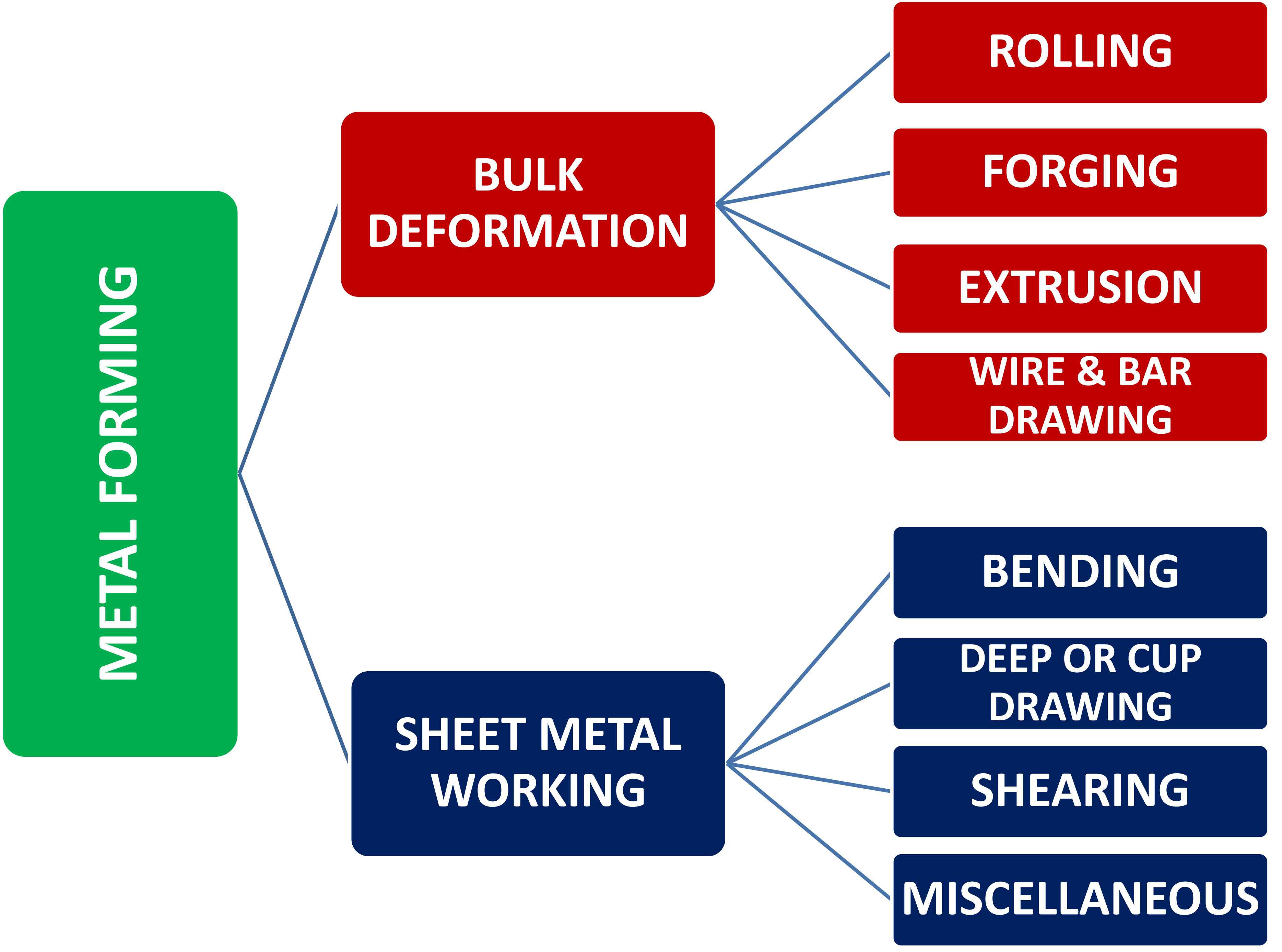

METAL FORMING
BULK DEFORMATION
SHEET METAL WORKING
ROLLING
FORGING
EXTRUSION
WIRE & BAR DRAWING
BENDING
DEEP OR CUP DRAWING
SHEARING
MISCELLANEOUS

BULK DEFORMATION PROCESSES

- ***Bulk deformation*** processes are those where the ***thicknesses*** or cross sections are ***reduced*** or ***shapes*** are ***significantly changed***.
- Since the volume of the material remains constant, changes in one dimension require proportionate changes in others.
- Thus the enveloping ***surface area*** changes significantly, usually ***increasing*** as the product lengthens or the shape becomes more complex.

BULK DEFORMATION PROCESSES

- ***Starting geometry*** of the raw material may be:
  - cylindrical bars and billets
  - rectangular billets and slabs
  - or any of the above similar shapes

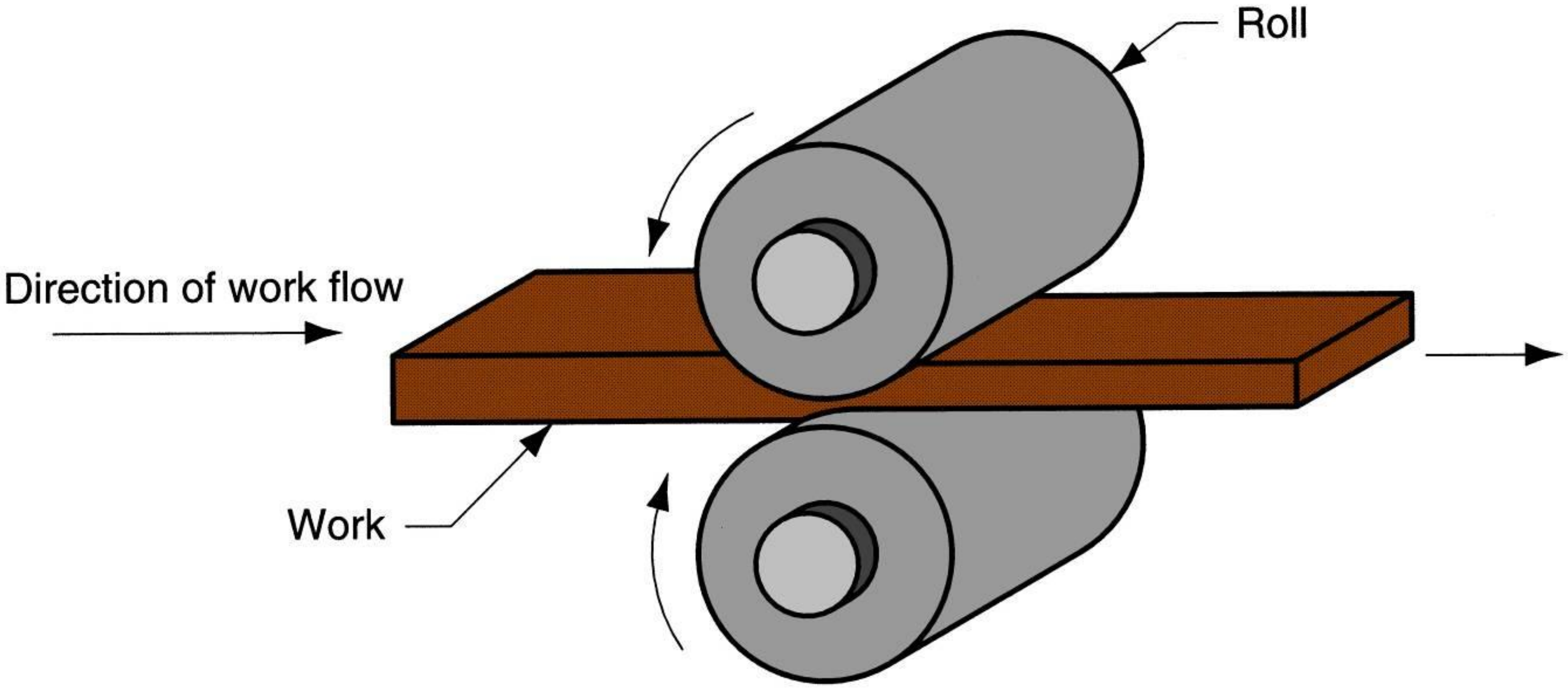
[redacted]

