) draw force required for the operation.

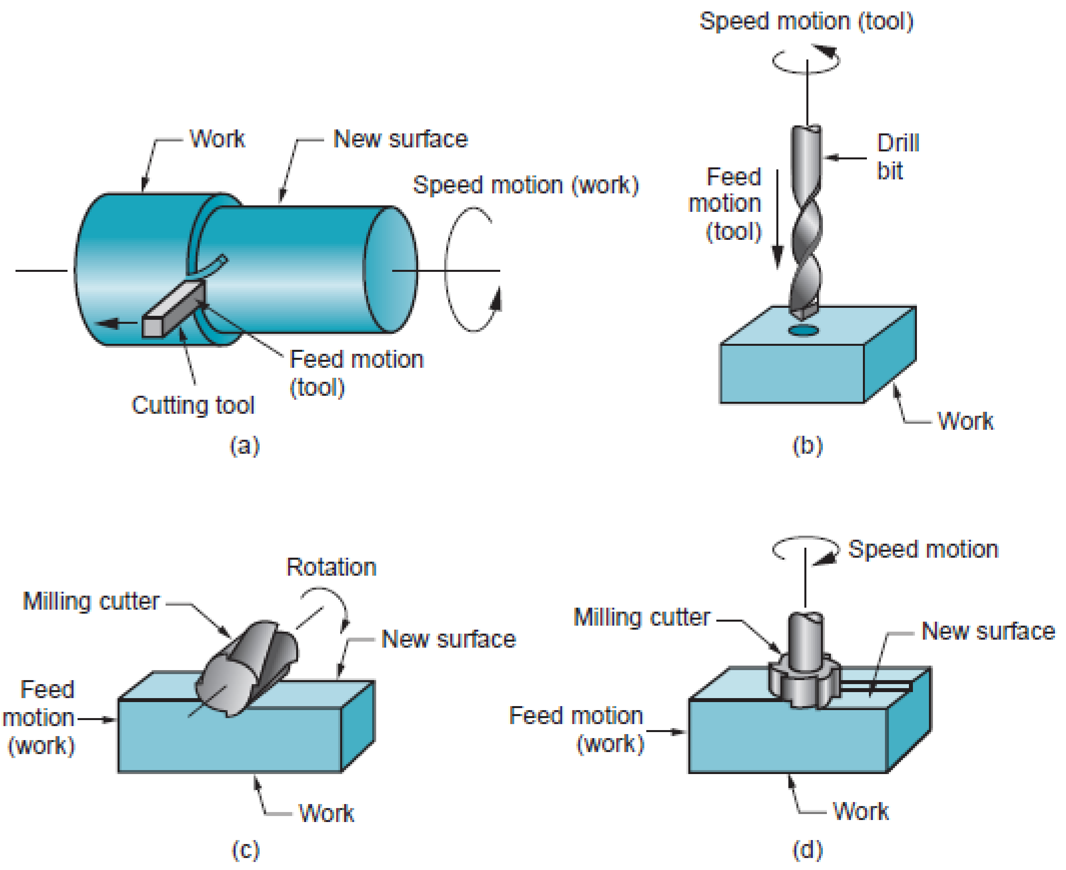
Q2/ Rod stock is drawn through a draw die with an entrance angle of 12°. Starting diameter = 0.50 in and final diameter = 0.35 in. Coefficient of friction at the work-die interface = 0.1. The metal has a strength coefficient = 45,000 lb/in2 and a strain hardening exponent = 0.22. Determine: (a) area reduction, (b) draw force for the operation, and

Q3/Bar stock of initial diameter = 90 mm is drawn with a draft = 15 mm. The draw die has an entrance angle = 18°, and the coefficient of friction at the work-die interface = 0.08. The metal behaves as a perfectly plastic material with yield stress = 105 MPa. Determine: (a) area reduction, (b) draw stress, (c) draw force required for the operation,

Metal Machining

Machining is not just one process; it is a group of processes. The common feature is the use of a cutting tool to form a chip that is removed from the workpart. To perform the operation, relative motion is required between the tool and work. This relative motion is achieved in most machining operations by means of a primary motion, called the cutting speed, and a secondary motion, called the feed. The shape of the tool and its penetration into the work surface, combined with these motions, produces the desired geometry of the resulting work surface.

Types of Machining Operations There are many kinds of machining operations, each of which is capable of generating a certain part geometry and surface texture, but for now it is appropriate to identify and define the three most common types: turning, drilling, and milling, illustrated in Figure


Work
New surface
Speed motion (work)
Cutting tool
Feed motion
(tool)
(a)
Speed motion (tool)
Drill
bit
Feed
motion
(tool)
Work
(b)
Rotation
Milling cutter
New surface
Feed
motion
(work)
Work
(c)
Speed motion
Milling cutter
New surface
Feed motion
(work)
Work
(d)

Why Machining is Important

- Variety of work materials can be machined
  - *Most frequently applied to metals*
- Variety of part shapes and special geometry features possible, such as:
  - *Screw threads*
  - *Accurate round holes*
  - *Very straight edges and surfaces*
- Good dimensional accuracy and surface finish

Disadvantages of Machining

- Wasteful of material
  - *Chips generated in machining are wasted material, at least in the unit operation*
- Time consuming
  - *A machining operation generally takes more time to shape a given part than alternative shaping processes, such as casting, powder metallurgy, or forming*

Machining Tools

Most modern cutting tool materials are ceramic or composite materials designed to be **very hard**.

