Hot rolling and rolling defects

1. Hot rolling and rolling defects:

1.1 Front and back tensions:

We have seen that the rolling load is dependent on roll diameter, higher the roll dia, higher the roll force. Similarly, smaller reductions requires lower roll force. In order to reduce the roll force, we can reduce roll diameter, or reducing the friction. Another method of reducing rolling force is to apply a small tensile force on the strip. Application of tensile force longitudinally reduces the compressive yield strength of the material in the transverse direction. This is apparent from the Tresca yield criterion.

In rolling, tensile force in longitudinal direction is applied at the entry section through a feeder oruncoiler with braking system. Forward tension is applied at the exit section through the coiler by controlling the torque on it. Back tension can be included with the roll pressure at entry section as followed:

For entry zone: p = $(Y' - \sigma_b)\frac{h}{h_o}e^{\mu(Ho-H)}$ ------5.1

For section between neutral section and exit p = $(Y' - \sigma_f)\frac{h}{h_f}e^{\mu H}$ -----------5.2

As a result of application of front tension or back tension, the neutral point is shifted forward or backward. Front tension leads to shift of the neutral point forward, whereas, application of back tension shifts the neutral point backward. Application of both forward and back tensions reduce the total roll force. Hence the torque and power for rolling get reduced.

The figure below exhibits the effects of front and back tension on rolling pressure:

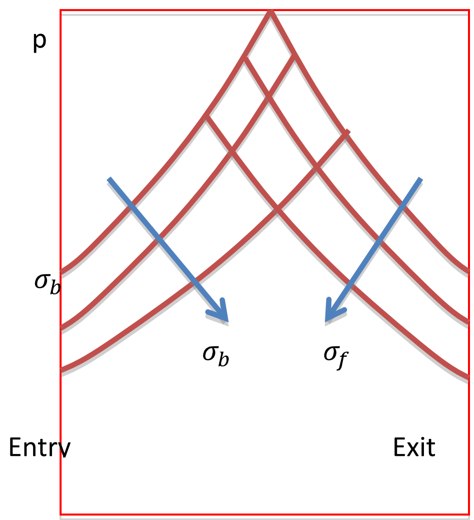


Fig. 1.1.1: Effect of front and back tensions on rolling load

1.2 Rolling force in hot rolling:

Material flow in hot rolling is less homogeneous. Strain rate also affects the flow stress of the material. Further, friction conditions are rather unpredictable. Friction coefficient in hot rolling may be high – ranges from 0.2 to 0.7. Strain rate in hot rolling can be found out from the expression:

$\dot{\varepsilon}$ = ln($\frac{h_0}{h_f}$) / time -------------- 5.3

Time can be writtenas : L/V, where V is velocity of roll, L is projected arc length.

Therefore, $\dot{\varepsilon}$ = (V/L)ln($\frac{h_0}{h_f}$) = (V/$\sqrt{R\Delta h}$)ln($\frac{h_0}{h_f}$) ------------------- 5.4

From flow curve we can determine the flow stress for the corresponding strain rate.

1.3 Total roll force:

Roll force is equal to roll pressure multiplied by area of contact between roll and work.

F = $\int_0^{\theta_n} pwRd\theta + \int_{\theta_n}^{\alpha} pwRd\theta$ ------------------------5.5

If friction is ignored, we can write an approximate expression for roll force as:

F = Lw$\overline{Y'}$ ---------------5.6

With friction:

F = Lw$\overline{Y'}$(1+$\frac{\mu L}{2h_{av}}$) ------5.7

Where, $h_{av}$is given by: (h_o+h_f)/2

1.4 Roll torque and power:

Roll torque can be estimated from the rolling force. Torque is equal to force multiplied by the radius at which the force acts.

We can assume that the roll force is acting perpendicular to the strip at a radius equal to one half of the projected arc length of contact.

For each roll, the torque is: T = FL/2

Roll power is given by:

Power = 2πNT ------------5.8

Torque can be more accurately determined from:

T = $\int_0^{\theta_n} pwR^2d\theta - \int_{\theta_n}^{\alpha} pwR^2d\theta$ --------------5.9

Here the minus sign is due to the fact that the friction force acts against the rolling direction beyond the neutral section. Total roll torque consists of the rolling torque plus the torque required to overcome friction in roll bearings plus torque at motor shaft plus torque for overcoming friction in transmission system.

Roll power is applied in order to deform the work material, to overcome friction in rotating parts etc.