[redacted]

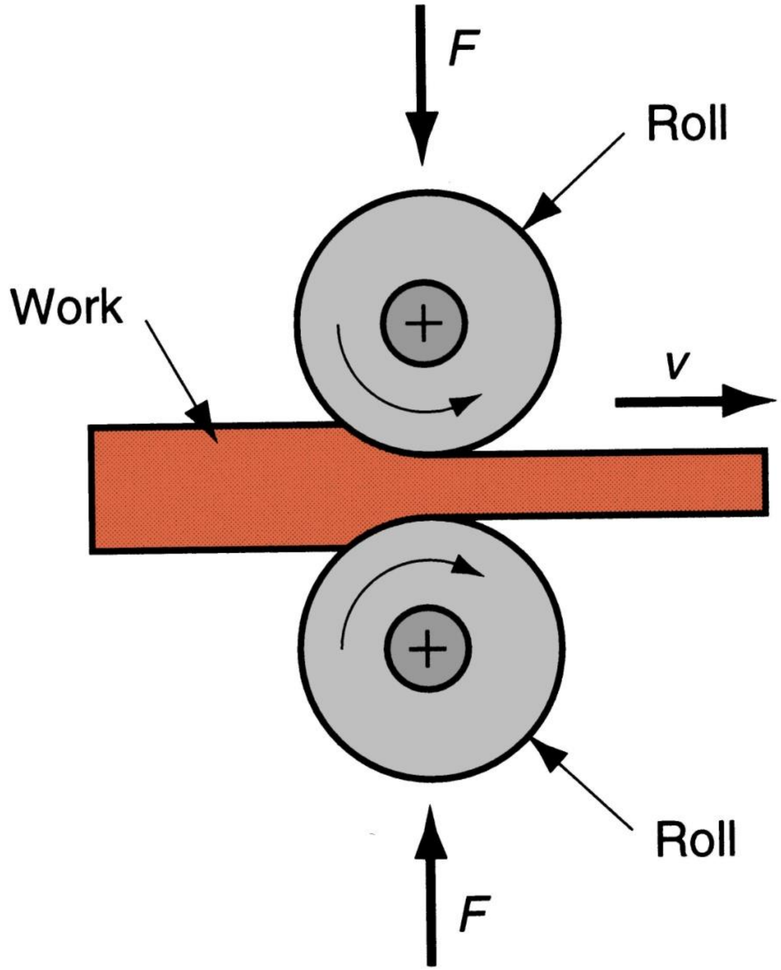
(1) ROLLING

- Rolling is a ***deformation process*** in which the ***thickness*** of the work is ***reduced*** by ***compressive forces*** exerted by two opposing rolls.
- Rolling operations ***reduce the thickness*** or ***change the cross section*** of a material through compressive forces exerted by rolls.

(1) ROLLING



(1) ROLLING



(1) ROLLING

- Rotating rolls perform two main functions:
  - Pull the work into the gap between them by friction between workpart and rolls
  - Simultaneously squeeze the work to reduce its cross section

(1) ROLLING

- Most rolling processes are ***very capital intensive***, requiring massive pieces of equipment, called rolling mills, to perform them.
- Most rolling is carried out by hot working, called ***hot rolling***, owing to the large amount of deformation required.
- Hot-rolled metal is generally free of residual stresses, and its properties are isotropic.
- Disadvantages of hot rolling are that the product cannot be held to close tolerances, and the surface has a characteristic oxide scale.

(1) ROLLING

- Rolling is often the first process that is used to convert material into a finished ***wrought product*** (*Products such as; sheet, rod, bar, tube, plate and wire that are produced by rolling and extrusion mills as well as forging*).
- Thick starting stock can be rolled into ***blooms, billets, or slabs,*** or these shapes can be obtained directly from continuous casting.

