Unit4 (Class10) Rolling

What we learnt in the last class

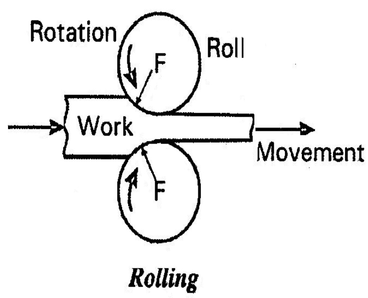
Effect of Hydrostatic Stress on Mechanical Working Process, Workability of Metals, Workability Limit Diagram(WLD), Residual Stress in Wrought Products.

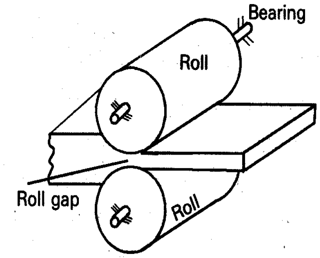
Today's class

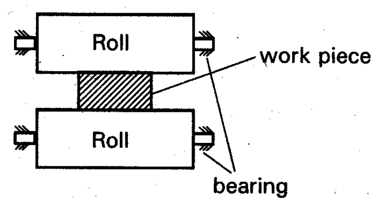
Introduction to Rolling. Concept of Rolling. Steps in rolling process, Classification of rolling process-based on temperature, roll arrangement, product. Metal flow pattern in rolling.

Typical Rolling Process

In Rolling the workpiece is drawn by friction through regulated opening of two rotating cylindrical rolls and reduction in the thickness is obtained.
The two cylindrical rollers are supported on bearings and are driven by a powerful motor. The opening between the rolls can be adjusted as required. This gap is normally referred to as roll gap or regulated opening.



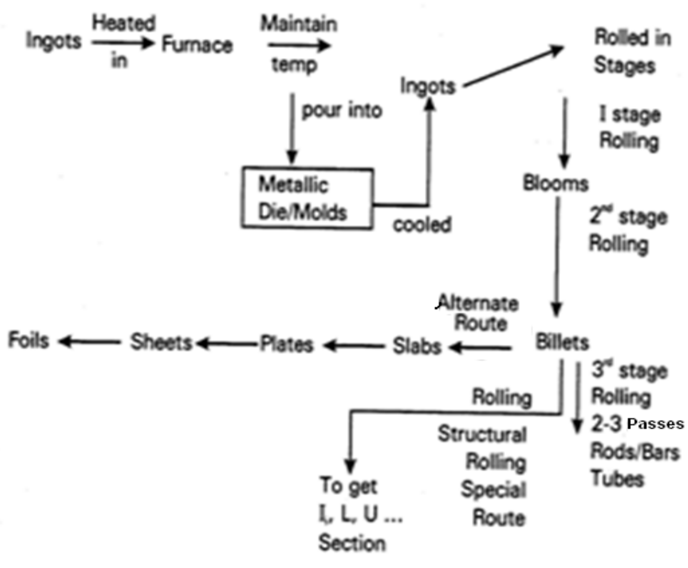




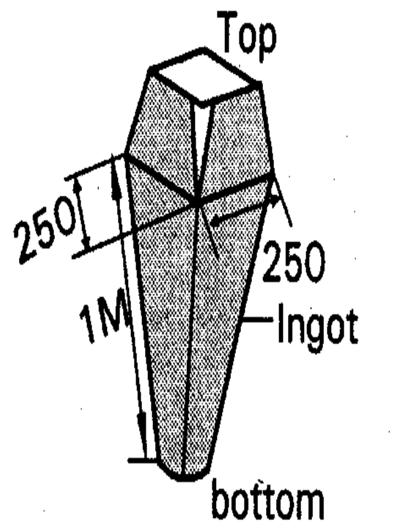
The work piece is subjected to compressive forces and is deformed plastically. The cross section decreases and length gets elongated where as the total volume
It is the main metal working process and offers itself to mass production. Close control of the final product is possible.
Rotating rolls will squeeze the work piece inducing direct compressive stress in it. Friction dominates the process.
Rolling of work piece can be carried out in hot or cold condition.
Components produced through rolling have higher mechanical properties than cast products.
Slabs, Sheets, Bars, Rods, Structural components like I, U, L etc., in long lengths can be produced easily.

Steps in Rolling Process

The staring raw material in rolling is the ingot which is obtained by using a metal die. Ingot will have a length of about 1 meter and a cross section of 100x100mm or 250x250mm etc,. Ingot may have any geometrical cross section.The details of Ingot production are:*Prepare molten metal in a furnace.*Pour clean well prepared molten metal with correct temperature into a metal die cavity and allow it to cool.*Take out the solid metal.* This solid metal is referred to as Ingot or Ingot casting.*The Ingot is then passed through the rolls to get the next set of products blooms, billets, bars, slabs, plates, sheets or Structural components.* The same is shown in the flow chart.



Flow chart for Rolling Process



Classification of Rolling Process

Rolling Process can be classified either

i) based on the temperature of the metal during rolling or
ii) based on the arrangement of the rolls and their number or
iii) based on the Products rolled.

i)based on the temperature:

Rolling can be classified as Hot Rolling or Cold Rolling. Hot rolling is carried out above RCT and cold rolling is carried out below RCT.
Hot rolling is used to convert ingots to blooms and blooms to billets to slabs to plates, billets to bars, and billets to structural shapes. It is used for heavy or thick sections. Surface finish will be poor but the mechanical properties will be uniform.
Cold rolling is used for converting small sections plates to sheets to foils or bars to wires. Good surface finish is obtained with enhanced properties.

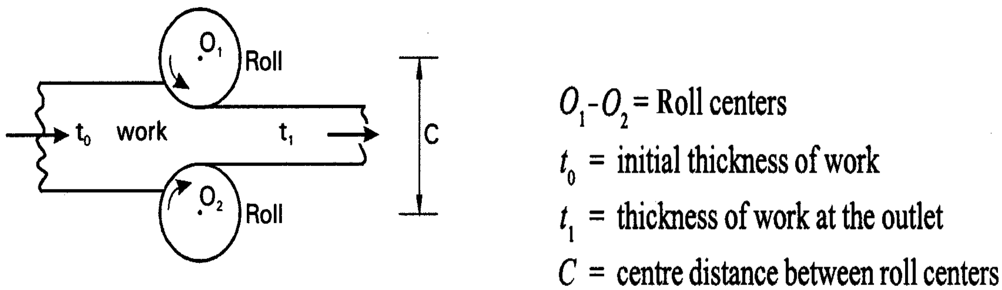
ii)Based on Roll arrangement

The minimum number of rolls required for rolling to take place is two and the higher end is dictated by the amount of reduction required, type of metal being rolled, configuration of the product etc., the rolls are cylindrical shaped. The arrangement of rolls could be:

*2 high roll mill- two rolls are used here.
*3 high roll mill- three rolls are used here.
*4 high roll mill- four rolls are used here.
*Cluster roll mill- a number of rolls are used in conjunction.
*Planetary roll mill- rolls are arrangement in the form of planetary movement.
*Tandem roll mill- continuous arrangement of rolls are used for continuous rolling.
*Sendizmer roll mill-similar to a cluster mill but large number of rolls are used.
Greatest reduction in the material is obtained.
All these arrangement are discussed below:
The term "mill" is generally used while referring to while referring to the type of rolling process. It signifies the station involving the arrangement of rolls contributing for rolling and type of rolling operation carried out. The term "high" signifies that the rolls are placed above the ground level.
As already discussed the starting raw material is the ingot. Ingot is rolled to blooms- billets-rods-wires in the first route.
In the second route Ingot-bloom-slab-plate-sheet-foil is obtained.
In the third route Ingot-bloom-structural configuration like I, U, V etc, is obtained.

Two high mill

It consists of two rolls located one above the other with their centers in vertical plane. A controlled opening or gap is provided between the rolls. This gap represents the required thickness of the product. The rolls are cylindrical and mounted on bearings. They are driven by motor and rotate in opposite directions as shown.
The rolling direction can be changed by changing the direction of rotation of the rolls. The center distance between the rolls (C) can be changed to change the roll gap to vary the thickness of the product. This is mainly used for producing blooms and billets.