1. *Single-Point Tools*
    - One cutting edge
    - *Turning* uses single point tools
    - Point is usually rounded to form a *nose radius*
2. *Multiple Cutting Edge Tools*
    - More than one cutting edge
    - Motion relative to work usually achieved by rotating
    - *Drilling* and *milling* use rotating multiple cutting edge tools.

Single point

Multiple point

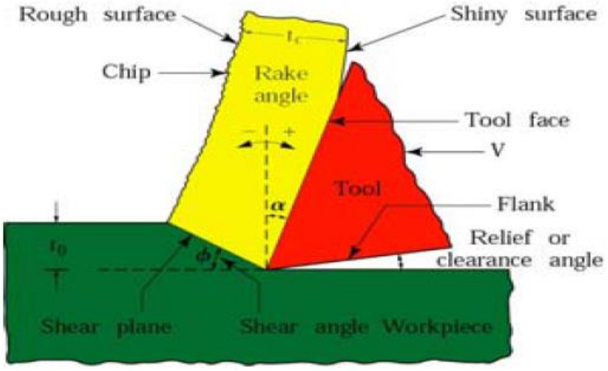
Cutting Conditions

Relative motion is required between the tool and work to perform a machining operation. The primary motion is accomplished at a certain cutting speed v. In addition, the tool must be moved laterally across the work. This is a much slower motion, called the feed f. The remaining dimension of the cut is the penetration of the Cutting tool below the original work surface, called the depth of cut d. collectively, speed, feed, and depth of cut are called the cutting conditions. They form the three dimensions of the machining process, and for certain operations (e.g., most single-point tool operations) they can be used to calculate the material removal rate for the process:

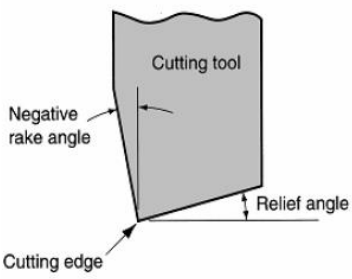
$$R_{MR} = vfd$$

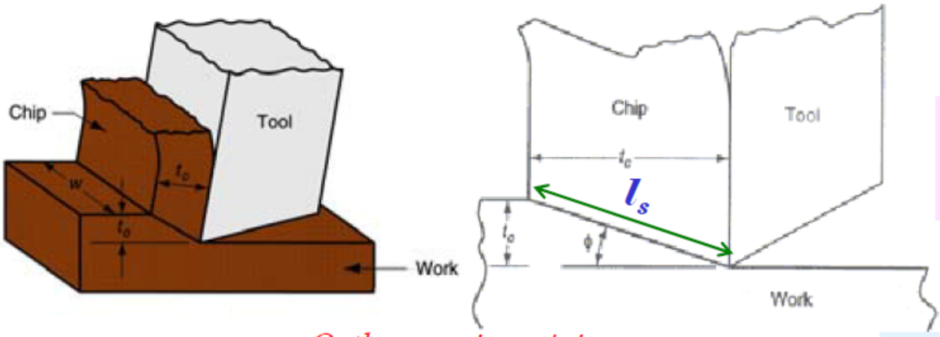
where R_{MR} = material removal rate, mm^3/s (in^3/min); v = cutting speed, m/s (ft/min), which must be converted to mm/s (in/min); f = feed, mm (in); and d = depth of cut, mm (in).

Machining Terminology



- **Speed** – surface cutting speed (v)
- **Feed** – advance of tool through the part
- **Depth of cut** – depth of tool into part
- **Rake face** – tool's leading edge
- **Rake angle** – slant angle of tool's leading edge (α)
- **Flank** – following edge of cutting tool
- **Relief angle** – angle of tool's following edge above part surface





Orthogonal model

Cutting edge is perpendicular to the cutting speed

Although it is a 3D process, 2D analysis will be enough

Chip thickness – thickness of machined chip (t_c)

Depth of cut = t_o

Shear plane length – measured along shear plane chip (l_s)

Chip width – width of machined chip (w)

Shear angle – angle of shearing surface measured from tool direction (φ)

Cutting Forces

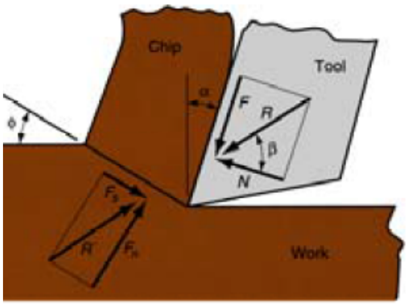
Since R = R' = R'', we can get the force balance equations:

$F = F_c \sin \alpha + F_t \cos \alpha$ F = friction force; N = normal to chip force

