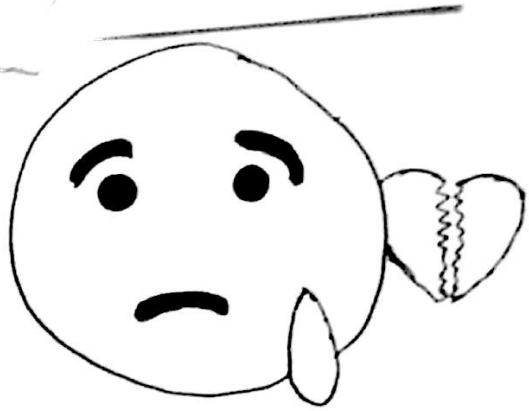
सौरभ यादव
(भारतीय प्रौद्योगिकी संस्थान, खड़गपुर)
⊙ यांत्रिकी अभियांत्रिकी विभाग ⊙

विषय : रूपांतरण



# सोनम गुप्ता बेवफा है!

संवैधानिक चेतावनी:

⊙ पाठ्य सामग्री निर्माता परीक्षा मे किसी भी प्रकार की प्राप्तांक हानि के लिए उत्तरदायी नही माना जाएगा।

⊙ पाठ्य सामग्री निर्माता किसी प्रकार की मानविक त्रुटि के लिए जिम्मेदार नही होगा।

⊙ लोकोक्ति " पहले इस्तेमाल करें! फिर विश्वास करें! "

21/07/16

Casting  Forming  welding

SK Panda  $\boxed{\text{SK Pal}}$  J Paw

| L | T | P | |
|---|---|---|---|
| 3 | 1 | 0 | ⇒ 4 |

L ⇒ 4 − 0 − 0 ⇒ 4

Monday : 1 Hr (casting)

Tu → 2 Hr (1 → welding) + (1 → F ⇒ 4, C ⇒ 4)

W ⇒ 4 classes first

Th → 1 hr ⇒ (Forming)

first 4 on welding

TA ⇒ 20

1st class test (MS) ⇒ (Endsem)

C + F + W

↓

{CT1 + CT2 + Attendance + surprise test}

S.K. Paul : Metrology lab

(Mon, Tue, Thr)

Attendance ≥ 75% (others)

≥ 45%

(de-registered)

Forming:

1. crystal structure
2. Fe-$Fe_3C$ Phase diagram
3. T-T-T diagram
4. Heat Treatment

Introduction to physical metallurgy S.H.

Process

5. Yield crition for deformation

bulk metal forming process

6. Rolling
7. drawing → wire bar tube
8. Extrusion
9. Forging

Scanned by CamScanner

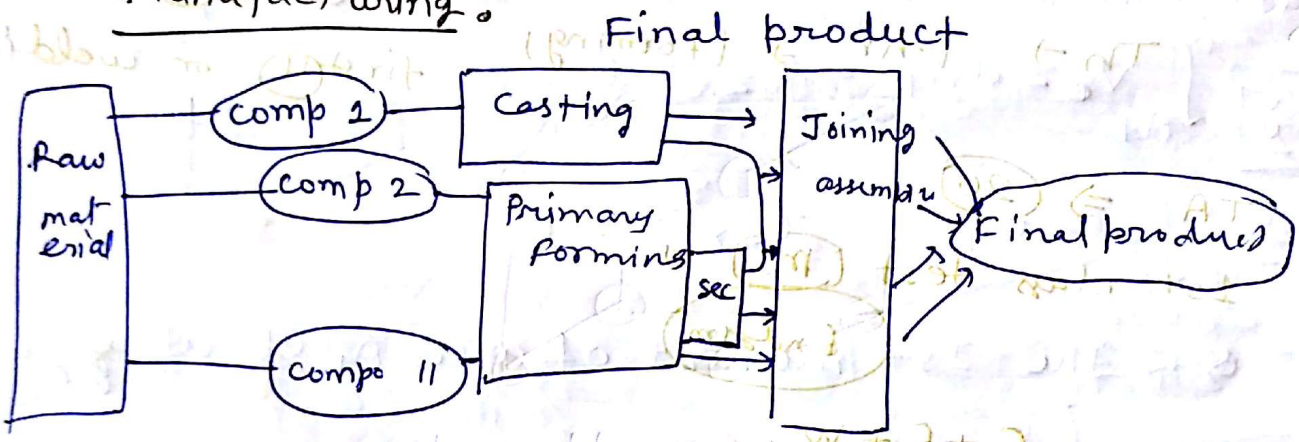
(10) deep drawing

(11) Non conventional forming process

book ⇒ (1) Manufacturing Process by ghosh + Malik

(2) Principles of metal working by G. W. Rowe

Manufacturing :




Forming

- conventional forming
  - (1) Rolling
  - (2) Forgin
  - (3) Extrusion
  - (4) Drawing
- Non conventional forming
  - (1) Electro hydratic
  - (2) Electromagnetic
  - (3) chemical
  - (4) explosive

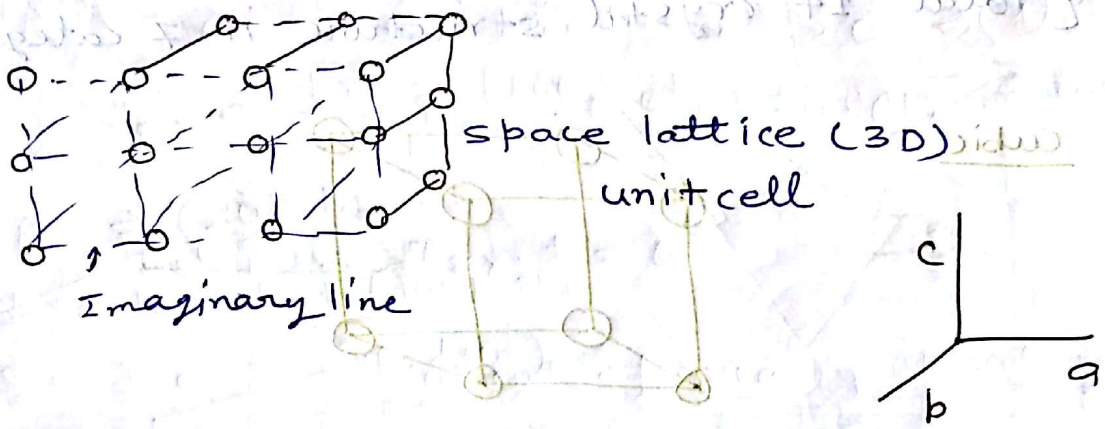
Raw → chip → Final ⇒ maching

Raw → Final ⇒ chipless

Scanned by CamScanner

crystal structure
↓
phase diagram
↓
Heat treatment

**Solid** → crystalling → all metals
→ non-crystalling




crystal geometry system

| unit cell | $\alpha, \beta, \gamma$ |
|---|---|
| | a b c |

↓
crystal structures

1. TRIclinic ($a \neq b \neq c$, $\alpha \neq \beta \neq \gamma \neq 90^\circ$) — 1
2. monoclinic ($a \neq b \neq c$, $\alpha = \beta = \gamma = 90^\circ$) $\beta \neq 90^\circ$
3. orthorhombic ($a \neq b \neq c$, $\alpha = \beta = \gamma = 90^\circ$)
4. Rhombohedral ($a = b = c$, $\alpha = \beta = \gamma \neq 90$)
5. Tetragonal ($a = b \neq c$, $\alpha = \beta = = \gamma = 90$)
6. Hexagonal ($a = b \neq c$, $\alpha = \beta = 90$, $\gamma = 120^\circ$)
7. Cubic ($a = b = c$, $\alpha = \beta = \gamma = 90^\circ$)

---

2. Simple monoclinic
Base centered "
3. Simple ortho..
Bodycentered "
Base " "
Face " "

Scanned by CamScanner

④ → ①

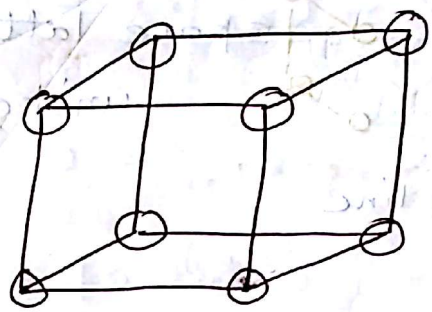
⑤ Simple tetragonal
Body centered "

⑥ → 1

⑦ simple cubic (SC)
body centered " (BCC)
Face centered cubic (FCC)

{Total 14 crystal structure in 7 category}

<u>cubic</u>

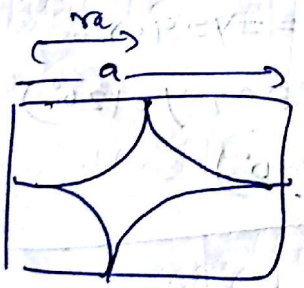


each cell 8 atoms at corners

effective atoms $= \frac{1}{8} \times 8$
$= 1$

Packing factor $= \frac{\text{Volume of atoms in a unit cell}}{\text{Volume of the unit cell}}$
or
(Packing efficiency)

$= \frac{\text{Effective no of atm} \times \text{Volume of atom}}{a^3}$




$a = 2r_a$

$= \frac{1 \times \frac{4}{3}\pi r_a^3}{a^3}$

$= \frac{\frac{4}{3}\pi \cdot \frac{a^3}{8}}{a^3}$

$= 0.5236$

Scanned by CamScanner

SC ⇒ only corner atoms

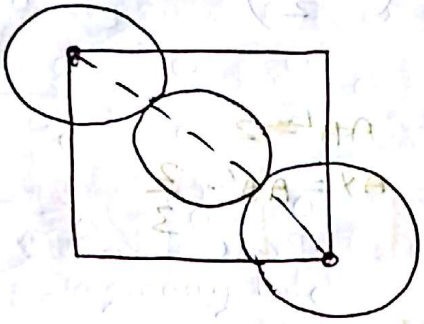
BCC ⇒ SC + (atom)

↓ Inside the cell

effective $= 8 \times \frac{1}{8} + 1 = 2$ atom

$$\text{efficiency} = \frac{(ENA) \times \frac{4}{3}\pi r_a^3}{a^3}$$

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



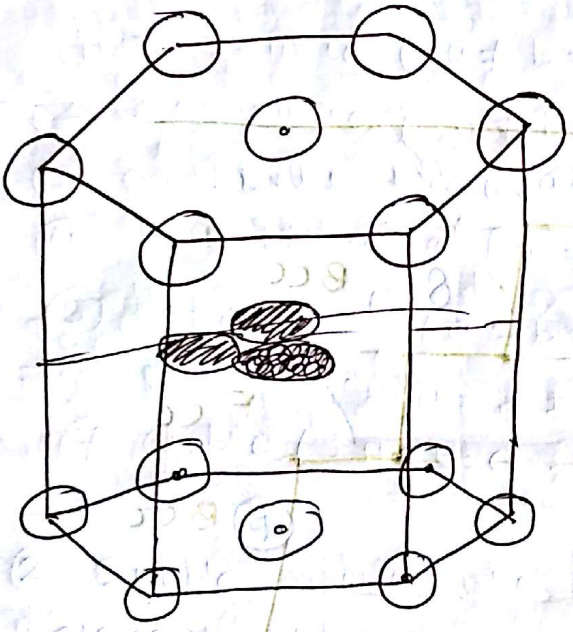
$\sqrt{2}a = 4r_a$

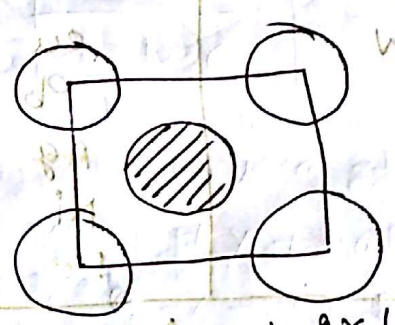
$r_a = \frac{a}{2\sqrt{2}}$

$$= \frac{\cancel{2} \times \cancel{4}}{3}\pi \times \frac{1}{\cancel{8} \times 2\sqrt{2}}$$