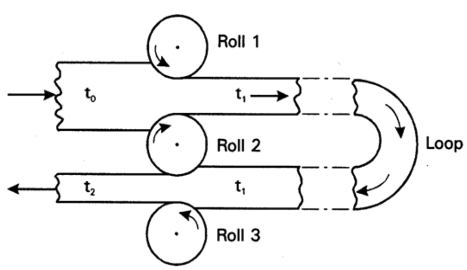


Two high mill

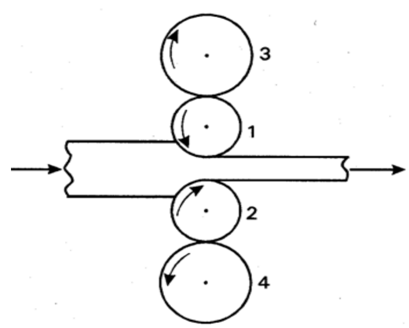
Three high mill

The arrangement consists of three rolls located one above the other, with their centers in a vertical plane. Outer rolls will be rotating in one direction and the center one will be rotating in the opposite direction. Here two passes of the work is possible unlike one pass in two roll mill. Work piece is fed between the gap of top set of rolls and its thickness is reduced. The out put of this is fed into the gap between the bottom set of rolls. One reduction in thickness of the work piece is obtained. Thus rolling will take place in both directions. Since the out put of one is taken and fed into the second set of rolls, the work forms a loop as shown. Hence, it is also named as looping mill. The mill has higher out put. Gap between roll1 and roll2= t_1 and between roll2 and roll3=t_2.

Where $t_1 > t_2$



Three high mill



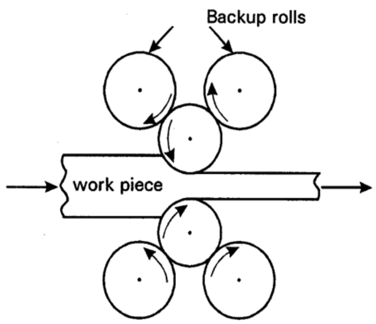
Four high mill

Four high mill

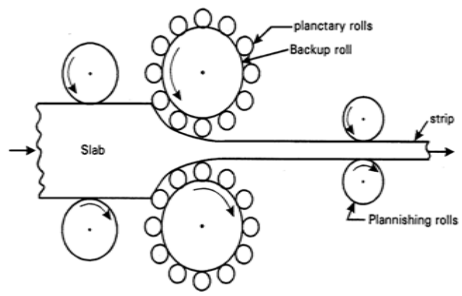
Here four rolls are used. Two smaller form the main rolls and come in contact with the work piece and cause deformation. These rolls are backed up by larger diameter rolls. Thus the mill is more rigid and can be used for higher reductions in the work. Back up rolls prevent roll deflection.

Cluster Mill

Here the main rolls are small and are backed up by two sets of rolls on each side. Higher rigidity and stability is imparted to the mill. Higher reductions are possible. Better deformation will take place.



Cluster Mill



Planetary Mill

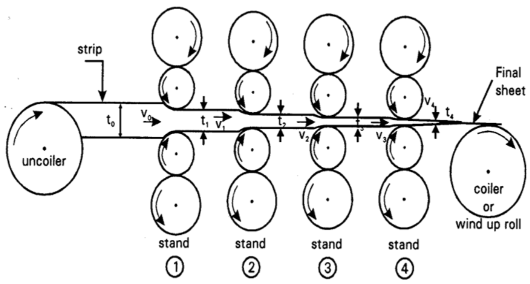
Planetary Mill

Here the large roll has very small rolls located along the circumference. A number of them will be arranged on each roll of a virtually two high roll mill. The arrangement looks like planets on the rolls. Hence, the name planetary mill. In fact the small rolls come in contact with the work piece and the big roll act as back up roll. Higher reduction of the order 25:1 is possible in one pass. The mill provides forging action as well as rolling action at the same time.

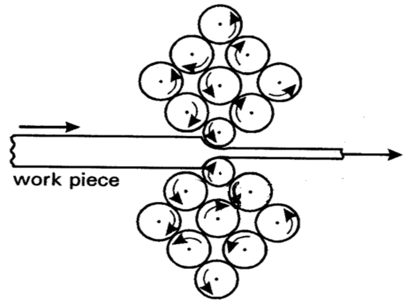
There will be two high mill at the beginning feeding the work piece to the planetary mill. At the out let end there will be another set of two high mill to take the out coming work. This arrangement provides roll tension at the beginning and at the out let. The mill is mainly used for converting slab to sheet or strip.

Tandem Mill

A series of four high mills are used one after the other. The work piece passes through each one of them. Reduction in the thickness will take place at each point. Each one of the mill is referred to as stand. There may be as many stands as necessary. This arrangement is referred to as "Tandem Mill". Continuous reduction will take place at each stand. There will be coiler and uncoiler which provides winding up of the work at the out let end and act as feed roll by releasing the work piece. Normally this arrangement is used for converting thick sheet to very thin sheet. Normally a cold rolling mill. Coiler and uncoiler provide the necessary tension in the work piece. Very smooth and good surface is obtained in the work piece.



Tandem Mill



Sendizmer Mill

Sendizmer Mill

It is basically a cluster mill. It is used to produce thin sheets and foils. Very strong metals can be rolled very easily. Basically a cold rolling mill. Stainless steels, Alloy steels etc., can be rolled easily. Very high reduction ratio is obtained.

Unit4 (Class11) Rolling

What was learnt in the last class

- Introduction to Rolling
- Concept of Rolling.
- Steps in rolling process
- Classification of rolling process- based on temperature, roll arrangement and product.

Today's Portion

- Classification based on the products rolled.
- Difference between Hot rolling and Cold rolling.
- Metal Flow Pattern in Rolling.
- Necessary condition for Rolling.
- Geometric Relationship in Rolling.
- Expression for angle of bite.
- Length of Deformation Zone.
- Max. Draft or Reduction in Rolling.
- Roll Separating Forces.
- Roll Camber.

iii)Based on the product

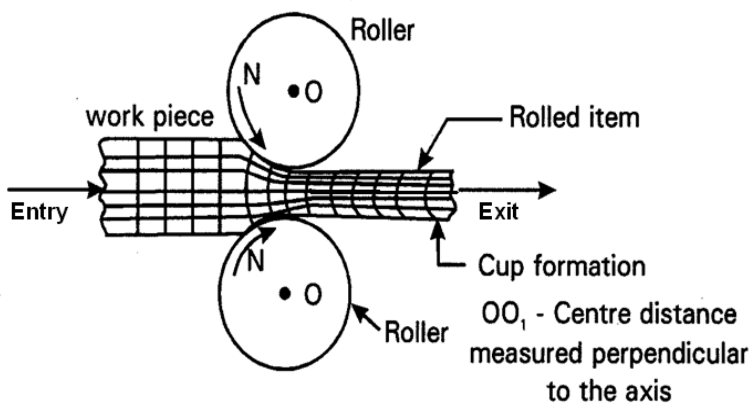
- Blooming Mill- Here only blooms are produced from the Ingot. Blooms will have a dimension of approx.150x150mm.
- Billet Mill- Here Billets are produced from Blooms. Billet will have a dimension of approx. 100x100mm.
- Rod/Bar Mill - Here bars or rods are produced from billets. Bar will have a dimension of 40x40mm.
- Slab Mill- Here slab is produced from the bloom. t>b and b=100mm
- Plate Mill- Here plate is produced from the slab. t>4mm.
- Sheet Mill – Here sheet is produced from plate. t<4mm.
- Structural Mill- Here structural shapes like I, U,L or channel sections are produced.

Metal flow pattern in Rolling

When the metal is rolled it is seen that the outer surface of the metal is deformed to a greater extent. This is due to the fact that the metal will be in direct contact with the roll surface. The frictional forces will be dragging it in the direction of rolling. The center portion of the metal is not at all deformed as it is free from any contact with the roll surface.

