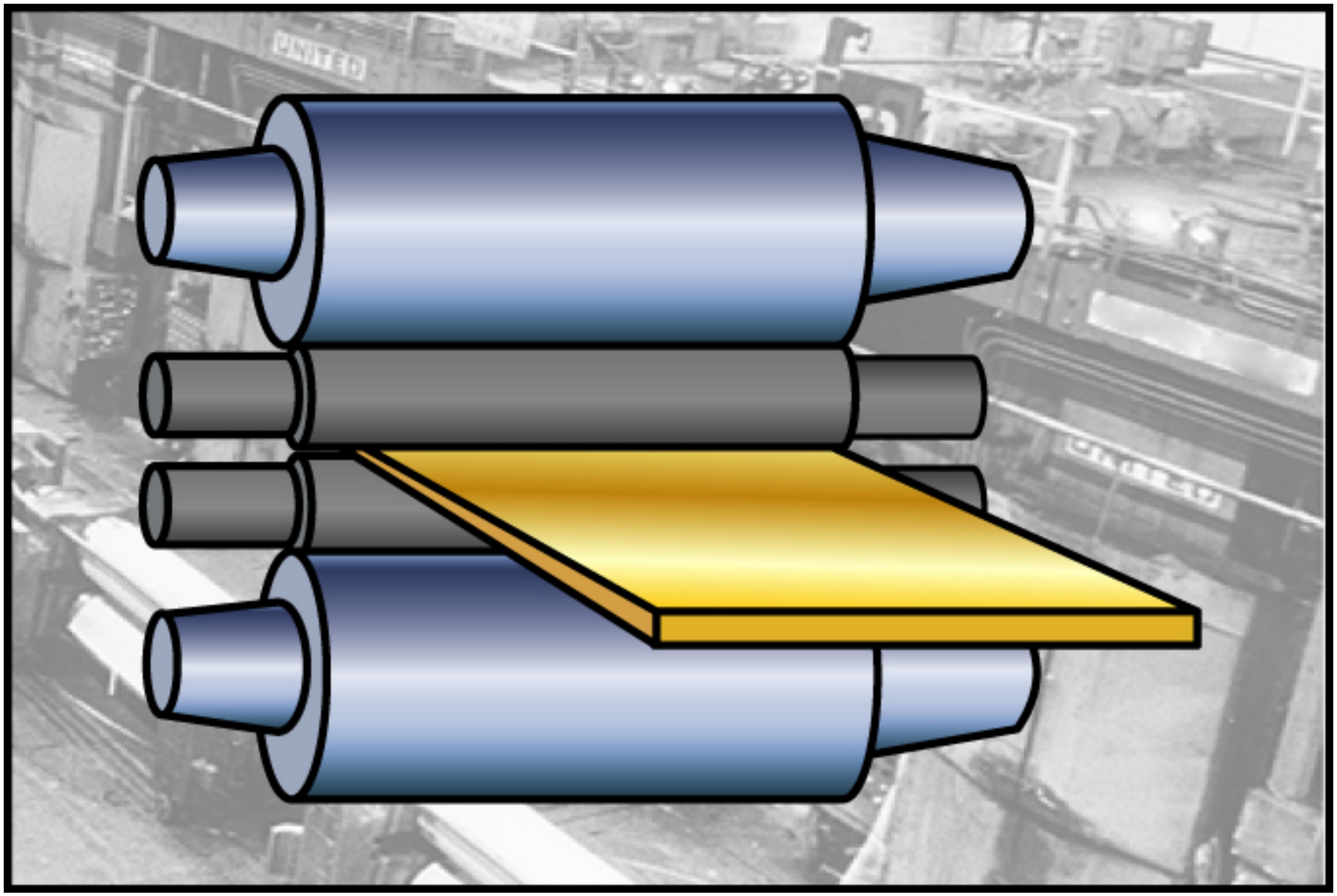
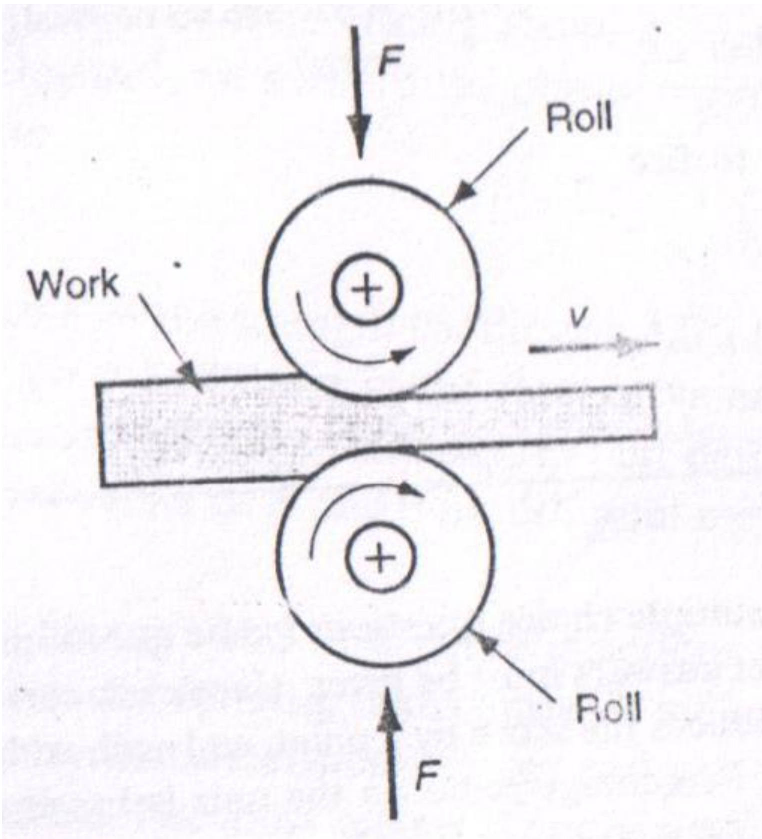
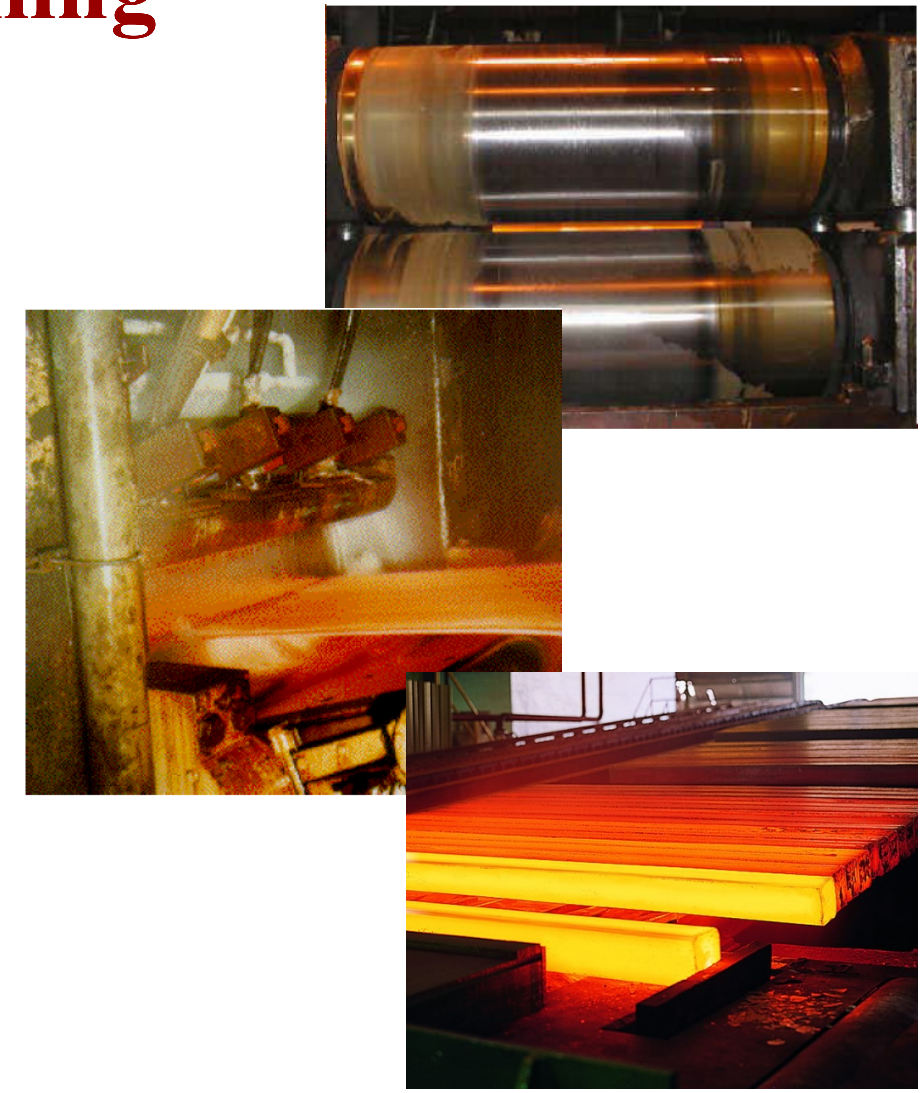
# Rolling Processes



# Rolling



- **About 75% of steel output is treated in rolling mill and about 25% is consumed for forging, extrusion etc.**
- **Both hot rolling & cold rolling**

# Introduction to Rolling

**Rolling** is a bulk deformation process in which the thickness of the work is reduced by compressive forces exerted by two opposing rolls. The rolls rotate to pull and simultaneously squeeze the work between them.

