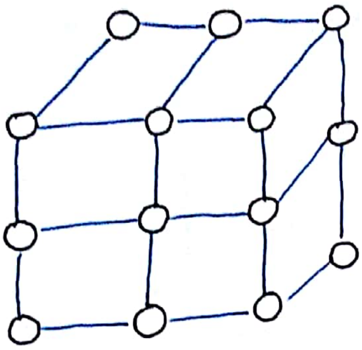
Crystal Structure



Unit cell
(smallest structure)

3 D Structure
↓
Space-lattice

a, b, c
α, β, γ → Type of unit cell

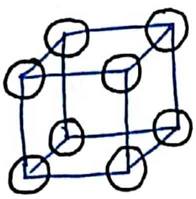
1. Triclinic
2. Mono-clinic
3. Orthorhombic
4. Rhombohedral
5. Tetragonal
6. Hexagonal
7. Cubic

Crystal systems

Crystal structure → No. of atoms present in a particular crystal system

Cubic [$a=b=c$; $\alpha=\beta=\gamma=90°$]

1. Simple Cubic

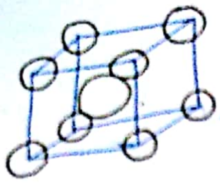


E.N.A. $\frac{1}{8} \times 8 = 1$

$$\text{Packing Factor} = \frac{\text{Vol. of atoms}}{\text{Vol. of unit cell}}$$

$$= \frac{\frac{4}{3}\pi r_a^3}{a^3}$$

Body-centred Cubic (bcc)

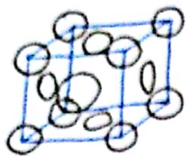


E.N.A. $= \frac{1}{8} \times 8 + 1 = 2$

$4r_a = d$ $\quad \sqrt{3}a = d$

$$\eta = \frac{2 \times \frac{4}{3}\pi r_a^3}{a^3} =$$

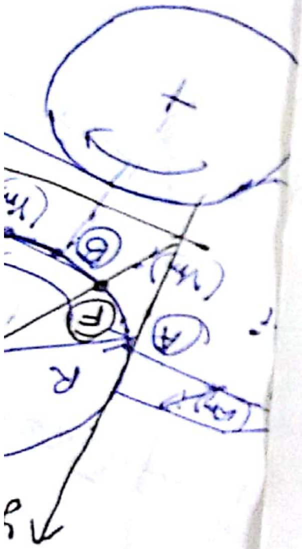
3. Face-centered Cubic (fcc)

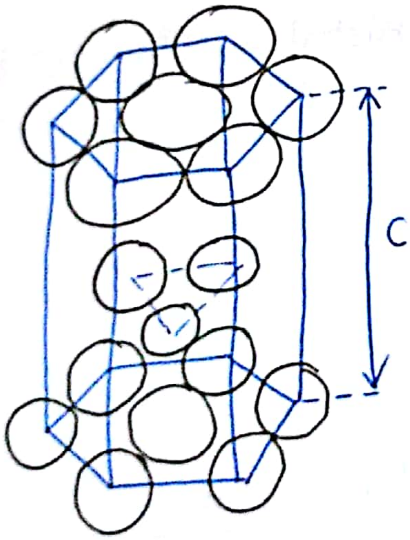


E.N.A. $= 8 \times \frac{1}{8} + \frac{1}{2} \times 6 = 4$

$4r_a = \sqrt{2}a$

$$\eta = \frac{4 \times \frac{4}{3}\pi r_a^3}{a^3} =$$





E.N.A. = 1 corner atom + 2 fac

+ 3 internal atoms =

Al, Cu $\rightarrow$ FCC

Fe $\rightarrow$ BCC $\downarrow\uparrow$ FCC

Ti $\rightarrow$ H

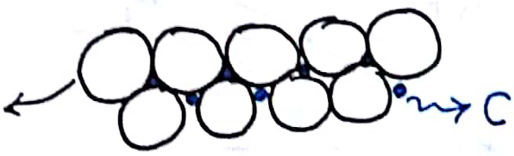
→ t

Alloy ≡ Solid Solution

Interstitial type (C-Fe alloy)

→ diameters are very diff. in size.