$= 0.37024$

FCC





$\Rightarrow 8 \times \frac{1}{2} + \frac{1}{8} \times 8$

$= 5$

ENA $= \frac{1}{6} \times$

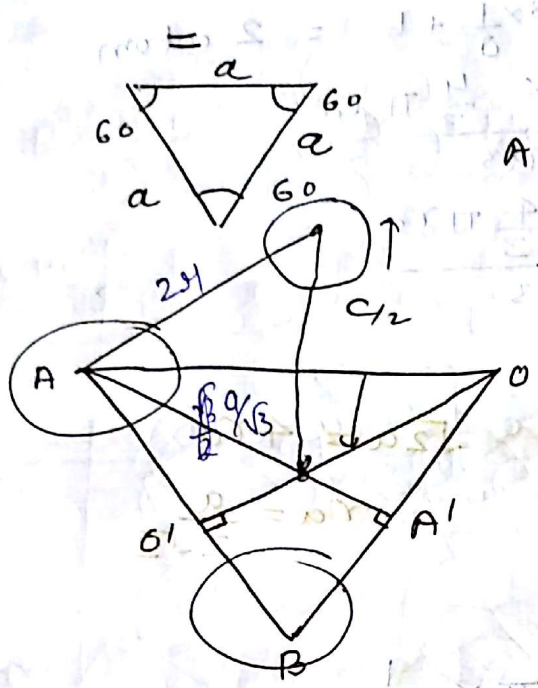
$$ENA = 3 + \frac{1}{2}(2) + \frac{1}{6}(12)$$

$$= 3 + 1 + 2 = 6$$

Scanned by CamScanner

$$(PF)_{HCP} = \frac{6 \times \frac{4}{3}\pi r_a^3}{\text{Volume of HCP unitcell}}$$

area of one equal triangle × 6 × height




$$A = \frac{2}{3} AA'$$

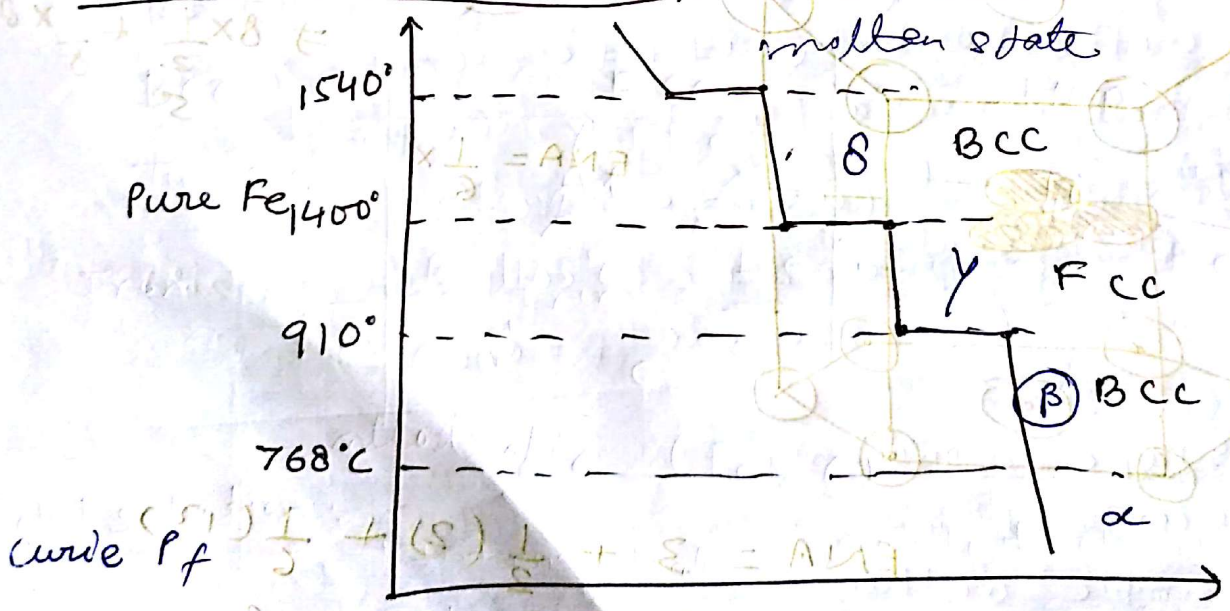
$$= a\left(\frac{\sqrt{3}}{2}\right)$$

$$\boxed{c = 4\sqrt{\frac{2}{3}}\, r}$$

~~AA'~~ = 2

$$AX = AA' \cdot \frac{2}{3}$$

| BCC | FCC | HCP |
|---|---|---|
| Cr<br>W | Al<br>Cu<br>Pb<br>Ag<br>Ni<br>Fe | Ti<br>Zn<br>Co<br>Mg |




Scanned by CamScanner

$\delta \rightarrow \gamma \rightarrow \alpha$

Reversible allotropic

Alloy

wt % of C & temp

← Fe

★ Fe – $Fe_3C$

solution = solvent + Solute

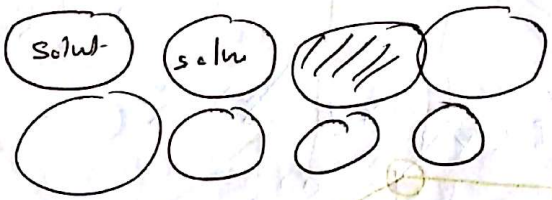
Fe – $Fe_3$

↓

solid

solid solution → Interstitial

→ Substitutional




Scanned by CamScanner

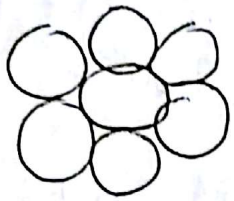
4 August 2016

## Crystal structure:

Face centered cubic (FCC)

+

Hexagonal close packed



Base plane #1 $\left[\frac{1}{6} \times 6 \times 2\right]$

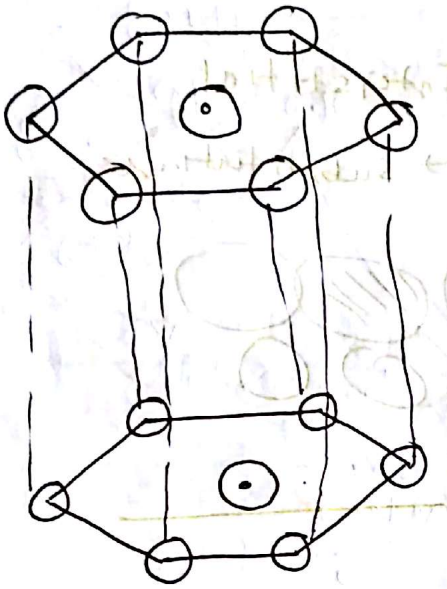
$\left(\frac{1}{2} \times 2\right)$ 2

1

+ 3

Base plane #2 3

6



$$PF = \frac{n \times \text{volume of each atom}}{\text{Volume of the unit cell}}$$

PF = 0.74

| BCC | FCC | HCP |
|---|---|---|
| Tungsten | Al | Ti |
| Iron | Iron | mg |

allotropic ($Fe_3C$)

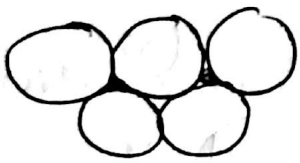
**Solid solution:**

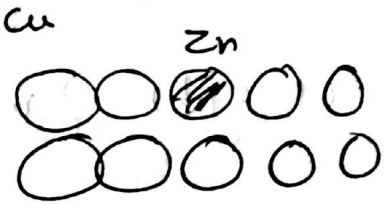
→ Interstitial

→ Substitutional

solute + solvent

$d_{solute} \leq d_{solvent}$



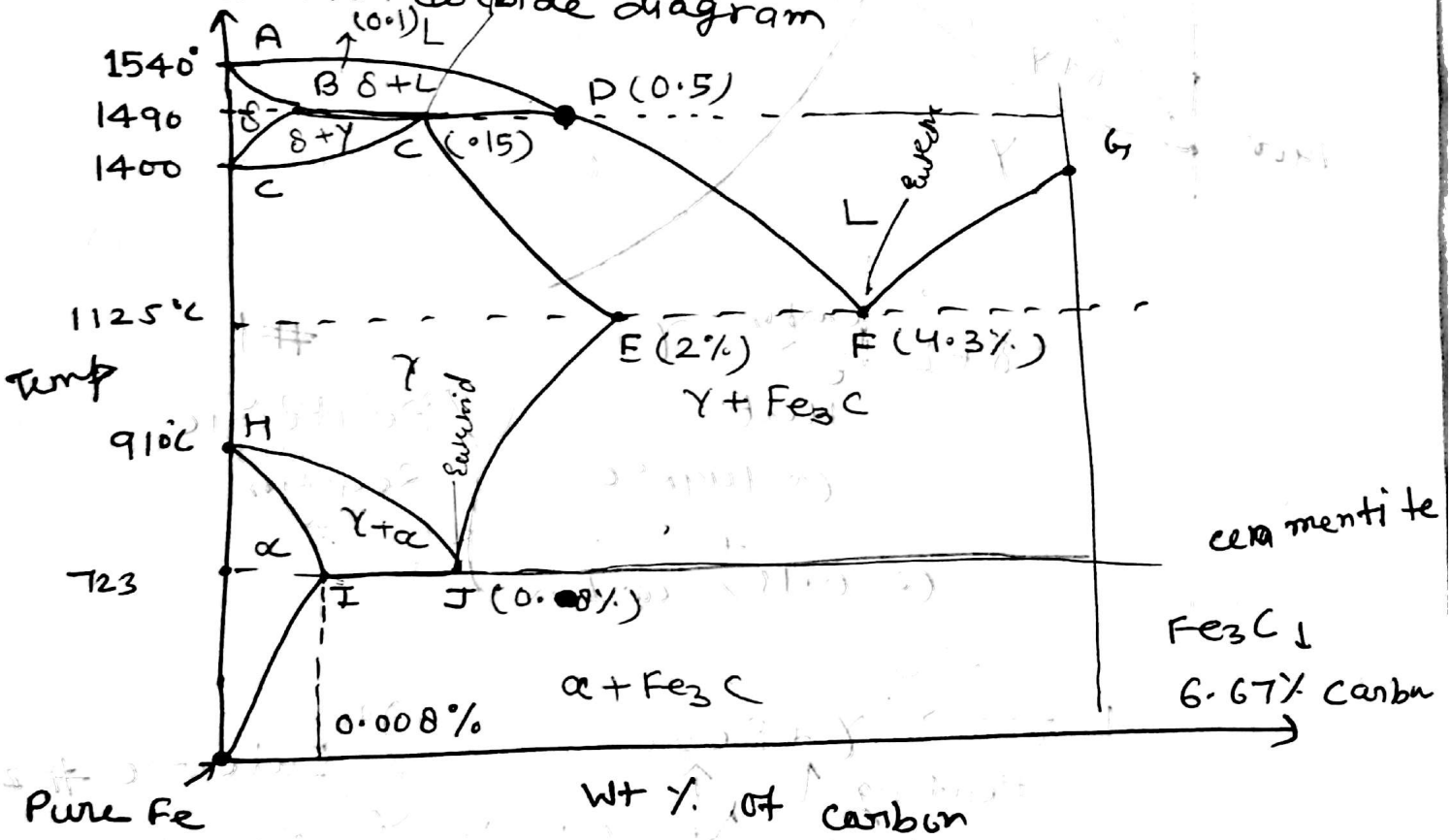



## Fe – $Fe_3C$ Phase diagram:

Alloy — wt % of carbon in Fe (Interstitial) → Phase change

Particular alloy → Phase change (Temp)

Iron – Iron carbide diagram




Cooling curve of Pure Iron

MP = 1540°C

910–1400°C = FCC ⇒ γ Fe

1400–1540 ⇒ δ Fe (BCC)

T < 910°C ⇒ α/β-Fe (α → β less than 768°C)

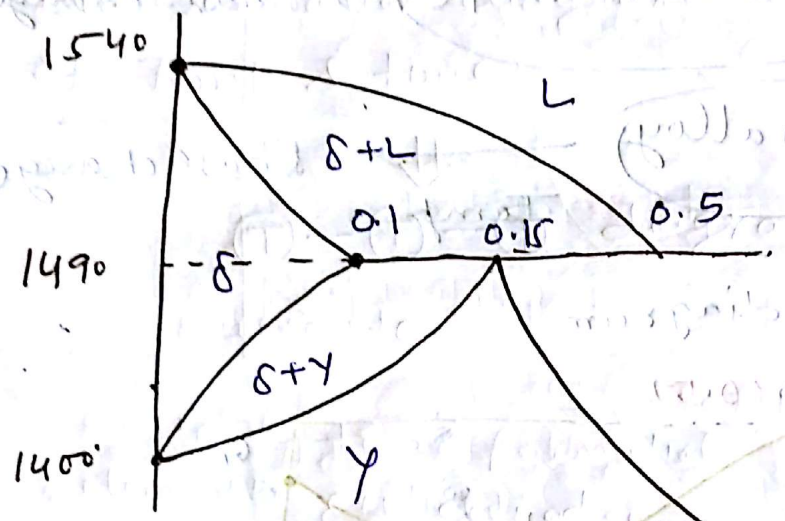
Scanned by CamScanner

$Fe_3C$ having 6.67 % of C.

★ wt of C(↓) metal soften

Cementite

Brittle ← Hardest compound




$\delta + L \underset{\text{Heat}}{\overset{\text{carbon}}{\rightleftharpoons}} \gamma$

@ 1490°C

+

@ 0.15% carbon

#1 Peritectic Reaction

$L \underset{\text{Heating}}{\overset{\text{carbon}}{\rightleftharpoons}} \gamma + Fe_3C$

@ 1125°C

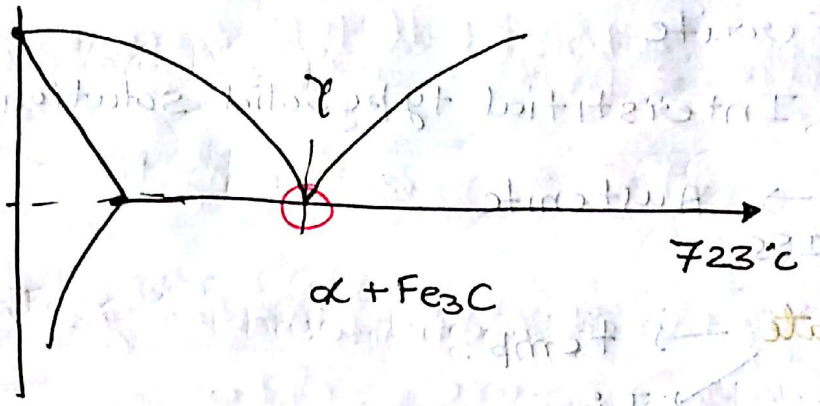
+

@ 4.3% C

Ledeburite

Eutectic #2 Reaction

Scanned by CamScanner




$\gamma \xrightarrow{\text{carbon}} \alpha + Fe_3C$

(FCC) (BCC)

← Heating

@ 723°C
@ 723°C
+
@ 0.8% carbon

Pearlite (Eutectiod)

---

★ 0 – 0.8% ⇒ Hypo eutectid steel

0.8% → 2% ⇒ Hyper " "

2% ⇒ 4.3% ⇒ Hypo eutectic cast Iron

4.3 → 6.67% ⇒ Hyper " "

---

δ Fe ⇒ 0.1 % of C

γ-Fe ⇒ 2% of C

α Fe ⇒ 0.008% of C

⇒ low carbon ⇒ upto 0.3

medium ⇒ 0.3 → 0.6

high ⇒ 0.6 → 2%

tool steel ⇒ 1 to 2%

≥ 2% cast iron

Scanned by CamScanner

$\alpha_{Fe} \Rightarrow$ Ferrite

Interstitial type solid solution (ISS)