- Developed in late 1500s
- Accounts for 75 to 90% of all metals produced by metal working processes
- Often carried out at elevated temperatures first (hot rolling) to change coarse-grained, brittle, and porous ingot structures to wrought structures with finer grain sizes and enhanced properties

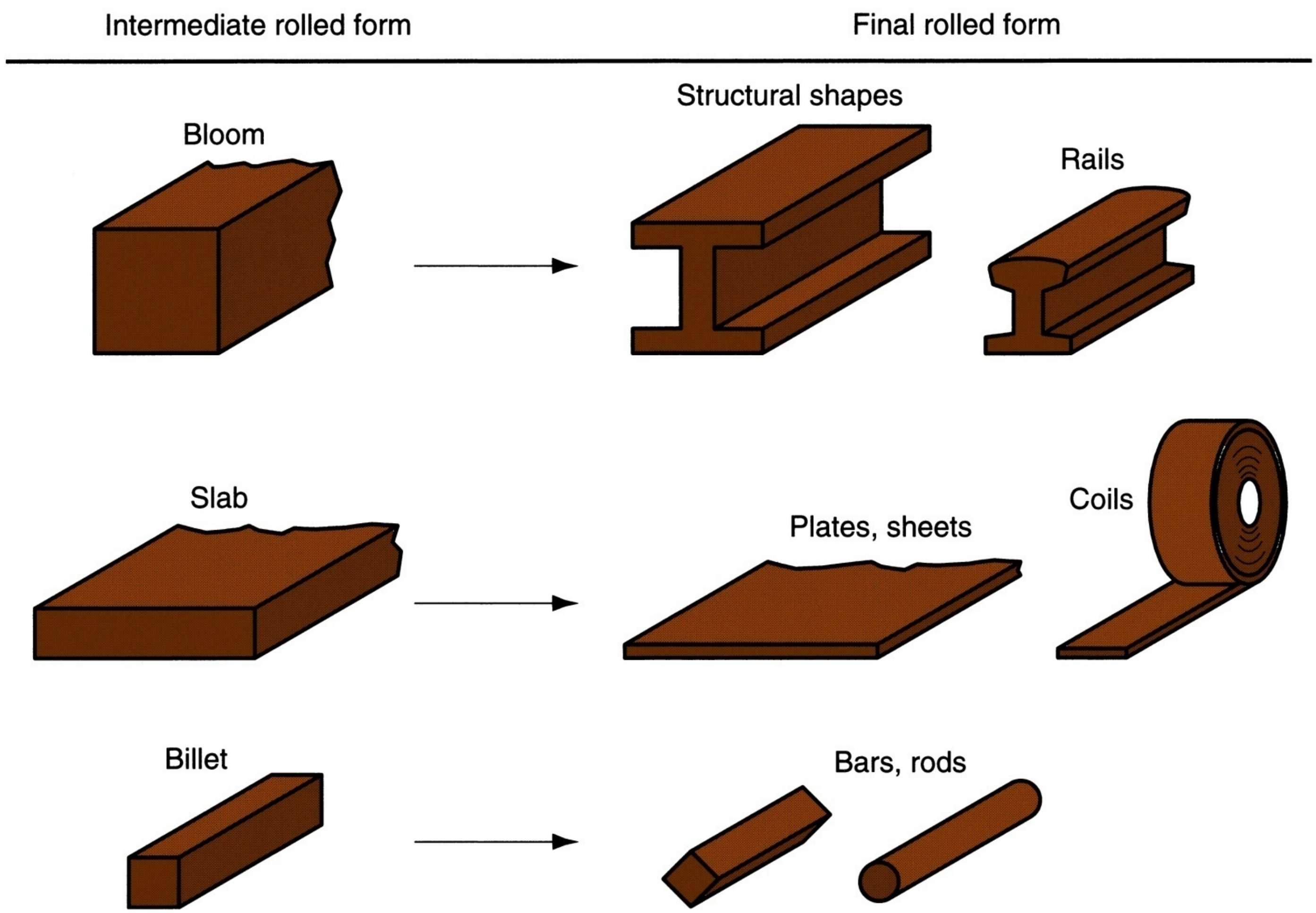
# The Rolls

The rotating rolls perform two main functions:

- Pull the workpiece into the gap between them by friction between workpiece and rolls
- Simultaneously squeeze the workpiece to reduce cross section

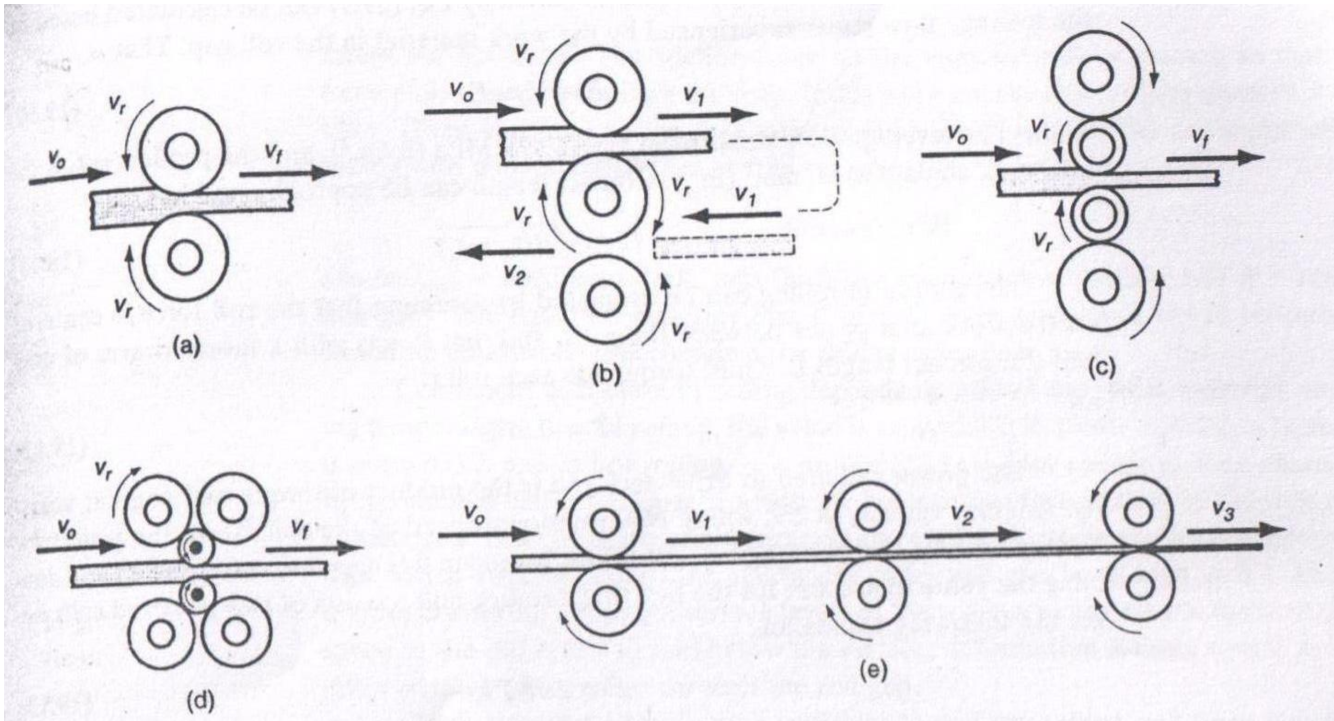
# Types of Rolling

- By geometry of work:
  - *Flat rolling* - used to reduce thickness of a rectangular cross-section
  - *Shape rolling* - a square cross-section is formed into a shape such as an I-beam
- By temperature of work:
  - *Hot Rolling* – most common due to the large amount of deformation required
  - *Cold rolling* – produces finished sheet and plate stock