$r_C << r_{Fe}$

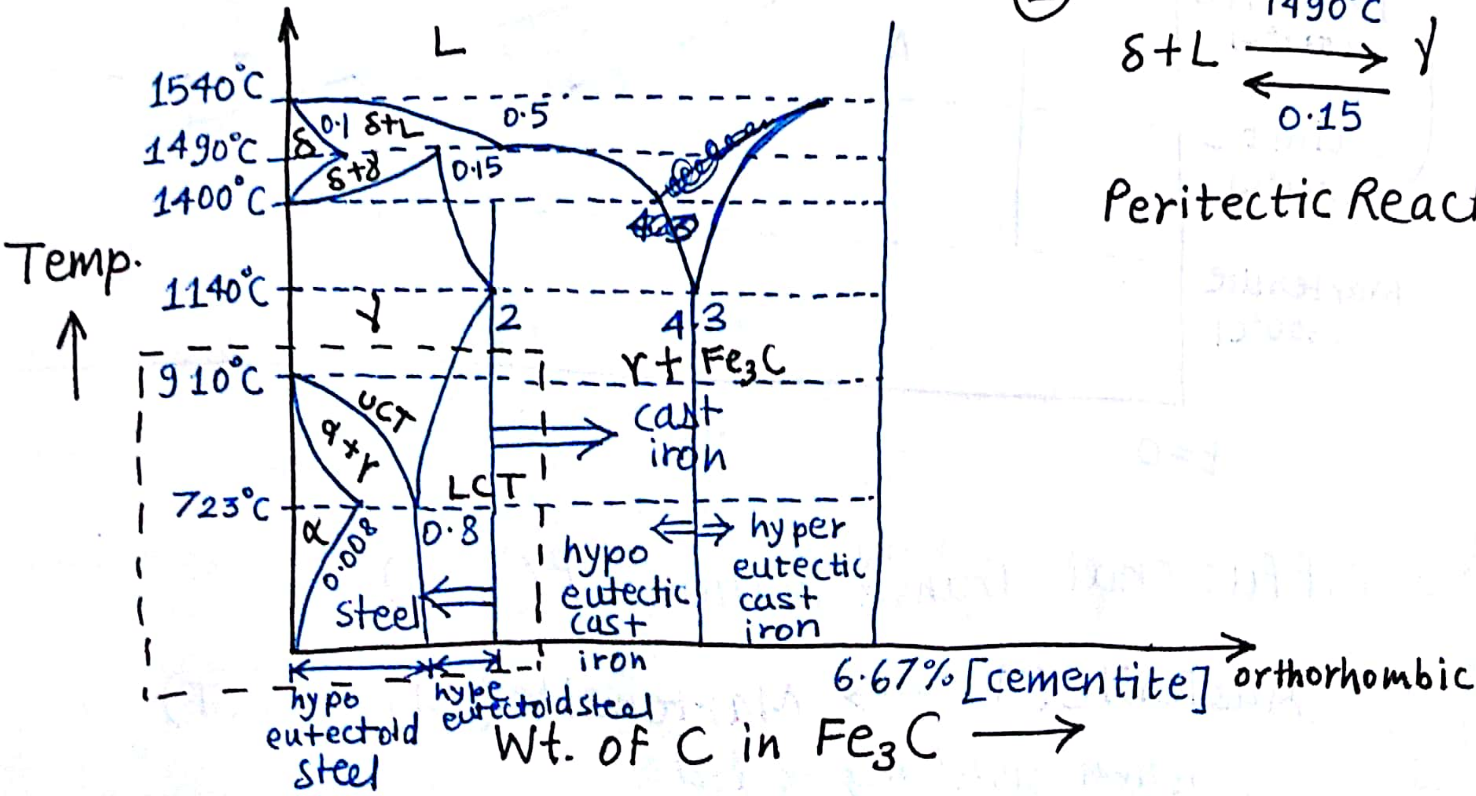


Substitute type (Cu-Zn alloy)

→ diameters are roughly of the same size

$r_{Cu} \approx r_{Zn}$

<u>diagram of Fe-Fe_3C :</u>



(1) $\delta + L \underset{0.15}{\overset{1490°C}{\rightleftharpoons}} \gamma$

Peritectic Reaction

$$L \underset{4.3\%}{\overset{1140^\circ C}{\rightleftharpoons}} \underbrace{\gamma + Fe_3C}_{\text{LEDEBURITE}}$$