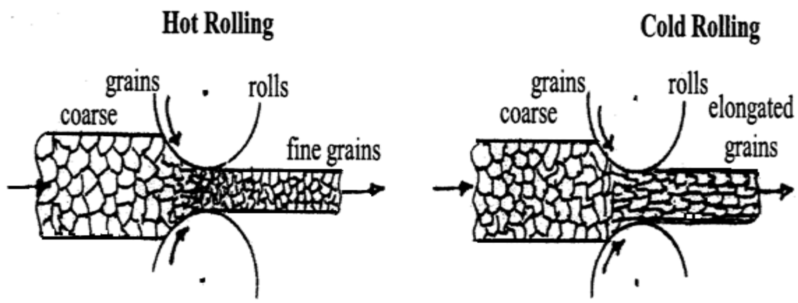
To study the effect of rolling on the deformation process grid markings are made in the vertical and horizontal directions. The deformation pattern is observed after rolling. It is observed that

distance between the horizontal grids decreases and they come closer. The distance between the vertical grids increases and are bent forward in the direction of rolling.
The velocity of the work piece as it leaves the rolls is greater than the circumferential velocity of the rolls due to stretching of the layers.
Thickness of the work piece is reduced and the length is increased as it passes out of the roll gap.



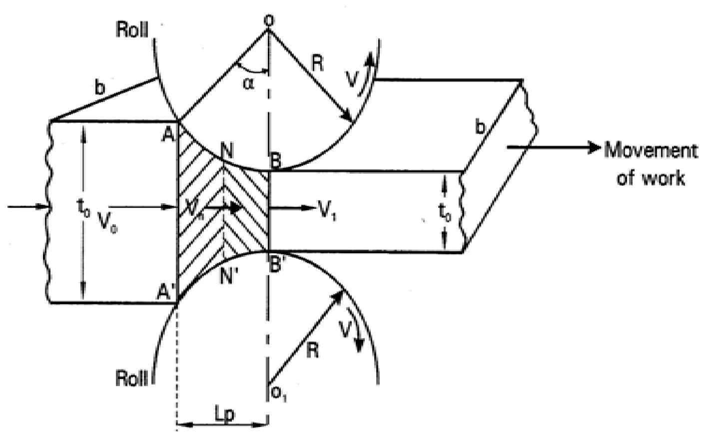
Difference between Hot rolling and Cold rolling.

Hot Rolling	Cold Rolling
Is Carried out above RCT	Is Carried out below RCT
Grain will be uniform even after rolling.	Grains will be elongated after rolling.
Surface finish will be poor.	Surface finish will be good.
Semi finished products like Blooms, Billets are produced. Structural shapes are also produced.	*Finished items like plates, flats, sheets and foils are produced.*
Load required for deformation is less.	Load required for deformation is more.



Difference between Hot rolling and Cold rolling.

Geometric Relationships in Rolling



NN'B'B is the leading zone $V_1 > V_0$.
As the metal is drawn between the rolls, it is compressed vertically due to friction, starting at AA'.This is translated into elongation in the direction of rolling.
There exists relative sliding between the roll surface and the work piece.
Volume rate of the metal flow is constant. ie., the volume of the metal passing through a point is constant per unit time.
Since there is no lateral spread b=constant

$$V_0 t_0 b = V_1 t_1 b$$

$$V_1 = V_0\{ t_0 / t_1 \}$$

Therefore V1 is > V_0 as $t_0 > t_1$

Similarly $V_n > V_0$ and $V_1 > V_n > V_0$

Phenomenon of Slip

Due to the variation in the velocities of roll surface and work surface there will be relative motion between them.
This relative motion between the roll and the work piece is referred to as slip.
There will be this slip taking place at the front and the back of the rolls. They are;

Backward slip = $(V_n - V_0)/ V_n$

Forward slip = $(V_1 – V_n)/ V_1$

The velocity of the work piece increases steadily from entrance to the exit.
At one point along the contact surface of the roll and work, the surface velocity of the roll will be equal to the velocity of the work.

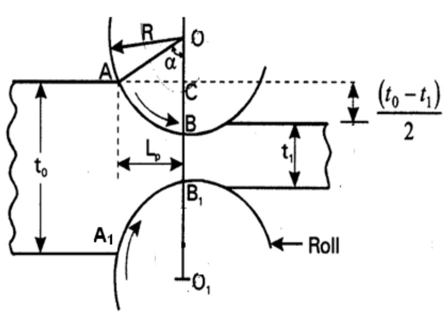
This point is referred to as “Neutral point” or “No Slip Point”.

Volume rate of
Deformation = (Volume of work)/(Time taken for deformation)

= $\{b\ (t_0-t_1)Lp\}/ T$

Where b= Width of the work
(t_0-t_1)=thickness of metal deformed
Lp =Length of work
T = time taken for deformation

Expression for Angle of bite



From Δ^{le}AOC $\cos\alpha = \dfrac{OC}{OA} = \dfrac{OB-BC}{OA}$

$$= \frac{R-(t_0-t_1)/2}{R}$$

R = Radius of the roll

$$BC = \frac{1}{2}(t_0 - t_1)$$

$$= \frac{\Delta t}{2}$$

$$\therefore \cos\alpha = 1 - \frac{\Delta t}{2R}$$

if R is more α is less
if R is less α is more for a given 'Δt'
Hence, R must be small to increase the arc of contact.

from the equation

$$\cos\alpha = 1 - \frac{\Delta t}{2R}$$

$$\text{or } (1 - \cos\alpha) = \frac{\Delta t}{2R}$$

$$2\sin^2 \alpha/2 = \frac{\Delta t}{2R} \qquad \cos^2\alpha = 1 - 2\sin^2 \alpha/2$$

$$\text{ie. } \sin \alpha/2 = \sqrt{\frac{\Delta t}{4R}} \qquad \text{ie., } 1 - \cos^2\alpha = 2\sin^2 \alpha/2$$

Length of Deformation Zone

From Δ^{le}OAC, $\frac{AC}{AO} = \sin\alpha$

$AC = AO \sin\alpha$ ·····(1)

$\therefore L_p = R\sin\alpha$

$AC = L_p$ = Length of deformation zone
or Length of projection of arc of contact

$AO = R$ = radius of roll

we know $\sin\alpha = (1 - \cos^2\alpha)^{1/2}$

Substituting for $\sin\alpha$ in the equation (1) we get

$$L_p = R\left[(1 - \cos^2\alpha)\right]^{1/2}$$

Substituting for $\cos\alpha = 1 - \frac{\Delta t}{2R}$

$$L_p = R\left[1-\left(1-\frac{\Delta t}{2R}\right)^2\right]^{\frac{1}{2}}$$

Now Expanding $\left(1-\frac{\Delta t}{2R}\right)^2$ equation 4.21 become

$$L_p = R\left[1-\left(1-2.\frac{\Delta t}{2R}+\left(\frac{\Delta t}{2R}\right)^2\right)\right]^{1/2} \text{ Leaving higher terms}$$

$$= R\left[\frac{\Delta t}{R}-\frac{\Delta t^2}{4R^2}\right]^{1/2}$$

$$= \left[R^2.\frac{\Delta t}{R}-R^2.\frac{\Delta t^2}{4R^2}\right]^{1/2}$$

$$\therefore L_p = \left[R.\Delta t-\frac{\Delta t^2}{4}\right]^{1/2}$$

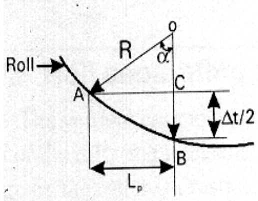
$$\text{or } \boldsymbol{L_p = \sqrt{R.\Delta t-\frac{\Delta t^2}{4}}}$$

$\left(\frac{\Delta t}{2}\right)$ is << $R.\ \Delta t$ $\quad\therefore \left(\frac{\Delta t}{2}\right)^2 = \frac{\Delta t^2}{4}$ can be neglected

$\therefore$ we get $\boldsymbol{L_p = \sqrt{R.\Delta t}}$.