$\gamma_{Fe} \rightarrow$ Austenite
ISS

cooling rate $\rightarrow$ temp
$\searrow$ Time

Transformation diagram through the representation of Temp & time

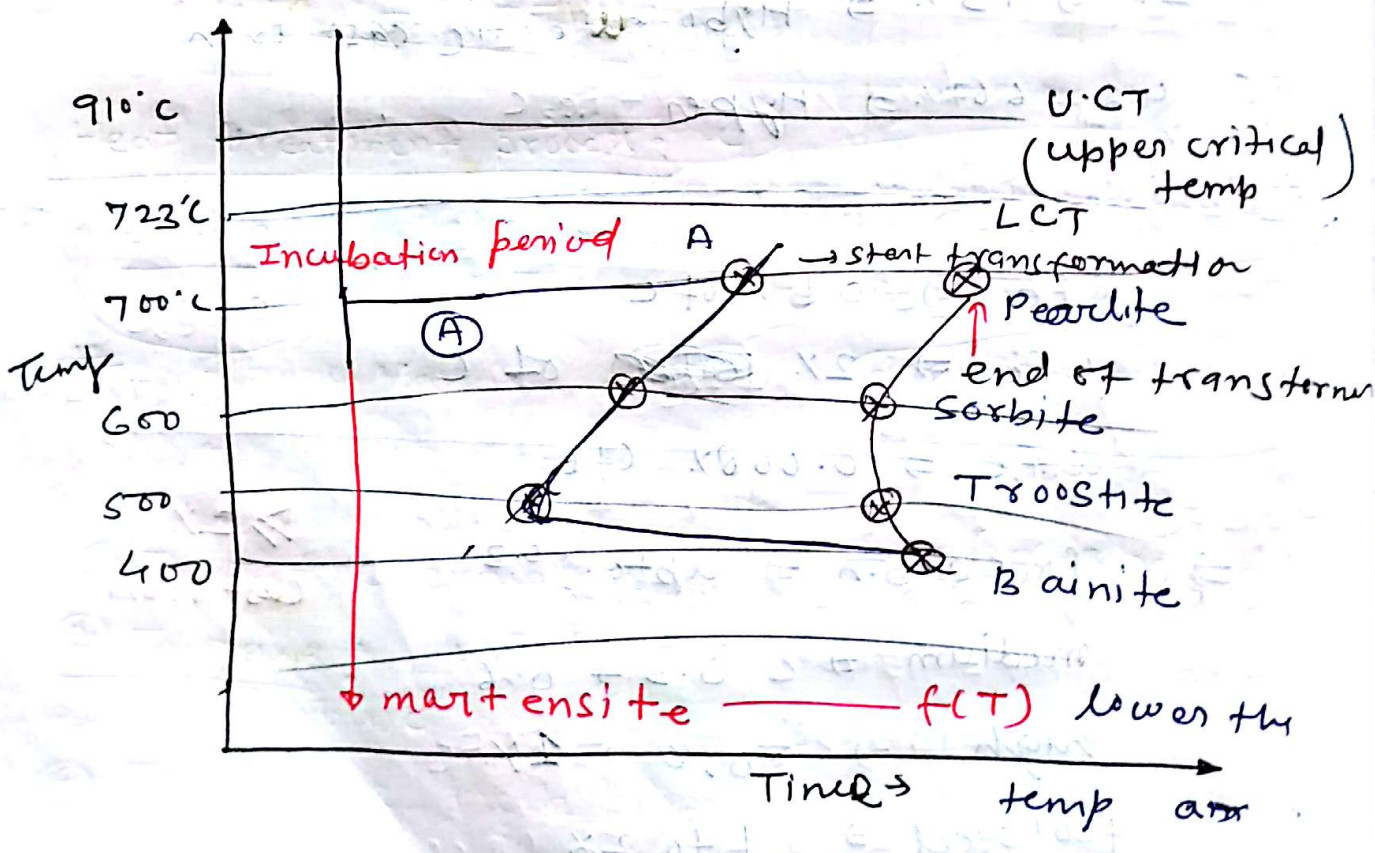
$\Downarrow$

T – T – T diagram

Austenite

Austenite transformation below the eutectiod temp $\Leftarrow$ T – T – T

Isothermal (IT)




f(T) lower the temp and amount of MAR(M)

11/08/2016

$Fe_3 - Fe_3C$ Phase diagram

Peritectic (~1490°C) ⇒ 0.15% C

Eutectic [~1125°C] ⇒ 4.3% C

Eutectoid [~723 °C] ⇒ 0.8% C

## T-T-T diagrame

Time – Temp – Transformation

↓

Austenite → Pearlite

Sorbite

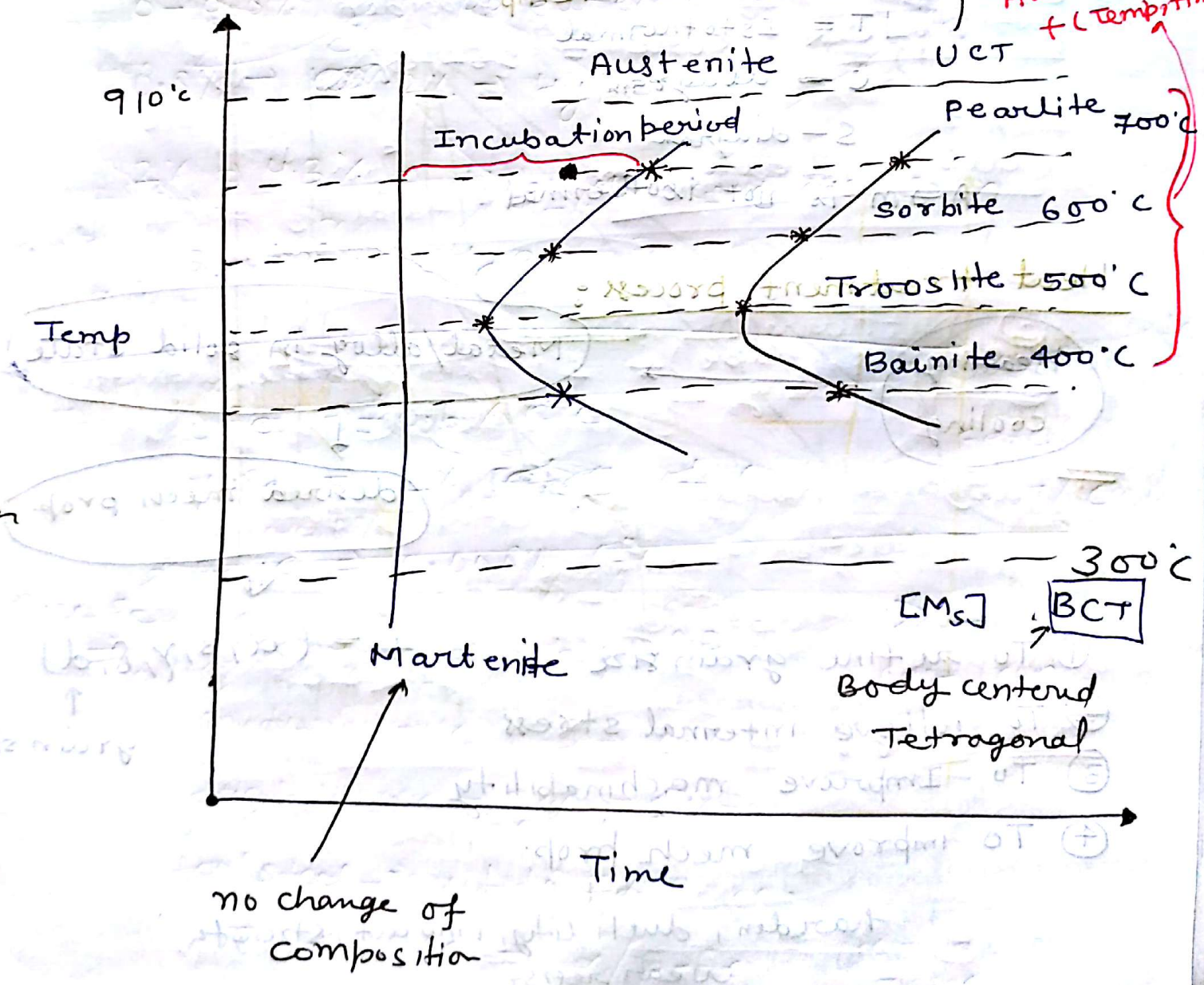
Troostite

Bainite

diffusion process = f(temp, time)

↓

log scale

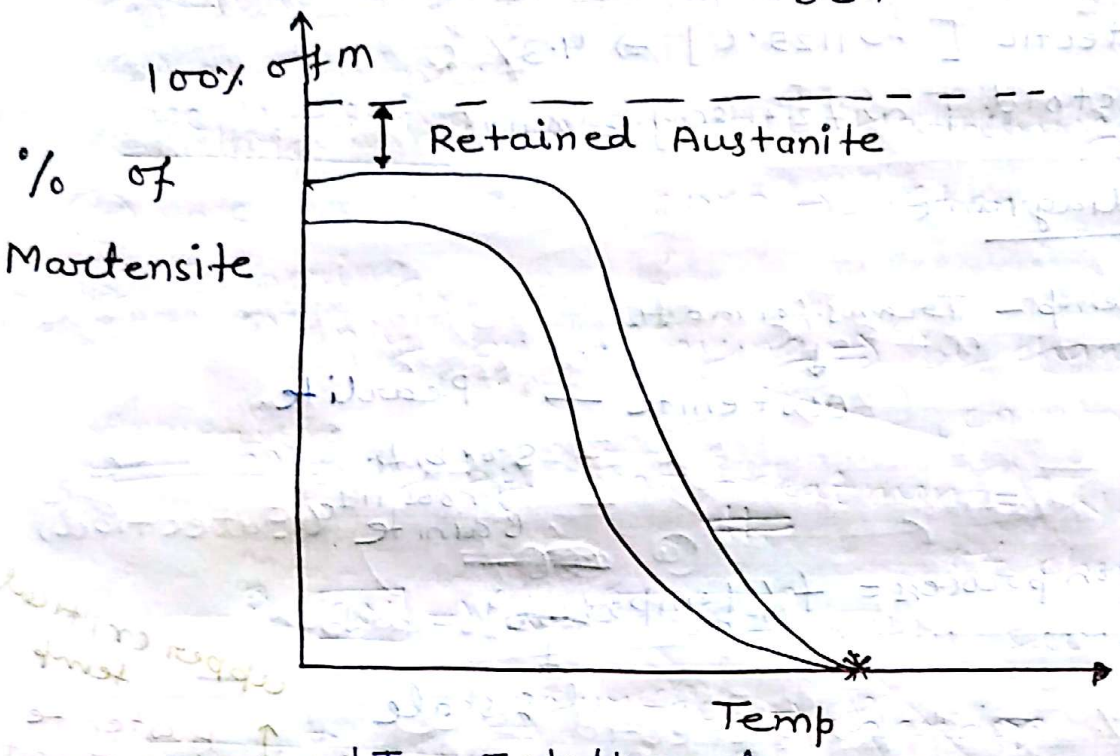



Scanned by CamScanner

Austenite → Interstitial type of carbon in FCC

↓

BCT




IT = Isothermal

C - diagram

S - diagram

A → m is not isothermal

## Heat treatment process:

Heating / cooling → Metal/alloy in solid state

↓

desired mech prop.

⇓

$f = (\alpha, \beta, \gamma, \delta, d)$

↑ grain size

① To refine grain size

② To relieve internal stress

③ To Improve machinability

④ To improve mech prop.

↓

harden, ductility, impact, strength, wear resist

Scanned by CamScanner

⑤ To increase resistance of corrison

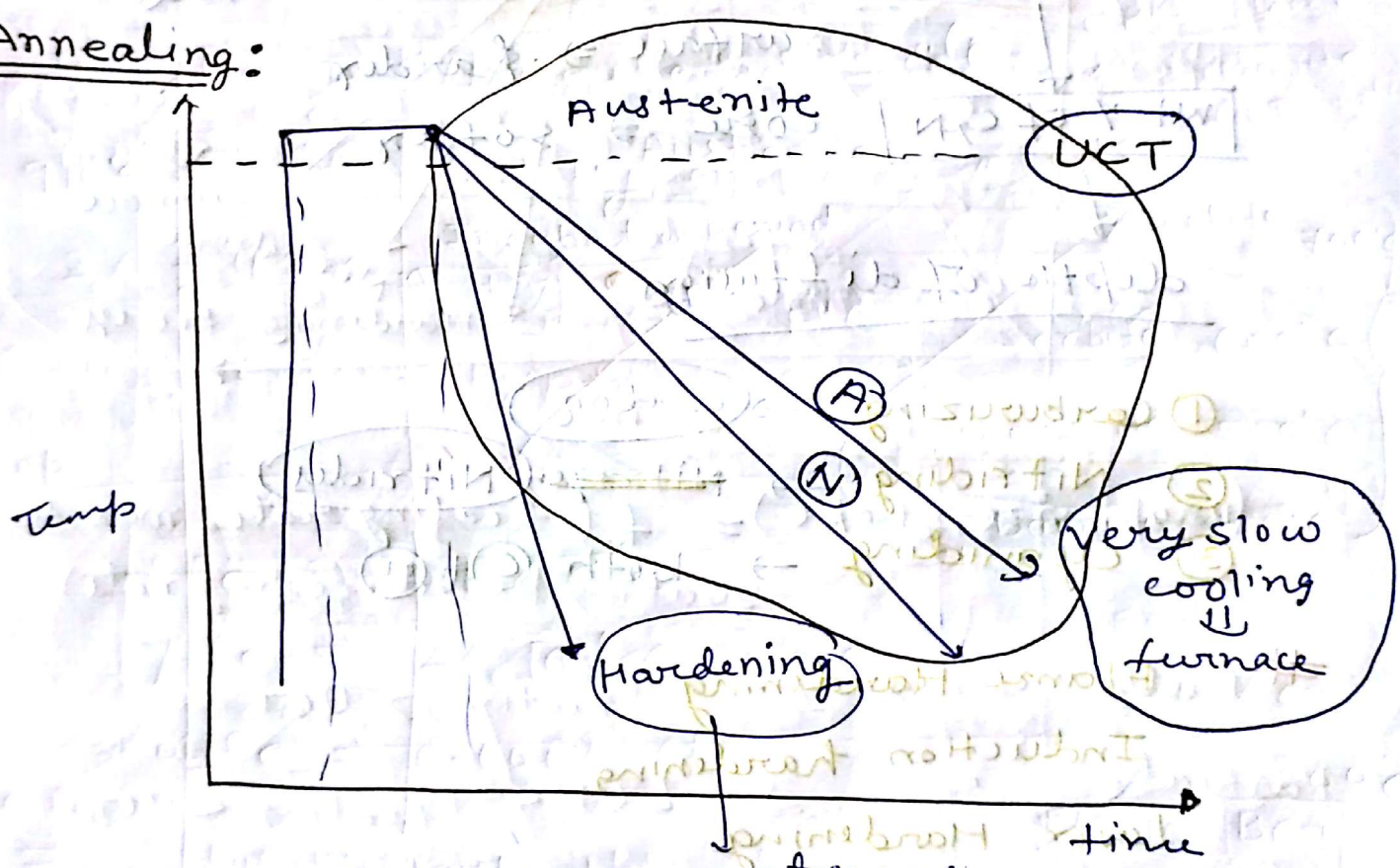
classification:

① Annealing
② Normalising
③ Hardening
④ Case - Hardening
⑤ ~~Temperature~~
⑤ Tempering

Heating + cooling ⇒ Heating rate, max. temp, soaking, cooling rate

A
N
H
CH
T

## Annealing:




① composition
② size
③ shape

Hardness Annealed product < Hardness Normalized product, Hardness Hardened product

Hardness (↑) ⇒ brittleness (↑) ⇒
⇒ Ductility (↓) ⇒ Impact strength (↓) } for (H) process

Case Hardening → surface Hardening
core → softer

① only by alloying ⇒ by changing chemical composition

② only by heat treatment ⇒ No change of chemical comp.