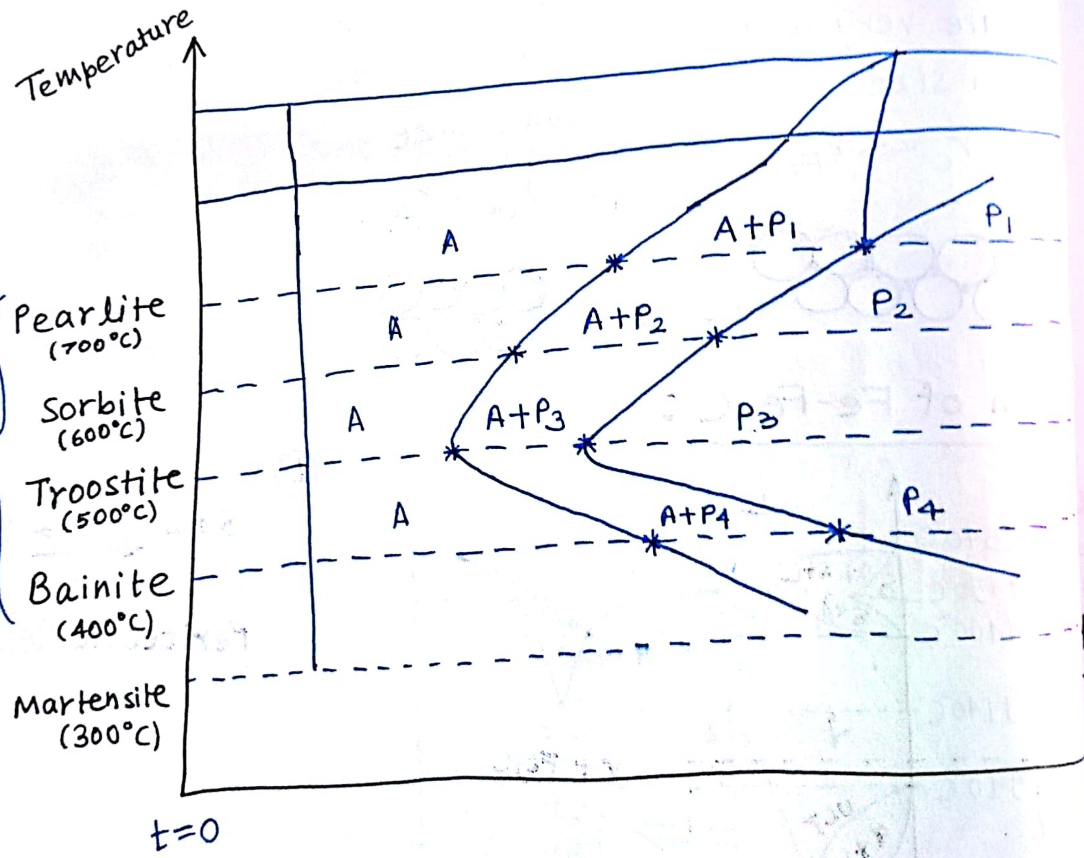
EUTECTIC REACTION

(bcc) $\alpha \Rightarrow$ FERRITE (softest)

(fcc) $\gamma \Rightarrow$ AUSTENITE

3. Low Carbon = upto 0.3%
   Medium Carbon = 0.3-0.6%
   High Carbon = 0.6-1%
   Tool Steel = 1-2%

TEMPERATURE, TIME, TRANSFORMATION DIAG



→ Diffusional Transformation $f(T,t)$

Austenite(A) ⟶ Martensite(M) $f(T)$
when suddenly cooled

Hypo-eutectoid, Hyper-eutectoid

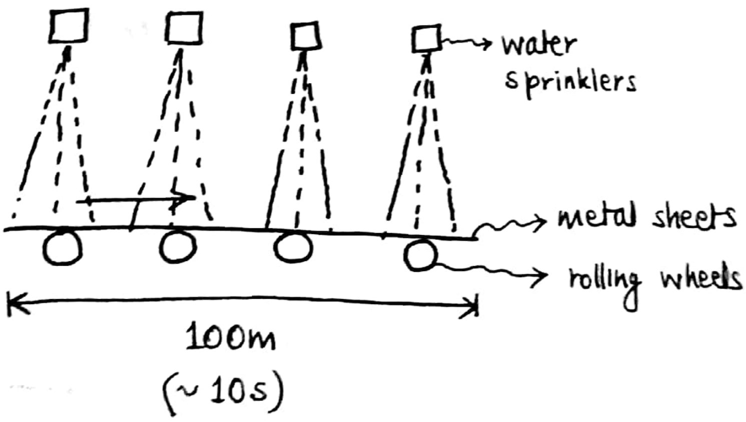
LCS, MCS, HCS → Steel Vs Cast iron → Hypo-eutectic, Hyper-eutectic

$\underbrace{\text{Hypo-eutectic / Hyper-eutectic}}_{4.3\ \text{wt.\% of C}}$

- $f(T, t) \equiv$ Diffusion
- P, S, T, B
- complete conversion is possible

- $f(T) \equiv$ Non-diffusion
- Martensite
- complete conversion not possible

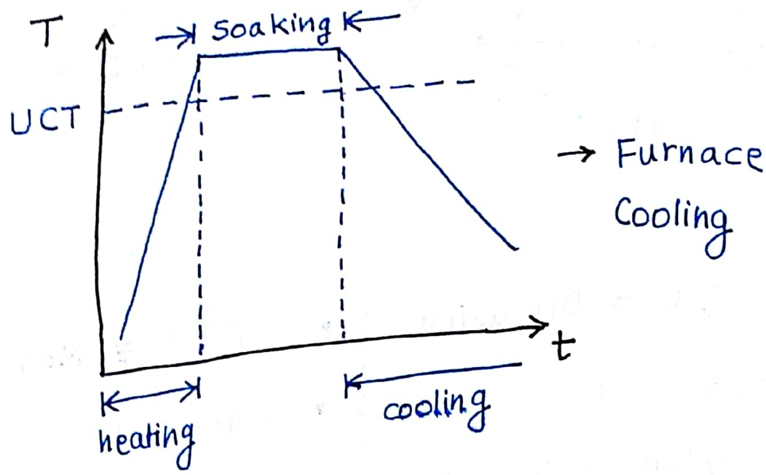
Casting ⇒ Ingot → Bloom/Billet → Rolling Process → Slab $\xrightarrow{\text{R.P.}}$ Sheet



Heat Treatment

- → Reduce Internal Stress
- → Refine Grain Structure
- → Hardness, Toughness, Ductility

1. [illegible]ing



2. Normalizing

→ Air Cooling

→ $(\text{Cooling rate})_{\text{Normalizing}} > (\text{Cooling rate})_{\text{Annealing}}$

→ $(\text{Hardness})_{\text{Normalizing}} > (\text{Hardness})_{\text{Annealing}}$

3. Hardening

→ Water Cooling / Oil Cooling

→ essentially conversion of Austenite into Martensite

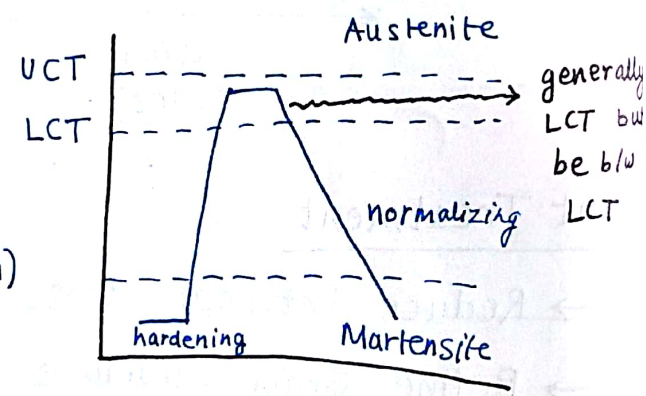
→ very hard

4. Tempering

→ Hardness + Ductility

normalizing

(Hard, strength) + (ductile + impact strength)



* Above 4 processes are both surface and core hardening processes. But when only surface needs to be hardened

like gears (where wear-and-tear at the surface is needed and soft core for vibration absorption), we use case hardening.