Maximum Draft

From Δ^{le} OAC, $\quad \tan\alpha = \frac{AC}{OC}$ Radius of the roll $OA = OB = R$



$$= \frac{L_p}{OC}$$

but $L_p = \sqrt{R.\Delta t}$ from 4.23

$OC = OB - BC$ from geometry $OB = R$

$$= R - \Delta t/2$$

$$\therefore \tan\alpha = \frac{\sqrt{R.\Delta t}}{R - \Delta ½} \quad ......(A)$$

$\frac{\Delta t}{2}$ is small $\therefore$ can be neglected

$\therefore$ equation.(A) becomes

$$\tan\alpha = \frac{\sqrt{R.\Delta t}}{R}$$

$$\therefore \mu = \sqrt{\frac{\Delta t}{R}} \quad \because \text{but } \tan\alpha = \mu \quad \text{coeff. of friction}$$

$$\text{or } \mu^2 = \frac{\Delta t}{R}$$

$\therefore$ Maximum draft

or $(\Delta t)_{max} = \mu^2 R$ but $\mu > \tan a$ for rolling

Limiting thickness of the workpiece that can be rolled depends on

i) Coeff of friction (μ)

ii) Radius of the roll (R)

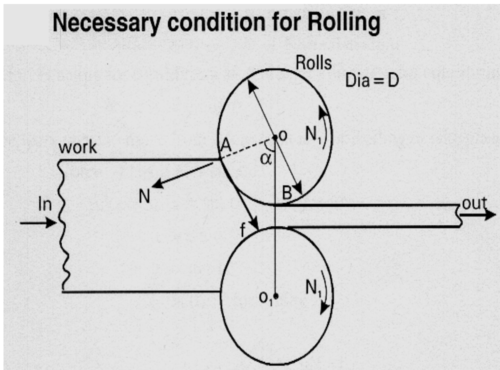
iii) Flow stress of the metal (σ_t)

iv) Inversely as elastic modulus of the rolls (E)

Limiting thickness is proportional to $\left(\frac{\mu R \sigma_t}{E}\right)$

- Larger diameter rolls and higher coeff of friction allow heavy draft (or higher deformation is possible)
- It is possible to roll with greater draft if the work is pushed into the rolls
- The work is accelerated prior to biting in order to make use of force of inertia.
- If the friction is too high the load becomes excessive

Necessary Condition for Rolling



α = angle of bite or angle of contact

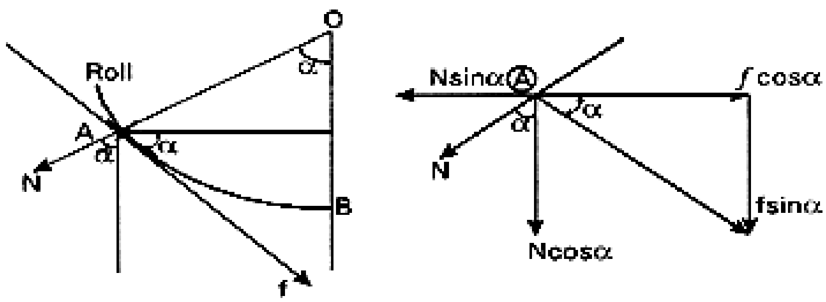
$\widehat{AB}$ = Arc of contact

N_1 = Speed of rotation of the rolls

$2R = D$ = Dia of the rolls

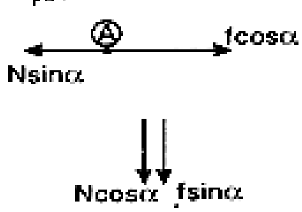
A = Point of contact at the entry

B = Point of contact at the exit.



(b) Resolution of forces

f = friction force = μN



(C) component of forces

μ = Coefficient of friction

N = Normal reaction

equating forces acting for equilibrium at A along x - direction for equilibrium, we get

$$N \sin \alpha = f \cos \alpha$$

but for the work piece to move from left to right ie., for Rolling to take place,

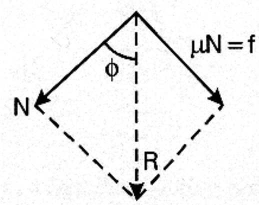
force $f \cos \alpha > N \sin \alpha$

ie. $\mu N \cos \alpha > N \sin \alpha$ as $f = \mu N$

$$\mu > \tan \alpha$$

$$\tan \phi > \tan \alpha$$

or $\phi > \alpha$ for rolling



ϕ = angle of friction

$$\frac{\mu N}{N} = \tan \phi \text{ ---- from fig.}$$

$$\mu = \tan \phi$$

if $\mu = 0$ $\tan \phi = 0$

∴ No rolling takes place

for increasing the value of friction grooves must be cut on the rolls.

∴ angle of friction (ϕ) must be greater than the angle of bite (α) for rolling.

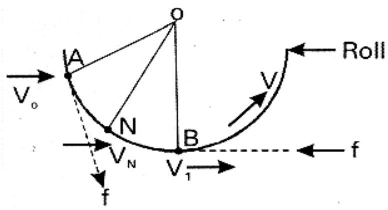
α = 24 - 30° (max) for blooms / billets

α = 15 - 20° for rolling of sheets & strips

α = 2 - 10° for cold rolling of sheets & foils

Grooves are cut on the rolls surfaces to increase friction.

Variation of Friction in Rolling



A = Entry Point
B = Exit Point
Velocities
$V_1 > V_N > V_O$

Friction force variation

Between surface AN, the work piece is moving slower than the roller and hence the friction force, act from A to N.

$$V_0 > V$$

This pushes the work into the roll gap.

At point N the velocities of work and roll are the same

$$V_N = V$$

Between surface NB, the work piece is moving faster than the roller, hence the friction force act in the direction from B to N.

This tend to retard the movement of the work piece.

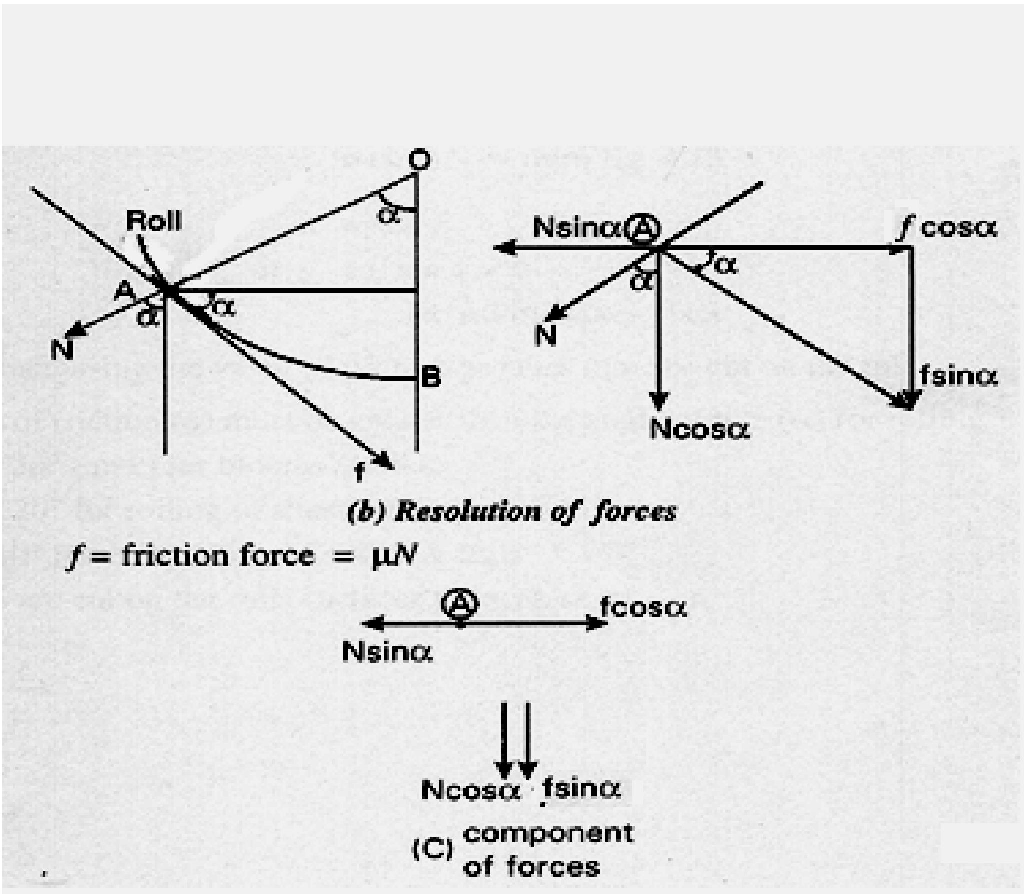
at point B, velocity $\quad V_1 > V$

Unit4 (Class12) Rolling

Rolling Separating Force

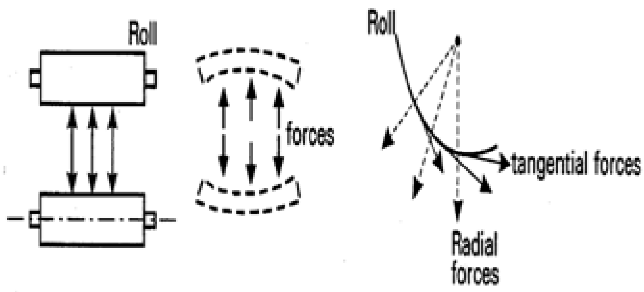
The vertical components of the forces N and f i.e. The total sum of NCosα and fSinα acting perpendicular to the axis of the roll has a tendency to push the roller from its horizontal position. This will make the roller to undergo deformation in the vertical direction. The roller will bend into an arc of a circle. And the metal rolled between such a roll will not be plane and horizontal.