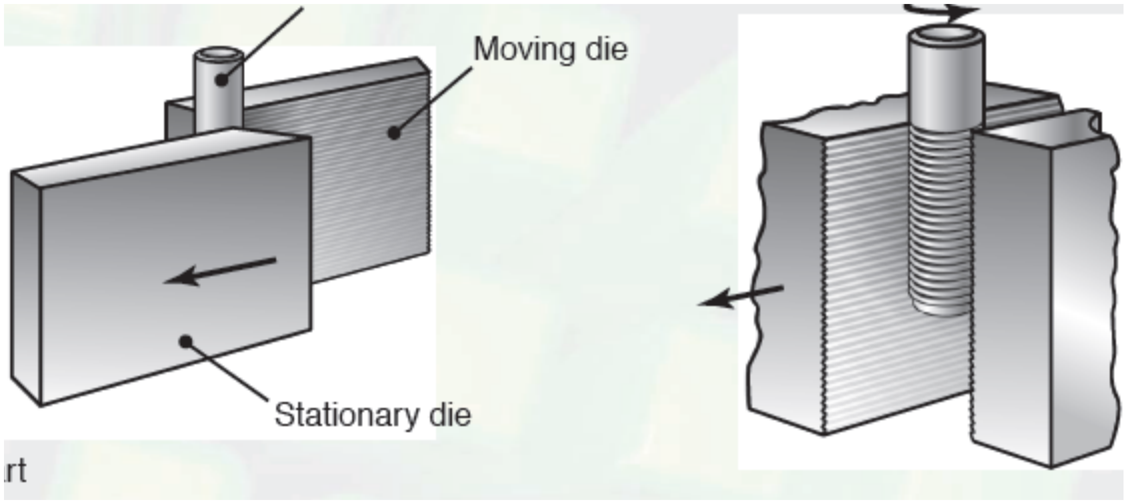

Some of the steel products made in a rolling mill

# Rolling Mills

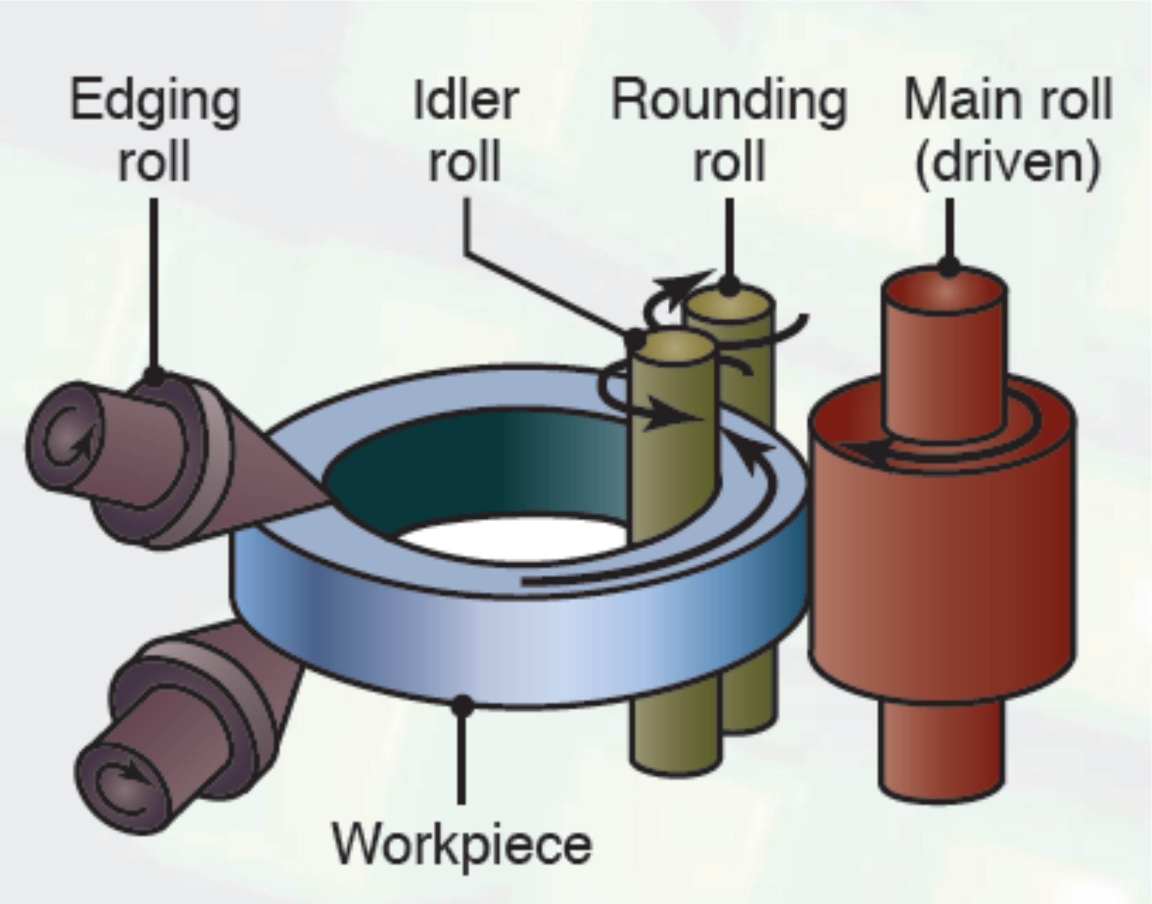



a. Two high mill
b. Three high mill
c. Four high mill
d. Cluster rolling mill
e. Tandem rolling mill

