Mechanical Working of Metals.

Tutorial 1.

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Q.1 →

For cold rolling :-

$h_0 = 300\,mm \quad \mu = 0.08 \quad D = 2R = 600\,mm \quad \therefore R = 300\,mm.$

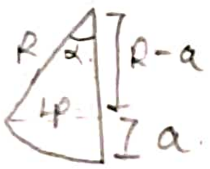
$$\therefore \Delta h_{max} = \mu^2 R$$
$$= (0.08)^2 \times 300$$
$$= 1.92\,mm.$$

For Hot rolling :-

$h_0 = 300\,mm \quad \mu = 0.5 \quad R = 300\,mm.$

$$\therefore \Delta h_{max} = \mu^2 R = 75\,mm.$$

Q.2 →



$$L_p^2 + (R-a)^2 = R^2$$
$$L_p^2 + \cancel{R^2} + a^2 - 2aR = \cancel{R^2}$$
$$\therefore L_p^2 = 2aR - a^2 \quad (\text{since } a \ll 1 \;\; a^2 \to 0)$$
$$\therefore L_p^2 = 2aR.$$

Also $\Delta h = h_0 - h_f = 2a \Rightarrow \therefore L_p = \sqrt{R\Delta h}.$

From Roll Bite condⁿ :-

$$\mu = \tan\alpha = \frac{L_p}{R-a} \simeq \frac{\sqrt{R\Delta h}}{R - \frac{\Delta h}{2}} \approx \sqrt{\frac{\Delta h}{R}}$$

$$\therefore \mu^2 \simeq \frac{\Delta h}{R} \quad \therefore \Delta h \simeq \mu^2 R.$$

$\therefore$ For cold rolling $\Delta h \simeq \mu^2 R = (0.08)^2 \times \underbrace{R}_{300\,mm} = 1.92\,mm.$

$\therefore$ For Hot rolling $\Delta h \simeq \mu^2 R \simeq (0.5)^2 \times 300 = 75\,mm.$

Q.3

$\rightarrow$ $\Delta h = h_o - h_f = 200 - 100 = 100 mm$.

(a) $\alpha = 60°$

$\therefore \tan\alpha = \sqrt{\frac{\Delta h}{R}}$ $\therefore$ $R = \frac{\Delta h}{\tan^2\alpha} = \frac{100}{\tan^2 60} = 33.33 mm$.

(b) $\alpha = 70°$

$R = \frac{100}{\tan^2 70} = 13.24 mm$

(c) $\alpha = 80°$

$R = 3.109 mm$.

Q.4

$\rightarrow$ $h_o = 250 mm$.

(a) $D = 300 mm$ $\therefore R = 150 mm$, $\mu = 0.3$.

$\therefore \Delta h_{max} = h_o - h_f = \mu^2 R = 13.5 mm$.

$\therefore h_f = 250 - 13.5 = 236.5$.

(b) $D = 400 mm$ $\therefore R = 200 mm$ $\mu = 0.4$.

$\therefore \Delta h_{max} = 32 mm$.

$\therefore h_f = 218 mm$.

(c) $D = 500 mm$ $\therefore R = 250 mm$ $\mu = 0.45$

$\therefore \Delta h_{max} = 50.625 mm$.

$\therefore h_f = 199.375 mm$.

(d) $D = 600 mm$ $\therefore R = 300 mm$ $\mu = 0.5$

$\therefore \Delta h_{max} = 75 mm$.

$\therefore h_f = 175 mm$.

Q.5

$b = 100\ mm$, $p = 200 MPa$.

$\therefore P = p \times b \times L_p$. $L_p = \sqrt{R \Delta h}$.

Rolling Load.