Case hardening

Changing of surface property

low carbon | medium carbon

1. Alloying C @ 800-900°C
   Carburizing
2. Heating in NH_4 @ 600°C
   Nitriding
3. Both C and N @ 900°C
   Cyaniding

Heat-treatment

1. Flame-hardening
2. Induction-hardening
3. Laser hardening

Classification of Metal Working:

Hot Working | **Cold Working**

$$T_W > T_{Reer} > T_W$$

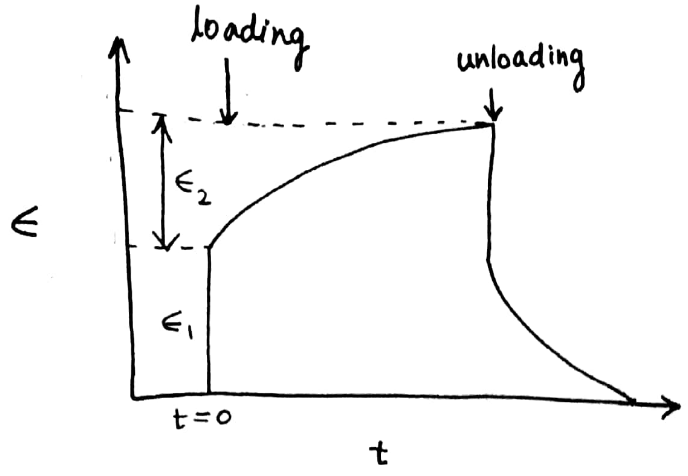
$$\left(\frac{1}{3} \text{ to } \frac{1}{2} \text{ of } T_{melting}\right)$$

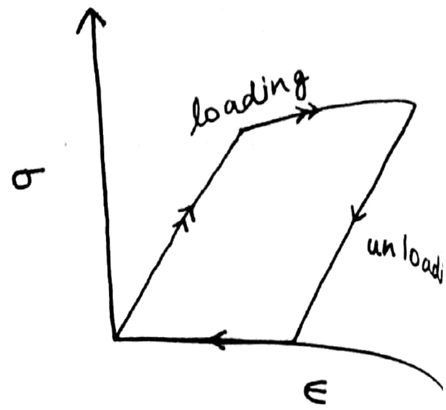
Deformation

Temporary | Permanent

Hooke's Law $\leftarrow$ $\epsilon = f(\sigma)$

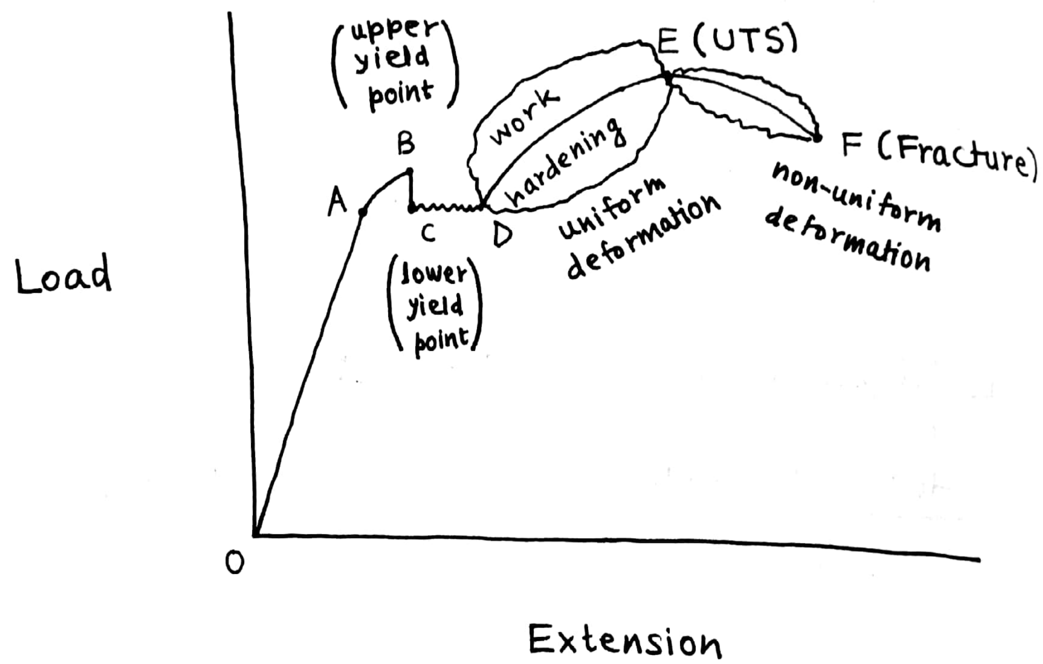
An elastic deformation $\leftarrow$ $\epsilon = f(\sigma, t)$