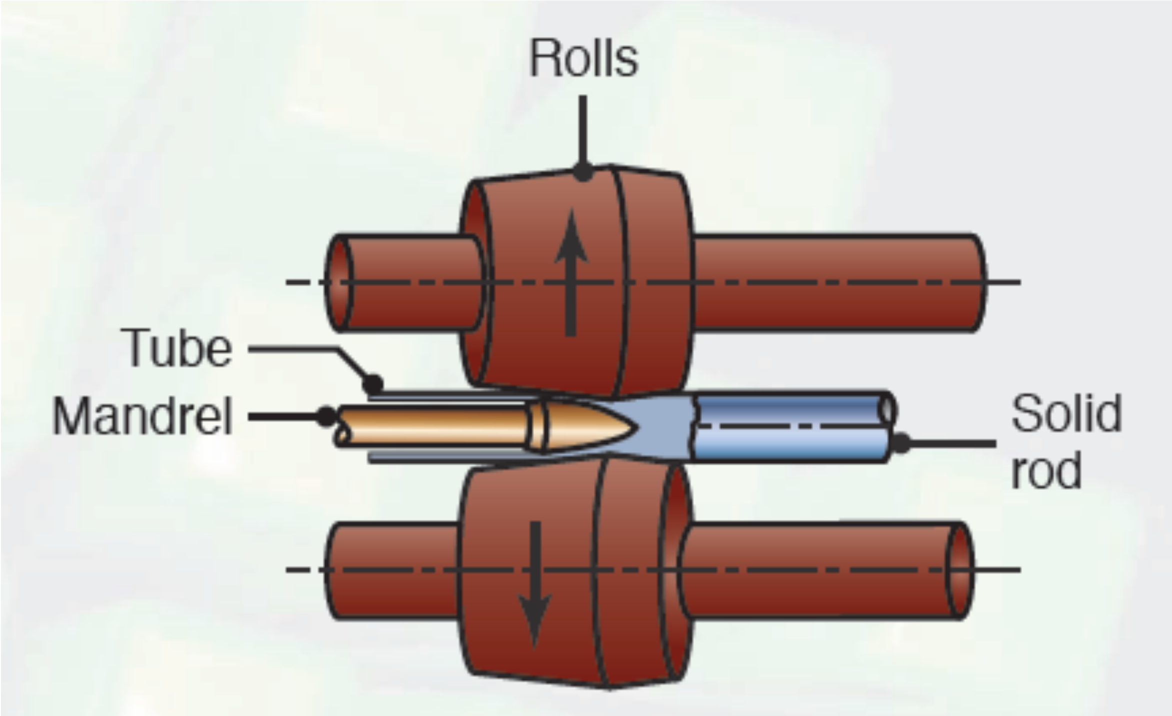
# Thread rolling



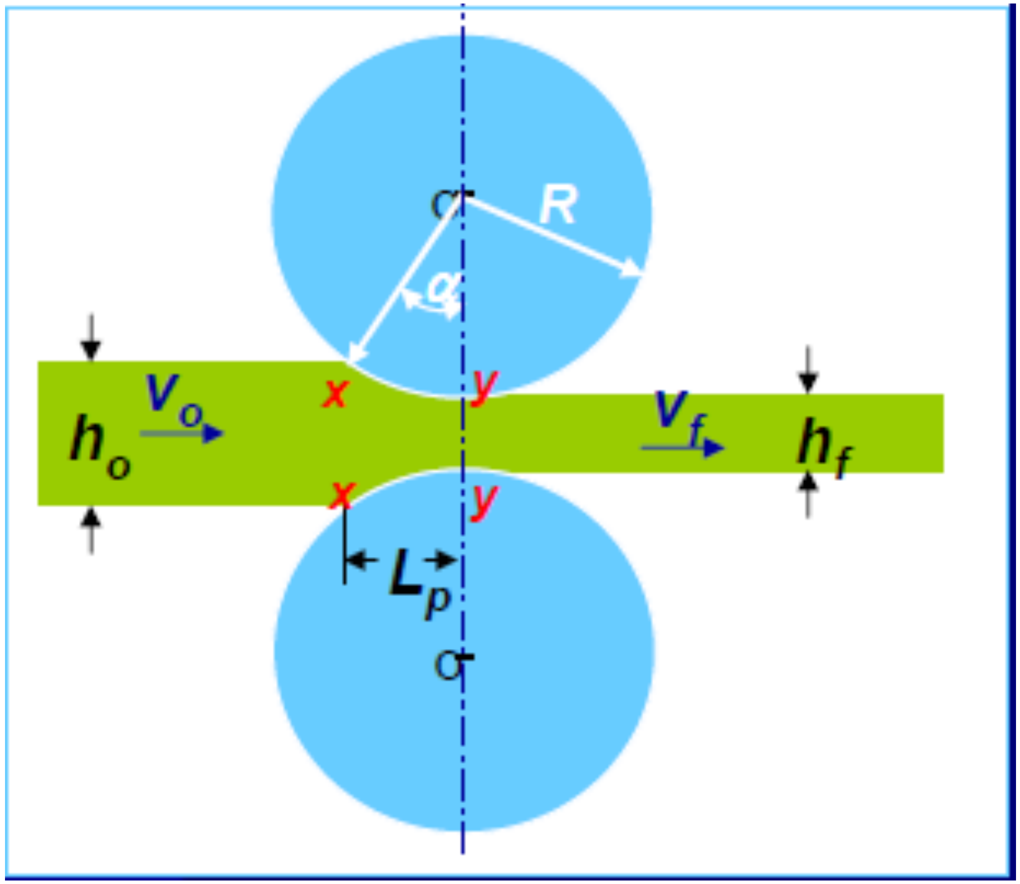

# Ring rolling



# Roll Piercing

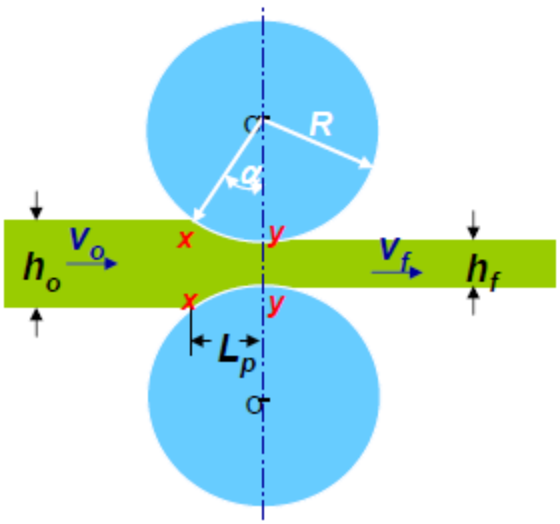


# Mechanics of flat rolling




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

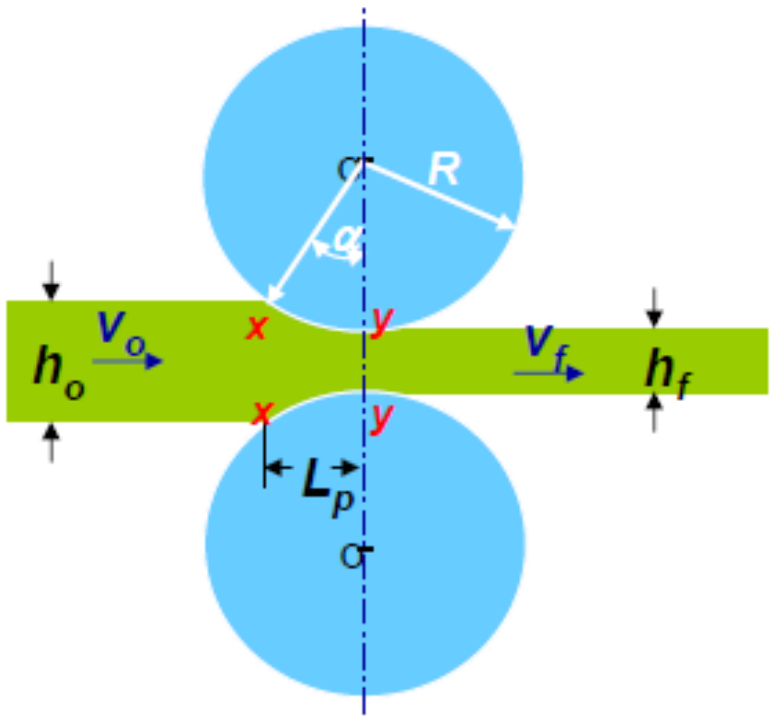
# Fundamentals concepts of metal rolling




## Assumptions

- -Arc on contact is a part of circle
- -Coefficient of friction, μ is constant
- -Material deform plastically
- -Volume of metal remains constant
- -Velocity of rolls assumed to be constant
- -No extension in the width

# Fundamentals concepts of metal rolling

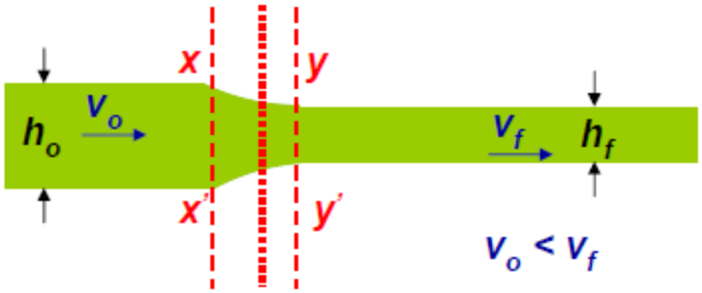



$$bh_o v_o = bhv = bh_f v_f$$

Where b is the width of the sheet

v is the velocity at any thickness h, intermediate between $h_o$ and $h_f$

# Fundamentals concepts of metal rolling




$$bh_o v_o = bh_f v_f$$

$$h_o v_o = h_f v_f$$

When $h_o > h_f$ then $v_o < v_f$

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

# Fundamentals concepts of metal rolling

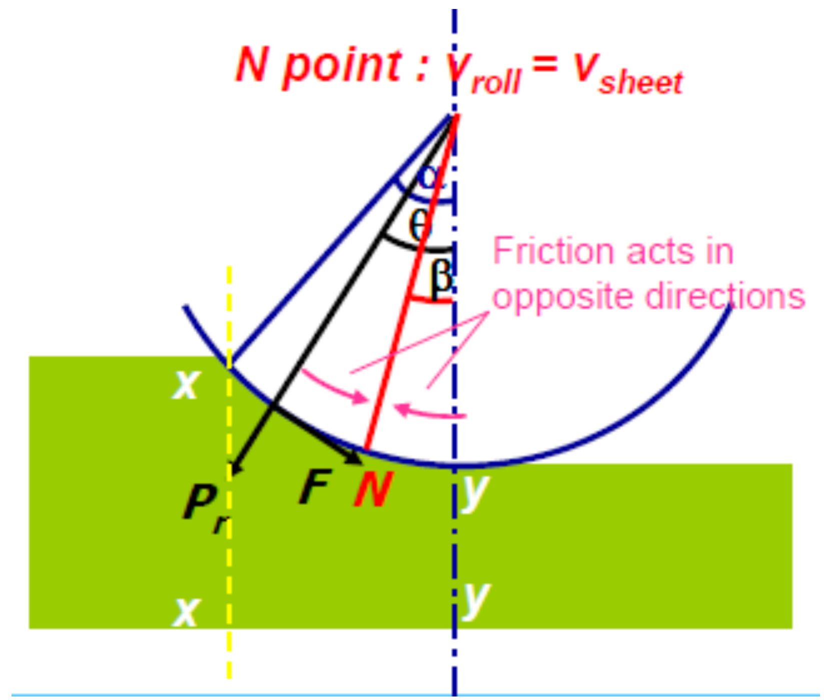
Radial force ($P_r$) and Tangential force (F)