# 

• $\boxed{C, N}$ ⇒ diffusion ⇒ to the surface
surface ⇒ harder
core ⇒ softer

$\boxed{\text{Wt. \% of C, N}}$

↓

depth of diffusion

① Carburizing → Carbon
② Nitriding → ~~Nitrogen~~ Nitrides
③ cyaniding → both (C) + (N)

# Flame Hardening
Induction hardening
Laser Hardening

Tempering: Toughness
↓
Hardness + ductility

(A) $\xrightarrow{\text{Hardening}}$ (M) ⇒ High Hardness

Scanned by CamScanner

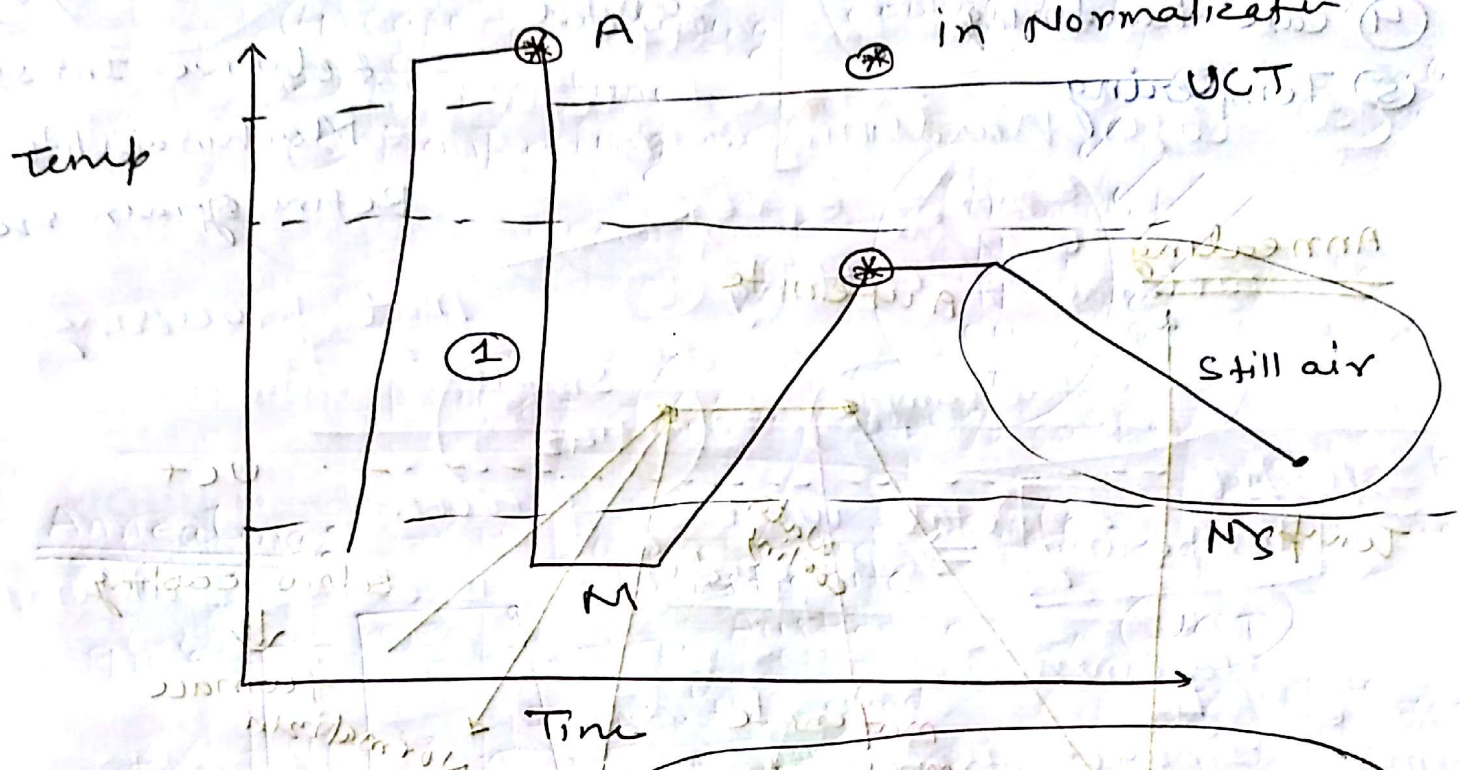
Hard ⇒ brittle

Less brittle, ductility (↑)

(A) ⟶ (m)

↓

Tempering process




Tempered product ⇒ Hardening + Normalizing with the exception of heating temp upto LCT

Next class trailor:

plastic deformation

Scanned by CamScanner

16/08

## Heat treatment process:

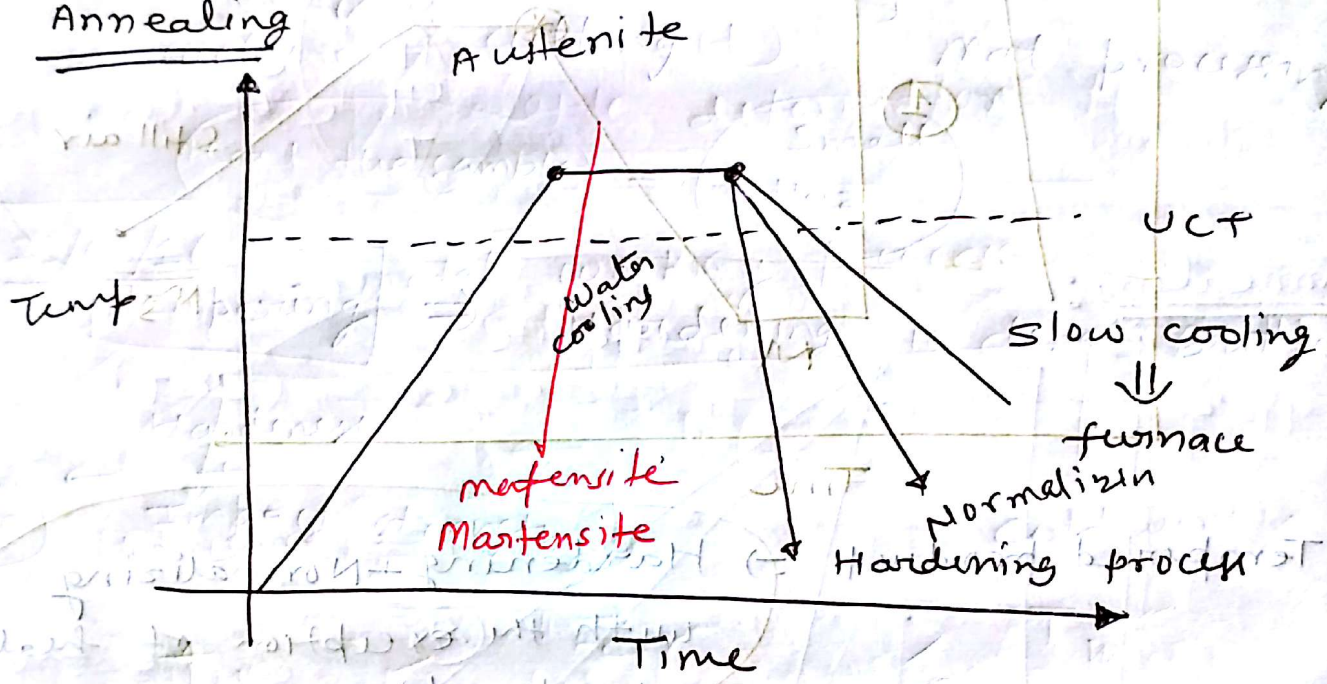
desired mech properties by heating and cooling

1. Annealing
2. Normalizing
3. Hardening
4. Case hardening
5. Tempering

strength, ductility, impact strength

Relative Int stress
Machinability
Refine grain size

### Annealing




(prop, size, shape) = f ( heating rate, max temp, soaking period, cooling rate)

Fully annealing ⇒ $T_{heating} > UCT$

Partial " ⇒ $LCT < T_{heating} < UCT$

sub critical " ⇒ $T_{heating} < LCT$

Scanned by CamScanner

Normalizing ( ) cooling ⇒ still air

(rate) Norm > (rate) Anneal

⇓

Harder product

Hardening ⇒ cooling rate > $(\text{cooling rate})_N$ >

(cooling rate) Ann

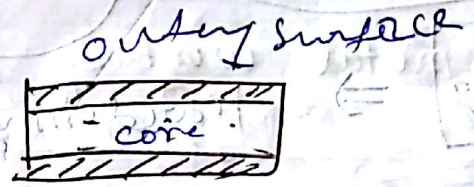
FCC ⇒ BCT

↓

C

Case Hardening

↓




alloying

A → M

Low carbon steel

→ carbon ⇒ Carborazing ≈ 900°C (HP ⇒ 10 Hours)

→ Nitrogen ⇒ $NH_3$ ≈ 600°C Nitriding

→ Carbon + Nitrogen ⇒ Cyaniding

CH → Heat treatment process

medium carbon steel (0.3% to 0.6% of C)

↓

① flame Hardening
② Induction Hardening
③ Laser Hardening

| change of hardens in a small part of the sample

① → progressive flame Hardening
→ spin flame Hardening

Scanned by CamScanner

② → Transformer

Primary coil (AC) → magnetic flow

↓

eddy current flow in the sample

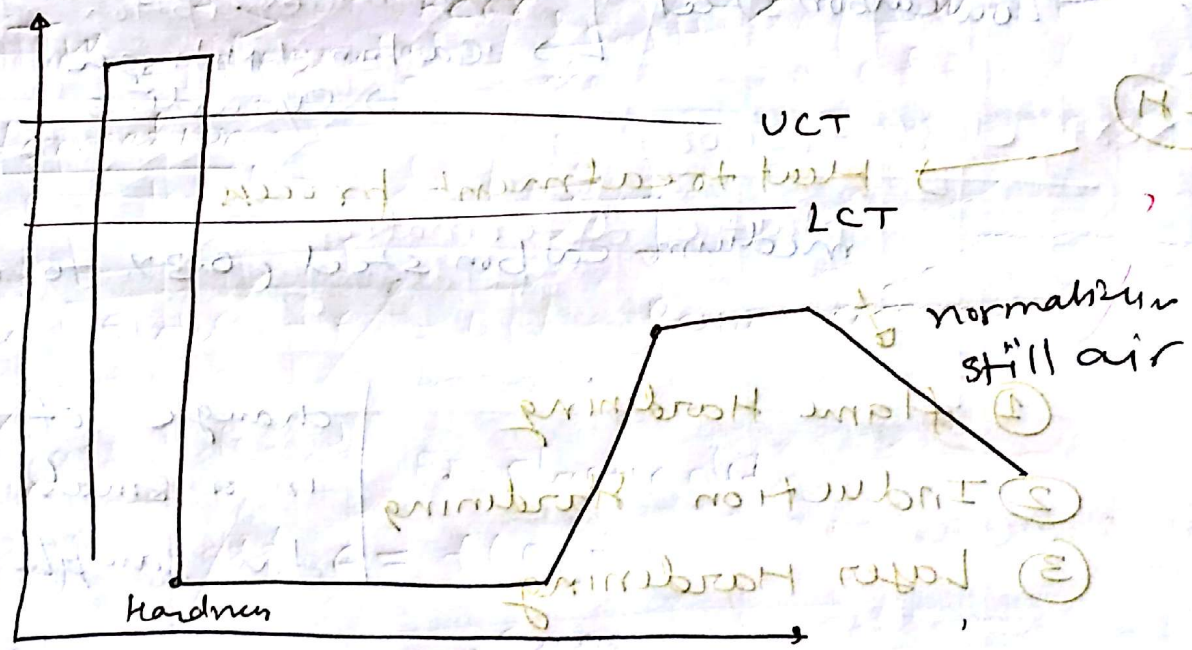
③ Laser hardening:

welding, cutting, mat processing

Heat the sample → Small HAZ

Tempering ⇒ Hardening is done ⇒ Brittleness

A→m ← Hardness + Impact strength




Scanned by CamScanner

# Metal Forming process:

Hot working | Cold working

$T_{Hot} > T_{Recrystallization} > T_{cold}$

$T_{Recrystallization} \Rightarrow \left(\frac{1}{3} \text{ to } \frac{1}{2}\right) T_m$