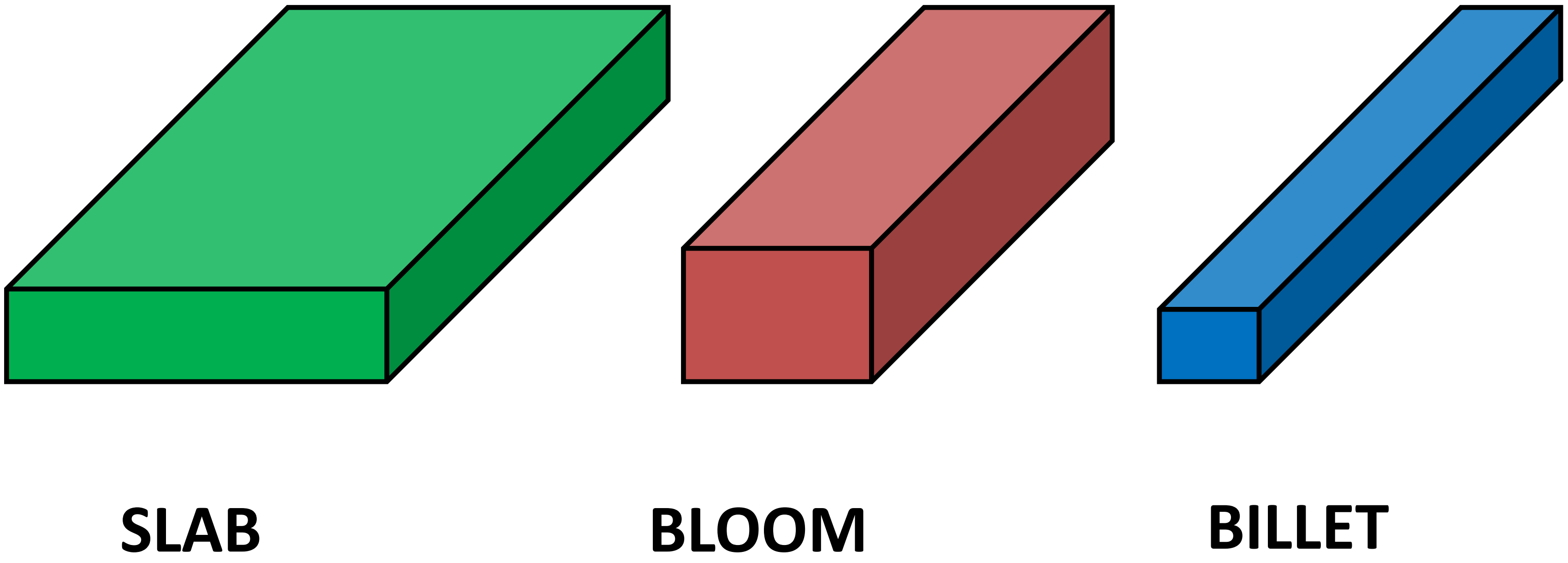
(1) ROLLING

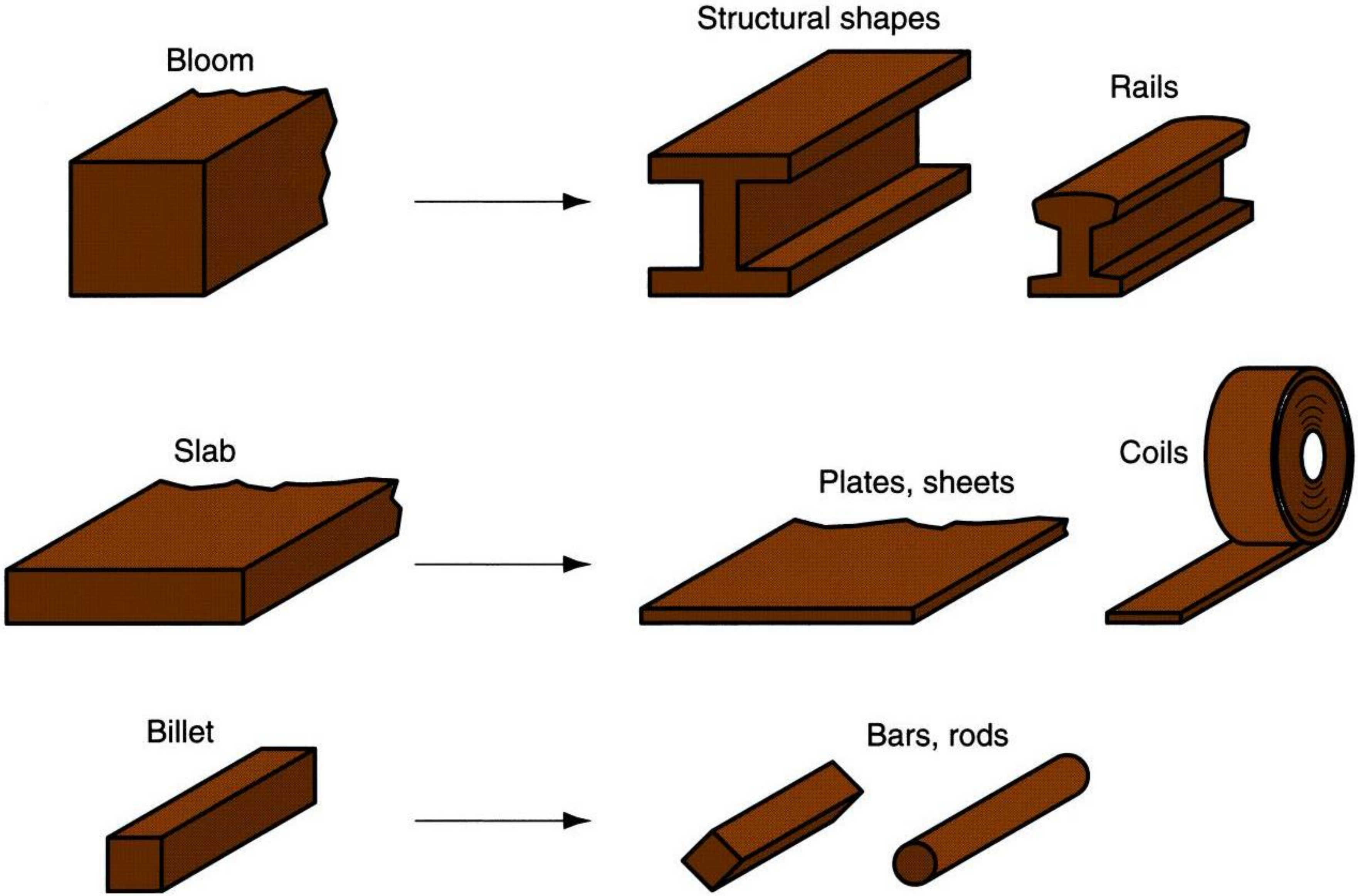
- A ***slab*** is a rectangular solid where the width is greater than twice the ***thickness*** (***25cm x 4 cm or more***). **Or 50 – 150mm thick and width ½ to 1.5 meters**
- Slabs can be further rolled to produce plate, sheet, and strip .
- A ***bloom*** has a ***square or rectangular*** cross section, with a thickness greater than ***15 cm*** and a width no greater than twice the thickness. **(150 –300mm.)**

(1) ROLLING

- A ***billet*** is usually ***smaller than a bloom*** and has a ***square or circular cross section*** (***4cm x 4 cm or more***).
- Billets are usually produced by some form of deformation process, such as rolling or extrusion.
- ***Plates*** have thickness greater than ***6 mm*** while ***sheet and strip*** range from ***6 mm to 0.1 mm***.

