# Analysis of strip rolling - 2:

R. Chandramouli

Associate Dean-Research

SASTRA University, Thanjavur-613 401

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# 1.Analysis of strip rolling - 2:

## *1.1 Simplified analysis:*

The parameters which influence the rolling process are: roll diameter, friction, material flow stress, temperature of working etc.

Without considering friction, we can get the rolling load, approximately, from the material flow stress and the area of contact between roll and strip.

Roll pressure p = $\overline{\boldsymbol{Y_f}}$ -------------------- **9**

Where $\overline{\boldsymbol{Y_f}}$ is average flow stress in plane strain compression.

It is given as: $\overline{\boldsymbol{Y_f}} = \frac{2}{\sqrt{3}}\boldsymbol{Y}$ ------------------ **10**

Here Y is yield strength of the material

Rolling load F is now written as:

F = $\overline{\boldsymbol{Y_f}}\, \boldsymbol{Lp}\, \boldsymbol{w_m} = \overline{\boldsymbol{Y_f}}\sqrt{\boldsymbol{R\Delta h}}\boldsymbol{w_m}$-------------------------- 11

$w_m$is the average width of the strip

We have assumed that the area over which the roll force is acting is the projected area of the arc of contact. Moreover, the above equation is for a single roll.

As we see from the above equation, the roll force increases with increase in roll radius or increase in reduction of thickness of the strip ($\Delta\boldsymbol{h}$).

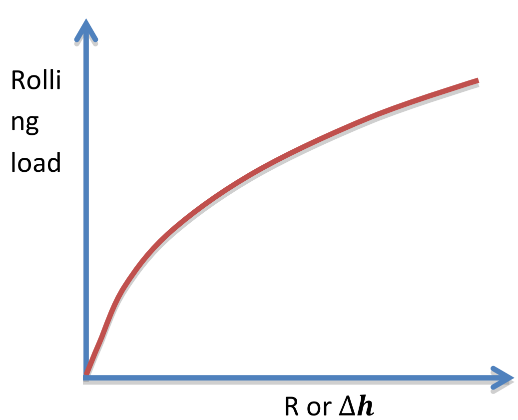

**Fig. 1.1.1: Variation of rolling load with roll dia or strip thickness reduction**

Alternatively, we can write the average flow stress based on true strain during rolling. For a material which obeys power law relation between plastic stress and strain, in the form: $\sigma = k\,\varepsilon^n$, average flow stress, $Y'_f$ is given by:

$\boldsymbol{Y'_f = \frac{K\varepsilon^n}{1+n}}$ ------------------- **12**

The true strain in rolling is given as:

$\varepsilon = ln\frac{h_o}{h_f}$ ---------- 13

Now, roll force F = $\boldsymbol{Y'_f L_p w_m}$ --------------------**14**

The above equation is based on the assumption that the material work hardens. In cold rolling, the work material gets work hardened considerably. Therefore, the above equation is more appropriate for cold rolling. The mean flow stress is determined from plane strain compression test, which is discussed in earlier module. It is assumed that the rolls do not undergo elastic deformation.

## *1.2 Slab analysis of strip rolling with friction – another approximate method:*

Consider the rolling of a strip of initial thickness ho. The interface between the roll and work has sliding friction with constant coefficient of friction. We assume that the roll pressure is constant over the arc of contact.The strain on the work material is plane strain – no strain in width direction. Further, we assume that there is no elastic deformation of work and also, the deformation of work is homogeneous.

To apply the slab analysis to the rolling processes, we assume that the rolling is plane strain compression process. Further, the contact surface between roll and work piece is equal to the projected area of the arc of contact.

Further, we approximate the deformation zone as a rectangular shape, instead of conical shape and apply the analysis for plane strain compression.

Assume that the deformation volume of the work piece is in the form of rectangular prism of width $L_p$, height $\bar{h} =$ ($h_o$+$h_f$)/2 and depth unity, as shown in figure