The sum of $\sum(NCos\alpha + fSin\alpha)$ is called as "Roll Separating Forces". These forces tend to separate the position of the rolls.



The sum of $\sum(N\cos\alpha + f\sin\alpha)$ is called the Roll separating forces.

The forces tend to separate the position of the rolls.



If P = Rolling load

A = Contact area between Surface of the roll & work

Then specific roll pressure p is given by

$$p = P/A$$

but A = Product of width 'b' of the work & the projected length of the are of contact 'L_p'

$$A = b.L_p$$

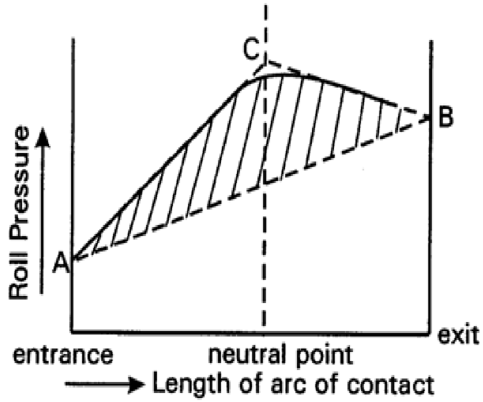
$$\therefore p = \frac{P}{b.L_P}$$

$$\text{Roll pressure} = \frac{P}{b.\sqrt{R.\Delta t}}$$

Rolling load is the force which the rolls exert on the metal. This is resisted (opposed) by the metal surface.

The roll pressure varies gradually and reaches a maximum value corresponding to the neutral point and then falls off.

Variation of Roll Pressure Vs Length of Arc of contact

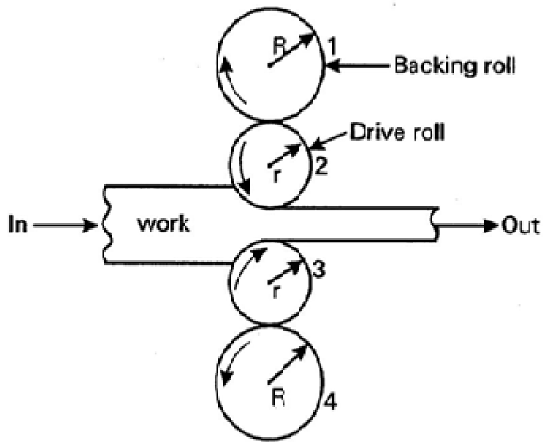


Distribution of Roll pressure

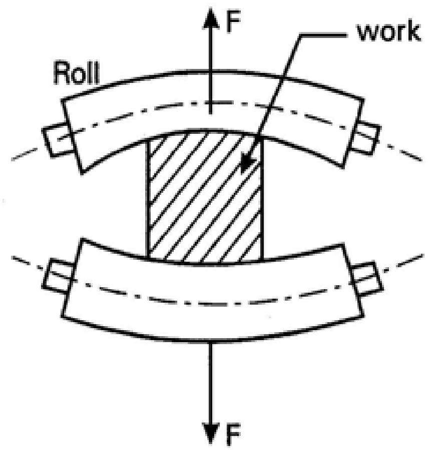
No sharp peak is observed at the neutral point suggesting that a surface exists instead of a contact point at the neutral point.Area under the curve ABC is proportional to the rolling load.Area under AB represents force required to deform the metal in plane homogeneous compression.Shaded area represents force required to overcome the frictional force between the roll and the work.

Roll Camber

For a given reduction in thickness of the work piece the roll separating force (influencing roll bending) increases linearly with roll radius. Forces will be set up along the length of the roll and try to separate the rolls and deflect. As already discussed roll separating force is the summation of the vertical force components. Hence to reduce the deflection due to bending in the rolls, the diameter of the rolls is to be kept to a minimum. A more economical way to reduce the deflection is to use back up rolls with larger radius to increase the rigidity. The radius of the back up rolls 'R' will be greater than the radius 'r' of drive roll.

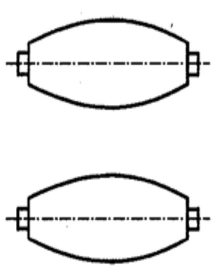


shows the arrangement of Backup rolls

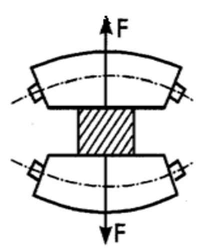


Flat rolls undergoing deformation

However, roll bending cannot be avoided completely. But by providing convex contour on the surface of the rolls along the length this can be taken care of.



Rolls with convex surface ie. camber before rolling



Camber rolls after deflection experiencing roll separating force

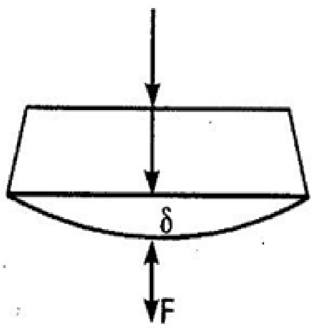
The convex contour provided on the rolls is called "Roll Camber".
Without Roll Camber the thickness of the work piece is more at the centre than at the ends. But with Roll Camber, uniform thickness is maintained across the width of the work.

Considering the rolls as thick, short beam and simply supported at the ends, the deflection at the center of the rolls can be expressed as

$$\delta = K_1 (FL^3/EI) + K_2 (FL/GA)$$

Where F = Roll separating force
L = Length of each roll
I = MI of the roll cross section about a diameter

A = Area of CS of rolls
E = Young's Modulus of the material of the roll
G = Rigidity Modulus of the material of the roll
K_1 and K_2 = Factors to account for the nature of load Distribution



Deflection of the roll

Roll Pressure

$$\text{Roll pressure} = \frac{\text{Rolling load}}{\text{Projected area}} = \frac{P}{b.L_P} = \frac{P}{b.\sqrt{R.\Delta t}}$$

$$\text{Roll force} = 2\sigma_f\, L.b\left[0.8 + \frac{L}{4t_2}\right] \quad \text{(Emperical)}$$

where L = distance between entry plane and exit plane.
b = Width of the bar being rolled
t_1 = thickness of bar at exit plane
σ_f = flow shear stress of material

The Main Parameters in Rolling

The parameters are:

1. Roll diameter
2. Friction between rolls and work piece
3. Deformation resistance of the metal as influenced by metallurgy, temperature and strain rate
4. Presence of roll tensions
5.

Roll Diameter:

*Rolling load increases with roll diameter at a rate greater than $D^{1/2}$
We know Rolling load $P = p.b.\sqrt{R.\Delta t}$
Substitute for $R=D/2$
$P = p.b.\sqrt{D/2.\Delta t}$
or $P \,\alpha \sqrt{D}$
*As roll diameter decreases both rolling load and length of arc of contact decreases.
*Small diameter rolls supported by large back up rolls can produce greater reduction and keep the work flat.