$\Downarrow$

New crystal

## Adv. of Hot working

① Less force is required

② defect like Porosity, blow holes can be eliminated

## Disadv:

① oxide scale ⇒ surface quality poor

② Dimensional accuracy is difficult to be maintained

③ Better material handling devices (mat)

## Cold working:

**Advantage:** ① reverse

dis ① Reverse

**Deformation** ⇒ change of dimensions

Force

Temp

Scanned by CamScanner

- elastic ⇒ $\epsilon = f(\sigma)$
- Plastic def ⇒ Permanent def

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

$\epsilon_1$ = Instant def

$\epsilon_2$ = Retained deformation

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

$\epsilon$

An-elastic deformation

---

23/08/16

metal working process

- Hot working
- Cold working

$T_w > T_{Recr} > T_w$

deformation;

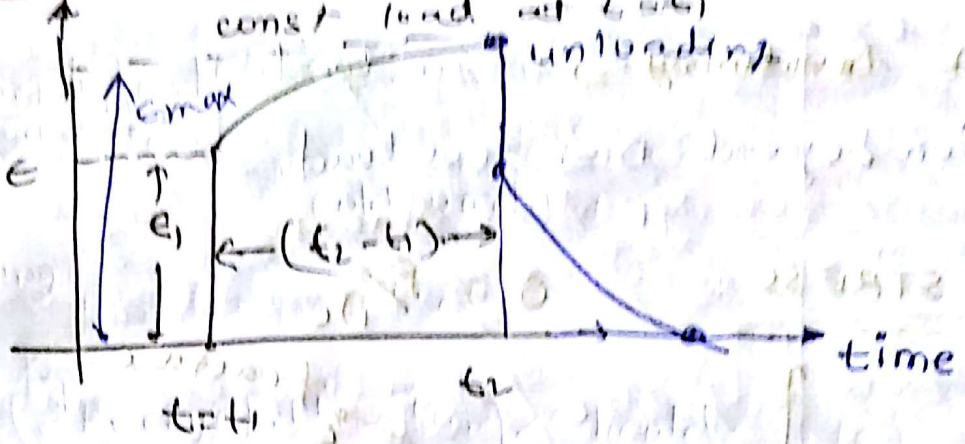
- Temporary
- Permanent

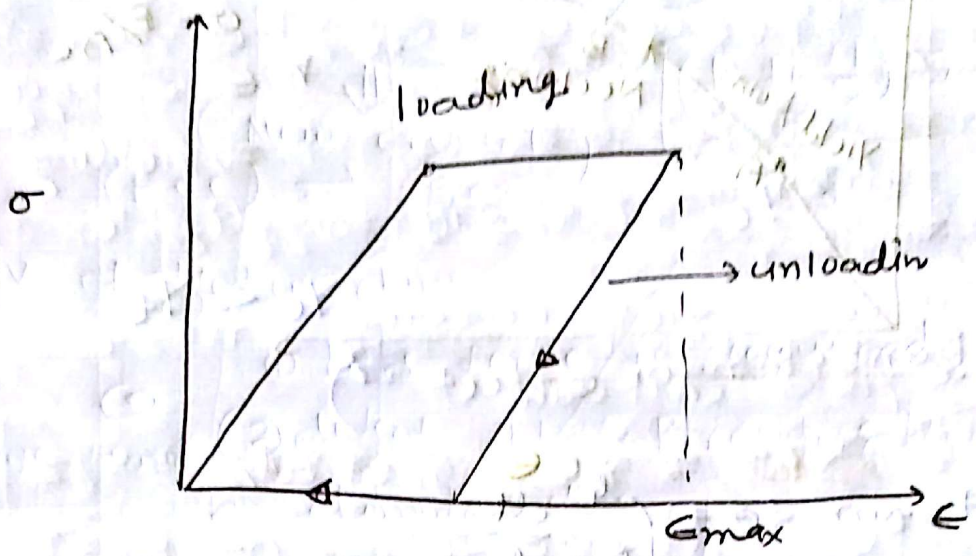
Temporary:

- Elastic
  - $\epsilon = f(\sigma)$
  - metal
- An-elastic def
  - $\epsilon = f(\sigma, t)$
  - $\epsilon_{max}$
  - Rubber

Scanned by CamScanner

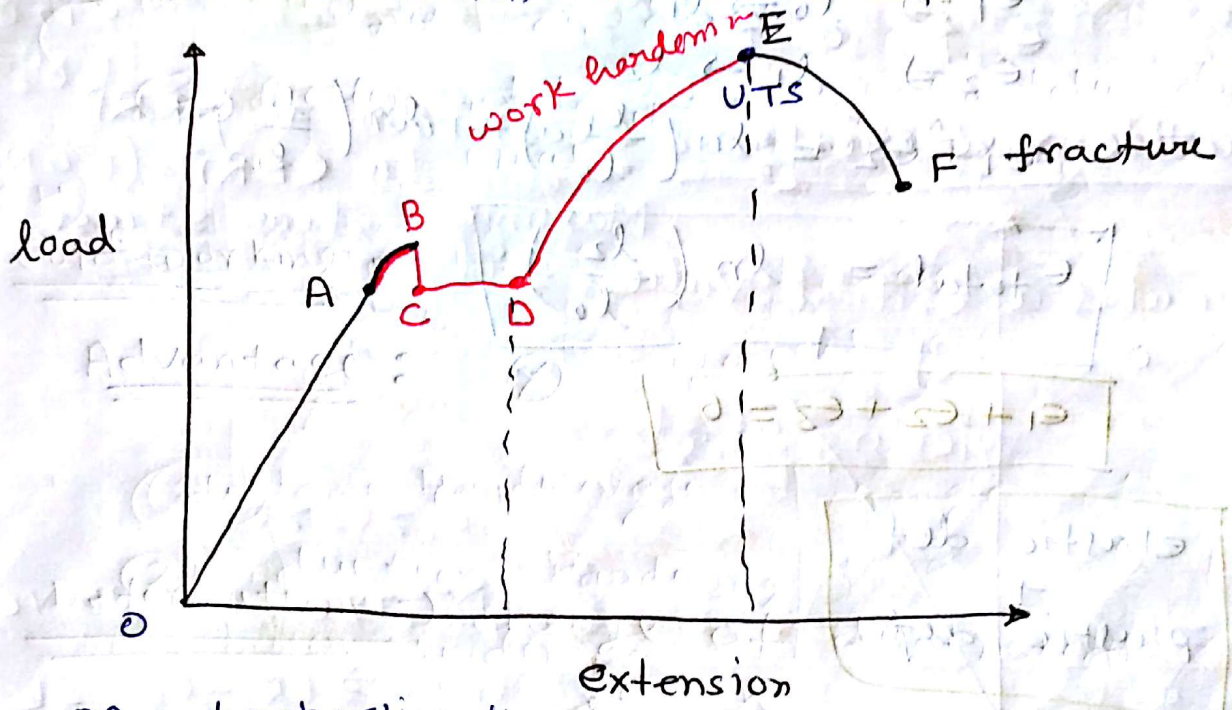
Rubber




$\epsilon = f(\sigma, T, \epsilon)$

load extension → mild steel




OA ⇒ proportion limit ] → elastic temporary deformation
AB ⇒ non linear

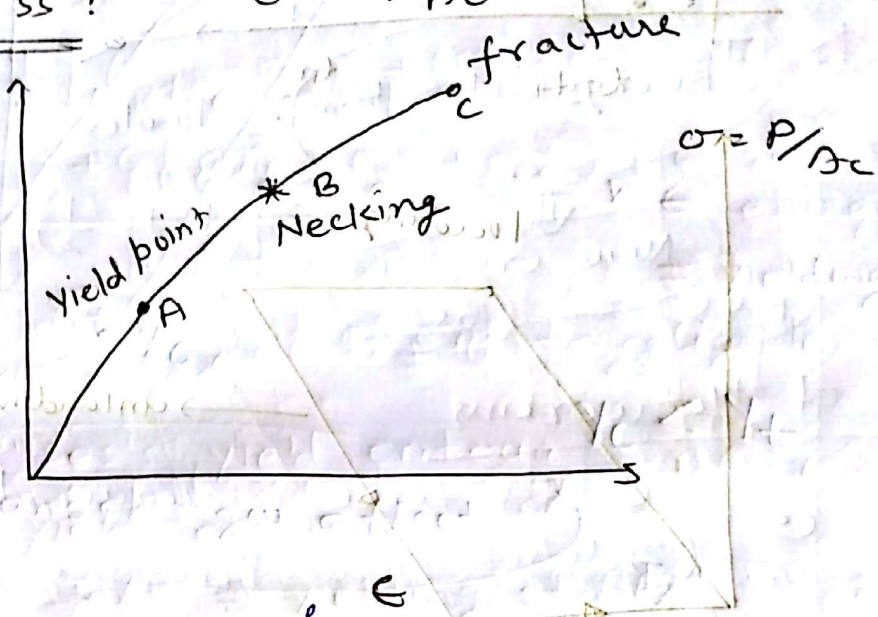
B = upper yield point ⇒ yielding starts ⇒ plastic

C = lower yield point

Scanned by CamScanner

Work hardening ⇒ more load
Extension beyond D ⇒ less load
} → opposing fact

**TRUE STRESS :** $\sigma = P/A_c$




strain $\epsilon = \int_{l_0}^{l_f} \frac{dl}{l}$

$$\epsilon = \ln\left(\frac{l_1}{l_0}\right)$$

$\epsilon_1 \Rightarrow l_0 \rightarrow l_1$

$\epsilon_2 \Rightarrow l_1 \rightarrow l_2$

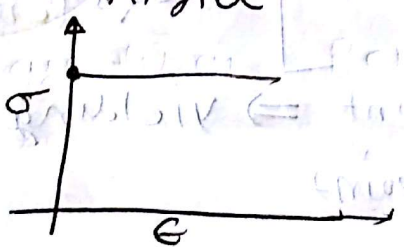
$$\epsilon_1 + \epsilon_2 = \ln\left(\frac{l_1}{l_0}\right) + \ln\left(\frac{l_2}{l_1}\right)$$

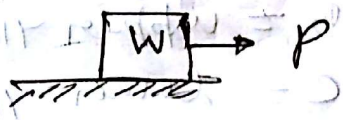
$$\boxed{\epsilon_{total} = \ln\left(\frac{l_2}{l_0}\right)}$$