1.5 Roll deflection and roll flattening:

Due to roll force, the rolls are subjected to deflection and they bend resulting in larger thickness at the centre of the rolled sheet and the edge being thinner. This defect is known as crown and camber. In order to avoid this rolls are given a slight curvature on surface by grinding so that the centre of the rolls has higher diameter than the edges. This is called cambering of rolls. The bulged rolls, when subjected to bending during rolling will produce flat sheets. For sheet rolling, normally camber of 0.5 mm on roll diameter is provided. Also during hot rolling, rolls get heated up and bulge out at the center, causing camber of the rolls. This is due to temperature variation between edges and the center of rolls. Roll camber has to be varied during rolling in order to take care of roll camber due to both thermal effects and roll deflection. This also avoids uneven roll wear – rolls wear more at edges than at center.

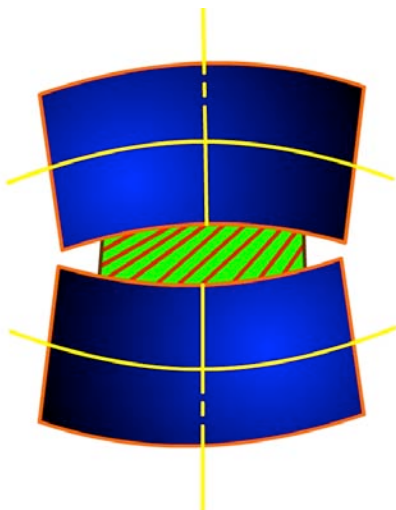


Fig. 1.5.1: Roll bending

Roll camber can be varied by 1] bending the work rolls by applying external force. 2] Shifting of work rolls laterally with respect to centerline of the strip, 3] using shaped rolls – rolls with profiles, 4] Rotation of the axis of the work roll with respect to axis of backup roll in horizontal plane – results in deflection of work roll ends, producing camber.

Roll flattening: There is increase in radius of curvature of rolls due to the roll pressure which causes elastic deformation of rolls. This is known as roll flattening. Roll flattening leads to increase in contact length and hence an increase in roll force. The distorted roll radius is given by:

R' = $R[1 + \frac{Cp'}{b(h_o - h_f)}]$ -------------5.10

C = $16(1-\upsilon^2)/\pi E$. C = 2.16×10^{-11} Pa^{-1} for steel

P' is roll pressure with flattened roll. Higher the Young's modulus of the roll material, the lower is roll flattening.

The above equation requires iteration. While calculating rolling force, the value of flattened roll radius R' has to be considered.

1.6 Spread:

Spread refers to the increase in width of rolled strips of low width to thickness ratios – square sectioned strips for example. Reducing the friction, increasing the roll radius to strip thickness ratio and using wider strips can reduce the roll spread. The spread given by w_o=w_f is given as:

$\Delta w = 1.15 \frac{\Delta h}{2h_o}[L - \frac{\Delta h}{2\mu}]$ ----5.11

Or in general, Δw= $w_o[e^{F\ ln(\frac{wf}{w1})} - 1]$ -------------5.12

A pair of vertical rolls called edger rolls can be used to reduce spread.

Lubrication:

Oils, soap emulsions, fatty acids are used as lubricants during hot rolling non-ferrous metals. Mineral oils, paraffin, fatty acids are used for cold rolling. Normally, foe ferrous alloys no lubricant is used.

1.7 Rolling mill control:

Production of continuous sheets and strips is one of the attractive features of modern rolling mills. However, control of sheet thickness and cross-section is a real challenge. In order to continuously monitor the thickness of sheets rolled, x-ray or gamma ray sensors are used. Precise control of gage of rolled sheets can be done by adjusting the roll gap. The following section explains the control.

Characteristic curves are drawn for the rolling process as shown below:

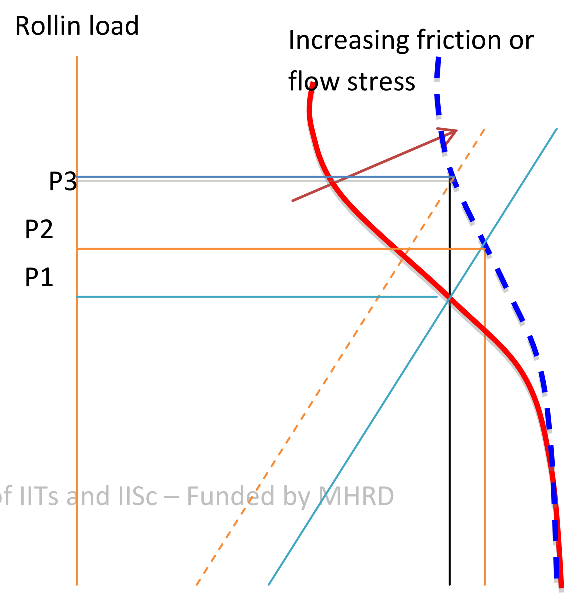


Fig. 1.7.1: Rolling mill control

From the above curves, we could understand the control of rolling mill. The solid curve, called plastic curve, represents the variation of rolling load with rolled thickness. As thickness reduces, roll force increases. This was shown earlier. The solid line represents the elastic deformation of the roll. The point of intersection of the solid curve and solid line on x axis represents the final rolled thickness obtained. The corresponding y axis value gives the rolling load. If for some reason, the friction coefficient increases. The plastic curve gets shifted to the right, as shown by dotted curve. As a result, without any control present, the final strip thickness increases to hf2 and the rolling load increases to p2. In order to maintain the thickness at hf1, the roll gap has to be reduced by shifting the elastic curve leftward. This is shown by the dotted straight line. Reducing the roll gap increases the roll pressure to p3. Gage control in multiple rolling mills is achieved through measurement of strip thickness using x-ray gage and adjusting the strip tension using feedback control system.

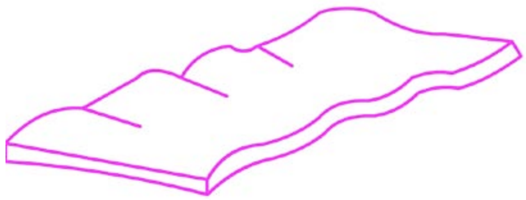
1.8 Rolling defects:

Mill spring is a defect in which the rolled sheet is thicker than the required thickness because, the rolls get deflected by high rolling forces. Elastic deformation of the mill takes place. If we use stiffer rolls, namely roll material of high stiffness or elastic constant, we could avoid mill spring. Normally elastic constant for mills may range from 1 to 4 GNm^{-1}.

Roll elastic deformation may result in uneven sheet thickness across. Roll material should have high elastic modulus for reducing the roll deformation. For producing very thin gage sheets like foils, small diameter rolls are used. They are supported with larger rolls. We can say the minimum thickness of rolled sheets achieved is directly proportional to roll radius, friction, flow stress.

Flatness of rolled sheets depends on the roll deflection. Sheets become wavy as roll deflection occurs.

If rolls are elastically deflected, the rolled sheets become thin along the edge, whereas at centre, the thickness is higher. Similarly, deflected rolls result in longer edges than the centre. Edges of the sheet elongate more than the centre. Due to continuity of the sheet, we could say that the centre is subjected to tension, while edges are subjected to compression. This leads to waviness along edges. Along the centre zipper cracks occur due to high tensile stress there. Cambering of rolls can prevent such defects. However, one camber works out only for a particular roll force.



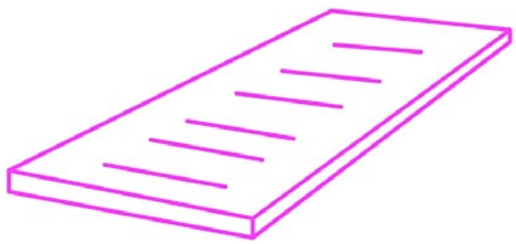


Fig 1.8.1:Wavy edge **Fig. 1.8.2: Zipper cracks**

In order to correct roll deflection for a range of rolling conditions, hydraulic jacks are used, which control the elastic deformation of rolls according to requirement.

Fig. 1.8.3: Centre crackFig. 5.8.4: Edge cracks

If rolls have excess convexity then the center of the sheet metal will have more elongation than the edges. This leads to a defect called centre buckle.

Fig. 1.8.5: Edge defect due to heavy reduction

Small thickness sheets are more sensitive to roll gap defects leading to greater defects. Thin strips are more likely to undergo waviness or buckling. These defects are corrected by doing roller leveling or stretch leveling under tension. Stretch leveling is carried out between roller leveler rolls.

During rolling the sheet will have a tendency to deform in lateral direction. Friction is high at the centre. Therefore, spread is the least at the centre. This leads to rounding of ends of the sheet. The edges of the sheet are subjected to tensile deformation . This leads to edge cracks. If the center of the sheet is severely restrained and subjected to excess tensile stress, center split may happen.

Non-homogeneous material deformation across the thickness leads to high secondary tensile stress along edge. This leads to edge cracks. Secondary tensile stresses is due to bulging of free surface. Edge cracks can be avoided by using edge rolls.

Due to non homogeneous flow of material across the thickness of the sheet, another defect called allegatoring occurs. This is due to the fact that the surface is subjected to tensile deformation and centre to compressive deformation. This is because greater spread of material occurs at center.

5.9 Residual stress in rolling:

Compressive stress is induced on the surface of rolled product if small diameter rolls are used or if smaller reductions are affected during rolling. Stress in the bulk of the strip is tensile in the above case. Larger reductions or rolling using large diameter rolls leads to tensile stress on the skin and compressive stress in the bulk of the metal. Stress relieving operation can be used to relieve the residual stresses of rolled products.

Source:
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