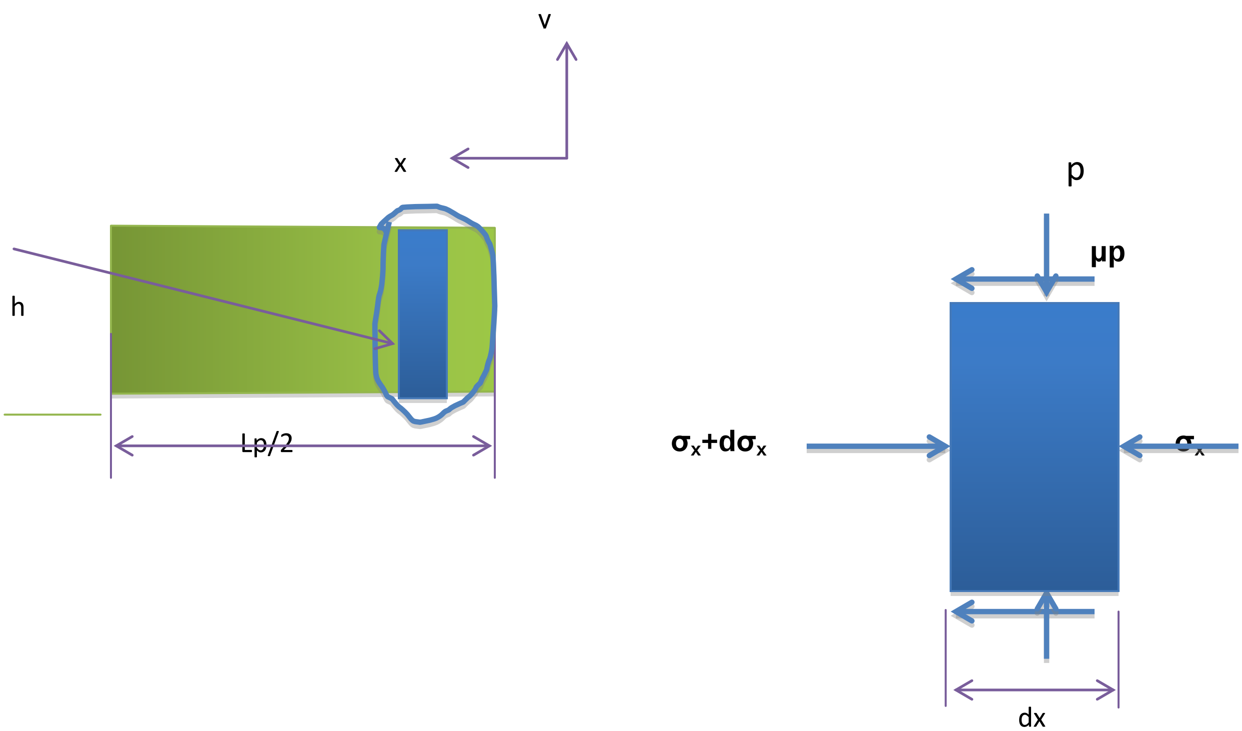


**Fig. 1.2.1: Stresses acting on elemental strip under plane strain rolling**

Consider an elemental strip of width dx, height h and depth of unity. The various stresses acting on the element are as shown in figure.

p is roll pressure, **μp**isthe shear stress due to friction, $\sigma_x$ is normal stress acting on the outward face of the element, $\sigma_x + d\sigma_x$ is the stress acting on inner face of the element.

Writing the force balance along the x axis,

$-(\sigma_x + d\sigma_x)h + \sigma_x h = 2\mu p dx$ ---------------------------15

$d\sigma_x h = -2\mu p dx$ -------------------------------16

Applying the Tresca yield criterion, assuming that p and $\sigma_x$ are principal stresses,

$\sigma_x + p = Y' \rightarrow \sigma_x = -p + Y'$, --------------------17

where Y' is plane strain flow stress which is given by:

Y' = $\frac{2}{\sqrt{3}}Y$

Note: we have taken p as negative here

And also we have: $d\sigma_x = dp$ ------------------18

Substituting equation into equation we have:

$\frac{dp}{p} = \frac{2\mu dx}{h}$ -----------19

On integration we get:

ln p = $\frac{2\mu x}{h} + A$ --------------------20

To solve for the constant A, we can apply the boundary condition:

AT x = 0, $\sigma_x = 0$ and from Tresca criterion, we have:

p = Y' at x=0

Applying this in equation 20 we get: A = ln(Y')

Substituting the expression for A in equation we get:

ln(p/Y') = $\frac{2\mu x}{h}$ Or $\frac{p}{Y'} = e^{\frac{2\mu x}{h}}$ ------------------------------21

To get average pressure we can write:

$\bar{p}$ = $\frac{2}{L_p}\int_0^{\frac{L_p}{2}} pdx$, Because: $\frac{\bar{p}L_p}{2} = \int_0^{\frac{L_p}{2}} pdx$

Substituting for p from equation 21 and integrating we get:

$$\frac{\bar{p}}{Y'} = \frac{\bar{h}}{\mu L_p}(e^{\frac{\mu L_p}{\bar{h}}} - 1)$$ --------------------22

The above equation gives the approximate average rolling pressure for plane strain rolling process, neglecting the curvature of the strip as it passes between the rolls.

The rolling load can be determined from the equation 22 by noting that the area of contact is taken as projected length of contact multiplied by the depth of the work piece.

From the above equation we understand that the rolling load increases with reduction in the height h of the work or increasing in rill diameter. Below a certain minimum height of the strip( below a critical thinning), the rolling load increases to very high value, because the resistance of the sheet increases to very high values. As a result, we may not be able to roll the sheet. Instead the sheet just gets pushed in between rolls, without appreciable reduction in thickness. In order to roll thin sheets, we can use rolls of smaller diameter, backed up by large diameter rolls. Also we understand that the length of arc of contact decreases with roll radius.

Please note that as the coefficient of friction increases, the rolling load also increases.

Example: A 35 mm thick steel slab is hot rolled using a 900 mm roll. There is a reduction of 40% on the thickness. The coefficient of friction is 0.5. The material flow stress increases from 200 MPa at the entrance of the rolls to 280 MPa at the exit. What is the rolling load calculated by the approximate method of analysis? Assume a constant width of 800 mm for the slab. Roll flattening can be ignored.

Solution: Equation 22 gives the average rolling pressure

$$\frac{\bar{p}}{Y'} = \frac{\bar{h}}{\mu L_p}\left(e^{\frac{\mu L_p}{\bar{h}}} - 1\right)$$

Let us take Y’ as average of the flow stress at exit and entry.

Y’ = 240 MPa

(ho-hf)/ho = 0.4 Therefore, hf = 21 mm

$\bar{h}$= (21+35)/2 = 28 mm

Lp = projected arc length = $\sqrt{R\Delta h}$ = 112.25 mm

Average roll pressure = 205.73 MPa

Rolling force = 205.73X112.25X800 = 18.5 MN