$$\boxed{\epsilon_1 + \epsilon_2 + \epsilon_3 = 0}$$

elastic def
+
plastic def

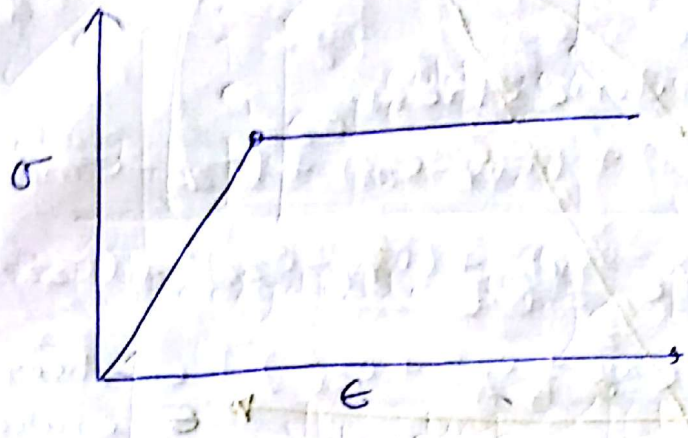
**Case I** Rigid + Perfectly plastic

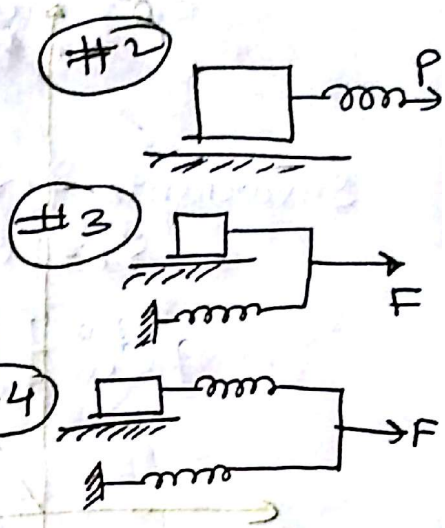


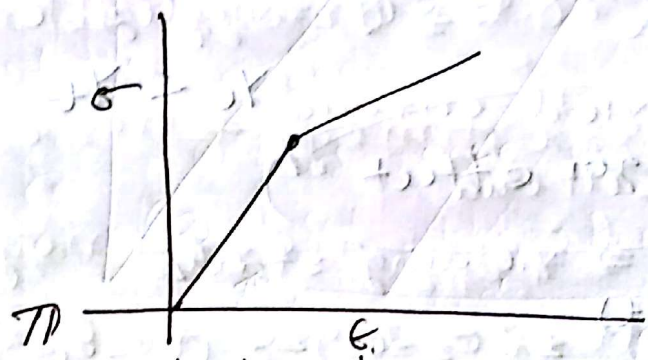

Scanned by CamScanner

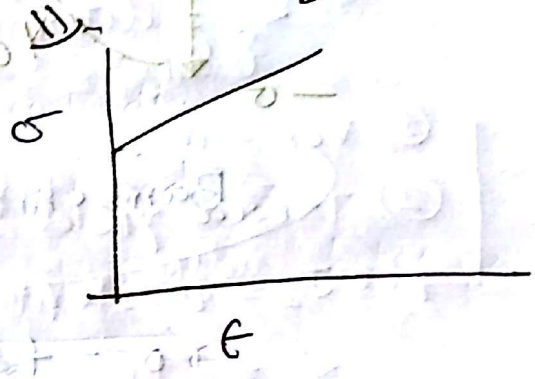
**Case II** Elastic + Perfectly plastic



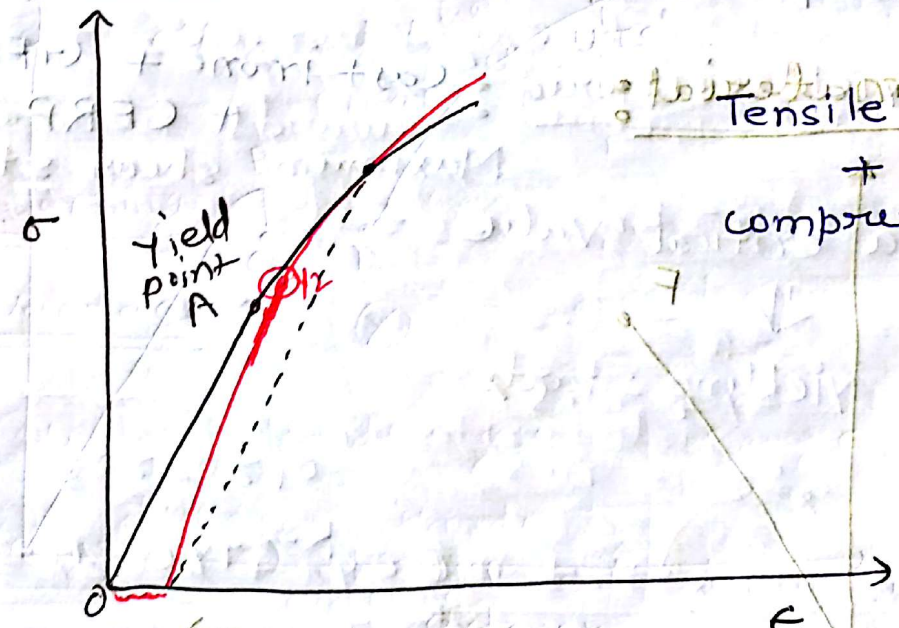

**Case III** Rigid - Linear ~~hard~~ work hardening



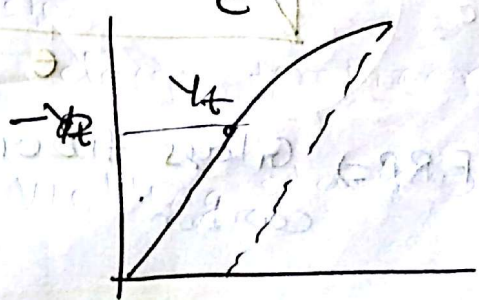




**Case IV** elastic + linear ~~work~~ work hardening

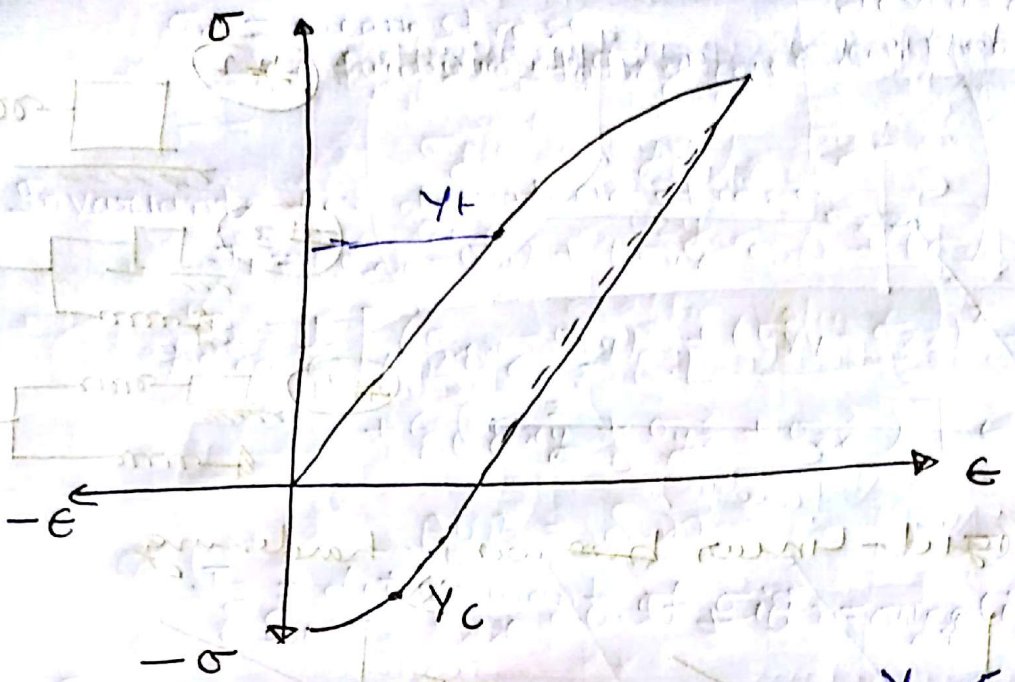
**Repeated loading** ⇒ Beyond yield point




Tensile loading + compressive load




Scanned by CamScanner




$Y_c < Y_t$

Banschinger effect

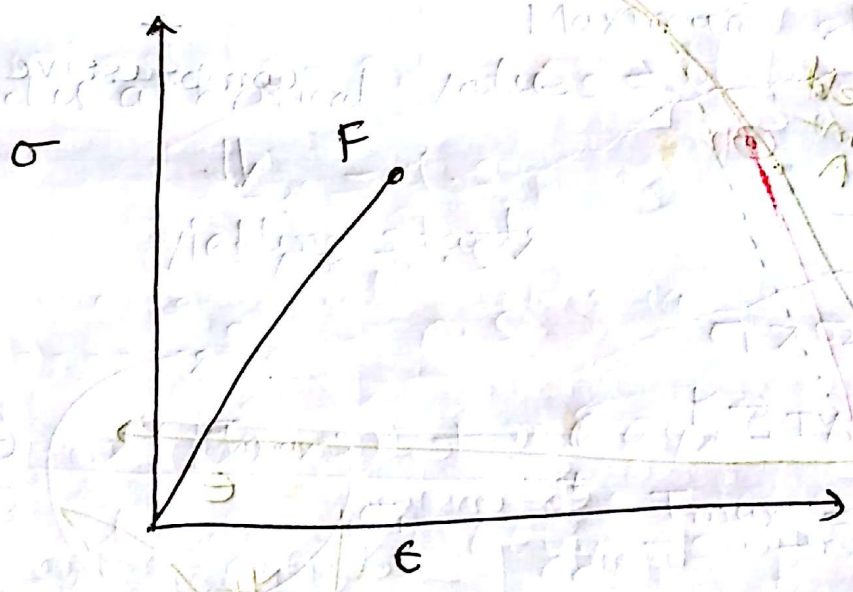
$\sigma = f(t)$

$T \uparrow \quad \sigma \downarrow$

$\sigma = f(\epsilon)$

$\epsilon \uparrow \quad \sigma \uparrow$

**Brittle material:** - Cast iron + GFRP + CFRP



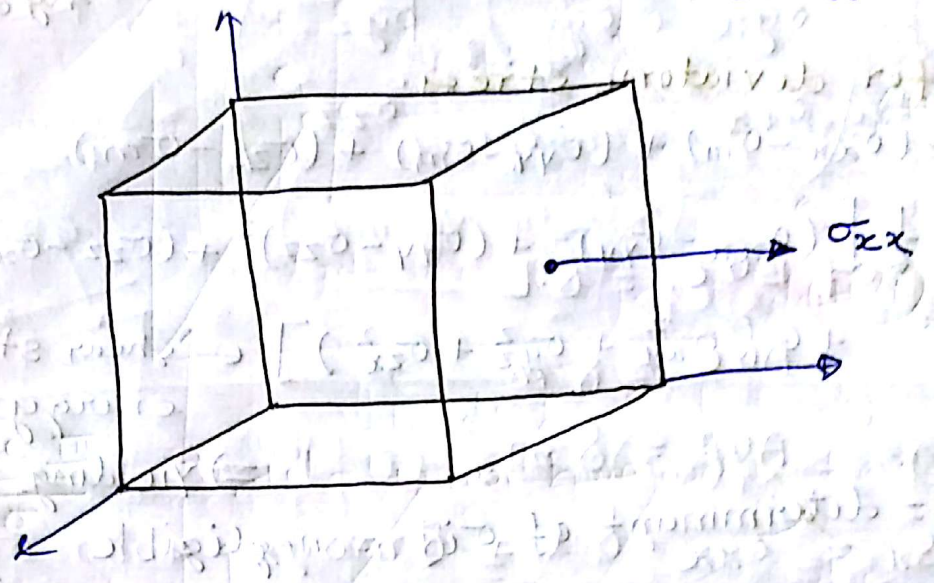

GFRP ⇒ Glass fiber Reinforced plastic

carbon "

Scanned by CamScanner

25/08/2016

solid Mech diagram




stress

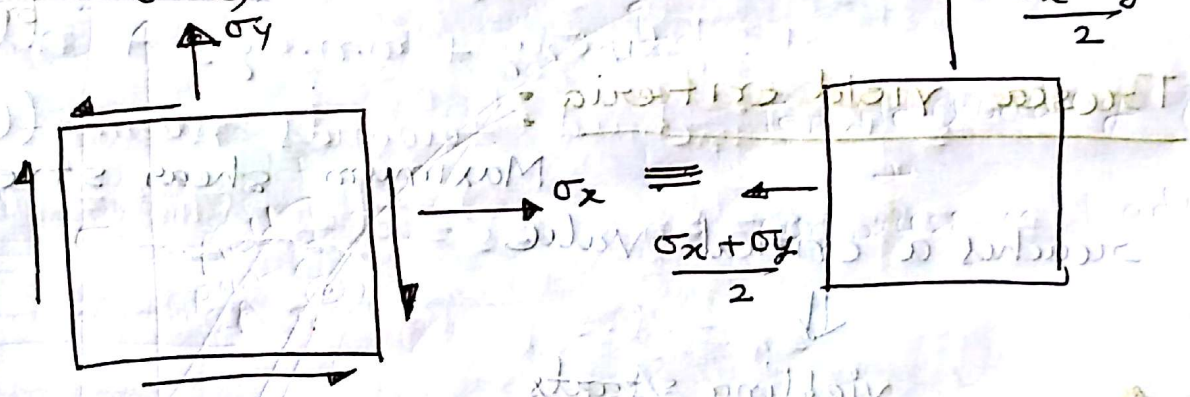
Hydrostatic

Deviatoric

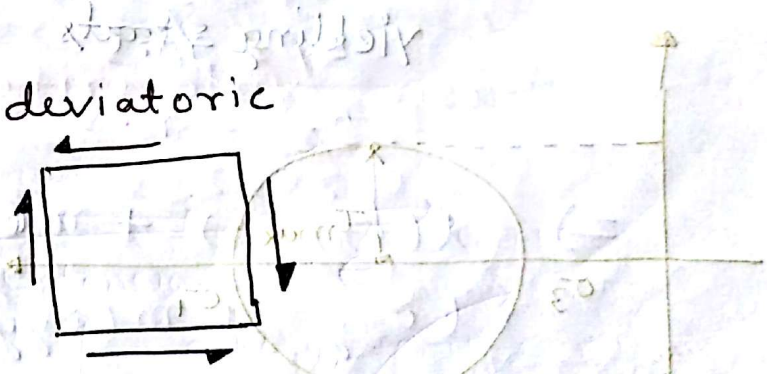
(Total stress hydrostic)

$$\sigma_m = \frac{\sigma_{xx} + \sigma_{yy} + \sigma_{zz}}{3}$$

change of elastic volume (size)




+ deviatoric



$$\sigma'_{ij} = \sigma_{ij} - \sigma_m \delta_{ij}$$

$\delta_{ij} = 1$ if $i = j$

$= 0$ if $i \neq j$

Scanned by CamScanner

$\sigma_m$ = mean stress or hydrostatic stress

deviatoric component $= \sigma_{ij} - \sigma_m$

hydrostatic component

Invariants for deviatoric stress:

$$J_1 = (\sigma_{xx} - \sigma_m) + (\sigma_{yy} - \sigma_m) + (\sigma_{zz} - \sigma_m)$$

$$J_2 = \frac{1}{6}\left[(\sigma_{xx} - \sigma_{yy})^2 + (\sigma_{yy} - \sigma_{zz})^2 + (\sigma_{zz} - \sigma_{xx})^2 + 6(\sigma_{xy}^2 + \sigma_{yz}^2 + \sigma_{zx}^2)\right]$$

← shear strain energy ⇒ yielding

$J_3$ = determinant of $\sigma_{ij}$ = negligible

① Von-mises's yield criteria

② Tresca yield criteria

$J_2$ = constant ⇒ yielding starts

$$J_2 = \frac{1}{6G}\left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2\right] = A$$

shear strain energy per unit volume = A ⇒ yielding

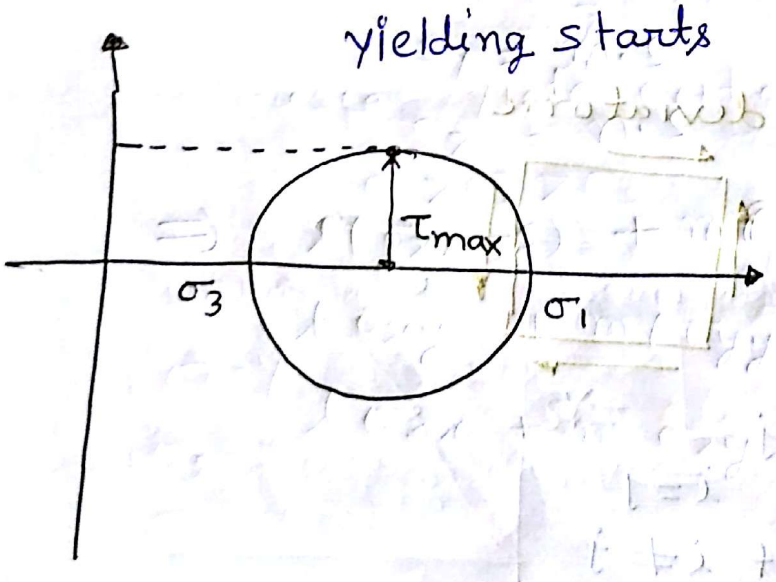
$\sigma_1, \sigma_2, \sigma_3$ principal stress

## Tresca yield criteria:

Maximum shear stress reaches a critical value

⇓

yielding starts




$\sigma_1 > \sigma_2 > \sigma_3$

K → TYC, A → UMVC

$$\tau_{max} = \frac{(\sigma_1 - \sigma_3)}{2} = K$$

↓

shear yield stress

Scanned by CamScanner

Uniaxial loading :

Yielding ??

