Rolling

Is a deformation process in which the thickness of the work is reduced by compressive forces exerted by two opposing rolls. The rolls rotate as illustrated in Figure (1) to pull and simultaneously squeeze the work between them. The basic process shown in our figure is flat rolling, used to reduce the thickness of a rectangular cross section. 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.

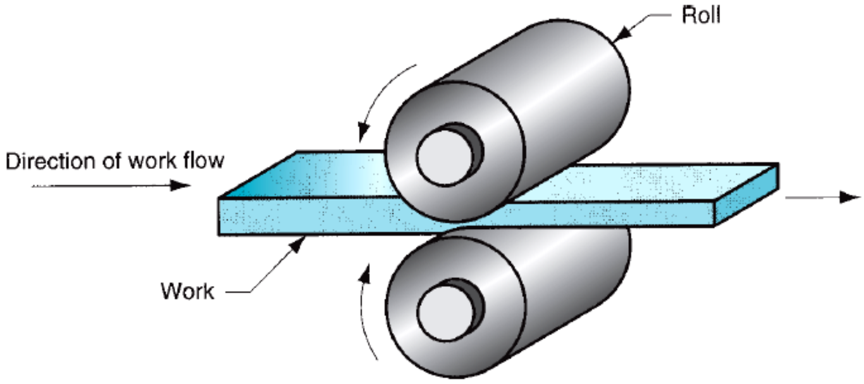

FIGURE (1) The rolling process (specifically, flat rolling).

The ingot is moved to the rolling mill, where it is rolled into one of three intermediate shapes called ***blooms, billets***, or ***slabs***.

Bloom has a square cross section 150 mm x150 mm or larger. Blooms are rolled into structural shapes and rails for railroad tracks.

Slab is rolled from an ingot or a bloom and has a rectangular cross section of width 250mm or more and thickness 40 mm or more. Slabs are rolled into plates, sheets, and strips.

Billet is rolled from a bloom and is square with dimensions 40mm on a side or larger. Billets are rolled into bars and rods. These shapes are the raw materials for machining, wire drawing, forging, and other metalworking processes.

These intermediate shapes are subsequently rolled into final product shapes. Hot-rolled plates are used in shipbuilding, bridges, boilers, welded structures for various heavy machines, tubes and pipes, and many other products. Figure (2) shows some of these rolled steel products.

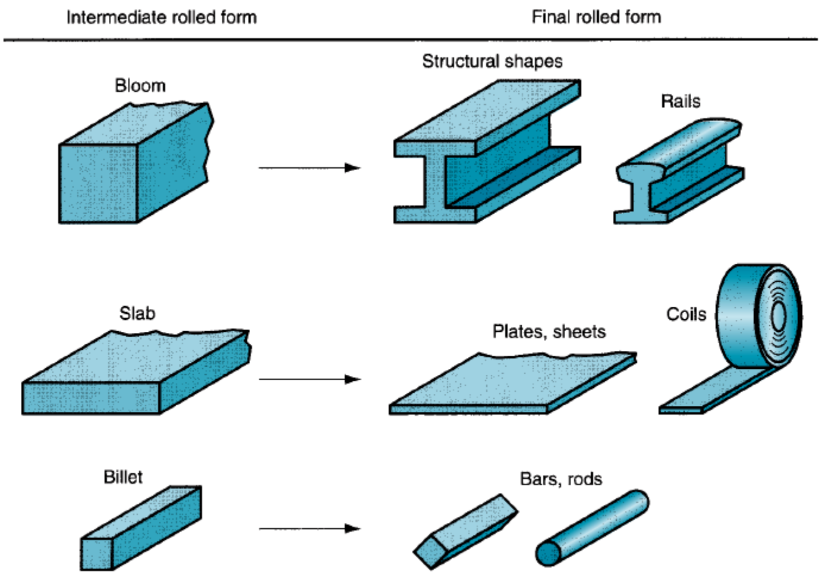

FIGURE (2) Some of the steel products made in a rolling mill.

FLAT ROLLING AND ITS ANALYSIS

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

$$d = t_o - t_f \quad \ldots\ldots\ldots\ldots\ldots\ldots 1$$

where d : draft, mm

t_o : starting thickness (mm)

t_f : final thickness (mm)

reduction:

$$r = d/t_o \quad \ldots\ldots\ldots\ldots 2$$

the volume of metal exiting the rolls equals the volume entering

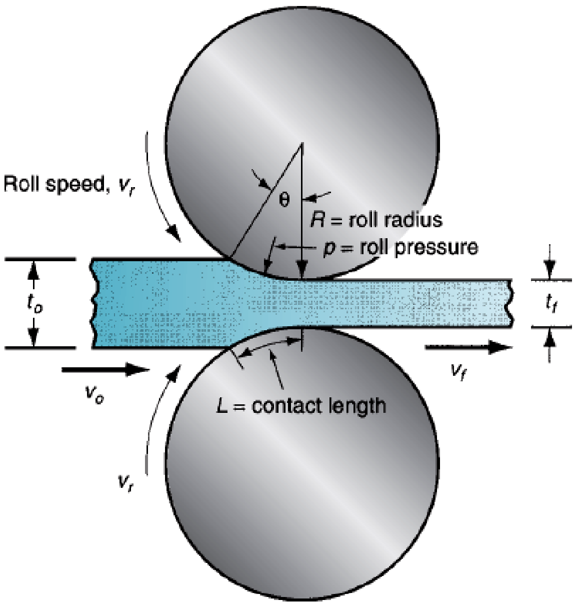

FIGURE (3) Side view of flat rolling, indicating before and after thicknesses, work velocities, angle of contact with rolls, and other features.