Neutral point/No slip point (N): $V_{roll} = V_{sheet}$

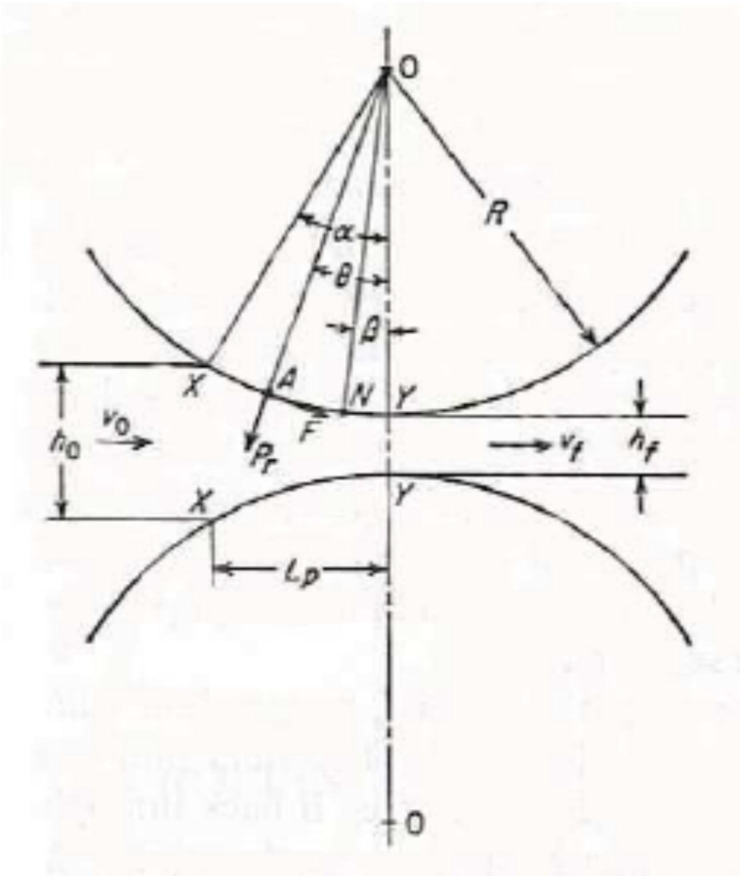
Tangential frictional force direction

Region 1: XX-N

Region 2: N-YY



# Fundamentals concepts of metal rolling




Specific roll pressure

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

p: Specific roll pressure

F: total force

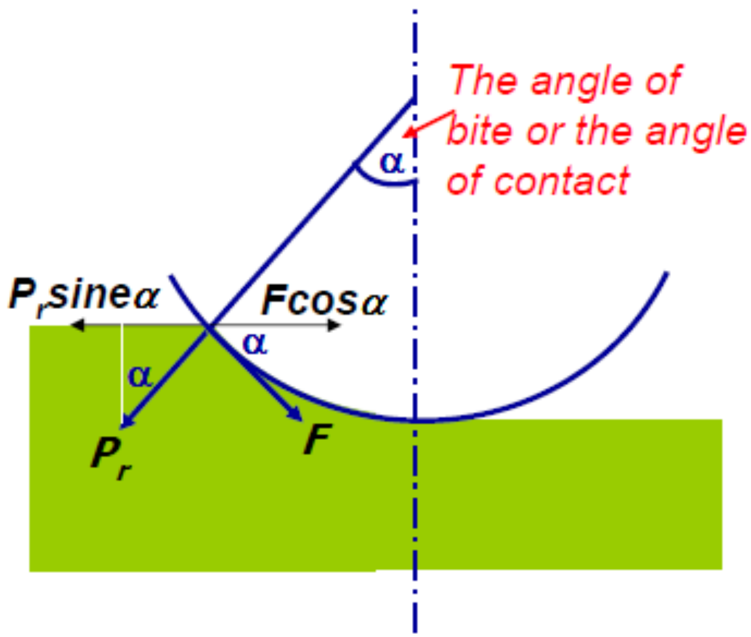
b: width

$L_p$: projected length of the arc of contact

$$\mathrm{Reduction}(r) = \Delta h / h_o$$

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

# Roll bite condition




For the workpiece to enter inside the rolls

$$F\cos\alpha \geq P_R \sin\alpha$$

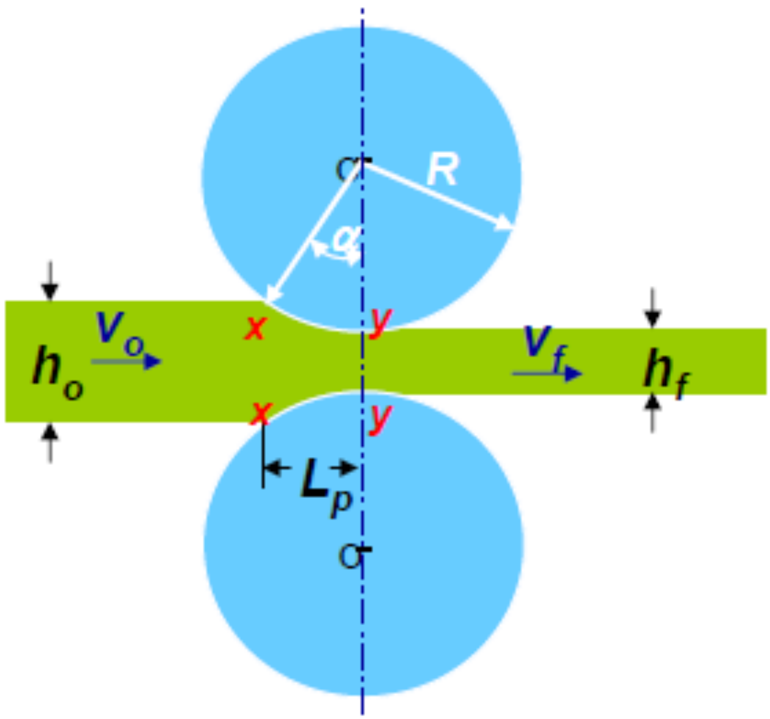
$$\frac{F}{P_R} \geq \frac{\sin\alpha}{\cos\alpha} \geq \tan\alpha$$

We know that $F = \mu P_R$

Therefore, $\mu = \tan\alpha$

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

# Maximum reduction




For the rolling to occur

$$F\cos\alpha \geq P_R \sin\alpha$$

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

$$\mu \geq \tan\alpha$$

$$(\Delta h)_{\max} = ?$$

$$(\Delta h)_{\max} = \mu^2 R$$

# Example

**Question:** Determine the maximum possible reduction for cold rolling a 300 mm-thick slab when $\mu = 0.08$ and the roll diameter is 600 mm. What is the maximum reduction on the same mill for hot rolling when $\mu = 0.5$?

**Answer:**
Cold rolling = 1.92 mm
Hot rolling: 75 mm

# Main variables in rolling

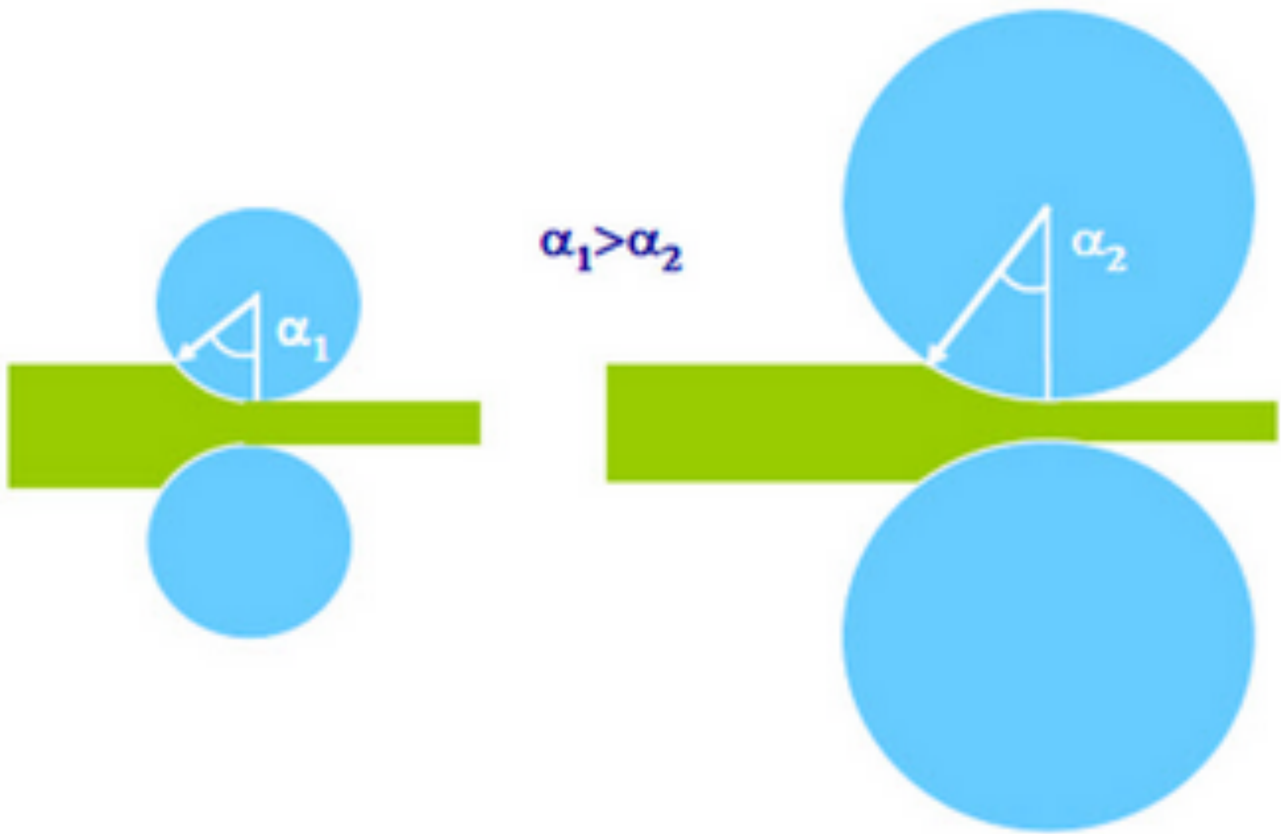
•The **roll diameter**.
Rolling load P increases with the roll radius

•The **reduction** $(\Delta h)$ .
Rolling load also increases as the sheet entering the rolls gets thinner.

•The deformation resistance of the metal as influenced by the **metallurgy, temperature** and **strain rate**.

•The **friction** between the roll and work piece.

# Main variables in rolling



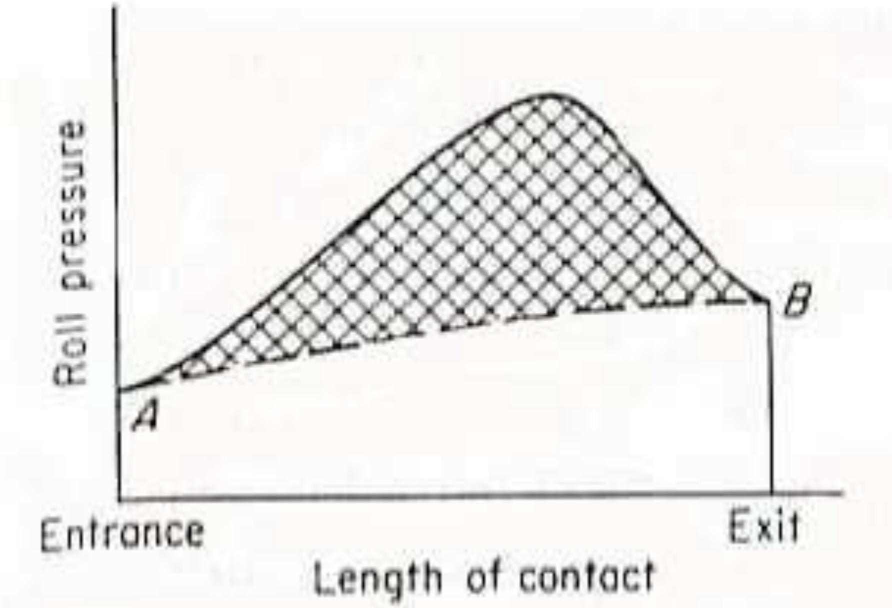
# Main variables in rolling

**Frictional force** is needed to pull the metal into the rolls and responsible for a large portion of the rolling load.

High friction results in high rolling load, a steep friction hill and great tendency for edge cracking.