$$\epsilon_{max} = \epsilon_1 + \epsilon_2$$

Mild Steel



$$e = \frac{\Delta L}{L_0} = \frac{L - L_0}{L_0}$$

$$S = \frac{P}{A_0}$$

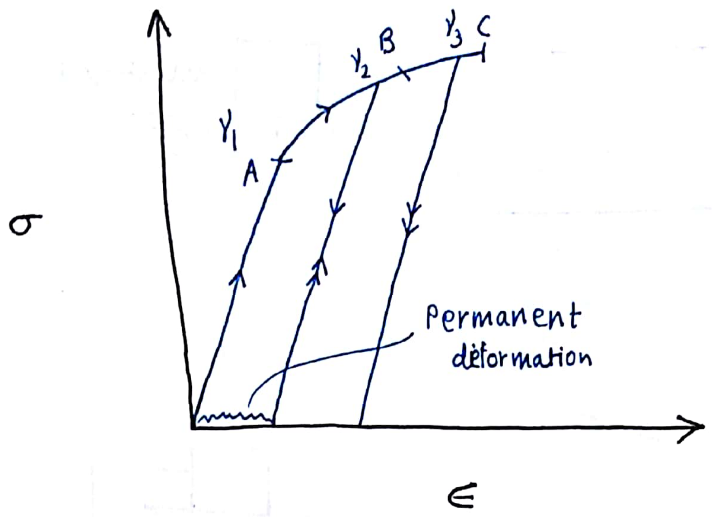
$$\epsilon = \int_{l_0}^{l} \frac{dl}{l} = \ln\left(\frac{l}{l_0}\right)$$

$$\sigma = \frac{P}{A}$$

$$\epsilon_1 = \ln\left(\frac{l_1}{l_0}\right) \qquad \epsilon_2 = \ln\left(\frac{l_2}{l_0}\right)$$

$$\epsilon_{12} = \ln\left(\frac{l_1}{l_0}\right) + \ln\left(\frac{l_2}{l_1}\right) = \ln\left(\frac{l_2}{l_0}\right)$$

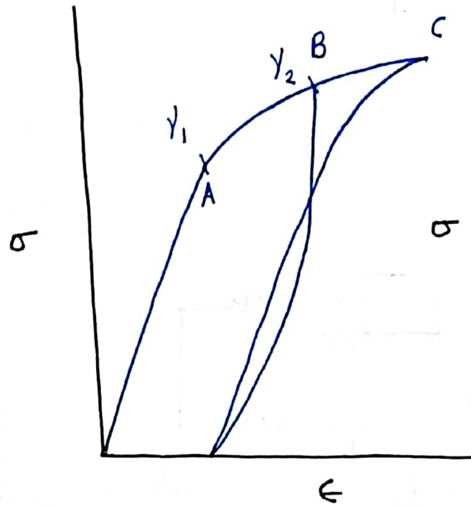
True Stress - Strain

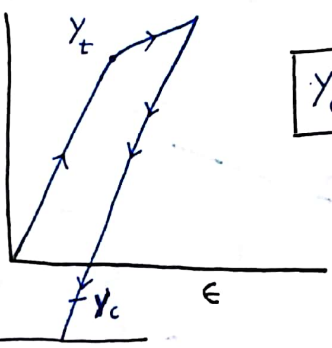


AB = uniform plastic deformation

BC = non-uniform plastic deformation

OA = linear elastic





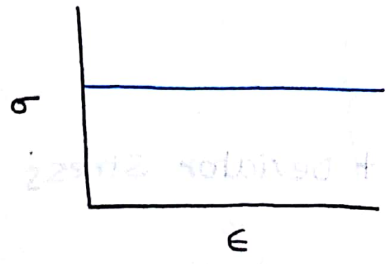
$\boxed{Y_c < Y_t}$

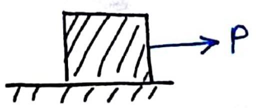
Bauschinger Effect

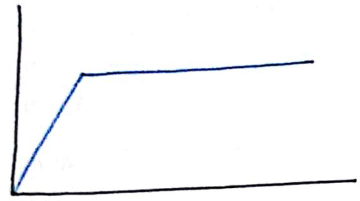
Total deformation = elastic + plastic

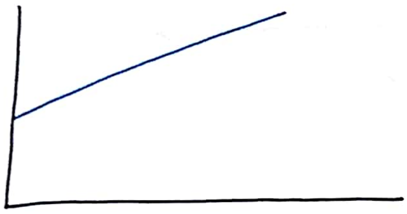
Materials ⇒ Rigid + Perfectly Plastic

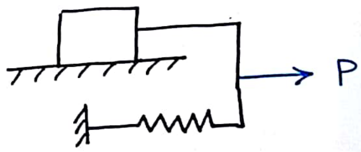
elastic + (−)