(1) ROLLING

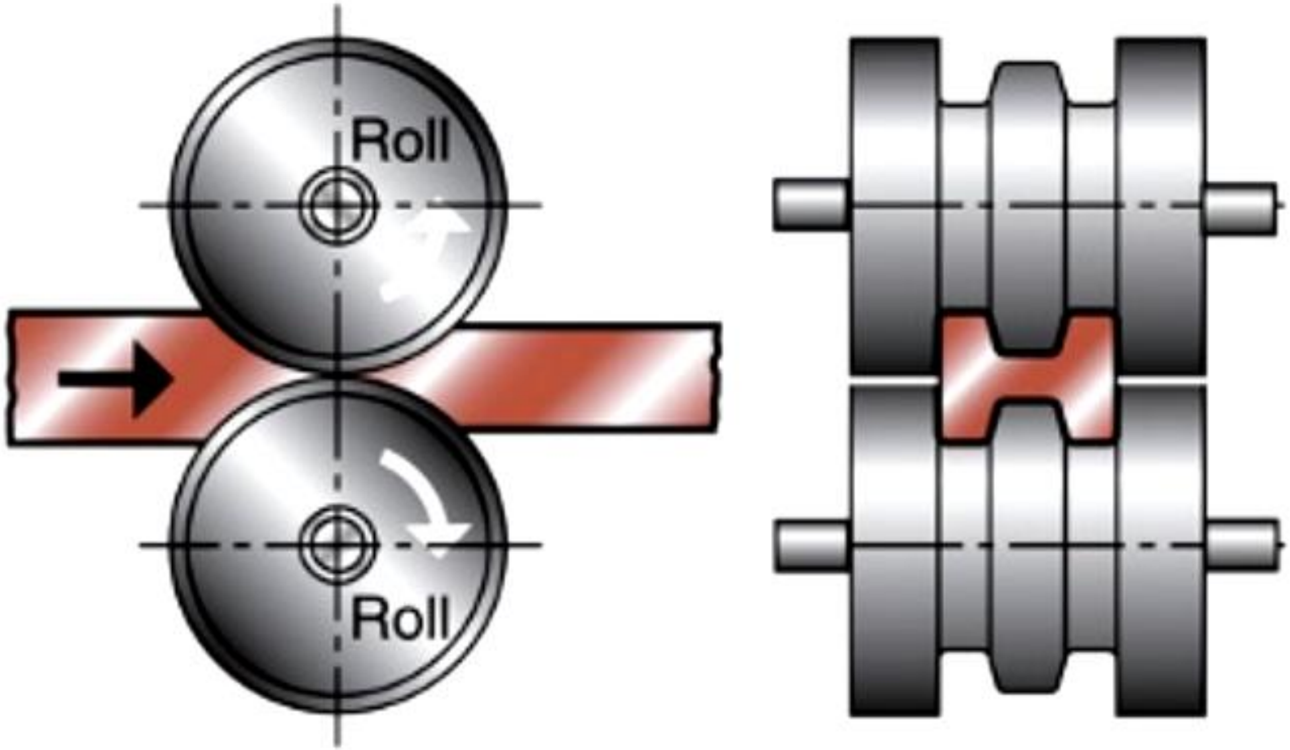



Bloom
Structural shapes
Rails
Slab
Plates, sheets
Coils
Billet
Bars, rods

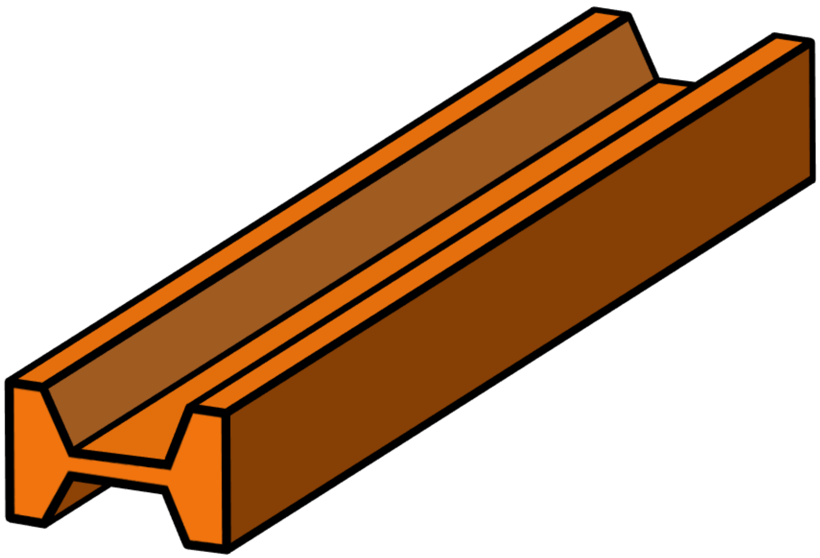
(1.1) SHAPE ROLLING

- In shape rolling, the ***work is deformed*** into a ***contoured cross section***.
- Products made by shape rolling include construction shapes such as ***I-beams, L-beams***, and ***U-channels***; ***rails*** for railroad tracks; and ***round and square*** bars and rods.
- The process is accomplished by passing the work through ***rolls*** that have the ***reverse of the desired shape.***

(1.1) SHAPE ROLLING



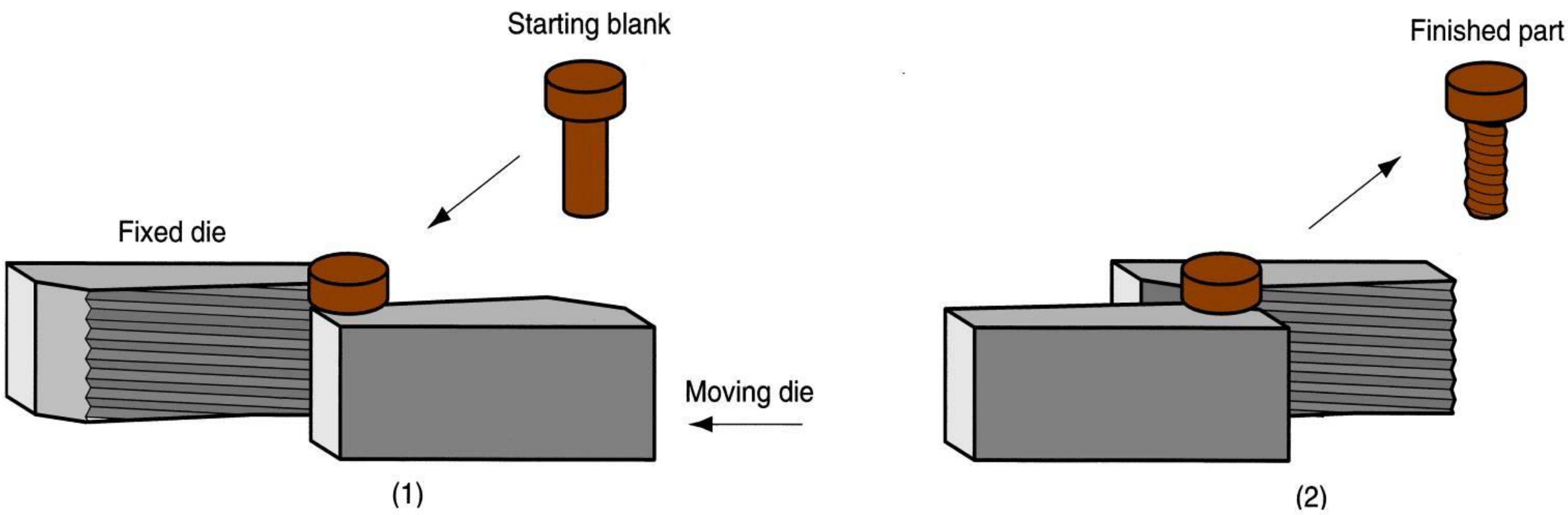
(1.1) SHAPE ROLLING



(1.2) Thread Rolling

- Bulk deformation process used to form threads on cylindrical parts by rolling them between two dies
- Important commercial process for mass producing bolts and screws
- Performed by cold working in thread rolling machines
- Advantages over thread cutting (machining):
  - Higher production rates
  - Better material utilization
  - Stronger threads and better fatigue resistance due to work hardening

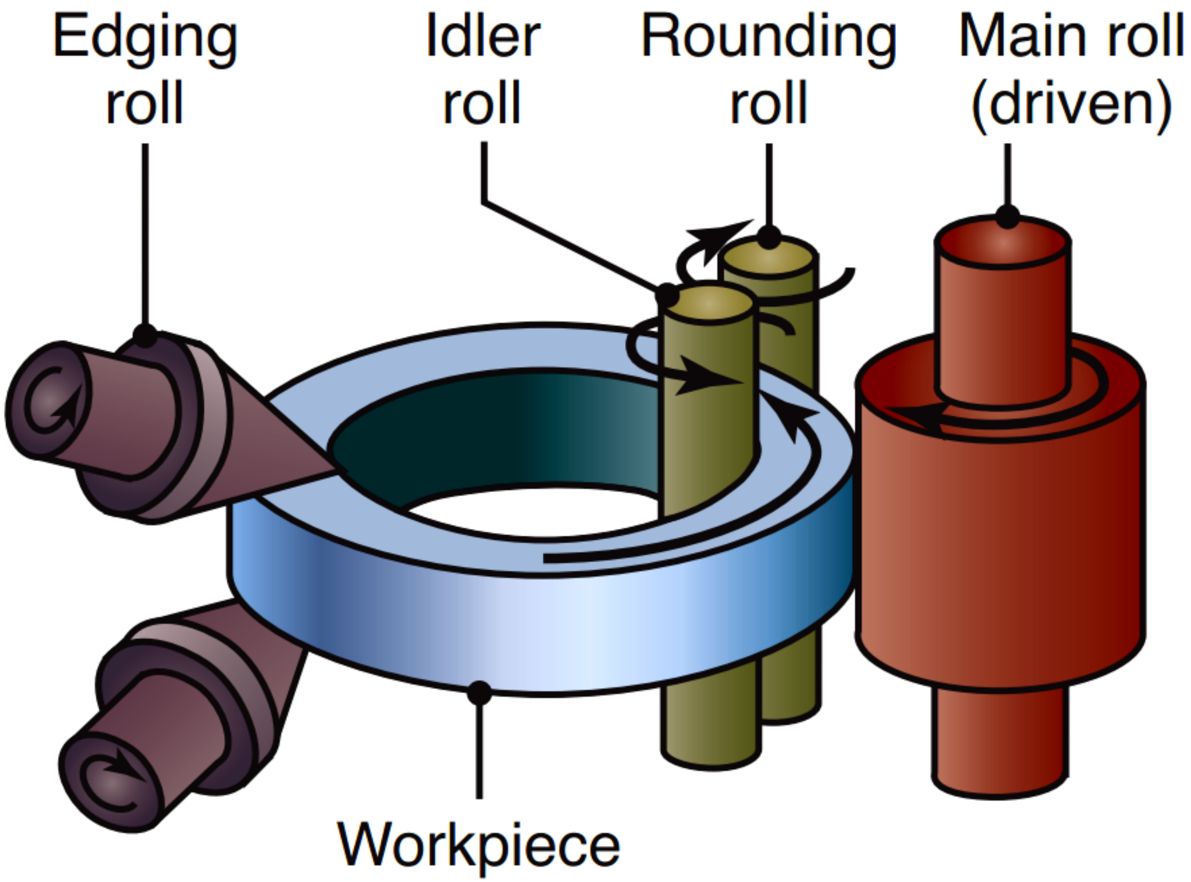
(1.2) Thread Rolling



(1.3) Ring Rolling

- Ring rolling is a deformation process in which a thick-walled ring of smaller diameter is rolled into a thin-walled ring of larger diameter.
- As the thick-walled ring is compressed, the deformed material elongates, causing the diameter of the ring to be enlarged.
- Ring rolling is usually performed as a hot-working process for large rings and as a cold-working process for smaller rings.