Cold rolling with lubricants, $\mu = 0.05\text{-}0.1$
Hot rolling with lubricants, $\mu = 0.4\text{-}0.7$ (sticking condition)
In sticking the hot wok surface adheres to roll and thus the central part of the strip undergoes with a severe deformation.

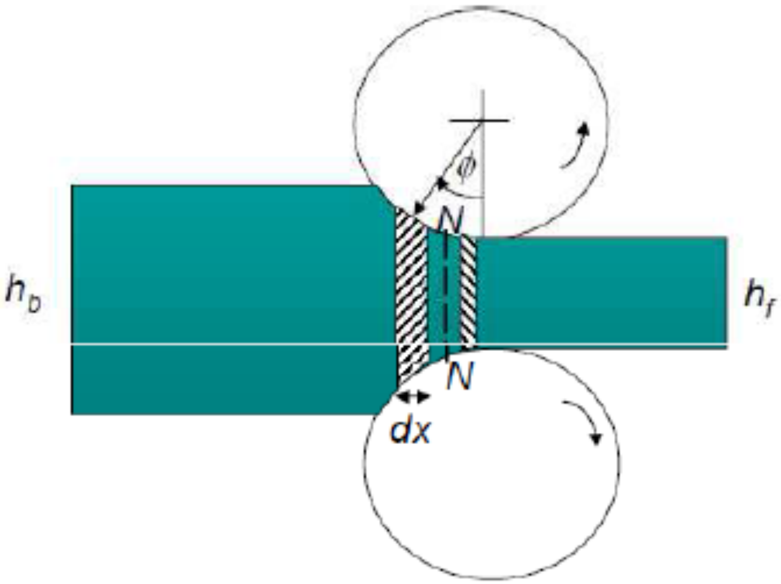
# Main variables in rolling



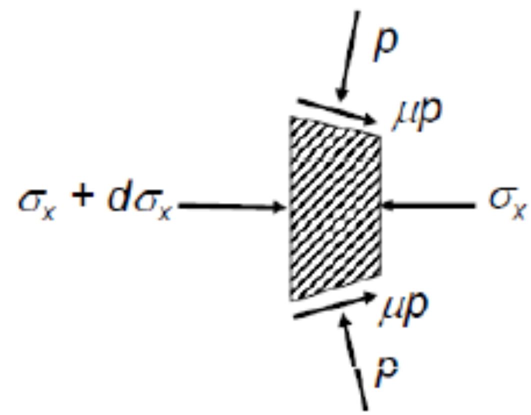

•The area in shade is the force required to overcome frictional forces.

•Area under the line AB represent force required for plastic deformation.

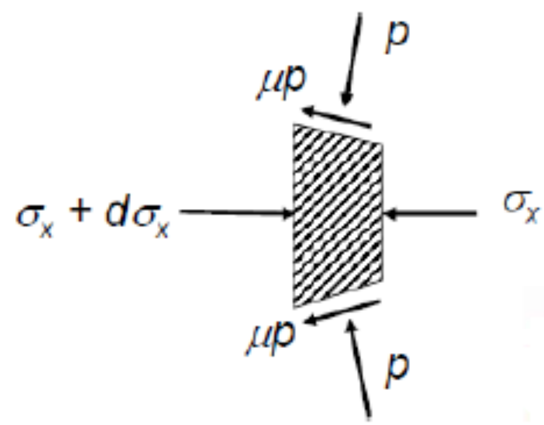
# Flat rolling analysis




### Stresses on slab in entry zone




### Stresses on slab in exit zone



# Flat rolling analysis

**Simplifying and ignoring the HOTs**

$$\frac{d(\sigma_x h)}{d\phi} = 2pR \cdot (\sin\phi \mp \mu\cos\phi)$$

Since $\alpha << 1$, then $\sin\phi = \phi$, $\cos\phi = 1$

$$\frac{d(\sigma_x h)}{d\phi} = 2pR \cdot (\phi \mp \mu)$$

# Slab Method for Rolling

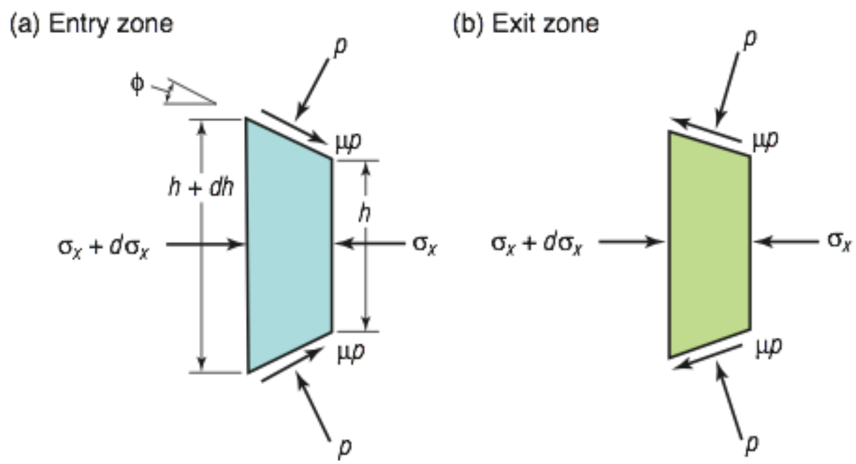



FIGURE 6.32 Stresses acting on an element in rolling: (a) entry zone and (b) exit zone.

Entry zone pressure:

$$p = Y_f' \frac{h}{h_0} e^{\mu(H_0 - H)}$$

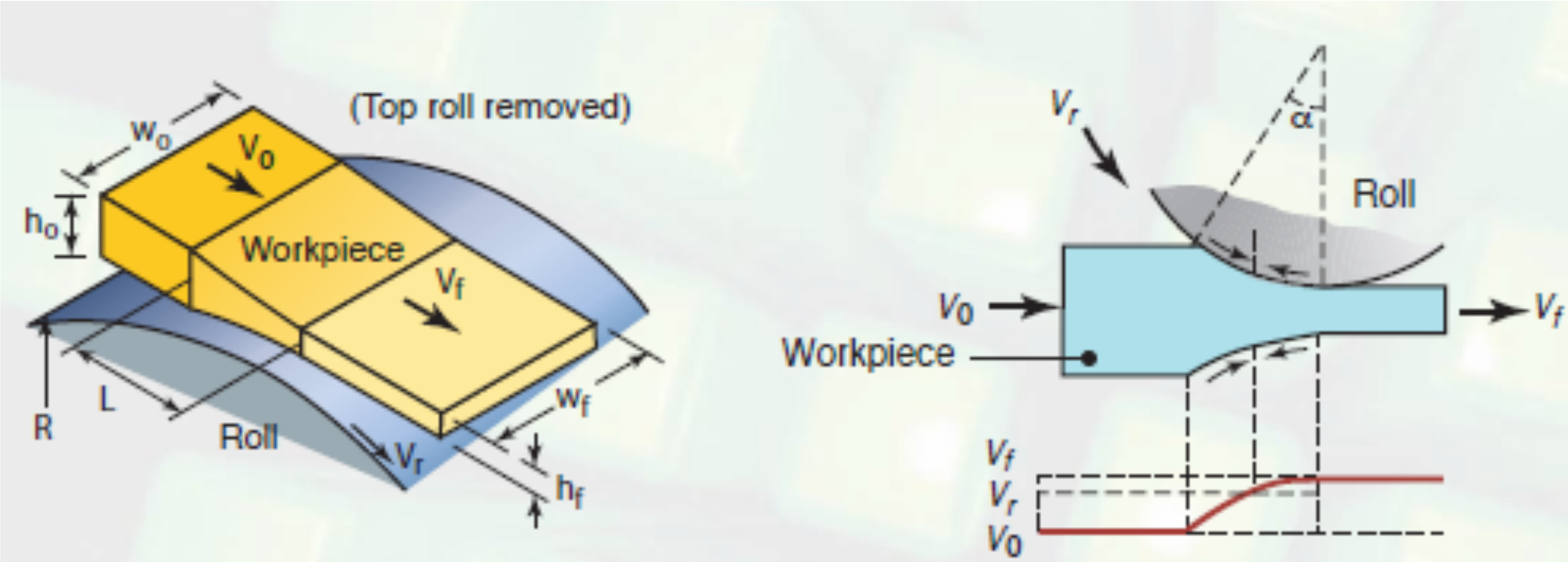
Exit zone pressure:

$$p = Y_f' \frac{h}{h_f} e^{\mu H}$$

where

$$H = 2\sqrt{\frac{R}{h_f}} \tan^{-1}\left(\sqrt{\frac{R}{h_f}}\phi\right)$$

# Forward slip




Forward slip:

$$\text{Forward slip} = \frac{V_f - V_r}{V_r}$$

# Pressure Distribution in Rolling

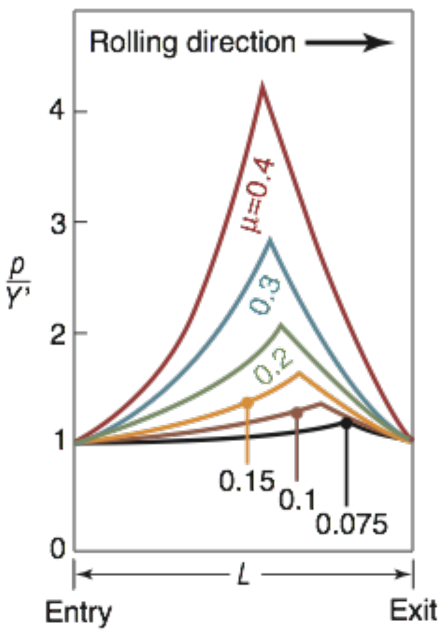



FIGURE 6.33 Pressure distribution in the roll gap as a function of the coefficient of friction. Note that as friction increases, the neutral point shifts toward the entry. Without friction, the rolls will slip, and the neutral point shifts completely to the exit. (See also Table 4.1.)