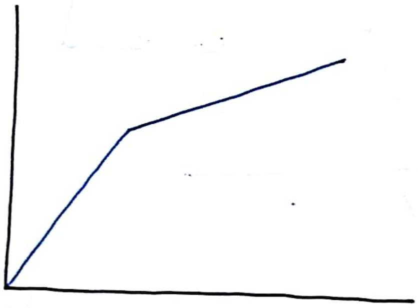


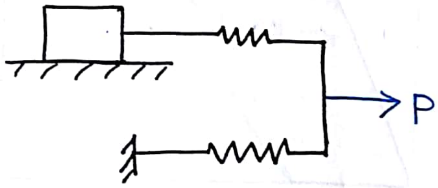






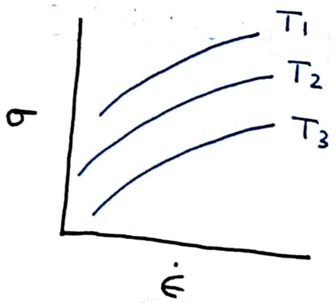






$\epsilon = f(\sigma, T, \dot{\epsilon})$

$\epsilon \uparrow \Rightarrow \sigma \uparrow$



$T_3 > T_2 > T_1$

Total Stress = Hydrostatic Stress + Deviator Stress

$\left(\frac{1}{3}(\sigma_{11} + \sigma_{22} + \sigma_{33})\right)$

change of elastic volume

plastic shear

$\sigma_{ij} = \sigma'_{ij} + \frac{1}{3}\sigma_{kk}\delta_{ij}$

$S_i = \sigma_{ij} n_j$

Stress normal to the inclined plane, $\sigma_n = \bar{S}\cdot\bar{n}$

$\Rightarrow \sigma_n = \sigma_{ij} n_j n_i$

Shear stress components, $\sigma_s = \sqrt{S^2 - \sigma_n^2}$

Principle Stresses

$\bar{S} = \sigma\bar{n}$

$\sigma \to$ scalar multiple

$\Rightarrow S_1 = \sigma n_1$, $S_2 = \sigma n_2$ & $S_3 = \sigma n_3$

$$\left.\begin{aligned}(\sigma_{11}-\sigma)n_1 + \sigma_{21}n_2 + \sigma_{31}n_3 &= 0\\ \sigma_{12}n_1 + (\sigma_{22}-\sigma)n_2 + \sigma_{32}n_3 &= 0\\ \sigma_{13}n_1 + \sigma_{23}n_2 + (\sigma_{33}-\sigma)n_3 &= 0\end{aligned}\right\} \begin{vmatrix}\sigma_{11}-\sigma & \sigma_{21} & \sigma_{31}\\ \sigma_{12} & \sigma_{22}-\sigma & \sigma_{32}\\ \sigma_{13} & \sigma_{23} & \sigma_{33}-\sigma\end{vmatrix} = 0$$

$$\sigma^3 - I_1\sigma^2 + I_2\sigma - I_3 = 0$$

$I_1 = \sigma_{11} + \sigma_{22} + \sigma_{33}$

$I_2 = \sigma_{11}\sigma_{22} + \sigma_{22}\sigma_{33} + \sigma_{33}\sigma_{11} - \sigma_{12}^2 - \sigma_{23}^2 - \sigma_{31}^2$

$I_3 = \sigma_{11}\sigma_{22}\sigma_{33} + 2\sigma_{12}\sigma_{23}\sigma_{31} - \sigma_{11}\sigma_{23}^2 - \sigma_{22}\sigma_{31}^2 - \sigma_{33}\sigma_{12}^2$

(From Deviatoric)

$\downarrow$

$$\left.\begin{aligned}J_1 &= \\ J_2 &= \\ J_3 &= \end{aligned}\right\}$$

$\sigma > Y \Rightarrow$ Yielding starts

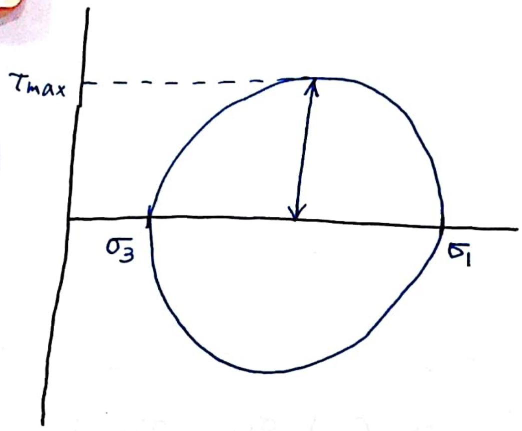
Yield Criteria : TRESCA
von - Mises

Maximum shear stress reaches a critical volume

$\Downarrow$

yielding starts $[\tau_{max.} = K]$

↳ shear yield stress



$$\tau_{max.} = \frac{\sigma_1 - \sigma_3}{2}$$

$$\boxed{\sigma_1 - \sigma_3 = 2K}$$

$Y \approx K$

1) uniaxial loading $\begin{bmatrix} \sigma_1 = Y \\ \sigma_2 = 0 \\ \sigma_3 = 0 \end{bmatrix}$

2) pure torsion $\begin{bmatrix} \sigma_1 = K \\ \sigma_2 = 0 \\ \sigma_3 = -K \end{bmatrix}$