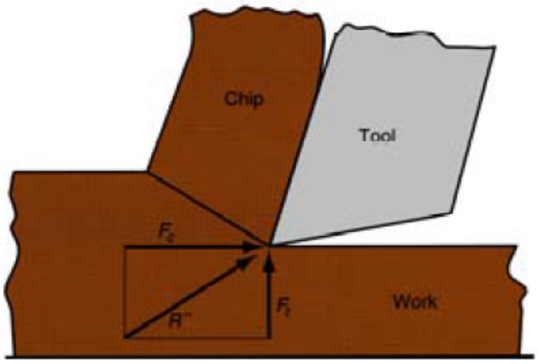
$N = F_c \cos \alpha - F_t \sin \alpha$ F_c = cutting force; F_t = thrust force

$F_s = F_c \cos \phi - F_t \sin \phi$ F_s = shear force; F_n = normal to shear plane force

$F_n = F_c \sin \phi + F_t \cos \phi$



(a)



(b)

Friction angle = β

$\tan \beta = \mu = F/N$

Shear plane stress:

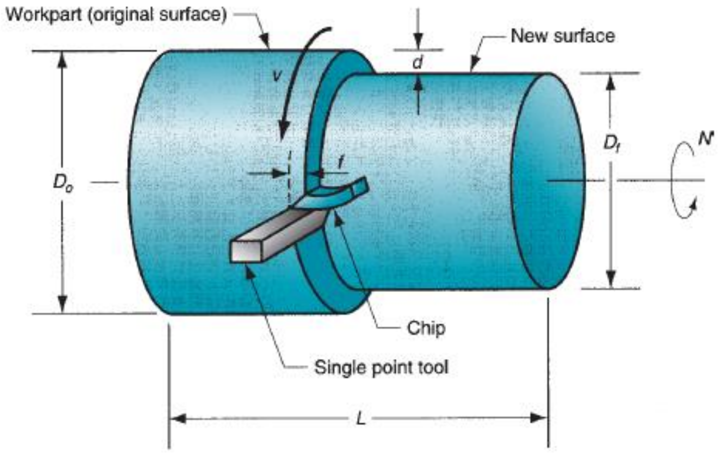
$\tau = F_s/A_s$

where

$A_s = t_o\, w/\sin \phi$

TURNING AND RELATED OPERATIONS

Turning is a machining process in which a single-point tool removes material from the surface of a rotating work piece. The tool is fed linearly in a direction parallel to the axis of rotation to generate a cylindrical geometry, as illustrated in Figures. Single point tools used in turning. Turning is traditionally carried out on a machine tool called a lathe, which provides power to turn the part at a given rotational speed and to feed the tool at a specified rate and depth of cut.



CUTTING CONDITIONS IN TURNING

The rotational speed in turning is related to the desired cutting speed at the surface of the cylindrical workpiece by the equation

$$N = \frac{v}{\pi D_o}$$

where N = rotational speed, rev/min; v = cutting speed, m/min (ft/min); and D_o = original diameter of the part, m (ft).

The turning operation reduces the diameter of the work from its original diameter D_o to a final diameter D_f, as determined by the depth of cut d:

$$D_f = D_o - 2d$$

The feed in turning is generally expressed in mm/rev (in/rev). This feed can be converted to a linear travel rate in mm/min (in/min) by the formula

$$f_r = Nf$$

where f_r = feed rate, mm/min (in/min); and f = feed, mm/rev (in/rev).

The time to machine from one end of a cylindrical workpart to the other is given by

$$T_m = \frac{L}{f_r}$$

where T_m = machining time, min; and L = length of the cylindrical workpart, mm (in). A more direct computation of the machining time is provided by the following equation:

$$T_m = \frac{\pi D_o L}{fv}$$

where D_o = work diameter, mm (in); L = workpart length, mm (in); f = feed, mm/rev (in/rev); and v = cutting speed, mm/min (in/min). As a practical matter, a small distance is usually added to the workpart length at the beginning and end of the piece to allow for approach and overtravel of the tool. Thus, the duration of the feed motion past the work will be longer than T_m.

The volumetric rate of material removal can be most conveniently determined by the following equation:

$$R_{MR} = vfd$$

where R_{MR} = material removal rate, mm^3/min (in^3/min). In using this equation, the units for f are expressed simply as mm (in), in effect neglecting the rotational character of turning. Also, care must be exercised to ensure that the units for speed are consistent with those for f and d.

OPERATIONS RELATED TO TURNING

A variety of other machining operations can be performed on a lathe in addition to turning; these include the following, illustrated in Figure

(a) Facing. The tool is fed radially into the rotating work on one end to create a flat surface on the end.

(b) Taper turning. Instead of feeding the tool parallel to the axis of rotation of the work, the tool is fed at an angle, thus creating a tapered cylinder or conical shape.

(c) Contour turning. Instead of feeding the tool along a straight line parallel to the axis of rotation as in turning, the tool follows a contour that is other than straight, thus creating a contoured form in the turned part.

(d) Form turning. In this operation, sometimes called forming, the tool has a shape that is imparted to the work by plunging the tool radially into the work.

(e) Chamfering. The cutting edge of the tool is used to cut an angle on the corner of the cylinder, forming what is called a ‘‘chamfer.’’