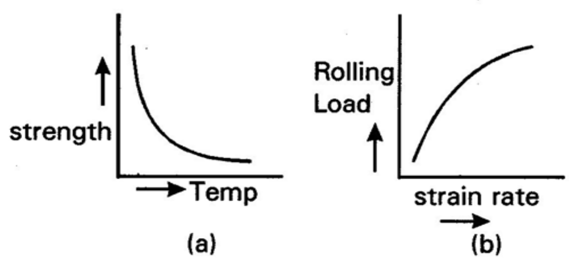
Friction:

*Frictional force is needed to pull the metal into the rolls.
*Large fraction of rolling load comes from the frictional force.

*Friction varies from point to point along the arc of contact of the roll, it will be acting from entry to neutral point long the direction of roll rotation and from neutral point to exit point it will be opposing the direction of roll rotation.
* High friction results in high rolling load and a steep friction hill will be realized.
*Since it is very difficult to measure the variation in coefficient of friction 'μ' it is assumed that 'μ' is constant. For cold rolling it is taken as 0.05-0.1 and for hot rolling it is taken as >= 0.2.
*Coeff.of friction is inversely proportional to the rolling speed. As μ decreases rolling speed increases. From $F= \mu/N \quad \mu = F/N$
*Thinner gage sheet can be produced in cold rolling as coeff.of friction is smaller.

Deformation resistance of metal:

Deformation resistance indicate how much a given metal offers resistance to deformation. Deformation resistance is the resistance offered by the metal for external load. Higher the deformation resistance higher is the difficulty to deform.
Coarser grains in the metal offer less resistance for deformation and vice versa. Higher the dislocation density higher is the deformation resistance. Higher the working temperature lesser is the deformation resistance.

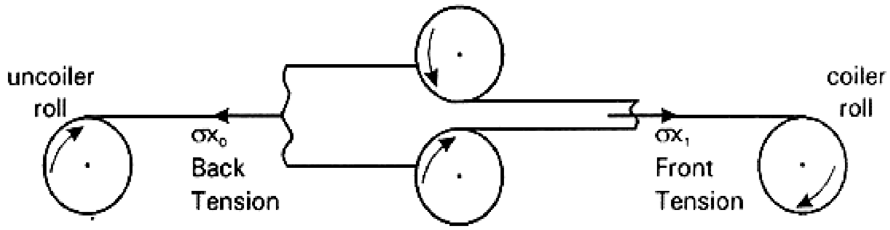


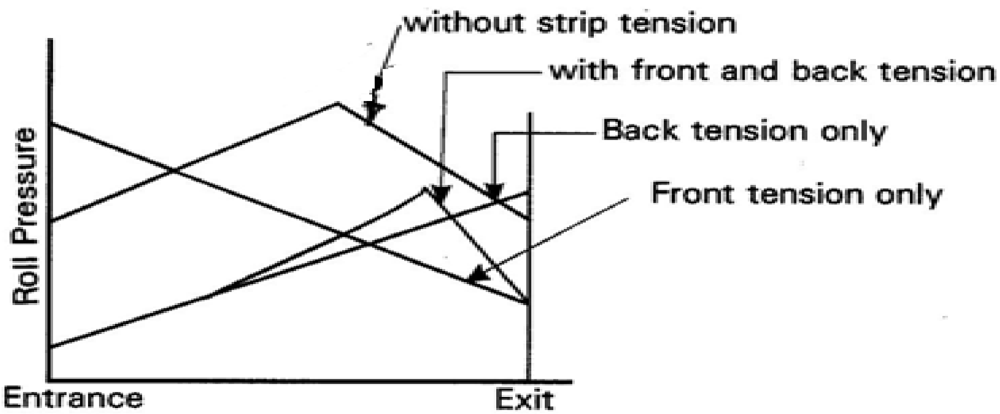
a) Effect of Temp on strength
b) Effect of strain rate on rolling load

Strip Tension:

The presence of tension in the plane of the sheet can reduce the rolling load.
Front tension can be controlled by the coiler where as back tension can be created by controlling the speed of the uncoiler relative to the roll speed.
Tension reduces wear of the rolls. Improves flatness in the sheet, induces uniform thickness across the width of the sheet.
Tension is used to shift the neutral point towards the exit plane. Proper back tension is achieved when the exit velocity V_1 of the sheet is equal to the surface velocity V of the roll. When forward slip $S_f = [V_1\text{-}V/V] = 0$, the required condition is achieved.
Back tension is about twice effective in reducing the load as compared to front tension.
Both front and back tension reduces the area under the curve. Slight shift in the neutral point towards the exit plane is observed.With only back tension, the neutral point moves towards the exit plane.

If a high enough back tension is applied, the neutral point eventually reaches the roll exit. At this point the rolls are moving faster than the work.
If only front tension is used the neutral point will move towards the roll entrance.



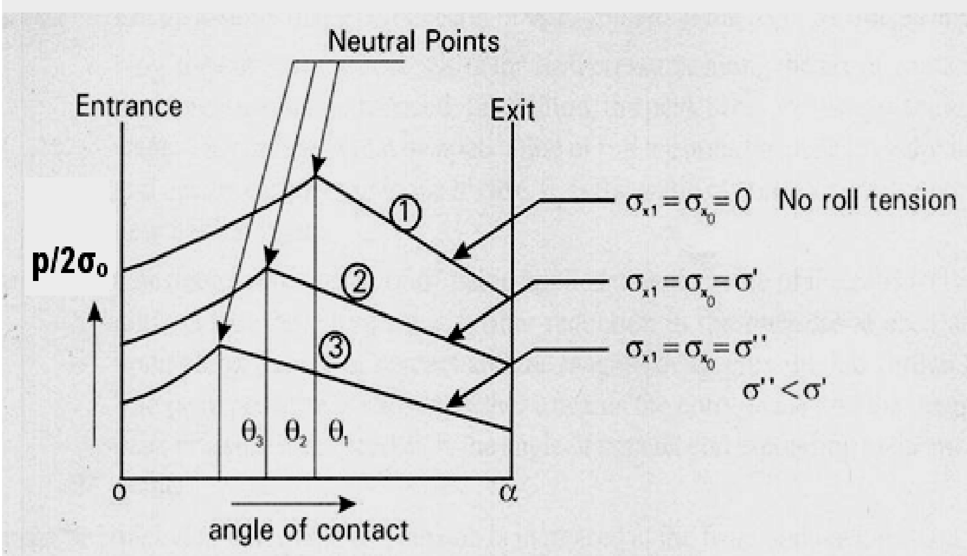


Variation of Roll Pressure

Pressure Distribution in Rolling:

The roll pressure 'p' increases continuously from the entry to the neutral point there after it decreases continuously.
The peak pressure at the neutral point is normally called as the "Friction Hill".
This peak pressure increases with increasing coefficient of friction.
The work piece may be subjected to forward pull by using a coiler. By this arrangement front tension is applied to the work piece. The velocity of the coiler is more than the velocity of the rolls.

This tension is σ_{xi} .
Again the work piece may be subjected to backward pull by using a unwinder. This unwinder will be rotating and releasing the work piece into the roll gaps. The velocity of rotation of the uncoiler will be less than the velocity of the rolls. Due to this, the work piece is pulled back and results in the creation of back pull or back tension. This tension is σ_{xo} .
Consider the graph shown in the figures showing the arrangements of roll tension.



Pressure distribution in Rolling

Curve1: The variation of roll pressure from the entrance to the exit plane is shown.
It can be observed that the pressure increases along the arc of contact and reaches maximum at the neutral point and later decreases towards the exit plane. θ_1 is the angle of contact at which then neutral point is present.
No roll tensions are applied $\sigma_{x1} = \sigma_{xo} = 0$.
The peak pressure obtained is the highest.

Curve2: Assume a roll tension of σ' is applied at the front as well as at the back. Now the curve show decrease in the roll pressure along the arc of contact and the peak pressure is also reduced. In addition, the peak pressure takes place at an early stage. This indicates that by application of roll tensions the peak pressure is reduced and occurs earlier than in the Curve1. θ_2 is the angle of contact corresponding to the new neutral point.

Curve3: Consider a roll tension of σ'' being applied on either side of the rolls (σ''> σ'), it is noticed that the curve show further reduction in the pressure at each and every point along the arc of contact and the magnitude of pressure has further reduced. The peak pressure is shifted towards the entry plane and the magnitude of peak pressure is reduced. θ_3 Is the angle of contact corresponding to the new neutral point.