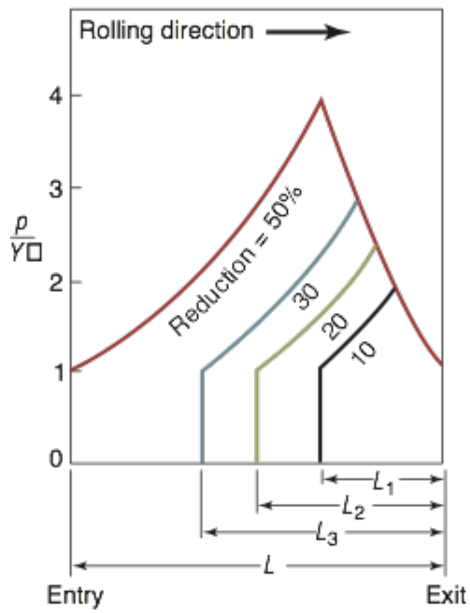



FIGURE 6.34 Pressure distribution in the roll gap as a function of reduction in thickness. Note the increase in the area under the curves with increasing reduction, thus increasing the roll force.

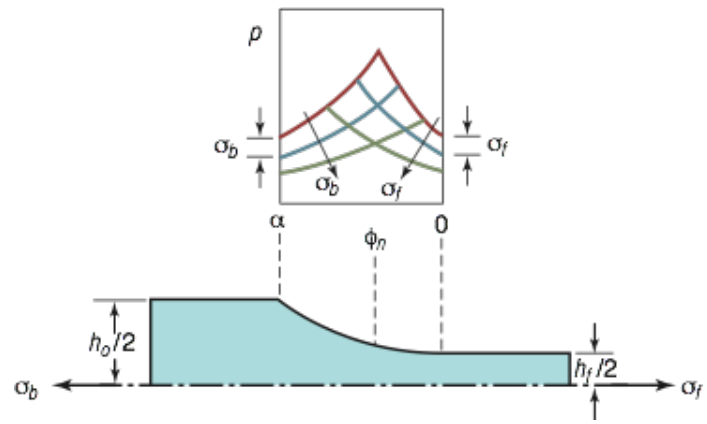



FIGURE 6.35 Pressure distribution as a function of front and back tension in rolling. Note the shifting of the neutral point and the reduction in the area under the curves (hence reduction in the roll force) as tensions increase.

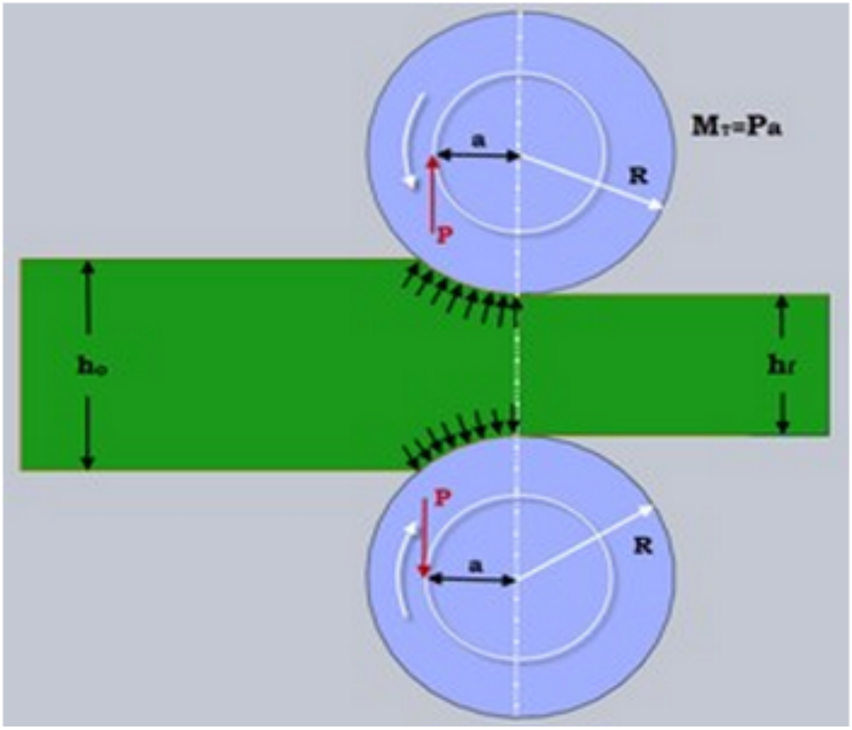
# Example

**Question:** Calculate the rolling load if steel sheet is hot rolled 30% from a 40 mm-thick slab using a 900 mm-diameter roll. The slab is 760 mm wide. Assume μ = 0.30. The plane-strain flow stress is 140 MPa at entrance and 200 MPa at the exit from the roll gap due to the increasing vel

$$P = \sigma_o'\left[\frac{1}{Q}(e^{Q}-1)b\sqrt{R\Delta h}\right] \qquad Q = \frac{\mu L_p}{\bar{h}} \qquad : \frac{\sigma'_{entrance} + \sigma'_{exit}}{2}$$

**Answer:**
Load = 13.4 MN

# Roll torque and power




$$Torque\,/\,roller = r \cdot F_{roller} = \frac{L}{2} \cdot F_{roller} = \frac{F_{roller} L}{2}$$

Power / roller = $T\omega$ = $F_{roller} L \omega / 2$

# Example

**Question:** A 250 mm wide annealed brass 70-30 strip is rolled from a thickness of 20 mm to 12 mm. For a roll radius of 300 mm and roll rpm of 100, estimate the total power required for this operation.
For brass K= 895 Mpa and n=0.49

**Answer:**
Load = 3111 kW

# Problems and defects in rolled products

**•Defects from cast ingots before rolling**
**-Porosity**
**-Cracks**
**-Blow holes**
**-Non metallic inclusions (Dross)**

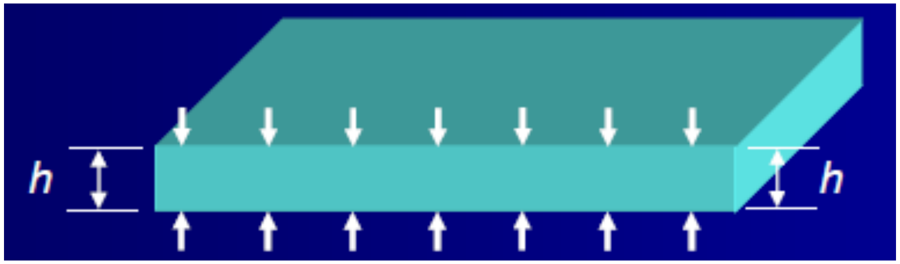
Drastically reduce the strength and ductility properties