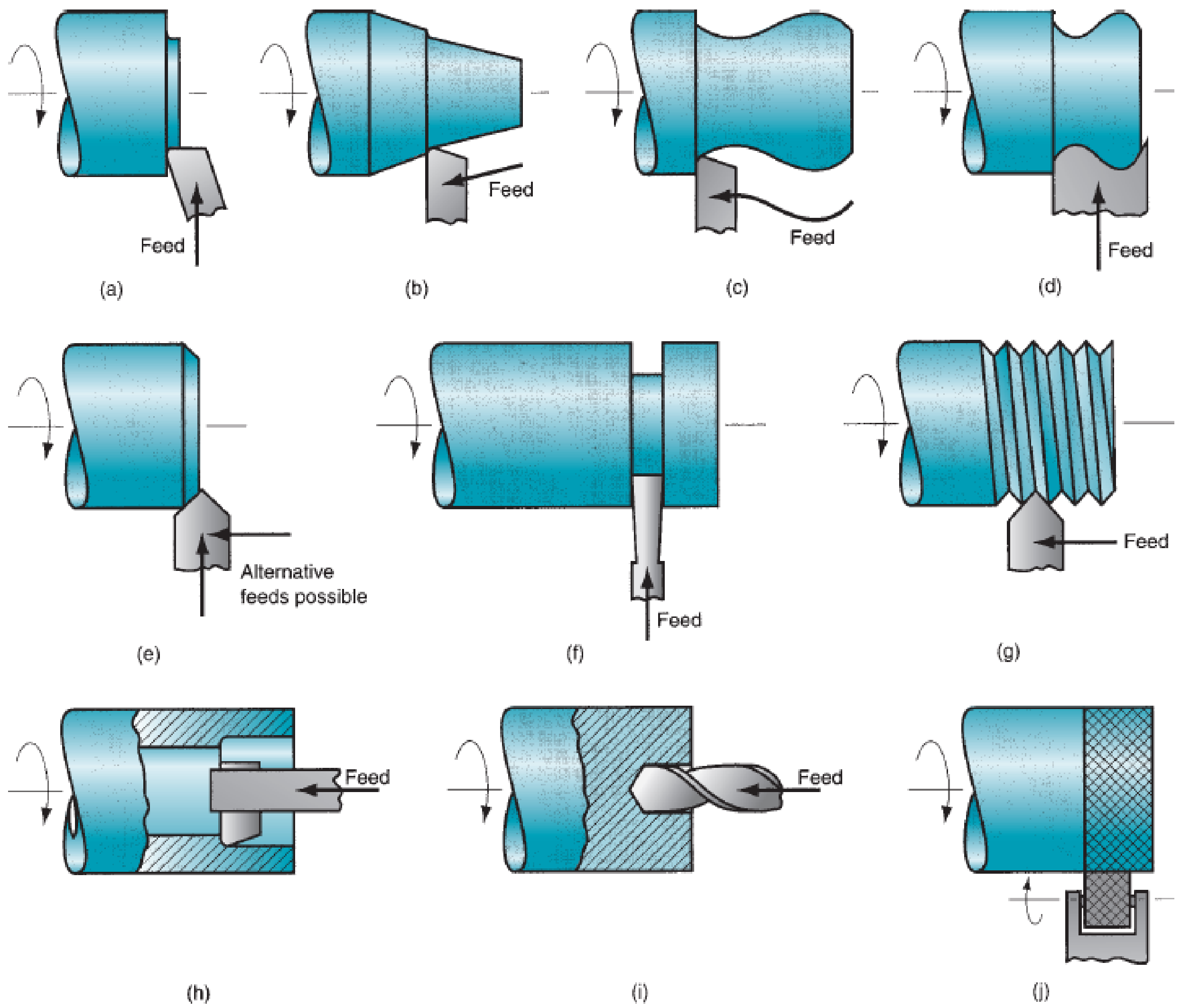
(f) Cutoff. The tool is fed radially into the rotating work at some location along its length to cut off the end of the part. This operation is sometimes referred to as parting.

(g) Threading. A pointed tool is fed linearly across the outside surface of the rotating workpart in a direction parallel to the axis of rotation at a large effective feed rate, thus creating threads in the cylinder.

(h) Boring. Asingle-point tool is fed linearly, parallel to the axis of rotation, on the inside diameter of an existing hole in the part.

(i) Drilling. Drilling can be performed on a lathe by feeding the drill into the rotating work along its axis. Reaming can be performed in a similar way.

(j) Knurling. This is not a machining operation because it does not involve cutting of material. Instead, it is a metal forming operation used to produce a regular crosshatched pattern in the work surface.



DRILLING AND RELATED OPERATIONS

Drilling, Figure, is a machining operation used to create a round hole in a work part. This contrasts with boring, which can only be used to enlarge an existing hole. Drilling is usually performed with a rotating cylindrical tool that has two cutting edges on its working end. The tool is called a drill or drill bit . The most common drill bit is the twist drill, described in Section 23.3.2. The rotating drill feeds into the stationary work part to form a hole whose diameter is equal to the drill diameter. Drilling is customarily performed on a drill press, although other machine tools also perform this operation. The video clip on hole making illustrates the drilling operation.