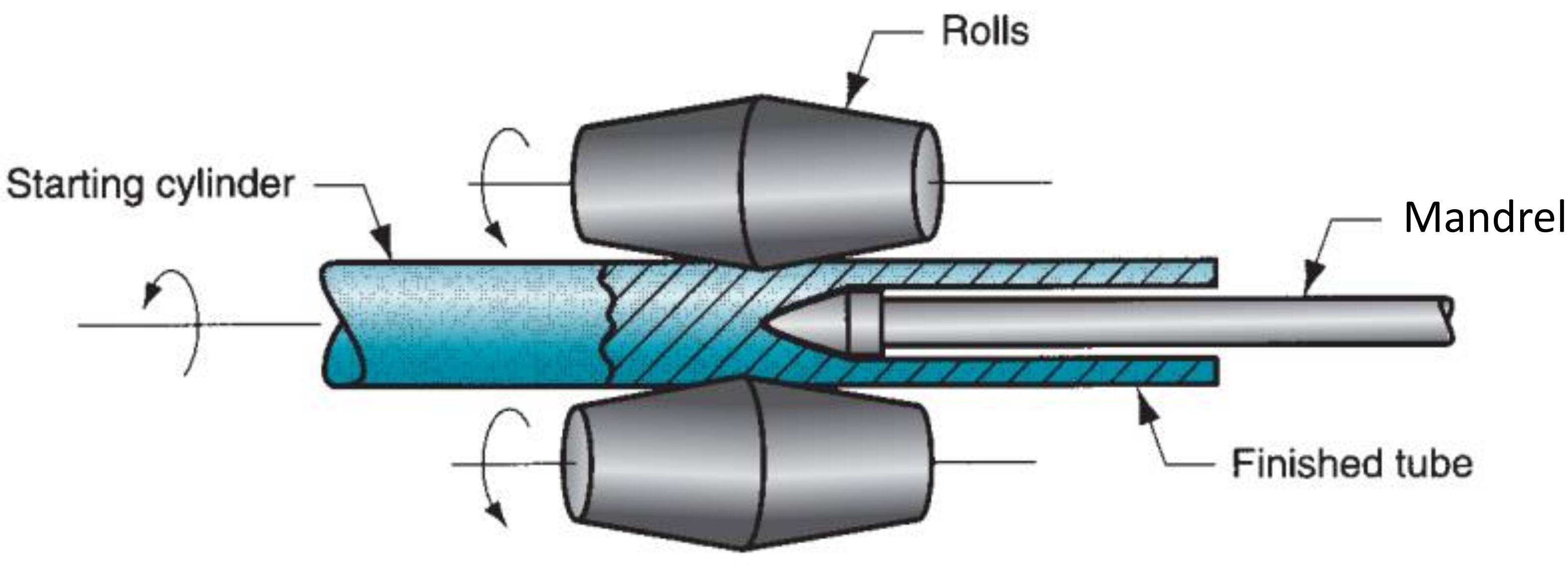
(1.3) Ring Rolling



Reducing the ring thickness results in an increase in its diameter.

(1.4) Roll Piercing

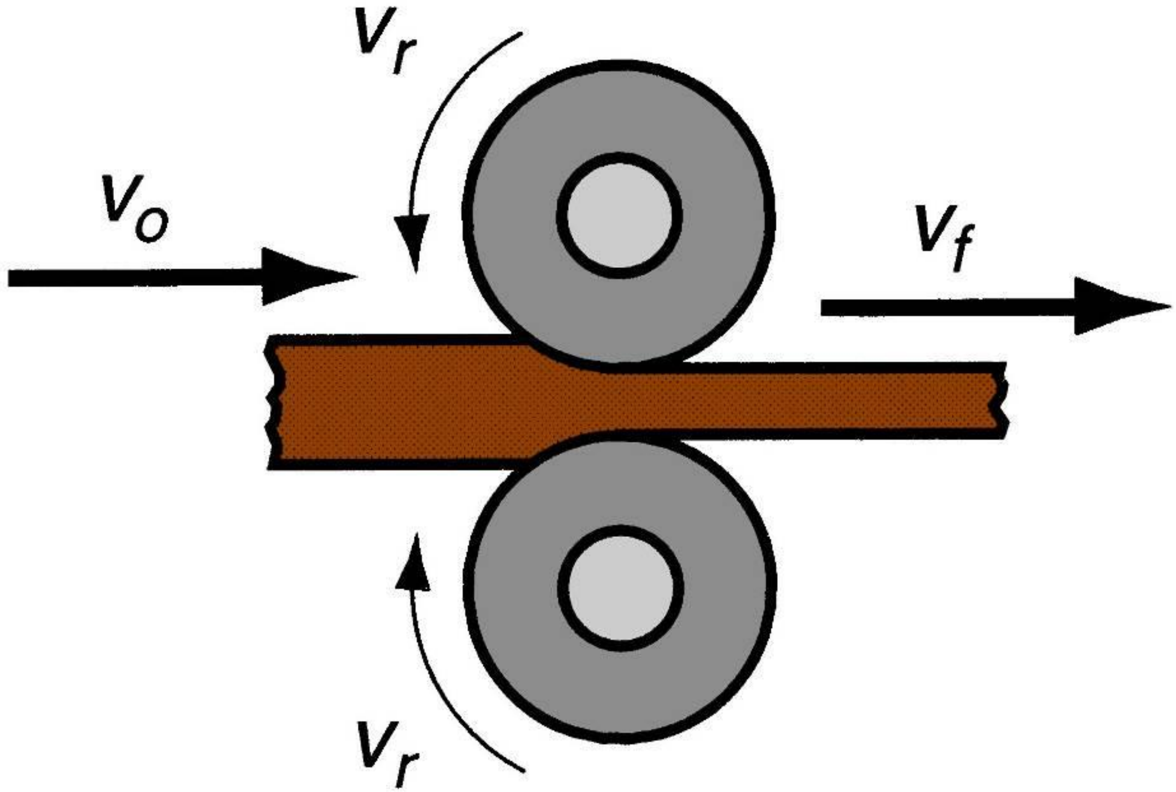
- Roll Piercing is a specialized hot working process for making seamless thick-walled tubes.
- It utilizes two opposing rolls, and hence it is grouped with the rolling processes.