(a) $D = 300mm$ $R = 150mm$ $\mu = 0.3$, $\Delta h = 13.5$

$$\therefore P = 200\ MPa \times 100mm \times \sqrt{150 \times 13.5\ mm^2}$$

$$= 200 \times 10^6 \times \frac{N}{m^2} \times 4500 \cdot mm^2.$$

$$= \frac{200 \times 10^6 \times 4500}{10^6} N.$$

$$= \underline{\underline{9 \times 10^5\ N}}$$

(b) $D = 400mm$ $\therefore R = 200\ mm$ $\mu = 0.4$. $\Delta h = 32.mm.$

$$\therefore P = 200\ MPa. \times 100\ mm \sqrt{200 \times 32\ mm^2}$$

$$= 1.6\ Mega\ N. = 1.6 \times 10^6\ N.$$

(c) $D = 500mm$ $\therefore R = 250mm$ $\mu = 0.45$ $\Delta h = 50.625$

$$\therefore P = 200 \times 100 \sqrt{250 \times 50.625}$$

$$= 2.25 \times 10^6\ N.$$

(d) $R = 300\ mm$ $\Delta h = 75\ mm$ $\therefore P = 200 \times 100 \sqrt{300 \times 75} = 3 \times 10^6 N$

Q.6 Back Tension $(\sigma_h) = 50 MPa$. , $p = 200\ MPa$.

New load,

$$\therefore P' = (p - \sigma_h) \times b\ L_p \quad L_p = \sqrt{R \Delta h}$$

(a) $D = 300\ mm$ $R = 150\ mm$ $\mu = 0.3$ $\Delta h = 13.5$.

$$P' = 150 \times 100 \times \sqrt{150 \times 13.5} = 6.75 \times 10^5\ N.$$

$\therefore$ Decrement of Load

$= 9 \times 10^5 - 6.75 \times 10^5 = 2.25 \times 10^5\ N.$

(b) $D = 400\ mm$ $\therefore R = 200\ mm.$ $\mu = 0.4$ $\Delta h = 32\ mm.$

$p' = 150 \times 100 \sqrt{200 \times 32.}$

$= 1.2 \times 10^6\ N.$

$\therefore$ Decrement of Load $= (1.6 - 1.2) \times 10^6\ N = 0.4 \times 10^6\ N.$

(c) $D = 500\ mm$ $R = 250\ mm$ $\mu = 0.45$ $\Delta h = 50.625.$

$\therefore p' = 150 \times 100 \sqrt{250 \times 50.625}$

$= 1.68 \times 10^6\ N$

$\therefore$ Decrement of Load $= (2.25 - 1.68) \times 10^6 = 0.57 \times 10^6\ N.$

(d) $R = 300\ mm$ $\Delta h = 75\ mm.$

$\therefore p' = 150 \times 100 \sqrt{300 \times 75}$

$= 2.25 \times 10^6\ N.$

$\therefore$ Decrement of Load $= (3 - 2.25) \times 10^6 = 0.75 \times 10^6\ N.$

Q.7.

$\rightarrow$ Roll Flattening :-

$$\underbrace{R'}_{R+25mm} = R\left(1 + \frac{c\,P'}{\underbrace{b}_{100mm}\,(h_0 - h_f)}\right)$$

new load.

$c = 2.16 \times 10^{-11}\ Pa^{-1}$ (for steel rolls).

(a) $R = 150$ mm $\mu = 0.3$ $\Delta h = 13.5$ mm.

$$\therefore 175 = 150\left(1 + \frac{2.16 \times 10^{-11} \times P'}{100 \times 13.5 \times 10^{-6}}\right)$$

$$\therefore P' = 104.16 \times 10^{5}\ N = 10.416 \times 10^{6}\ N.$$

Change in Rolling load :- (without σ_n).

Extra load required

$$= 104.16 \times 10^{5} - \underbrace{9 \times 10^{5}}_{\text{from (Q.5)}} = 95.16 \times 10^{5}\ N.$$

~~Change in Rolling Load :- (with σ_n).~~

$$\cancel{= 104.16 \times 10^{5} - \underbrace{6.75 \times 10^{5}}_{\text{from (Q.6)}} = 97.41 \times 10^{5}\ N.}$$

(b) $R = 200$ mm $\mu = 0.4$ $\Delta h = 32$ mm.

$$\therefore 225 = 200\left(1 + \frac{2.16 \times 10^{-11} \times P'}{100 \times 32 \times 10^{-6}}\right)$$

$$\therefore P' = 18.5 \times 10^{6}\ N.$$

$\therefore$ Change in rolling load (without σ_n)

$= 18.5 \times 10^6 - 1.6 \times 10^6 = 16.9 \times 10^6$ N.