CUTTING CONDITIONS IN DRILLING

The cutting speed in a drilling operation is the surface speed at the outside diameter of the drill. It is specified in this way for convenience, even though nearly all of the cutting is actually performed at lower speeds closer to the axis of rotation. To set the desired cutting speed in drilling, it is necessary to determine the rotational speed of the drill. Letting N represent the spindle rev/min,

$$N = \frac{v}{\pi D}$$

where v = cutting speed, mm/min (in/min); and D = the drill diameter, mm (in). In some drilling operations, the workpiece is rotated about a stationary tool, but the same formula applies.

Feed f in drilling is specified in mm/rev (in/rev). Recommended feeds are roughly proportional to drill diameter; higher feeds are used with larger diameter drills. Since there are (usually) two cutting edges at the drill point, the uncut chip thickness (chip load) taken by each cutting edge is half the feed. Feed can be converted to feed rate using the same equation as for turning:

$$f_r = Nf$$

where f_r = feed rate, mm/min (in/min).

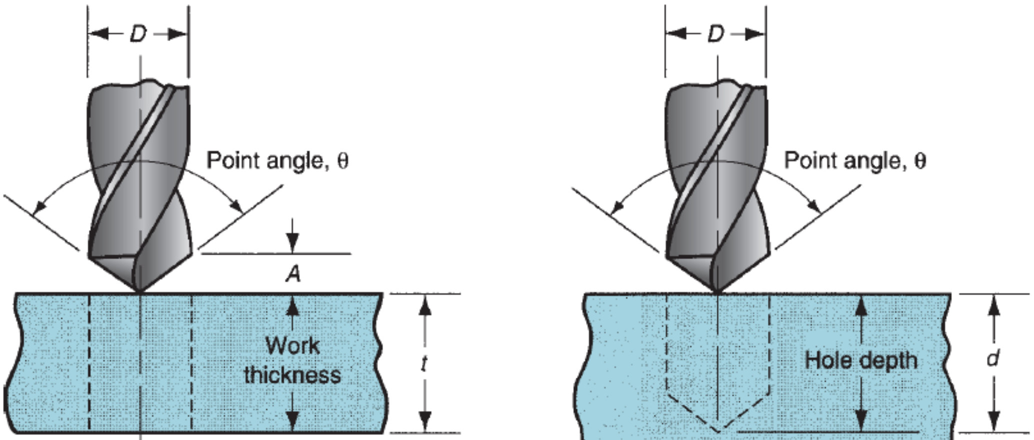
Drilled holes are either through holes or blind holes, Figure 22.13. In ***through holes,*** the drill exits the opposite side of the work; in ***blind holes,*** it does not. The machining time required to drill a through hole can be determined by the following formula:

$$T_m = \frac{t + A}{f_r}$$

where T_m = machining (drilling) time, min; t = work thickness, mm (in); f_r = feed rate, mm/min (in/min); and A = an approach allowance that accounts for the drill point angle, representing the distance the drill must feed into the work before reaching full diameter, Figure 22.10(a). This allowance is given by

$$A = 0.5\, D \tan\left(90 - \frac{\theta}{2}\right)$$

where A = approach allowance, mm (in); and θ = drill point angle. In drilling a through hole, the feed motion usually proceeds slightly beyond the opposite side of the work,



In a blind-hole, hole depth d is defined as the distance from the work surface to the depth of the full diameter, Figure 22.13(b). Thus, for a blind hole, machining time is given by

$$T_m = \frac{d + A}{f_r}$$

where A = the approach allowance by Eq. (22.10).

The rate of metal removal in drilling is determined as the product of the drill cross-sectional area and the feed rate:

$$R_{MR} = \frac{\pi D^2 f_r}{4}$$

This equation is valid only after the drill reaches full diameter and excludes the initial approach of the drill into the work.

OPERATIONS RELATED TO DRILLING

Several operations are related to drilling. These are illustrated in Figure and described in this section. Most of the operations follow drilling; a hole must be made first by drilling, and then the hole is modified by one of the other operations. Centering and spot facing are exceptions to this rule. All of the operations use rotating tools.

(a) Reaming. Reaming is used to slightly enlarge a hole, to provide a better tolerance on its diameter, and to improve its surface finish. The tool is called a reamer, and it usually has straight flutes.