$$t_o\, w_o\, L_o = t_f\, w_f\, L_f \quad \ldots\ldots\ldots 3$$

where

w_o and w_f are the before and afterwork widths (mm)

L_o and L_f are the before and after work lengths (mm)

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

$$t_o\, w_o\, v_o = t_f\;\; w_f\;\; v_f \quad \ldots\ldots\ldots\ldots\ldots\ldots 4$$

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:

$$s = \frac{v_f - v_r}{v_r} \quad \text{.................... 5}$$

where

S : forward slip; ***V*$_f$** : final (exiting) work velocity, m/s ***V*$_r$** : roll speed m/s.

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

$$\epsilon = \ln\frac{t_o}{t_f} \quad \text{........................ 6}$$

The true strain can be used to determine the average flow stress Y_f applied to the work material in flat rolling.

$$\overline{Y}_f = \frac{K\epsilon^n}{1+n} \quad \text{..................7}$$

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

$$d_{max} = \mu^2 R \quad \text{.................. 8}$$

where: d_{max}= maximum draft (mm), μ = coefficient of friction and R= roll radius (mm).

Coefficient of friction in rolling depends on lubrication, work material, and working temperature. In cold rolling, the value is around 0.1; in warm working, a typical value is around 0.2; and in hot rolling, μ is around 0.4.

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 3) over the roll-work contact area. This can be expressed:

$$F = w\int_0^L p\,dL \quad \text{........................ 9}$$

Where: F = rolling force (N); w = the width of the work being rolled (mm); p =roll pressure (MPa); and L = length of contact between rolls and work (mm).

An approximation of the results obtained by Eq. (9) can be calculated based on the average flow stress experienced by the work material in the roll gap. That is,

$$F = \overline{Y}_f w L \quad \ldots\ldots\ldots\ldots\ldots\ldots 10$$

Where: $\overline{Y}_f$ = average flow stress from Eq. (7) MPa ; and the product wL is the roll-work contact area (mm^2) . Contact length can be approximated by

$$L = \sqrt{R(t_o - t_f)} \quad \ldots\ldots\ldots\ldots 11$$

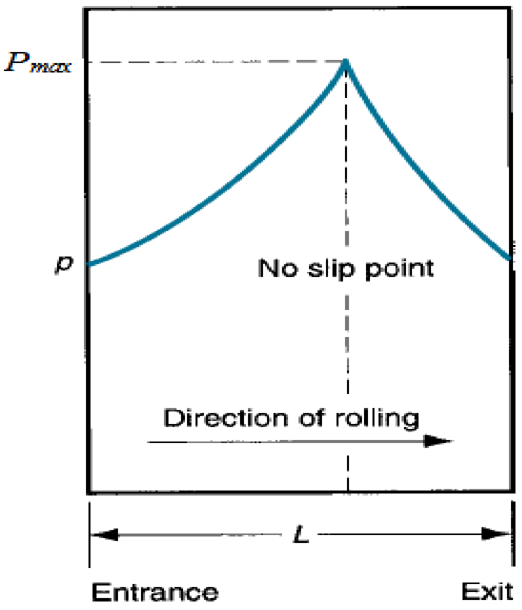

FIGURE (4): Typical variation in pressure along the contact length in flat rolling. The peak pressure is located at the neutral point. The area beneath the curve, representing the integration in Eq. (9), is the roll force F.

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

$$T = 0.5\,FL \quad \ldots\ldots\ldots\ldots\ldots\ldots 12$$

The power required to drive each roll is the product of torque and angular velocity. Angular velocity is 2πN, where N = rotational speed of the roll. Thus, the power for each roll is 2πNT. Substituting Eq. (12) for torque in this expression for power, and doubling the value to account for the fact that a rolling mill consists of two powered rolls, we get the following expression:

$$P = 2\pi N F L \quad \ldots\ldots\ldots\ldots\ldots\ldots 13$$

Where: P = power (J/s) ; N = rotational speed, 1/s (rev/min); F = rolling force (N) and L = contact length (m).

Example (1) Flat Rolling

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

$d = 25 - 22 = 3$ mm

From Eq. (19.8), the maximum possible draft for the given coefficient of friction is

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

Since the maximum allowable draft exceeds the attempted reduction, the rolling operation is feasible. To compute rolling force, we need the contact length L and the average flow stress $\overline{Y}_f$. 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):

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

It can be seen from this example that large forces and power are required in rolling. Inspection of Eqs. (10) and (13) indicates that force and/or power to roll a strip of a given width and work material can be reduced by any of the following:

(1) Reducing the draft in each pass.
(2) Using a smaller roll radius R to reduce force.
(3) Using a lower rolling speed N to reduce power.
(4) Using hot rolling rather than cold rolling to reduce strength and strain hardening (K and n) of the work material.