It can be concluded that as the roll tension is increased at the front and back the roll pressure can be reduced along the arc of contact. Peak pressure is reduced and shifted towards the entry side. As a result the load required for rolling gets reduced.

Unit 4 (Class13) Rolling

Power in Rolling

Power is applied to the rolling mill by applying Torque to the rolls and by using roll strip tension.The total rolling load is distributed over the arc of contact. However, the total rolling load can be assumed to be concentrated at point along the arc of contact ata distance 'a' from the line of centers of the rolls.

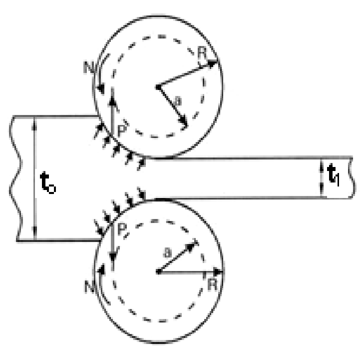
The ratio $\lambda = [\ a/L_p] = [a/\sqrt{R.\Delta t}]$ is used to calculate the moment arm 'a'

λ =0.5 for hot rolling and 0.45 for cold rolling.

The torque is equal to the product of total rolling load and the effective moment arm.

Since there are two work rolls Torque $M_t = 2P.a$

Consider two high roll mill as shown in the figure. For one revolution of the top roll the resultant rolling load P moves along the circumference of a circle equal to $2\pi.a$



Since there are two work rolls involved, the work done is equal to Work done =2 (2.π.a).P = 4P.π.a

If N is the speed of rotation of the rolls then

Power = Work done/sec= 4P.π.a.N/60

Ie. Power= (4P.π.a.N/60x1000) Kw

Where P=Load in Newton, a=moment arm in meters and
N=speed rollers
This gives the power required for deformation of metal only.

Power Distribution:

The power in rolling process is expended principally in four ways:
1. The energy required to deform the metal.
2. The energy required to over come frictional force in bearings.
3. The energy lost in power transmission system.
4. The energy lost in the form of electrical losses in the motor etc.,

Torque and Power in Cold Rolling

*Power is applied to the rolling mill by applying Torque to the rolls and by using roll strip tension.*The total rolling load is distributed over the arc of contact.

*However, the total rolling load can be assumed to be concentrated at a point along the arc of contact at distance 'a' from the line of centers of the rolls.

Power Loss in Bearings

Due to friction in the bearings that support the rolls, there will be some power loss.

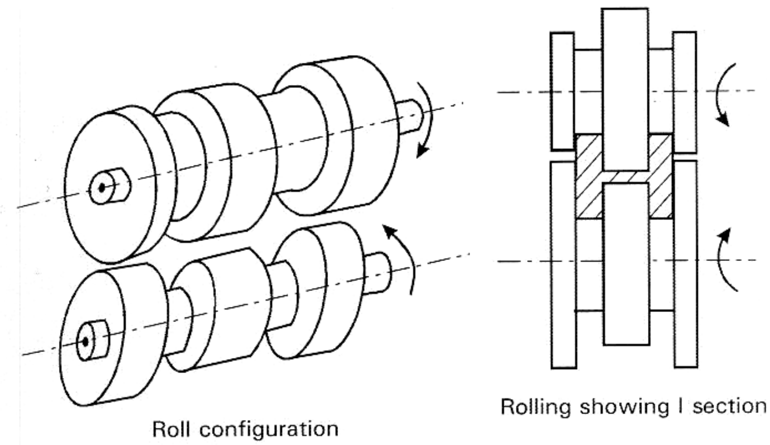
Since exact estimation of power loss in bearings is too complicated, approximate power loss estimation is done as shown.

Power loss in each bearings is given by:

$P_{bearing} = \frac{1}{2} \mu . F_b . d . \omega$

where μ= Coefficient of friction in the bearings
(typical values lies in the range 0.002-0.01)
F_b=Radial load for each bearing
=(1/2)x Roll separating force
=(1/2) x F(assuming rolls being supported on two bearings)
d=diameter of the bearing
ω=angular speed

Structural shapes such as I,L,U,V ..etc., are produced by hot rolling process using grooved or contoured rolls.



Rolling of I section

Usually 2 or 3 high mills are used for the purpose.
Reduction is carried out at several roll stands.
A tandem mill used for the purpose.
The design of roll pass is extremely complex and lot of experience is required for the purpose. The contoured rolls will have half the shape of the section on each roll pairs. When assembled in the mill complete cross section is obtained. To control the lateral spread of the work it is turned through 90^0 after each pass before entering the next roll. The work passes through a series of such grooved rolls till the final size and shape is obtained. Grooves provide increased friction and large reduction in a short time is obtained effectively. The rolling of bars and other shapes is done in two directions ie., the CS is reduced in two directions by rotating by 90^0 between each rolling. Whereas rolling of strip and sheet is carried out in one direction ie., rolling is done without rotating the work piece.

Unit4 (Class14) Rolling

Defects in Metal Working Process

Defects in the Final Product of Mechanically worked metal may have originated from any one or a combination of the following:The ingot used for MW may contain defects (pores, microcracks or inclusions) which may remain as such or get aggravated during working operation.

- Operational Parameters Localized to a particular type of MW process (not following the proper practice).

Defects in Rolled Products

a) General b) Operational

a) General

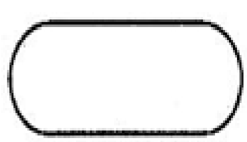
The defects may arise due to

i)Surface irregularities: The ingot or the raw material may be having irregularities due to scaling which will get trapped in the metal and remain inside the metal surface as laps. This needs to be removed by grinding and there will be metal loss. If the defect is deep and severe the product may get rejected.

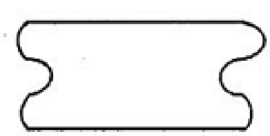
ii)Non-metallic inclusions: The inclusions may results from oxides or nitrides or silicates etc., especially in steels. These are present in the molten metal during the preparation. If less in volume may cause small cracks in the metal and if more in volume will result in severe cracks called crocodile cracks separating the product into two halves.

iii)Internal Pores: There may be pores in the product due to the presence of gases like hydrogen,oxygen,nitrogen etc., If too much gases are present leads to elongation of the pores and the product may become weaker. Sometimes separation may take place resulting in cracks.

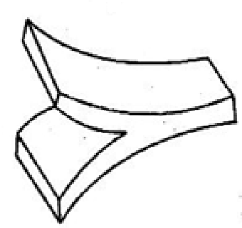
i)Barrel: Due to friction at the edges of the product barrel action takes place. Surface in contact experience severe friction as compared to center of the work. Hence, with heavy reduction in the work the center tends to expand laterally more than the outer surfaces in contact with the dies and produces barreled edges.



Barelling



Non uniform defomation



Alligator Cracks

ii) Non uniform deformation: When the rolling conditions a re such that only surface of the work piece is deformed. The cross section of the slab is deformed into the shape as shown.

The middle portion is less deformed as compared to the outer surface.

This may be due to variation in temperature in the metal. Surface temperature being more than the inside temperature of the slab.

iii) Alligator Cracks: If there is any metallurgical weakness in the metal (due to the presence of inclusions) along the centre line of the slab, fracture will occur. This results in the separation of the layer giving rise to opening of the slab which looks like an alligator mouth in opening position. Hence, the name.

Others:

i) **Hydrogen cracks:** During preparation of the melt in the furnace several gases tries to get into the melt. Out of this Hydrogen gas diffuses into the melt to a large extent and is retained in the solid metal. Due the presence of hydrogen in excess internal cracks appear through the cross section during rolling and cannot be used. It is a major problem with alloy steels especially.

ii) **Non metallic inclusion:** Inclusions are non metallics appearing in the metal as a result of entrapment. During the preparation of the molten metal non metallic like oxides, nitrides, silicates enter the melt and remain as such in the solid metal. These are discontinuities in the metal and reduce the properties of the metal. On rolling they may result in cracks which may reach a critical value and make the product rejectable.

Defects: Operational

i) Waviness..Varying thickness.

ii) Edge Cracking

i)Waviness..Varying thickness.