(1) ROLLING MILLS CONFIGURATIONS

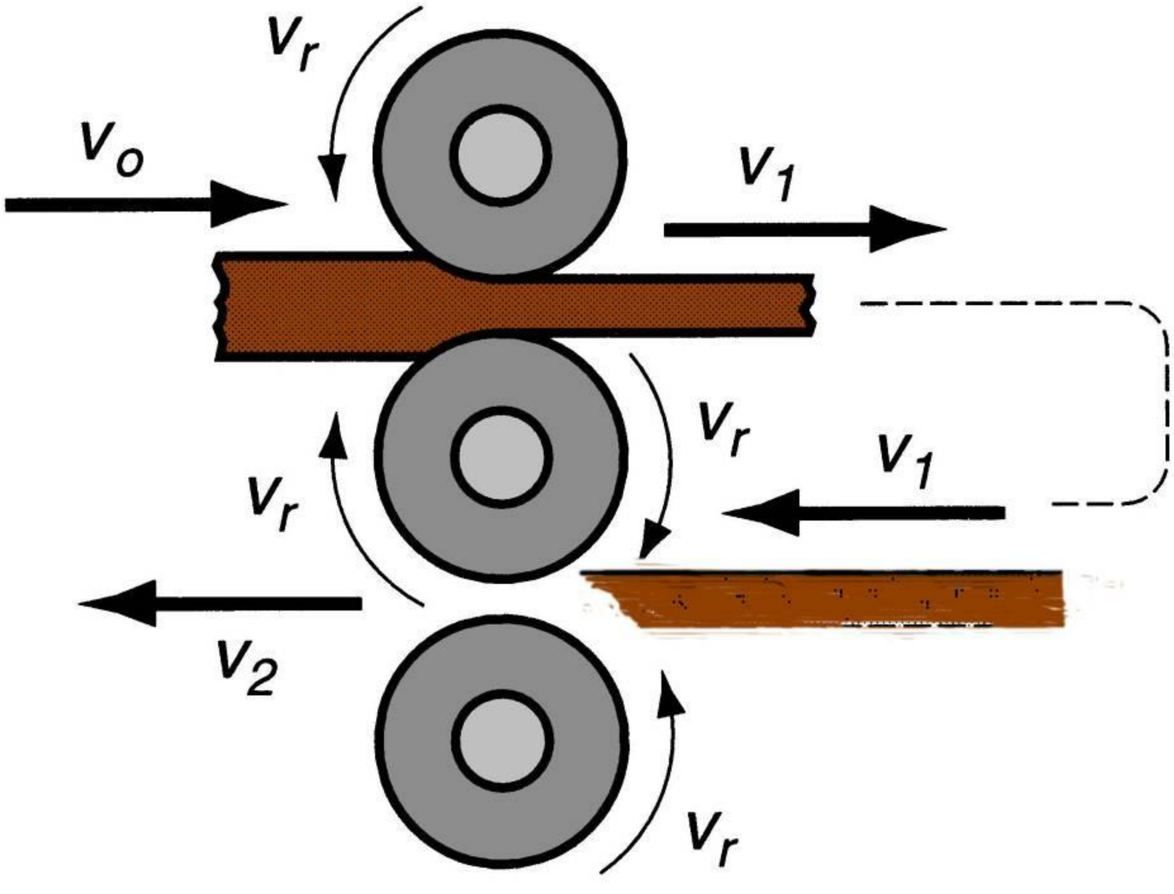
- Various rolling mill configurations are available to deal with the variety of applications and technical problems in the rolling process.
  - *Two-high* – two opposing rolls
  - *Three-high* – work passes through rolls in both directions
  - *Four-high* – backing rolls support smaller work rolls
  - *Cluster mill* – multiple backing rolls on smaller rolls
  - *Tandem rolling mill* – sequence of two-high mills

(1.a) Two-High Rolling Mill



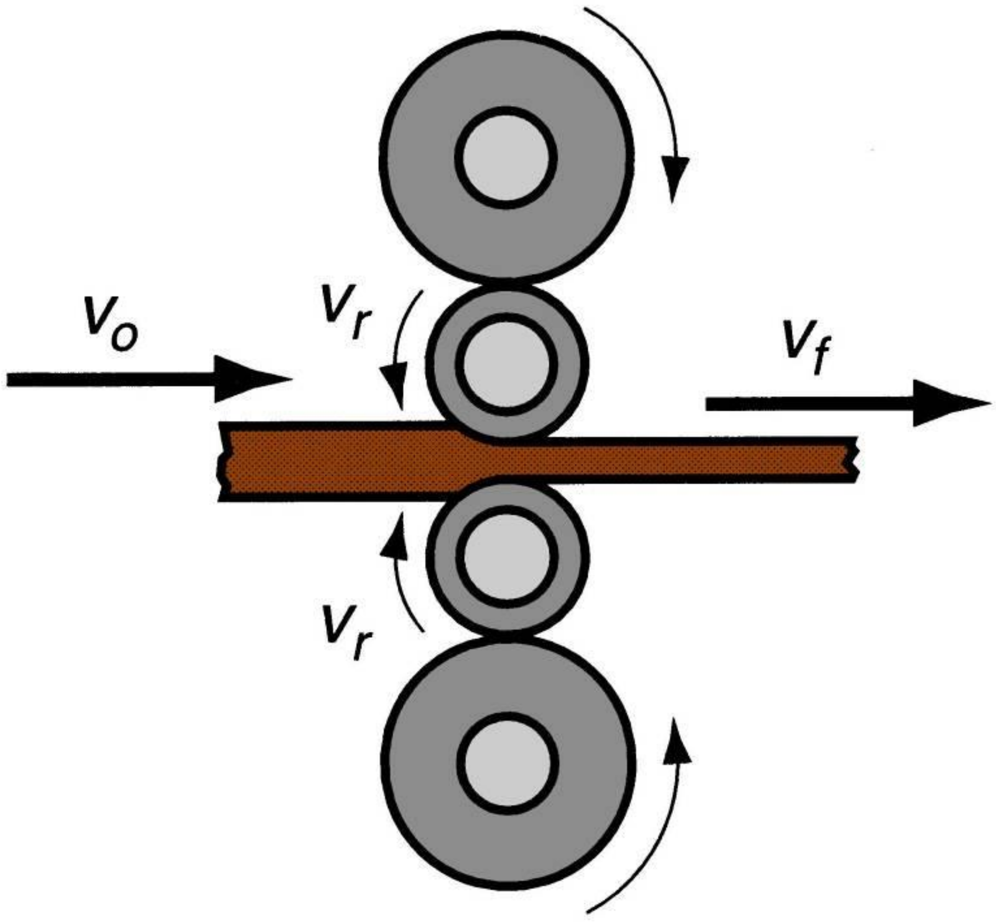
(a)