Shear strain energy per unit volume ⟶ Reaches a critical value

$\Downarrow$

Yielding

$$(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 = \text{constant}$$

1

ROLLING

Slab / Plate / Sheet / Strip

Rail / Channel

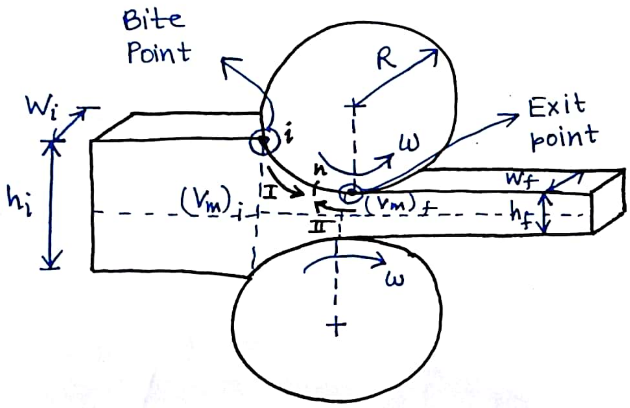
* $t > 6\,mm \longrightarrow$ Plate

$t < 6\,mm$ $\begin{cases} w > 600\,mm \rightarrow \text{sheet} \\ w < 600\,mm \rightarrow \text{strip} \end{cases}$

Ingot

Bloom ← Ingot → Slab; Ingot ↓ Billet

Bloom   Billet   Slab



$V_R = \omega \times R$

$\omega >> h$

$w_i = w_f$

Plane-strain deformation

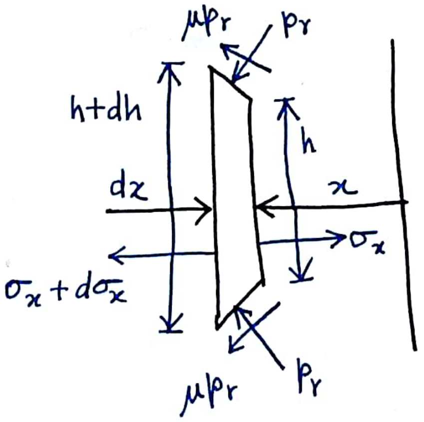
$V_R > (V_m)_i$

$(V_m)_f > V_R$

$(V_m)_n = V_R$

I → Lagging Zone

II → Outstripping Zone



$\sum f_x = 0$

$\sum f_y = 0$

$\sigma_1 =$

$\sigma_2 =$

$-p_r = \sigma_y = -p$

yield criteria

$\sigma_1 - \sigma_3 = 2k$

$\sigma_x - (-p) = 2k$

$\sigma_x + p = 2k$

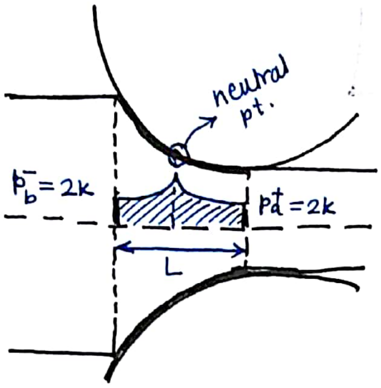
Boundary conditions:

#1 No pull at front & back ends.

$\sigma_{xa} = 0 \Rightarrow H_a = 0$ at the exit ~~pta~~ point

Exit Point $\Rightarrow p_a^+ = 2K$

Bite Point $\Rightarrow p_b^- = 2k$



Mill Load

Front Pull $\Rightarrow F_a$

$\sigma_{xa} \Rightarrow \sigma_x + p = 2K$

$p = 2K - \sigma_{xa}$

$(p_a^+)_{\text{with pull}} < (p_a^+)_{\text{no-front pull}}$

$\sigma_{xb} + p^- = 2k$

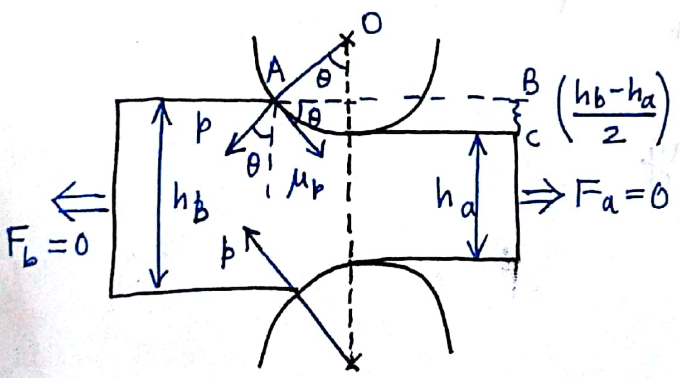
$(p_b^-)_{\text{no back pull}} < (p_b^-)_{\text{with pull}}$

Rolling load

$$F = \int_{\alpha_n}^{\theta} p_r() + \int_{0}^{\alpha_n} p_r()$$

$$\text{Torque} = \int \mu p_r() + \int \mu p_r()$$

$$\text{Power} = T \cdot w$$



Draft for un-aided rolling

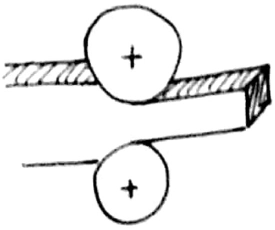
$h_b - h_a \equiv \Delta h$ for unaided rolling