~~$\therefore$ Change in rolling load (with σ_n)~~

~~$= (18.5 - 1.2) \times 10^6 = 17.3 \times 10^6$ N.~~

(c.) R = 250 mm $\Delta h = 50.625$.

$$\therefore 275 = 250 \left(1 + \frac{2.16 \times 10^{-11} \times P'}{100 \times 50.625 \times 10^{-6}}\right)$$

$\therefore \quad P' = 23.4 \times 10^6$ N.

$\therefore$ Change in rolling load (without σ_n).

$= 23.4 \times 10^6 - 2.25 \times 10^6 = 21.15 \times 10^6$ N.

~~$\therefore$ Change in rolling load (with σ_n).~~

~~$= (23.4 - 1.68) \times 10^6 = 21.72 \times 10^6$ N.~~

(d) R = 300 mm $\Delta h = 75$ mm.

$$\therefore 325 = 300 \left(1 + \frac{2.16 \times 10^{-11} \times P'}{100 \times 75 \times 10^{-6}}\right)$$

$\therefore \quad P' = 28.93 \times 10^6$ N

$\therefore$ Change in Rolling load (without σ_n)

$= (28.93 - 3) \times 10^6 = 25.93 \times 10^6$ N.

~~$\therefore$ Change in Rolling Load (with σ_n)~~

~~$= (28.93 - 0.75) \times 10^6 = 28.18 \times 10^6$ N.~~

Q.8

$\rightarrow$ $h_{min} = \dfrac{\mu R \bar{\sigma}_0'}{12.8}$ (R in meter, $\bar{\sigma}_0' \to 200$ MPa.)

(a) $R = 150$ mm $\mu = 0.3$ $\therefore$ ~~$h_{min} = \dfrac{150 \times 0.3 \times 200}{12.8 \times 10}$~~

$\therefore R = 0.15$ m. ~~$= 703.125$ mm.~~

$h_{min} = \dfrac{0.3 \times 0.15 \times 200}{12.8}$

$= 0.703.$

(b) $R = 200\text{mm} = 0.2\text{m}$, $\mu = 0.4$.

$\therefore h_{min} = \dfrac{0.4 \times 0.2 \times 200}{12.8} = 1.25$

(c) $R = 250\text{mm} = 0.25\text{m}$ $\mu = 0.45$.

$\therefore h_{min} = \dfrac{0.45 \times 0.25 \times 200}{12.8} = 1.75$

(d) $R = 300\text{ mm} = 0.3\text{ m}$ $\mu = 0.5$

$\therefore h_{min} = \dfrac{0.5 \times 0.3 \times 200}{12.8} = 2.34$

Q.9

$\rightarrow$ $P = \dfrac{2}{\sqrt{3}} \bar{\sigma}_0 \left[\dfrac{1}{Q} (e^{Q} - 1) \right) b \sqrt{R \Delta h}$).

($\bar{\sigma}_0 \to$ 200 MPa, $\Delta h \to$ 100 mm.)

$Q = \dfrac{\mu L_p}{h}$ ($L_p \to \sqrt{R \Delta h}$, $h \to \dfrac{h_0 + h_f}{2}$.)

(a) $R = 150$ mm $\mu = 0.3$. $\Delta h = 13.5$ mm.

$\therefore p' = \frac{2}{\sqrt{3}} \times 200$ $\quad Q = \frac{\mu L_p}{\bar{h}} = \frac{0.3 \times \sqrt{150 \times 13.5}}{\left(\frac{250 + 236.5}{2}\right)} = 0.055$

$\therefore p' = \frac{2}{\sqrt{3}} \times 200 \left[\frac{1}{0.055}(e^{0.055} - 1) \times 100 \times \sqrt{150 \times 13.5}\right]$

$= 1.06 \times 10^6$ N.