(1.b) Three-High Rolling Mill



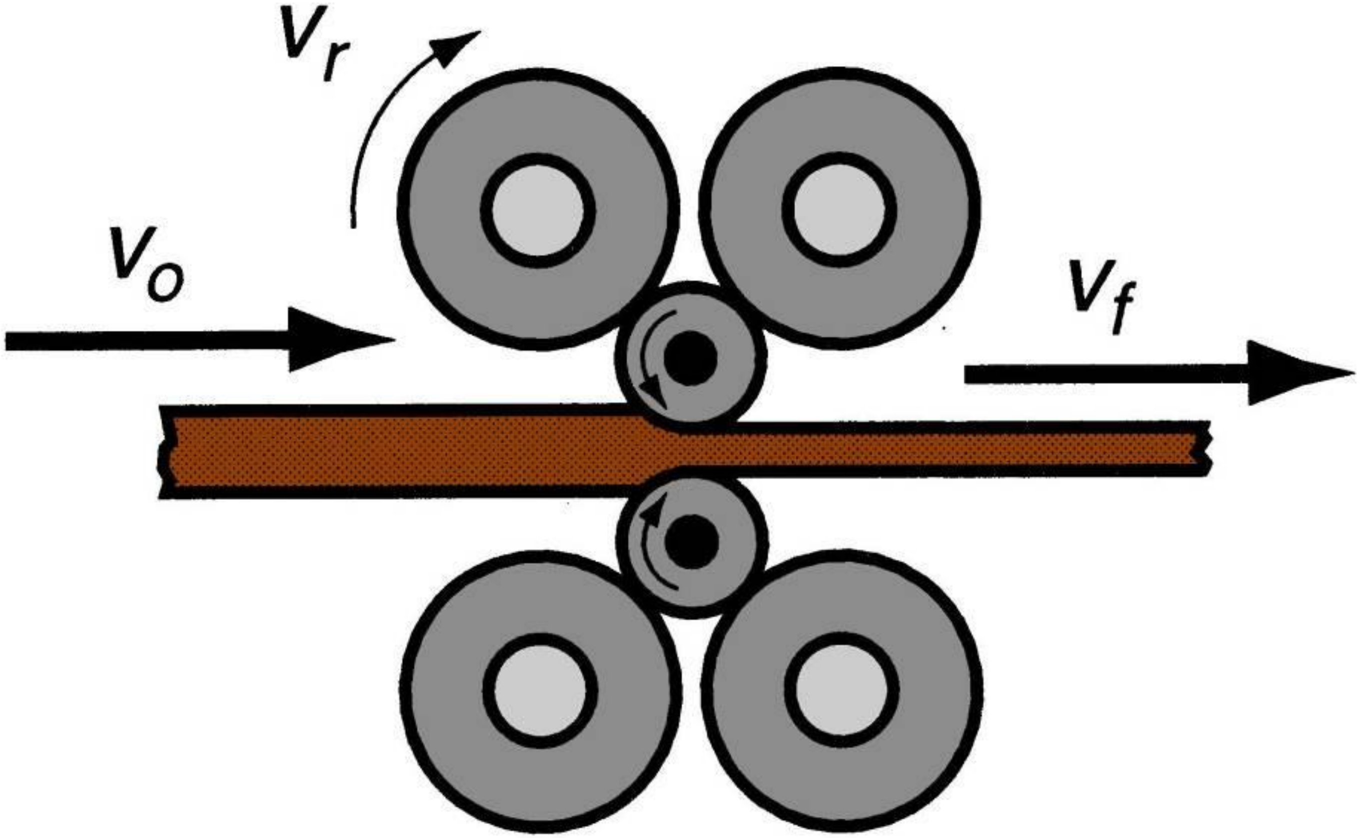
(b)

(1.c) Four-High Rolling Mill



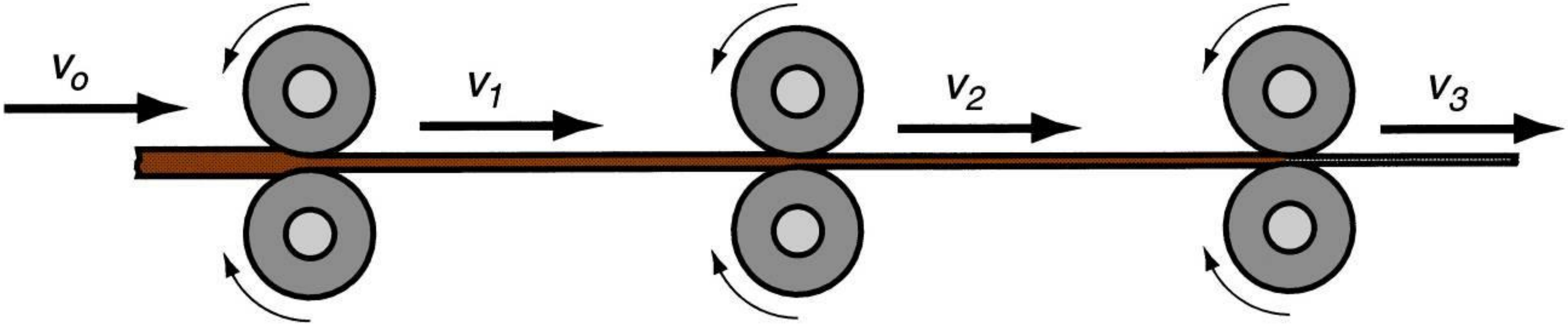
(c)

(1.d) Cluster Mill



(d)

(1.e) Tandem Rolling Mill



(e)

FLAT ROLLING ANALYSIS

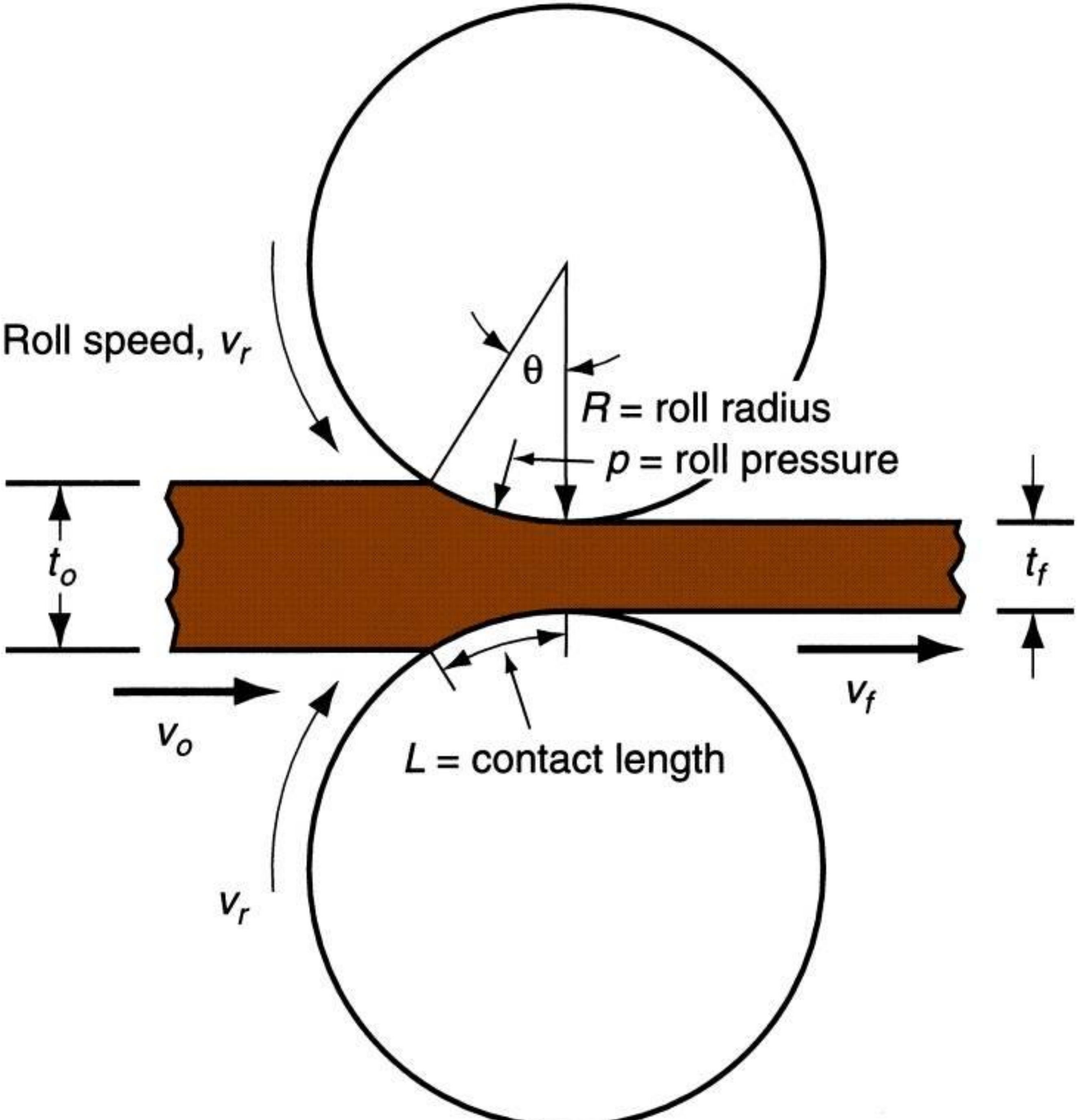
- In flat rolling, the work is squeezed between two rolls so that its thickness is reduced by an amount called the ***DRAFT***:

$$d = t_o - t_f \qquad \textbf{(1)}$$

d = draft, mm

t_o = starting thickness, mm

t_f = final thickness, mm



Roll speed, v_r
θ
R = roll radius
p = roll pressure
t_o
t_f
v_o
v_f
L = contact length
v_r

FLAT ROLLING ANALYSIS

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

$$t_o w_o L_o = t_f w_f L_f \qquad (2)$$

w_o and w_f are the before and after work widths, mm

L_o and L_f are the before and after work lengths, mm

FLAT ROLLING ANALYSIS

- Similarly, before and after volume rates of material flow must be the same, so ***the before and after velocities*** can be related

$$t_o w_o v_o = t_f w_f v_f \qquad \textbf{(3)}$$

v_o and v_f are the entering and exiting velocities of the work.