$p \sin\theta < \mu p \cos\theta$

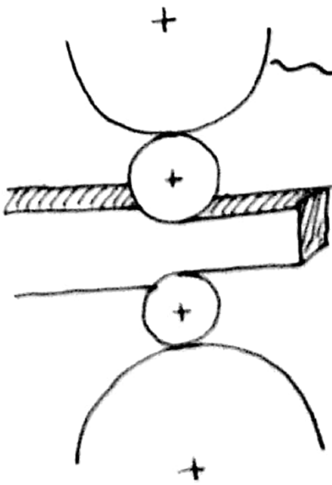
$\mu \geq \tan\theta$

1. <u>Single-stand Rolling</u>

i. Two-high rolling stand

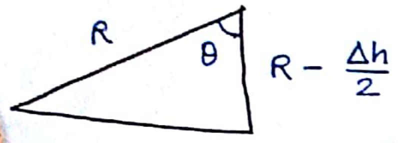


ii. Four-high rolling stand



large gears to provide force to support the smaller rollers

2. Multi-stage/Stand Rolling



$$\tan\theta = \frac{\left[R^2 - \left(R - \frac{\Delta h}{2}\right)^2\right]^{1/2}}{R - \frac{\Delta h}{2}}$$

$$= \left[\cancel{R^2} - \cancel{R^2} - \cancel{\frac{\Delta h^2}{4}}^{\,0} + R\,\Delta h\right]^{1/2} \Big/ \left(R - \frac{\Delta h}{2}\right)$$

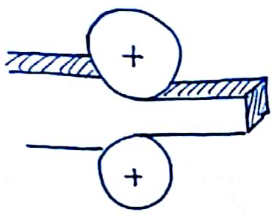
$$= \frac{\cancel{R}\left\{\frac{\Delta h}{R}\right\}^{1/2}}{\cancel{R}\left\{1 - \underbrace{\frac{\Delta h}{2R}}_{0}\right\}} = \sqrt{\frac{\Delta h}{R}} = \mu$$

$$\Rightarrow \boxed{\Delta h = \mu^2 R}$$

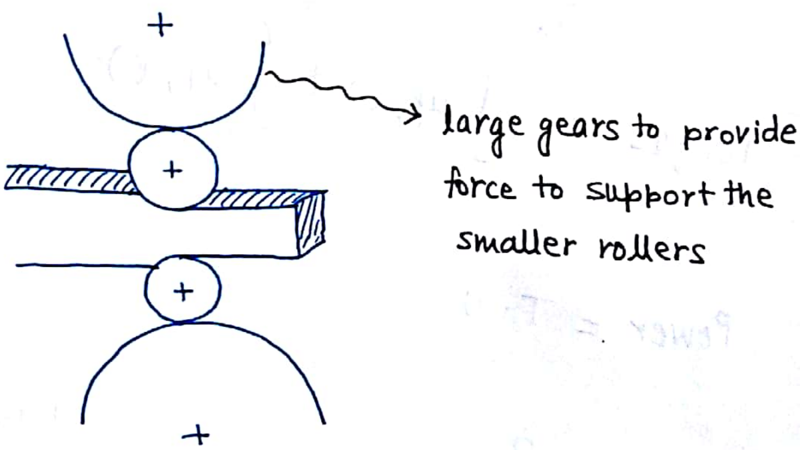
Classification of Rolling Process

1. Single-stand Rolling

   i. Two-high rolling stand



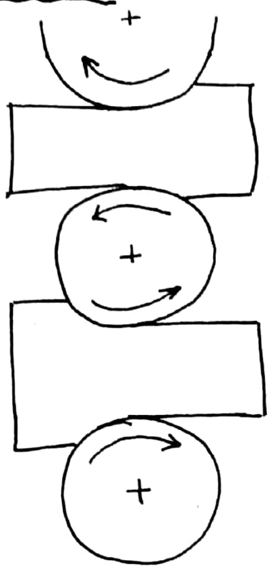
   ii. Four-high rolling stand



2. Multi-stage/Stand Rolling

3. Cluster- rolling mill

4. Three-high rolling mill

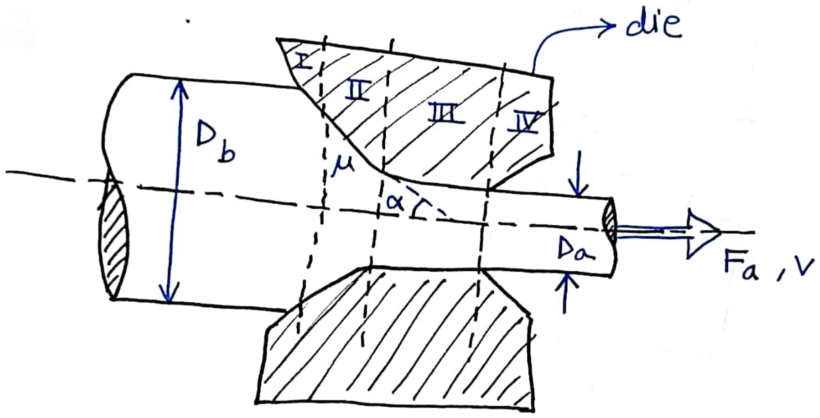


Defects:

1. Thicker product (but uniform)
2. Non-uniform thickness
3. Waviness / Lack of flatness
4. Alligatoring

DRAWING

- Wire
- Rod
- Bar
- Tube
- Strip



$$\left(\frac{D_b - D_a}{D_b}\right)$$

* If $\left(\frac{D_b - D_a}{D_b}\right)$ is very high, then heat gen. ΔH is also very high which consequently decreases the life span of the die.

* Steps

1. Elemental stress distribution & its equillibrium condⁿ.
2. Yield criteria
3. Boundary condⁿs,
4. Get the value of F_a