$\sigma_1, \sigma_2, \sigma_3 \Rightarrow \sigma_1 = Y$

$\sigma_2 = 0$

$\sigma_3 = 0$

Pure Torison + uniaxial loading $\Rightarrow$ yielding # 1 critera

yield crite # 2

$\sigma_1 = K$

$\sigma_2 = 0$

$\sigma_3 = -K$

$\boxed{Y \leq K}$

unit axial loading

$$J_2 = \frac{1}{6} \times [Y^2 + Y^2] = \frac{1}{6} \times 2Y^2$$

pure torison

$$J_2 = \frac{1}{6} \times [K^2 + K^2 + (2K)^2] = \frac{1}{6} \times 6K^2$$

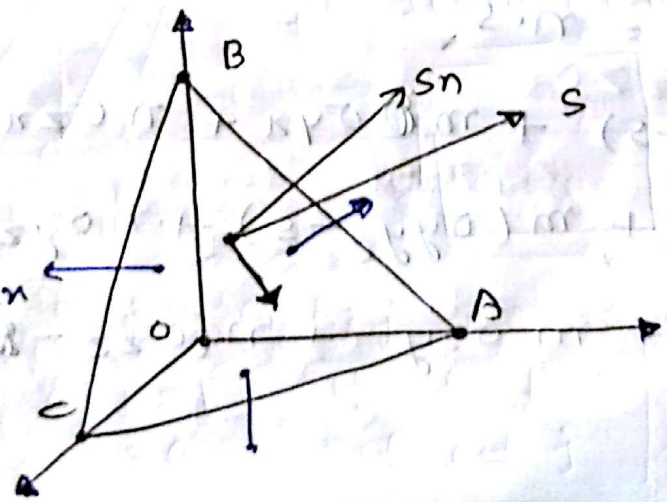
$J_2$ is constant von Mines criteria

$$2Y^2 = 6K^2$$

$$\boxed{Y^2 = 3K^2}$$

30/08/2016

Components of stresses on a element




Scanned by CamScanner

$$\begin{pmatrix} \sigma_{xx} & \sigma_{xy} & \sigma_{xz} \\ \sigma_{yx} & \sigma_{yy} & \sigma_{yz} \\ \sigma_{zx} & \sigma_{zy} & \sigma_{zz} \end{pmatrix}$$

Area of $BOC = \delta \cdot L$

$AOC = \delta m$

$AOB = \delta n$

$$\delta S_x = \sigma_{xx} \cdot \delta \cdot l + \delta m \sigma_{yx} + \delta n \sigma_{zx}$$

$$\Rightarrow S_x = l\sigma_{xx} + m\sigma_{yx} + n\sigma_{zx}$$

similarly $S_y = l\sigma_{xy} + m\sigma_{yy} + n\sigma_{yz}$

$$S_z = l\sigma_{zx} + m\sigma_{zy} + n\sigma_{zz}$$

$$\Rightarrow S_n = lS_x + mS_y + nS_z$$

$$S_n = l^2\sigma_{xx} + m^2\sigma_{yy} + n^2\sigma_{zz} + 2[lm\sigma_{xy} + m.n.\sigma_{yz} + n.l.\sigma_{zx}]$$

s is inclined towards normal (ON)

$$S = S_n, \quad S_s = 0$$

$$S_x = l.S$$

$$S_y = m.S$$

$$S_z = n.S$$

$$\Rightarrow l(\sigma_{xx} - S) + m\sigma_{yx} + n\sigma_{zx} = 0$$

$$l\sigma_{xy} + m(\sigma_{yy} - S) + n\sigma_{yz} = 0$$

$$l\sigma_{zx} + m\sigma_{zy} + n(\sigma_{zz} - S) = 0$$

Scanned by CamScanner

$$l_i(\sigma_{ij} - \delta_{ij} s) = 0$$

$$\Downarrow$$

$$\delta_{ij} = 1 \quad i = j$$
$$= 0 \quad i \neq j$$

To have non-trivial soln.

$$\det(\ ) = 0$$

$$\begin{vmatrix} \sigma_{xx} - s & \sigma_{yx} & \sigma_{xz} \\ \sigma_{yx} & \sigma_{yy} - s & \sigma_{yz} \\ \sigma_{zx} & \sigma_{zy} & \sigma_{zz} - s \end{vmatrix} = 0$$

$$\Rightarrow \boxed{s^3 - I_1 s^2 - I_2 s - I_3 = 0}$$

$I_1, I_2, I_3, \Rightarrow$ Invariants of deviatory stress

$$I_1 = \sigma_{xx} + \sigma_{yy} + \sigma_{zz}$$

$$I_2 = \sigma_{xy}^2 + \sigma_{yz}^2 + \sigma_{zx}^2 - (\sigma_{xx}\sigma_{yy} + \sigma_{yy}\sigma_{zz} + \sigma_{zz}\sigma_{xx})$$

$$I_3 = \begin{vmatrix} & \end{vmatrix}$$

$I_1, I_2, I_3 \Rightarrow$ Total stress vector

stress $\longrightarrow$ Hydrostatic

$\longrightarrow$ deviatoric comp

$$\sigma_{hyd} = \frac{\sigma_{xx} + \sigma_{yy} + \sigma_{zz}}{3}$$

Scanned by CamScanner

$$\sigma_{ij} = \sigma'_{ij} + \sigma_{hyd} \Rightarrow \frac{1}{3}\delta_{ij}\sigma_{KK}$$

$\sigma'_{ij}$ → Shear stresses → Shape

$\sigma_{hyd}$ → change of elastic volume

$\delta_{ij}$: $1 \Rightarrow i = j$, $0 \Rightarrow i \neq j$

---

$$(\sigma')^3 - J_1(\sigma')^2 - J_2(\sigma') - J_3 = 0$$

$$J_1 = \Sigma \sigma'_{KK} = 0$$

$$J_2 = \frac{1}{6}\left[(\sigma_{11}-\sigma_{12})^2 + (\sigma_{22}-\sigma_{33})^2 + (\sigma_{33}-\sigma_{11})^2 + \sigma_{12}^2 + \sigma_{23}^2 + \sigma_{31}^2\right]$$

$$J_2 = \frac{1}{2}\sigma'_{ij}\sigma'_{ij}$$

$$J_3 = \frac{2}{27}I^3 - \frac{1}{3}I_1 I_2 + I_3$$

$$= \frac{1}{3}\sigma'_{ij}\sigma'_{jk}\sigma'_{ki}$$

$$(\sigma_{11}-\sigma_{12})^2 + (\sigma_{22}-\sigma_{33})^2 + (\sigma_{33}-\sigma_{11})^2 = \text{constant}$$

$$\sigma_1 - \sigma_3 = 2K$$

Tresca yield criteria

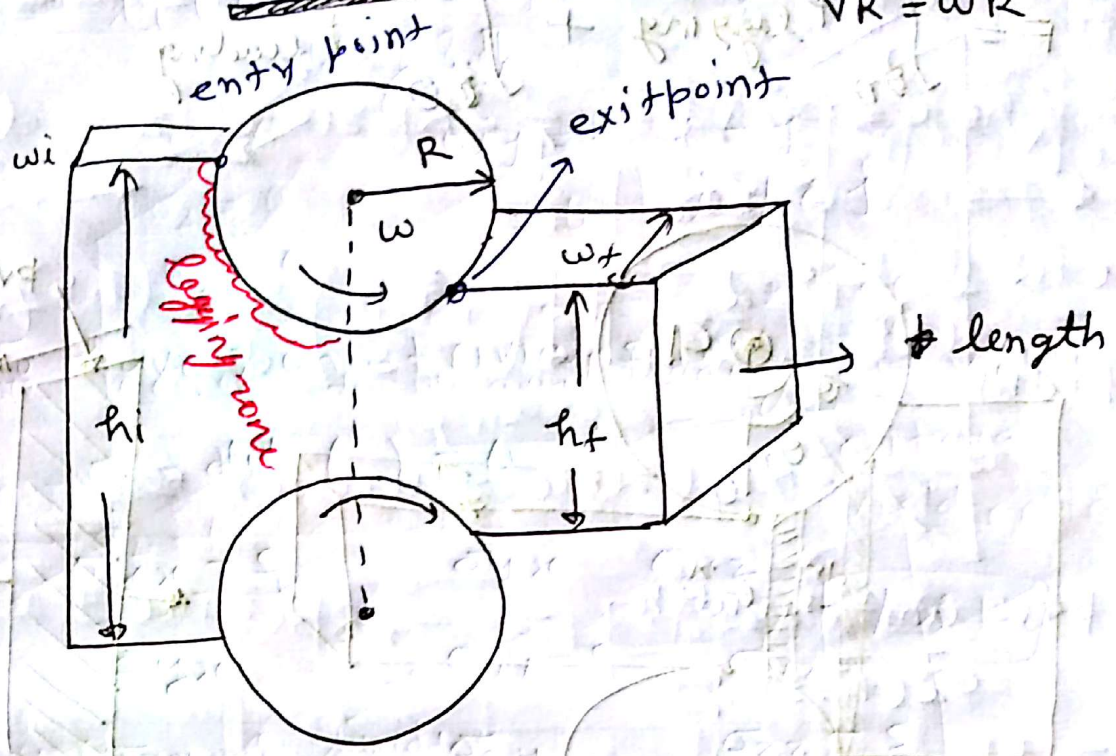
$$\sigma_1 > \sigma_2 > \sigma_3$$

| uniaxial | Pure torsion | |
|---|---|---|
| $\sigma_1 = Y$ | $\sigma_1 = K$ | Ans |
| $\sigma_2 = 0$ | $\sigma_2 = 0$ | |
| $\sigma_3 = 0$ | $\sigma_3 = -K$ | |

Scanned by CamScanner

# Rolling

$VR = \omega R$




$\omega_i = \omega_f$

$\Downarrow$

plane stress deformation

$\boxed{\omega >> h}$

$\boxed{(V_m)_f > V_R}$

$\boxed{V_m = V_R}$

$V = l \cdot \omega \cdot h \Rightarrow$ Constant

$\downarrow$

$\epsilon_1 + \cancel{\epsilon_2}^{\,0} + \epsilon_3 = 0$

$\boxed{\epsilon_1 = -\epsilon_3}$

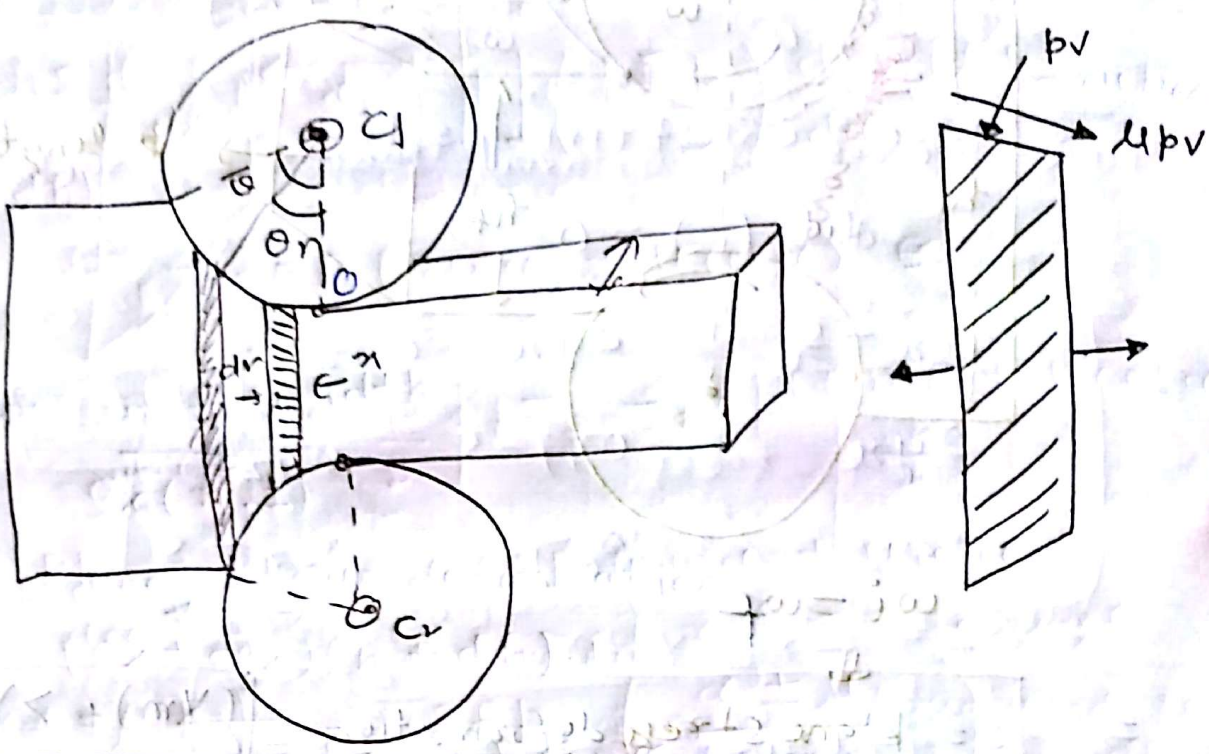
Roll force: $\longrightarrow$ Pressure distribution in outstripping zone