FLAT ROLLING ANALYSIS

- The rolls contact the work along an arc defined by the angle θ.
- Each roll has radius R , and its rotational speed gives it a surface velocity v_r .
- This velocity is greater than the entering speed of the work v_o and less than its exiting speed v_f .
- Since the metal flow is continuous, there is a gradual change in velocity of the work between the rolls.

FLAT ROLLING ANALYSIS

- However, there is ***one point*** along the arc where ***work velocity equals roll velocity***.
- This is called the ***no-slip point***, also known as the ***neutral point***.
- On either side of this point, slipping and friction occur between roll and work.

FLAT ROLLING ANALYSIS

- 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 as

$$s = \frac{v_f - v_r}{v_r} \qquad (4)$$

v_f = final (exiting) work velocity, m/s

v_r = roll speed, m/s

FLAT ROLLING ANALYSIS

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

$$\boxed{d_{max} = \mu^2 R} \qquad (5)$$

d_{max} = maximum draft, mm

μ = coefficient of friction

R = roll radius mm

FLAT ROLLING ANALYSIS

- The roll ***force F*** required to maintain separation between the two rolls is given by:

$$F = \sigma w L \qquad (6)$$

σ = average flow stress, N/mm²

$w L$ = roll-work contact area, mm²

FLAT ROLLING ANALYSIS

- ***Contact length*** can be approximated by

$$L = \sqrt{R(t_o - t_f)} \qquad \textbf{(7)}$$

FLAT ROLLING ANALYSIS

- ***Torque for each roll is***

$$T = 0.5\,FL \qquad \textbf{(8)}$$

FLAT ROLLING ANALYSIS

- The ***power required to drive each roll*** is

$$P = 2\pi NT \qquad (9)$$

FLAT ROLLING NUMERICAL 1

- A ***40 mm*** thick plate is to be reduced to ***30 mm*** in one pass in a rolling operation. ***Entrance speed = 16 m/min***. ***Roll radius = 300 mm***, and ***rotational speed = 18.5 m/min***. Determine: (a) the minimum required coefficient of friction that would make this rolling operation possible, (b) exit velocity under the assumption that the plate widens by 2% during the operation, and (c) forward slip.

FLAT ROLLING NUMERICAL 1

- t_o = ***40 mm***
- t_f = ***30 mm***.
- v_o = ***16 m/min***.
- R = ***300 mm***
- ***rotational speed = 18.5 m/min***.
- plate ***widens by 2%*** during the operation

FLAT ROLLING NUMERICAL 1

(a) Maximum draft $\boxed{d_{max} = \mu^2 R}$ **(5)**

Given that $d = t_o - t_f = 40 - 30 = 10$ mm,

$\mu^2 = 10/300 = 0.0333$

$\mu = (0.0333)^{0.5} = \mathbf{0.1826}$

FLAT ROLLING NUMERICAL 1

(b) Plate widens by 2%.

$$\boxed{t_o w_o v_o = t_f w_f v_f} \qquad \textbf{(3)}$$

$$w_f = 1.02\ w_o$$

$$40(w_o)(16) = 30(1.02 w_o) v_f$$

$$v_f = 40(w_o)(16) / 30(1.02 w_o)$$

$$= 640/30.6 = \mathbf{20.915\ m/min}$$

FLAT ROLLING NUMERICAL 1

(c) $\boxed{s = (v_f - v_r)/v_r}$ **(4)**

$= (20.915 - 18.5)/18.5 = \mathbf{0.13}$

FLAT ROLLING NUMERICAL 2

- A ***2.0 in thick*** slab is ***10.0 in wide*** and ***12.0 ft*** long. Thickness is to be reduced in ***three steps*** in a hot rolling operation. ***Each step*** will reduce the slab to ***25%*** of its previous thickness. It is expected that for this metal and reduction, the slab will ***widen by 3%*** in each step. If the entry speed of the slab in the first step is ***40 ft/min***, and ***roll speed is the same for the three steps***, determine: (a) length and (b) exit velocity of the slab after the final reduction.

FLAT ROLLING NUMERICAL 2

- t_o = ***2 in***
- w_o = ***10 in***.
- L_o = ***12 ft***.
- ***Each step*** will reduce the slab to ***25%*** of its previous thickness
- ***widen by 3%*** in each step
- v_o = ***40 ft/min (same for the three steps)***

FLAT ROLLING NUMERICAL 2

(a) After three passes,

$$t_f = (0.75)(0.75)(0.75)(2.0)$$

$$= 0.844 \text{ in.}$$

$$w_f = (1.03)(1.03)(1.03)(10.0)$$

$$= 10.927 \text{ in.}$$

FLAT ROLLING NUMERICAL 2

$$\boxed{t_o w_o L_o = t_f w_f L_f} \qquad (2)$$

$$(2.0)(10.0)(12 \text{ x } 12) = (0.844)(10.927)L_f$$

$$L_f = 312.3 \text{ in.} = \mathbf{26.025\ ft}$$

FLAT ROLLING NUMERICAL 2

(b) *Given that entry speed is the same at all three steps*

$$t_o w_o v_o = t_f w_f v_f \qquad \textbf{(3)}$$

Step 1

$$v_f = (2.0)(10.0)(40)/(0.75 \text{ x } 2.0)(1.03 \text{ x } 10.0)$$

$$v_f = 51.78 \text{ ft/min.}$$

FLAT ROLLING NUMERICAL 2

Step 2

$$v_f = (0.75 \text{ x } 2.0)(1.03 \text{ x } 10.0)(40)/(0.75^2 \text{ x } 2.0)(1.03^2 \text{ x } 10.0)$$

$$v_f = 51.78 \text{ ft/min.}$$

FLAT ROLLING NUMERICAL 2

Step 3

$$v_f = (0.75^2 \times 2.0)(1.03^2 \times 10.0)(40)/(0.75^3 \times 2.0)(1.03^3 \times 10.0)$$

$$v_f = 51.78 \text{ ft/min.}$$

FLAT ROLLING NUMERICAL 3

- A series of cold rolling operations are to be used to reduce the thickness of a plate from ***50 mm down to 25 mm*** in a reversing two-high mill. ***Roll diameter = 700 mm*** and ***coefficient of friction*** between rolls and work = ***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?

FLAT ROLLING NUMERICAL 3

- t_o = ***50 mm***
- t_f = ***25 mm***.
- R = ***700/2 mm = 350 mm***
- μ = ***0.15***
- ***draft is to be equal on each pass***.

FLAT ROLLING NUMERICAL 3

(a) Maximum draft $d_{max} = \mu^2 R$

$$= (0.15)^2 (350) = 7.875 \text{ mm}$$

Minimum number of passes = $(t_o - t_f)/d_{max}$

$= (50 - 25)/7.875 = \mathbf{3.17 \rightarrow 4\ passes}$

(b) Draft per pass $d = (50 - 25)/4 =$ **6.25 mm**