# Problems and defects in rolled products

- **Defects during rolling**

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

**- Uniform thickness: over the width and length**

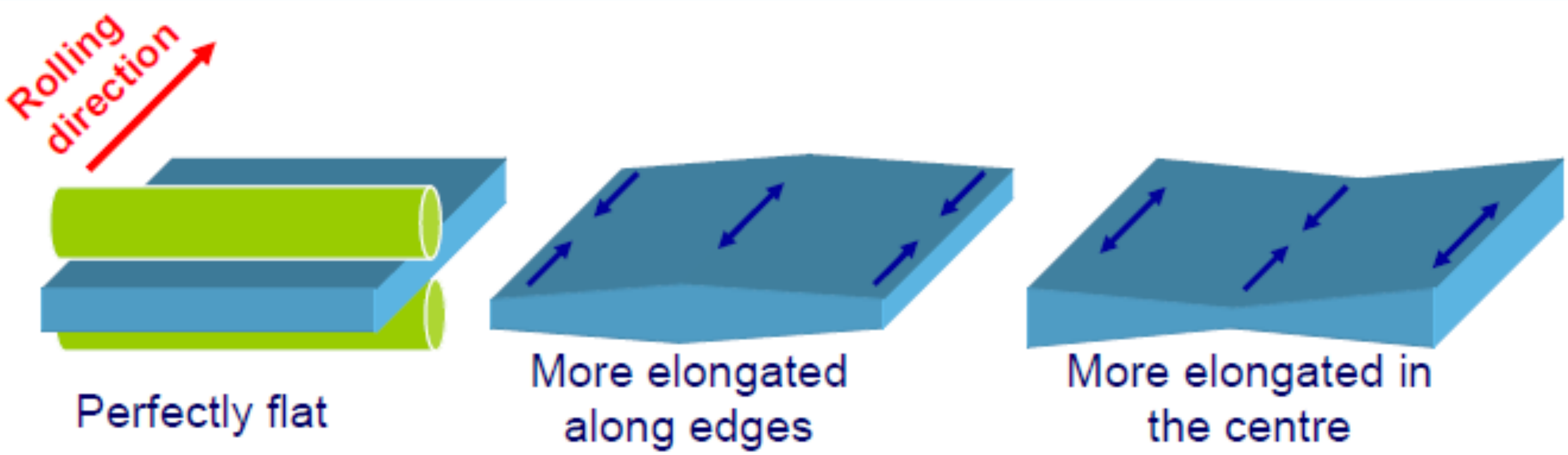



**- Flatness: difficult to measure accurately**

# Flatness

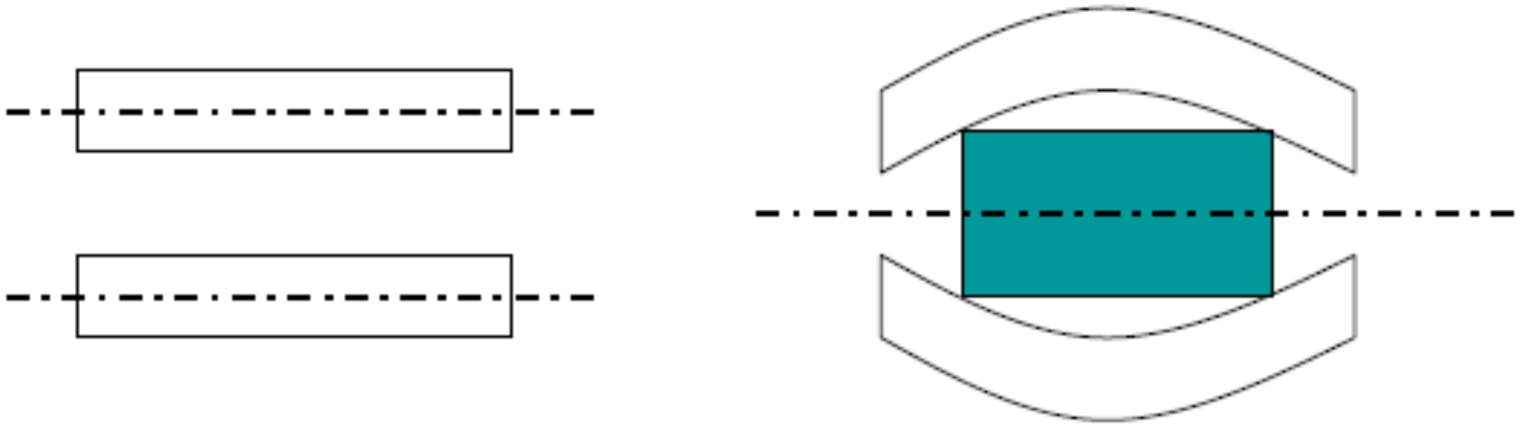
• The roll gap must be perfectly parallel to produce sheets/ plates with equal thickness at both ends.

• The rolling speed is very sensitive to flatness. A difference in elongation of one part in the sheet can cause waviness.

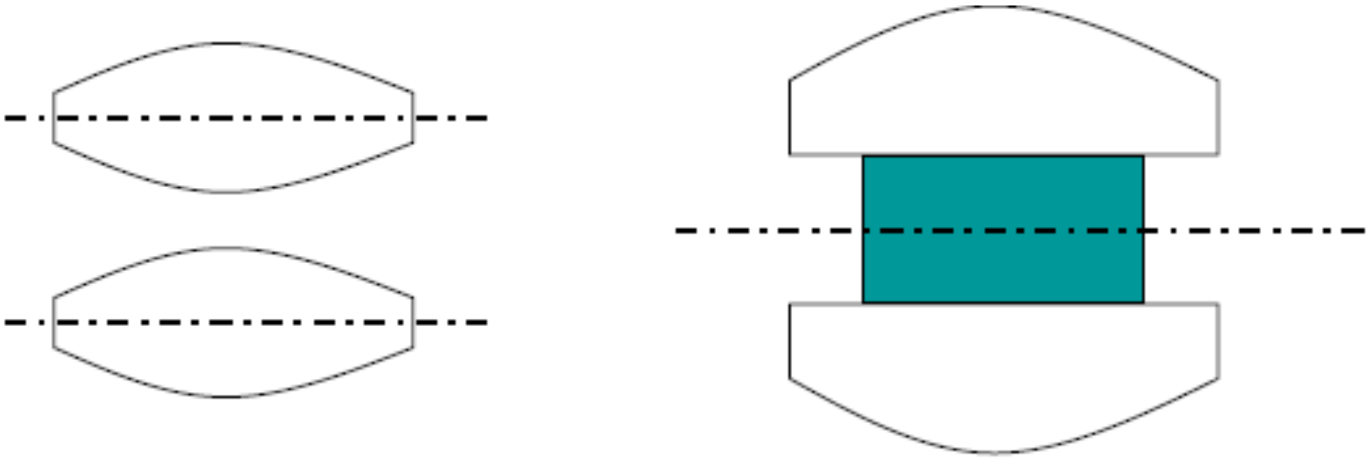


# Solutions to flatness problem

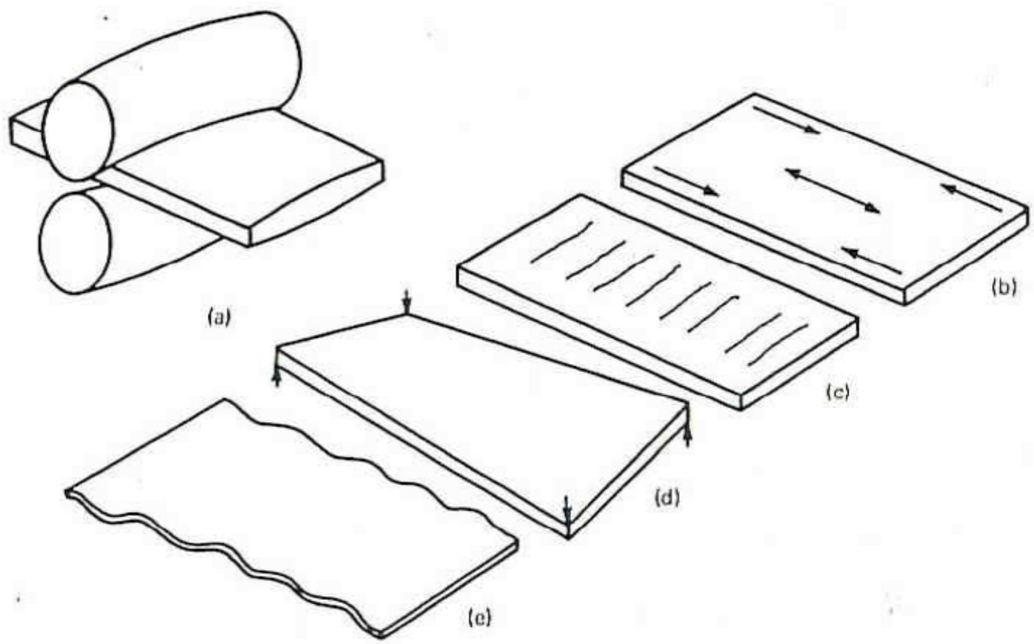
- Rolls can deflect under load



- Rolls can be crowned



# Defects due to insufficient camber

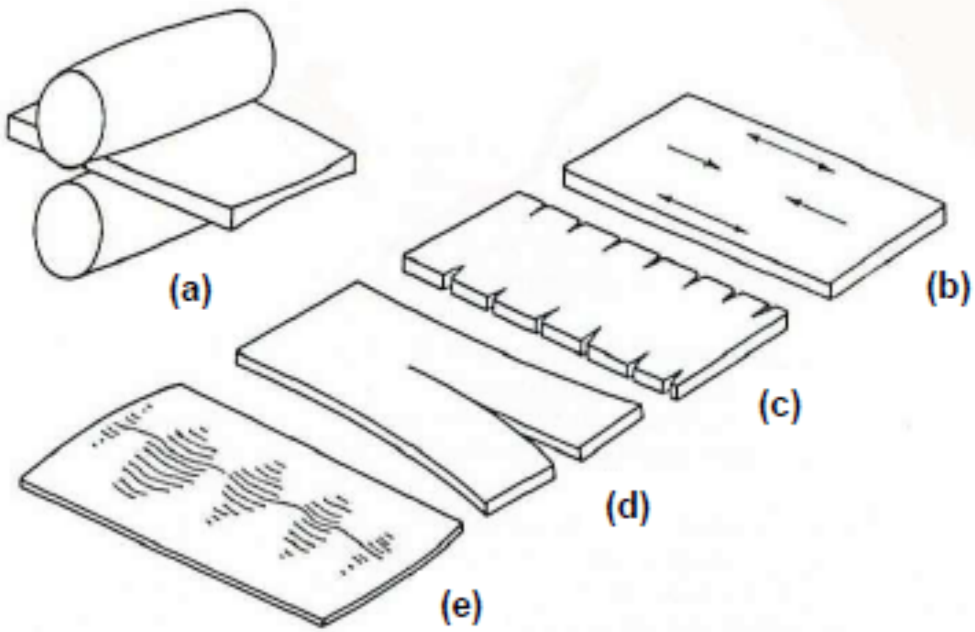



• Thicker centre means the edges would be plastically elongated more than the centre, normally called long edges.

• This induces the residual stress pattern of compression at the edges and tension along the centreline.

This can cause centreline cracking (c), warping (d) or edge wrinkling or crepe-paper effect or wavy edge (e).

# Defects due to insufficient camber




• Thicker edges than the centre means the centre would be plastically elongated more than the edges, resulting in lateral spread.

•The residual stress pattern is now under compression in the centreline and tension at the edges.

• This may cause edge cracking (c), centre splitting (d), centreline wrinkling (e).