~~(b) $R = 200$ mm $\mu = 0.4$ $\Delta h = \cancel{50.625 \text{ mm}} = 32$ mm~~

~~$\therefore Q = \frac{0.4 \times \sqrt{200 \times \cancel{50.625}}}{\left(\frac{250 + 218}{2}\right)} = 0.17$~~ ~~32 mm.~~

~~$\therefore p' = \frac{2}{\sqrt{3}} \times 200 \left[\frac{1}{0.17}(e^{0.17} - 1) \times 100 \sqrt{200 \times 50.625}\right)$~~

~~$p' = 2.53 \times 10^6$ N.~~

~~(c) $R = 250$ mm $\mu = 0.45$ $\Delta h = 50.62$.~~

(b) $R = 200$ mm $\mu = 0.4$ $\Delta h = 32$ mm.

$\therefore Q = \frac{0.4 \sqrt{200 \times 32}}{\left(\frac{250 + 218}{2}\right)} = 0.136$.

$$\therefore p' = \frac{2}{\sqrt{3}} \times 200 \left[\frac{1}{0.136} \cdot (e^{0.136} - 1) \times 100 \times \sqrt{200 \times 32} \right]$$

$$= 1.97 \times 10^6 \, N.$$

(c.) $R = 250$. $\mu = 0.45$ $\Delta h = 50.625$. $h_f = 199.375$.

$$\therefore Q = \frac{\cancel{\mu}\, 0.45 \times \sqrt{250 \times 50.625}}{\left(\frac{250 + 199.375}{2} \right)} = 0.225$$

$$\therefore p' = \frac{2}{\sqrt{3}} \times 200 \left[\frac{1}{0.225} (e^{0.225} - 1) \times 100 \sqrt{250 \times 50.625} \right]$$

$$= 2.91 \times 10^6 \, N.$$

(d.) $R = 300\,mm$ $\mu = 0.5$ $\Delta h = 75\,mm$.

$$\therefore Q = \frac{0.5 \sqrt{300 \times 75}}{\left(\frac{250 + 175}{2} \right)} = 0.35$$

$$\therefore p' = \frac{2}{\sqrt{3}} \times 200 \left[\frac{1}{0.35} (e^{0.35} - 1) \times 100 \sqrt{300 \times 75} \right]$$

$$= 4.14 \times 10^6 \, N.$$

Q.10

$\rightarrow$ $\sigma_h = 70\,MPa$. is applied.

$\therefore P = \frac{2}{\sqrt{3}} \underbrace{(\bar{\sigma}_0 - \sigma_h)}_{200\,MPa.} \left[\frac{1}{Q} (e^{Q} - 1) \times b \sqrt{R \times \Delta h} \right]$

where $Q = \frac{\mu L_p}{h}$.

$\therefore$ (a.) $R = 150\,mm$, $\mu = 0.3$, $\Delta h = 13.5$.

$Q = 0.055$.

$P = \frac{2}{\sqrt{3}} \times 130 \left[\frac{1}{0.055} \times (e^{0.055} - 1) \times 100 \times \sqrt{150 \times 13.5} \right]$

$= 0.689 \times 10^6\,N$.

(b.) $R = 200\,mm$, $\mu = 0.4$, $\Delta h = 32\,mm$.

$Q = 0.136$.

$\therefore P = \frac{2}{\sqrt{3}} \times 130 \left[\frac{1}{0.136} (e^{0.136} - 1) \times 100 \sqrt{200 \times 32} \right]$

$= 1.28 \times 10^6\,N$.

(c.) $R = 250\,mm$ $\mu = 0.45$ $Q = 0.225$

$\therefore P = \frac{2.91 \times 10^6}{200} \times 130 = 1.89 \times 10^6\,N$.

(d.) $R = 300\,mm$ $\mu = 0.5$ $Q = 0.35$ $P = \frac{4.14}{200} \times 130 \times 10^6 = 2.69 \times 10^6\,N$

Q.11

→ For 2 Rolls $M_T = 2Pa$.