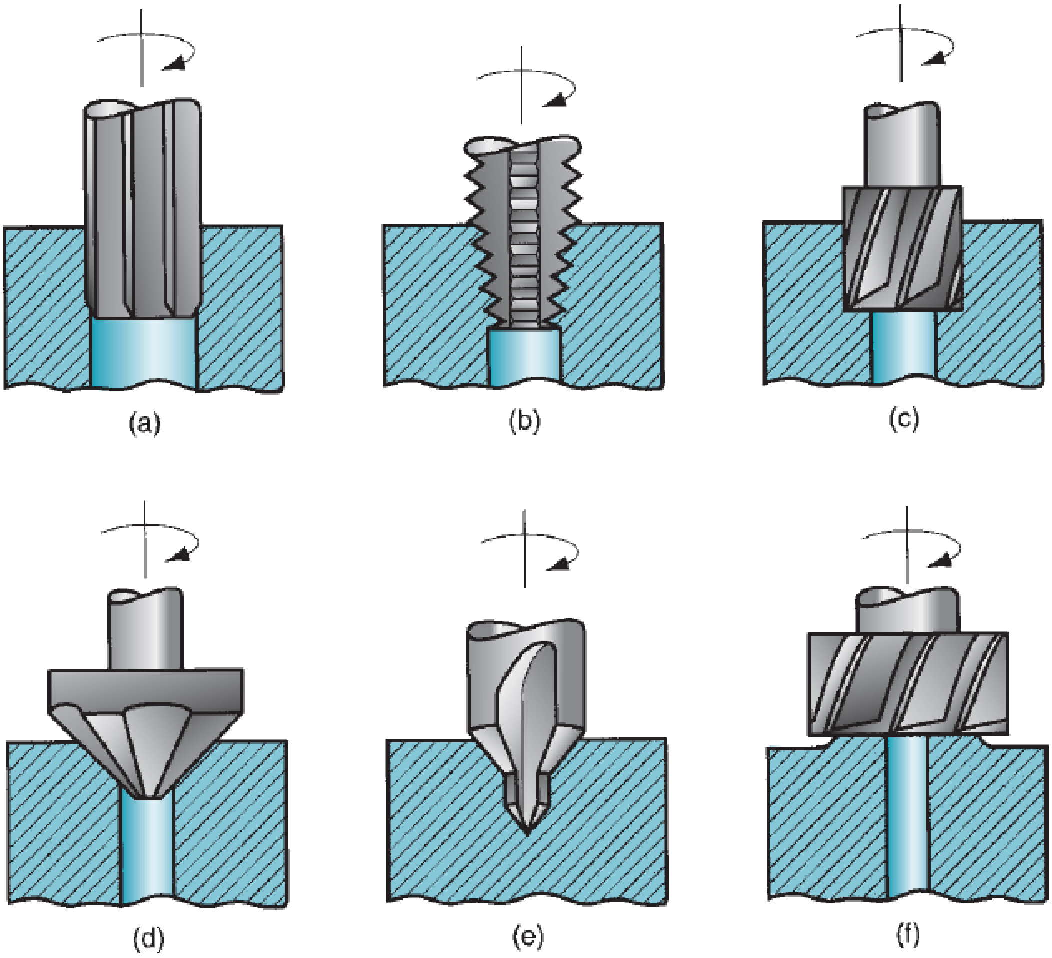
(b) Tapping. This operation is performed by a tap and is used to provide internal screw threads on an existing hole.

(c) Counter boring. Counter boring provides a stepped hole, in which a larger diameter follows a smaller diameter partially into the hole. A counter bored hole is used to seat bolt heads into a hole so the heads do not protrude above the surface.

(d) Countersinking. This is similar to counter boring, except that the step in the hole is cone-shaped for flat head screws and bolts.

(e) Centering. Also called center drilling, this operation drills a starting hole to accurately establish its location for subsequent drilling. The tool is called a center drill.

(f) Spot facing. Spot facing is similar to milling. It is used to provide a flat machined surface on the workpart in a localized area.