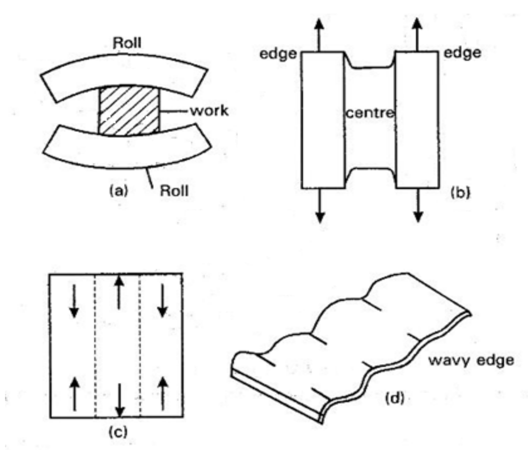
Variation in the work across the width in sheet rolling occurs because the roll gap is not perfectly parallel (a).

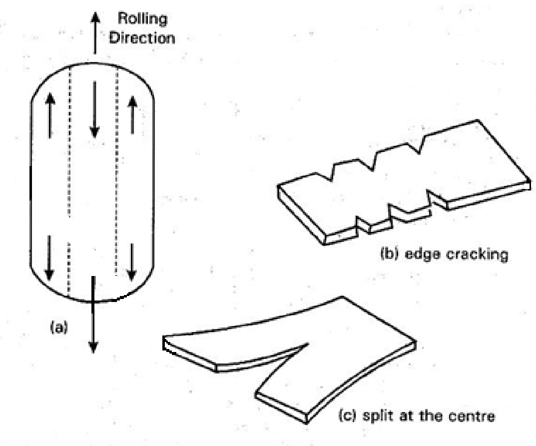
Since width and volume are constant and thickness is varying, the edges elongate more than the center (b).

But the sheet is a continuous body; the strains readjust to maintain continuity.

Thus the center portion is in tension and the edges are in compression (c).

The result is a wavy edge (d).





ii)Edge Cracking

The length of the center portion increases but the edges are prevented due to frictional force. As a result the material gets rounded off (a).

The edges are strained in tension leading to edge cracking along the width of the slab (b).

When the difference in the strains become excess i.e. under severe condition, split at the center of the slab occurs (c).

Numericals

Prob,1. Determine the max. possible reduction for cold rolling a 300mm thick slab when μ=0.08 and the roll diameter is 600mm.

i) $\Delta t)_{max}$= ? for cold rolling t=300mm

R=600/2 = 300mm

ii) for hot rolling $\Delta t)_{max}$= ?

iii)%reduction=?

i) Max.Possible reduction

i) Cold rolling

We know $\Delta t)_{max} = \mu^2 . R$

Substituting the values we get

$= (0.08)^2.(300)$

Max.Possible reduction = 1.92mm

ii) hot rolling

$\Delta t)_{max} = \mu^2.R$

$= (0.5)^2.(300)$

Max.Possible reduction = 75mm

ii) %reduction

Cold rolling= $(\Delta t/t).100$

$= (1.92/300).100$

$= 0.64\%$

Hot rolling = $(75/300).100$

$= 25\%$

Prob.2. If the max. reduction in rolling of slab is from 25 to 20 mm, calculate the value of coeff.friction. Take the roll diameter as 500mm. Also find the length of projection of arc of contact.

Given:

t_0 =25mm t_1=20mm 2R=500mm μ=? L_p=?
R=250mm

Max.reduction $\Delta t = 25-20 = 5$mm

From $\cos\alpha = (1 - \Delta t/2R)$

$= (1 - 5/500)$

$\cos\alpha = 0.99$

Angle of bite $\alpha = 8.11^0$

We know $\mu = \tan\alpha = \tan(8.11)$

Coeff.of friction μ=0.1425

Length of Projection of arc of contact L_p

$$L_p=\sqrt{(R.\ \Delta t)}$$

$$=\sqrt{(250)(5)}$$

$$L_p=35.35mm$$

Prob.3. If the coeff. Of friction in cold rolling is 0.08,determine the i) length of projection of arc of contact ii) the velocity of the slab at the exit
iii) specific roll pressure. Neglect lateral spread. Use the following data.

Width of the slab=b=80mm, Roll radius=800mm thickness of the slab=t_o=400mm, velocity of the slab at the entry=V_o=200mm/sec, Rolling load=P=14MN.

from $\Delta t)_{max}= \mu^2.R$

$$=(0.08)^2.(800)= 5.12mm$$

i)$L_p=\sqrt{(R.\ \Delta t_{max})} =\sqrt{(800)(5.12)}$=64mm

we need to calculate

thickness of the slab after rolling

$$\Delta t_{max}=(t_o-t_f)$$

$$5.12 = 400- t_f$$

$$t_f = 400-5.12 =394.88mm$$

ii) Specific roll pressure is given by

$$p= (P/b.\ L_p)$$
$$= (14x10^6/800.64) = 273.44\ N/mm2$$
$$= 273.44\ Mpa$$

iii)The velocity of the slab at the exit

we know for constant volume of the metal in rolling assuming constant width

$$bV_0t_0 = bV_ft_f$$

$$200(400)= V_f(394.88)$$

V_f = 202.593 mm

Prob.4. Aluminium strip of 400mm wide and 25 mm thick is rolled using a 1800mm dia. Roll at 250rpm. The thickness is reduced to 20mm. If λ is 0.5 for hot rolling and 0.45 for cold rolling, calculate the torque and power required to roll the metal. Take the specific roll pressure 250Mpa for hot rolling and 300 Mpa for cold rolling.

Given: b=400mm, R=D/2 =1800/2 =900mm

t_o=25mm, t_f=20mm, p=250Mpa (hot rolling) and p= 300Mpa (for cold rolling)

N=250rpm=(250/60), λ =0.5 for hot rolling

=0.45 for cold rolling

Torque M_t= ? Power =?

a=distance from the center of the roll where total rolling load is assumed to be concentrated.

We know

$\lambda = (a/L_p) = (a/\sqrt{R.\Delta t})$

$=a/\sqrt{900(25-20)}=a/(67.08)$

For hot rolling substitute λ =0.5

0.5= a/67.08

therefore a= 33.54mm

again $p= (P/b. L_p)$

250 = P/(400.33.54)

Rolling load=67080000N or 6.708 MN

Torque Mt = 2P.a

= 2(6.708)(33.54)/1000

= 0.45MNm

Work done = 2 (2.π.a).P = 4Pπ.a

= 4π(33.45)6.708/1000

= 2.83MNm

Power = Work done/sec=(4P.π.a)N/60

= (2.83x250)/60

$= 11.79MW$

For cold rolling $\lambda= a/(67.08)$

$0.45= a/67.08$

$a= 30.186mm$ or $0.030m$

again from $p= (P/b.\ L_p)$

$300= P/(400x67.08)$

$P= 8049600\ N\ =8.05MN$

Torque $M_t = 2P.a$

$=2x8.05x0.03=0.483\ MNm$

Work done= $4P\pi.a =4\pi(8.05)(0.03)$

$= 3.035\ MNm$

Power required = $(4P.\pi.a)N/60$

$= 3.035x\ 250/60$

$= 12.648MW$

Equations used in Rolling Process

i) Maximum draft $\Delta t)_{max}=\mu^2R$, $\mu=\tan\alpha$ and $\Delta t)_{max}=t_o-t_f$

ii) $\cos\alpha=1- \Delta t/2R$

iii)Length of arc of contact $Lp=\sqrt{R}.\ \Delta t$

iv)Specific Roll Pressure $p=P/b.Lp$

v)Constant Volume Rate , $bV_ot_o= bV_1t_1=$ constant

vi)Torque $M_t=2Pa$ $\lambda=a/Lp$

λ =0.50 hot rolling

=0.45 cold rolling

vii)Power required=$(2.2\pi a.P)N/60$

$=(4\pi a.P)(N/60)$

viii)Forward slip=$(V_1-V_n)/ V_1$

x)Backward slip=$(V_n-V_0)/ V_0$

xi)Volume rate of deformation is the ratio of volume of the work to the time for deformation

$=\{b(t_o- t_1) Lp\}/T$