& $\lambda = \frac{a}{\sqrt{R\Delta h}}$ $\lambda = 0.5$ (for H.T)
$\lambda = 0.45$ (for C.T).

(a) For $R = \cancel{200}\,150$ mm. $\mu = 0.3$ $\Delta h = 13.5$ mm.

For Hot Rolling.

$$Torque = 2 \times 1.06 \times 10^6 \times 0.5 \times \frac{\sqrt{150 \times 13.5}}{10^3}$$

$$= 47.7 \times 10^3 \text{ N.m}$$

For Cold rolling. → $Torque = 2 \times 1.06 \times 10^6 \times 0.45 \times \frac{\sqrt{150 \times 13.5}}{10^3}$

$$Torque = \frac{47.7 \times 10^3}{0.5} \times 0.45 = 42.93 \times 10^3 \text{ N.m}$$

(b) For $R = 200$ mm, $\mu = 0.4$ $\Delta h = 32$ mm.

For Hot cond^n.

$$Torque = 2 \times 1.97 \times 10^6 \times 0.5 \times \frac{\sqrt{200 \times 32}}{10^3}$$

$$= 157.6 \times 10^3 \text{ N.m}$$

For Cold Cond^n.

$$Torque = 141.84 \times 10^3 \text{ N.m}$$

(c) For. $R = 250$ $\mu = 0.45$ $\Delta h = 50.625$

For Hot ~~cold~~ condition

$$\text{Torque} = 2 \times 2.91 \times 10^6 \times 0.5 \times \sqrt{\frac{250 \times 50.625}{10^3}}$$

$$= 327.37 \times 10^3 \text{ N.m.}$$

For Cold condⁿ

$$\text{Torque} = 294.63 \times 10^3 \text{ N.m.}$$

(d.) for $R = 300mm$ $\mu = 0.5$ $\Delta h = 75mm.$

for Hot condⁿ

$$\text{Torque} = 2 \times 4.14 \times 10^6 \times 0.5 \times \sqrt{\frac{300 \times 75}{10^3}}$$

$$= 621 \times 10^3 \text{ N.m.}$$

For Cold Condⁿ

$$\text{Torque} = 558.9 \times 10^3 \text{ N.m.}$$

Q.12 $\text{Power} = 4 \cdot P \pi a \times N.$

N — 50 rpm → $\frac{50}{60}$ rev per sec

$= 0.833.$

(a) For. $R = 150mm$.

~~For~~ For Hot Condⁿ

$$\text{Power} = 2 \times 47.7 \times 10^3 \times 3.14 \times 0.833 = 249.53 \times 10^3 \text{ Watts.}$$

For Cold Cond^n

$$\text{Power} = 2 \times 42.93 \times 10^3 \times 3.14 \times 0.833$$

$$= 224.577 \times 10^3 \text{ Watts.}$$

(b.) For $R = 200$ mm.

~~For~~ Hot Cond^n.

Power =

$$= 2 \times 157.6 \times 10^3 \times 3.14 \times 0.833$$

$$= 824.4 \times 10^3 \text{ Watts.}$$

For Cold Cond^n

$$\text{Power} = 2 \times 141.84 \times 10^3 \times 3.14 \times 0.833$$

$$= 741.99 \times 10^3 \text{ Watts.}$$

(c.) For $R = 250$ mm.

For Hot Cond^n

$$\text{Power} = 2 \times 327.37 \times 10^3 \times 3.14 \times 0.833$$

$$= 1712.55 \times 10^3 \text{ W.}$$

For Cold Cond^n

$$\text{Power} = 2 \times 294.63 \times 10^3 \times 3.14 \times 0.833 = 1541.28 \times 10^3 \text{ W.}$$

(d.) For $R = 300$ mm.

For Hot Cond^n $\text{Power} = 2 \times 621 \times 10^3 \times 3.14 \times 0.833 = 3248.6 \text{ KW.}$

For Cold Cond^n $\text{Power} = 2 \times 558.9 \times 10^3 \times 3.14 \times 0.833 = 2923.7 \text{ KW.}$