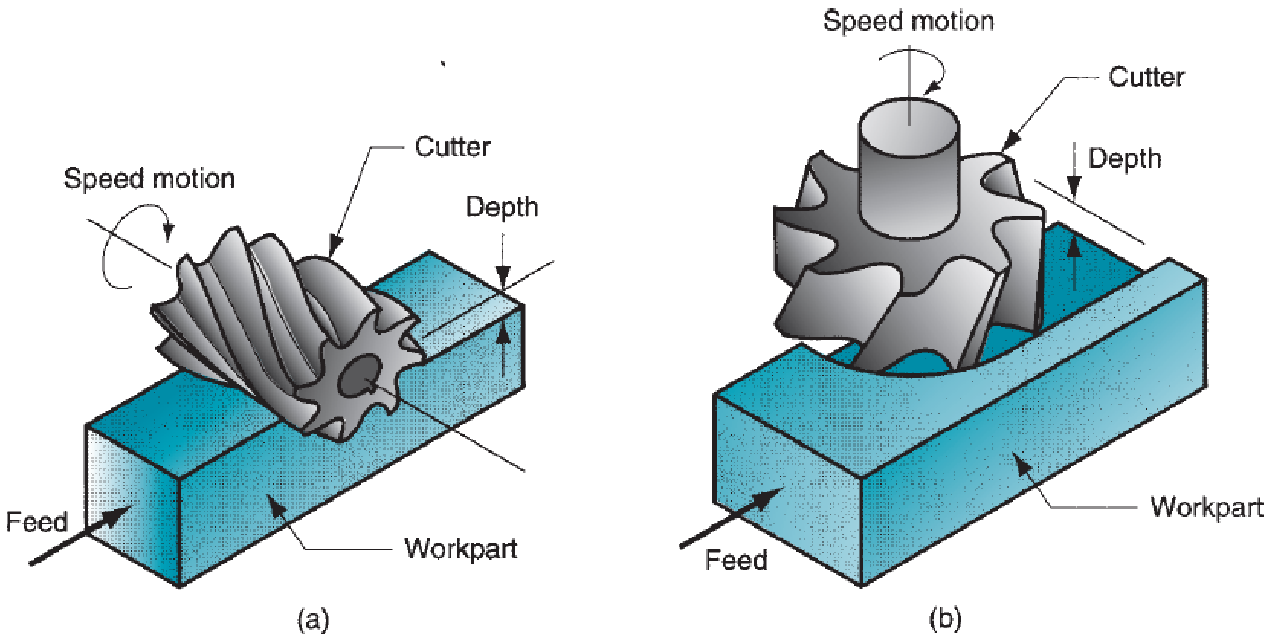
MILLING

Milling is a machining operation in which a workpart is fed past a rotating cylindrical tool with multiple cutting edges, as illustrated in Figure . (In rare cases, a tool with one cutting edge, called a fly-cutter, is used). The axis of rotation of the cutting tool is perpendicular to the direction of feed. This orientation between the tool axis and the feed direction is one of the features that distinguishes milling from drilling. In drilling, the cutting tool is fed in a direction parallel to its axis of rotation. The cutting tool in milling is called a milling cutter and the cutting edges are called teeth. Aspects of milling cutter.

The conventional machine tool that performs this operation is a milling machine.
The reader can view milling operations and the various milling machines in our video clip on milling and machining centers

TYPES OF MILLING OPERATIONS

There are two basic types of milling operations, shown in Figure: (a) peripheral milling and (b) face milling. Most milling operations create geometry by generating the shape .



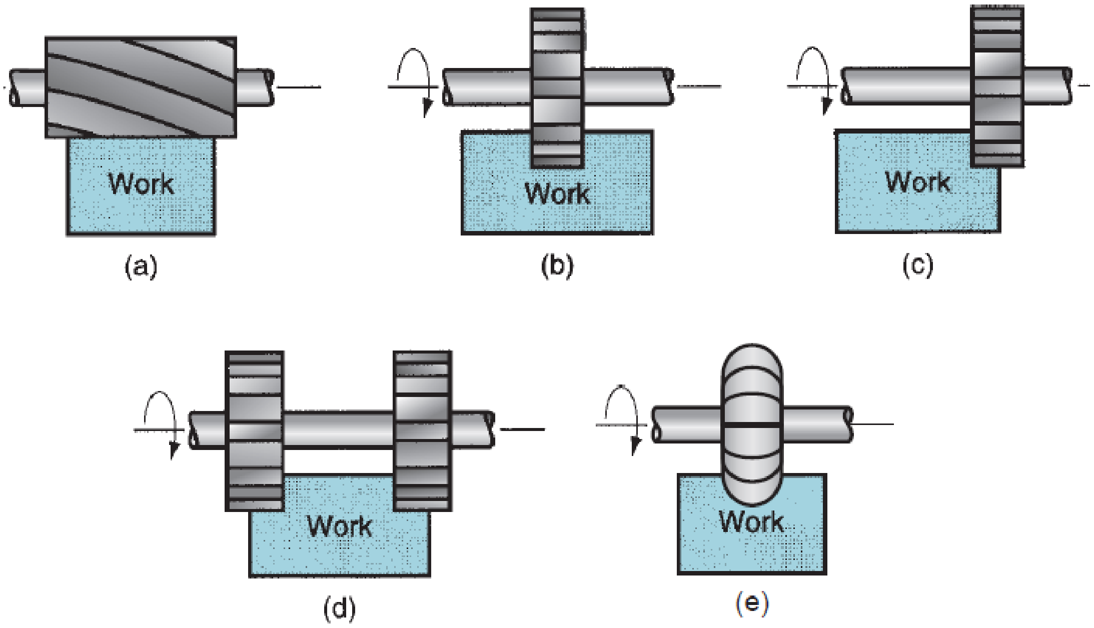
Peripheral Milling In peripheral milling, also called plain milling, the axis of the tool is parallel to the surface being machined, and the operation is performed by cutting edges on the outside periphery of the cutter. Several types of peripheral milling are shown in Figure

(a) slab milling, the basic form of peripheral milling in which the cutter width extends beyond the workpiece on both sides;

(b) slotting, also called slot milling, in which the width of the cutter is less than the workpiece width, creating a slot in the work—when the cutter is very thin, this operation can be used to mill narrow slots or cut a workpart in two, called saw milling;

(c) side milling, in which the cutter machines the side of the workpiece;

(d) straddle milling, the same as side milling, only cutting takes place on both sides of the work; and form milling, in which the milling teeth have a



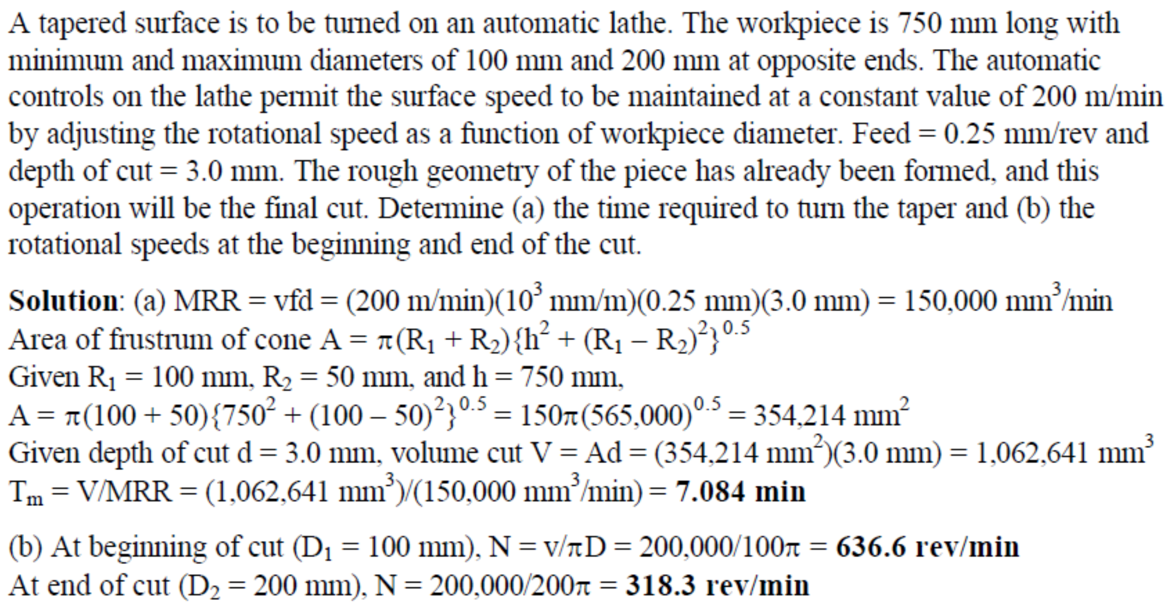
Example 1/

A cylindrical workpart 125 mm in diameter and 900 mm long is to be turned in an engine lathe. Cutting conditions are: v = 2.5 m/s, f = 0.3 mm/rev, and d = 2.0 mm. Determine: (a) cutting time, and (b) metal removal rate.

Solution: (a) $N = (2.5 \text{ m/s})/.125\pi = 6.366$ rev/s.
$f_r = 6.366(.3) = 1.91$ mm/s
$T_m = 900/1.91 = 471.2$ s = **7.85 min.**

(b) $MRR = vfd = (2.5 \text{ m/s})(10^3)(.3 \text{ mm})(2.0 \text{ mm}) = \mathbf{1500\ mm^3/s}$

Example 2/



A tapered surface is to be turned on an automatic lathe. The workpiece is 750 mm long with minimum and maximum diameters of 100 mm and 200 mm at opposite ends. The automatic controls on the lathe permit the surface speed to be maintained at a constant value of 200 m/min by adjusting the rotational speed as a function of workpiece diameter. Feed = 0.25 mm/rev and depth of cut = 3.0 mm. The rough geometry of the piece has already been formed, and this operation will be the final cut. Determine (a) the time required to turn the taper and (b) the rotational speeds at the beginning and end of the cut.

Solution: (a) MRR = vfd = (200 m/min)(10^3 mm/m)(0.25 mm)(3.0 mm) = 150,000 mm^3/min
Area of frustrum of cone $A = \pi(R_1 + R_2)\{h^2 + (R_1 - R_2)^2\}^{0.5}$
Given R_1 = 100 mm, R_2 = 50 mm, and h = 750 mm,
$A = \pi(100 + 50)\{750^2 + (100 - 50)^2\}^{0.5} = 150\pi(565{,}000)^{0.5} = 354{,}214\ mm^2$
Given depth of cut d = 3.0 mm, volume cut V = Ad = (354,214 mm^2)(3.0 mm) = 1,062,641 mm^3
T_m = V/MRR = (1,062,641 mm^3)/(150,000 mm^3/min) = **7.084 min**

(b) At beginning of cut (D_1 = 100 mm), N = v/πD = 200,000/100π = **636.6 rev/min**
At end of cut (D_2 = 200 mm), N = 200,000/200π = **318.3 rev/min**

Q1/ A workbar with 5.0 in diameter and 48 in length is chucked in an engine lathe and supported at the opposite end using a live center. A 40.0 in portion of the length is to be turned to a diameter of 4.75 in one pass at a speed = 400 ft/min and a feed = 0.012 in/rev. Determine: (a) the required depth of cut, (b) cutting time, and (c) metal removal rate

Q2/ A 4.00 in diameter workbar that is 25 in long is to be turned down to 3.50 in diameter in two passes on an engine lathe using the following cutting conditions: v = 300 ft/min, f = 0.015 in/rev, and d = 0.125 in. The bar will be held in a chuck and supported on the opposite end in a live center. With this workholding setup, one end must be turned to diameter; then the bar must be reversed to turn the other end. Using an overhead crane available at the lathe, the time required to load and unload the bar is 5.0 minutes, and the time to reverse the bar is 3.0 minutes. For each turning cut an allowance must be added to the cut length for approach and overtravel. The total allowance (approach plus overtravel) = 0.50 in. Determine the total cycle time to complete this turning operation

Q3/ The end of a large tubular workpart is to be faced on a NC vertical boring mill. The part has an outside diameter = 45.0 in and inside diameter = 25 in. If the facing operation is performed at a rotational speed = 30 rev/min, feed = 0.020 in/rev, and depth = 0.150 in, determine: (a) the cutting time to complete the facing operation, (b) the cutting speeds and metal removal rates at the beginning and end of the cut.