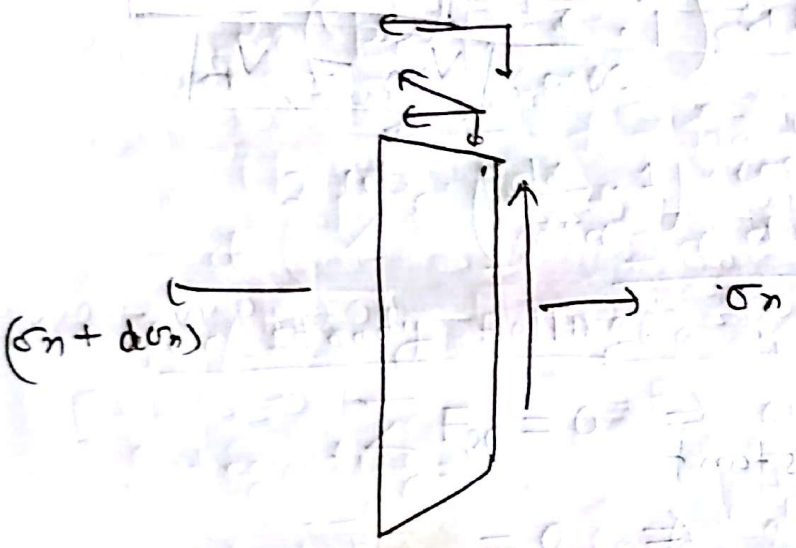
$\swarrow$

Pressure distribution in lagging zone

Scanned by CamScanner

$$F = \int_{\theta_n}^{\theta} P_{lagging} + \int_{0}^{\theta_n} P_{leading}$$

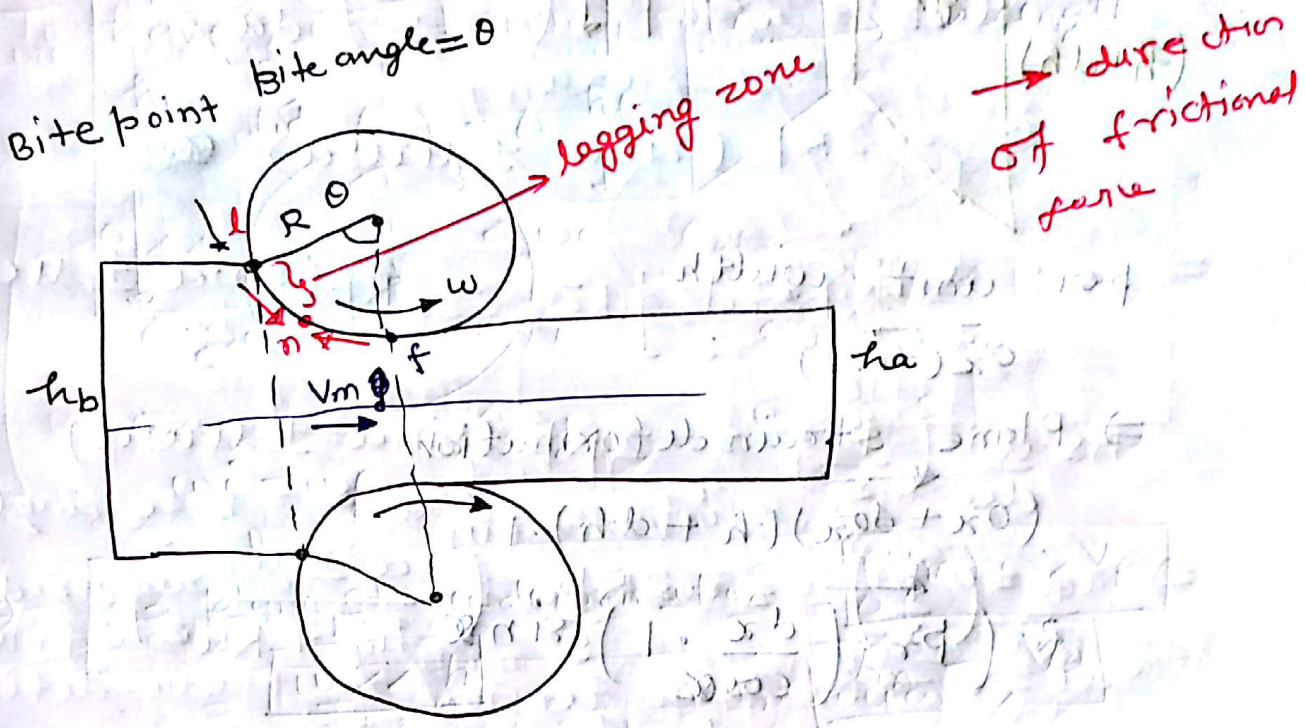



Scanned by CamScanner

$\boxed{\Sigma F_x = 0}$ ⇒ elements in out stripping zone

$\Sigma F_n = 0$ → for lagging zone




$\omega_a = \omega_b$

$h_b > h_a$

$V_R = \omega \cdot R$

$V_R > (V_m)_i$

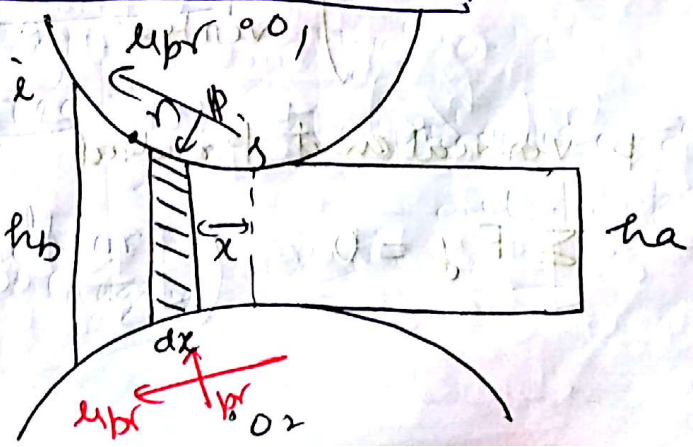
$(V_m)_f > V_R$

$l - n$ ⇒ lagging zone

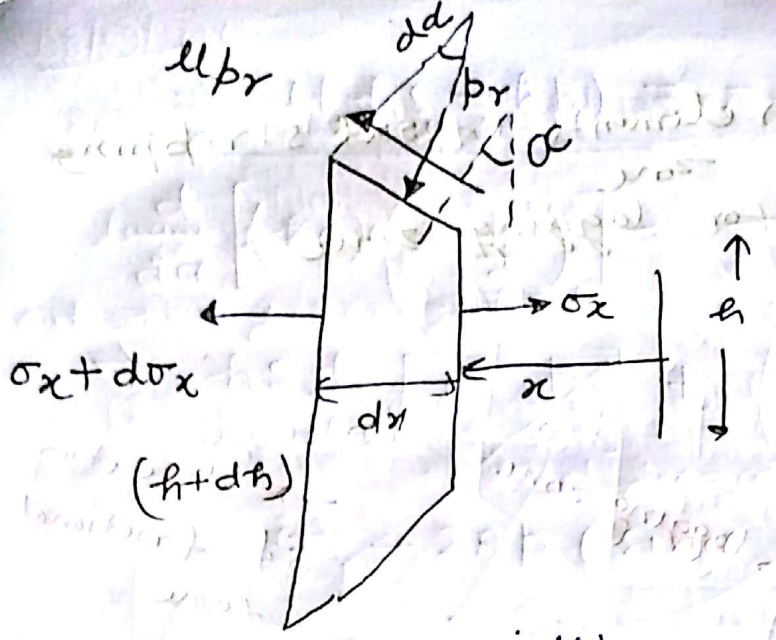
$n - f$ ⇒ out stripping zone

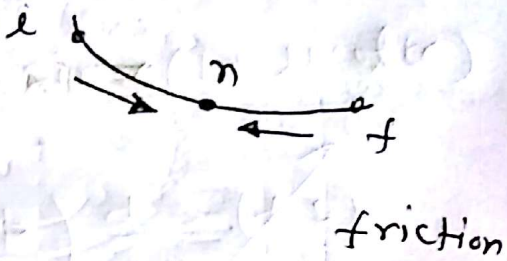
~~Roll sep~~ $V_R = (V_m)_n$ neutral point

$\boxed{\text{Roll separating} \Rightarrow f}$




Scanned by CamScanner




per unit width

$\sigma_x (h \cdot 1)$

$\Rightarrow$ Plane strain deformation

$(\sigma_x + d\sigma_x)(h + dh) \cdot 1$

$2 \cdot \left( p_r \cdot \left( \frac{dx}{\cos\alpha} \cdot 1 \right) \sin\alpha \right.$

$2 \mu p_r \left( \frac{dx}{\cos\alpha} \cdot 1 \right) \cdot \cos\alpha$

<u>for steady Rolling:</u>

$\sum F_x = 0 \Rightarrow$ out stripping zone

$\sum F_x = 0 \Rightarrow$ lagging zone

$\downarrow$ out

$\int p_{vertical} \quad + \int p_{vertical}$ lagg zon

p vertical and p radial

$\sum F_y = 0$ mill load

Scanned by CamScanner

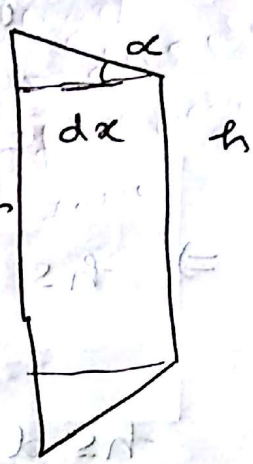
out stripping zone ⇒

$$h\,d\sigma_x + \sigma_x\,dh + 2p_r\,dx\tan\alpha + 2\mu p_r\,dx = 0$$

(lagging zone ⇒

$$h\,d\sigma_x + \sigma_x\,dh + 2p_r\,dx\tan\alpha - 2\mu p_r\,dx = 0$$

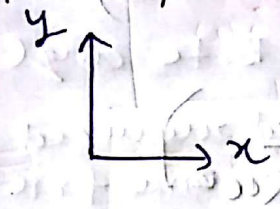
$$dh = 2\,dx\tan\alpha$$




$$h\,d\sigma_x + \sigma_x\,dh + p_r\,dh \pm \mu p_r\,dh\cot\alpha = 0$$

$$\Rightarrow d(h\sigma_x) = -p_r(1 \pm \mu\cot\alpha)\,dh$$

principal stress




$$\left[\begin{array}{l}\sigma_1 = \sigma_x \\ \sigma_3 = -p = \sigma_y\end{array}\right] \Rightarrow \text{Tresca's yield criteria}$$

$$\sigma_2 = \quad ] \text{ von mises yield criteria}$$

$$\sigma_y\,dx = -\left(p_r\frac{dx}{\cos\alpha}\right)\cos\alpha + \mu p_r\frac{dx}{\cos\alpha}\cdot\sin\alpha$$

$$\Rightarrow \sigma_y = -p_r(1 - \mu\tan\alpha)$$

$$\Rightarrow \boxed{\sigma_y = -p_r = -p}$$

$$\sigma_x + p = 2K = S$$

$$\sigma_x = S - p$$

$$\Rightarrow h\sigma_x = hS - hp$$

$$\Rightarrow d(h\sigma_x) = -p(1 \pm \mu\cot\alpha)\,dh$$

$$dh = 2(R\,d\alpha)\sin\alpha$$

Scanned by CamScanner

$$\Rightarrow d(hs - hp) = -2Rp\sin\alpha(1 \pm \mu\cot\alpha)\,d\alpha$$

$$\frac{d}{d\alpha}\left[(hs)\left(1-\frac{p}{s}\right)\right] = -2Rp\sin\alpha(1 \pm \mu\cot\alpha)$$

$$\Rightarrow hs\frac{d}{d\alpha}\left[1-\frac{p}{s}\right] + \left(1-\frac{p}{s}\right)\frac{d}{d\alpha}\cdot(hs)$$

$$= -2Rp(\sin\alpha \pm \mu\cos\alpha)$$

$$\Rightarrow hs\frac{d}{d\alpha}\left[1-\frac{p}{s}\right] = -2Rp(\sin\alpha \pm \mu\cos\alpha)$$

$$hs\frac{d}{d\alpha}\left(\frac{p}{s}\right) = 2Rp(\sin\alpha \pm \mu\cos\alpha)$$

for small $\alpha$

$$\Rightarrow \frac{d}{d\alpha}\left(\frac{p}{s}\right) = \frac{2Rp}{s}\left(\frac{\alpha \pm \mu}{h_a + R\alpha^2}\right)$$

$$h = h_a + R\alpha^2$$

$$\frac{d(p/s)}{\left(\frac{p}{s}\right)} = \frac{2\alpha\,d\alpha}{\frac{h_a}{R} + \alpha^2} \pm \left(\frac{2\mu\,d\alpha}{\frac{h_a}{R} + \alpha^2}\right)$$

Integrating $\Rightarrow$

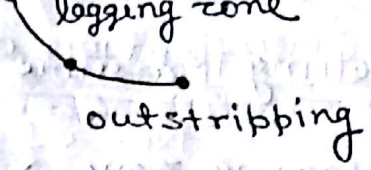
$$\ln\left(\frac{p}{s}\right) = \ln\left(\frac{h_a}{R} + \alpha^2\right) \pm 2\mu\cdot\frac{1}{\sqrt{\frac{h_a}{R}}}\cdot\tan^{-1}\left(\frac{\alpha}{\sqrt{h_a/R}}\right) + \text{constant}$$

$$\Rightarrow \ln(p/s) = \ln(h/R) \pm \mu H + \text{const}$$

$$H = 2\sqrt{\frac{R}{h_a}}\cdot\tan^{-1}\left(\sqrt{\frac{R}{h_a}}\,\alpha\right)$$

Scanned by CamScanner

out stripping zone




$$\left(\frac{p^+}{s}\right) = (c^+)\frac{h}{R}e^{\mu H}$$

lagging zone

$$\left(\frac{p^-}{s}\right) = (c^-)\frac{h}{R}e^{-\mu H}$$

Case 1 # No front pull No back pull

case # 2 $\sigma_{ax} = t_a$

$\sigma_{xb} = t_b$

$p^+/p^\ominus$ for case # 1

$p^+/p^\ominus$ for case # 2

apply BC

| | |
|---|---|
| $c^+$ | $R/h$ |
| $c^\ominus$ | $\frac{Re^{\mu H}}{h}$ |

mid sem syllabus

1. crystal struct
2. Heat treatment
3. Phase equilibrium diagram
   T-T-T dia
4. Plastic deformation (stress/strain)
5. Yield criteria

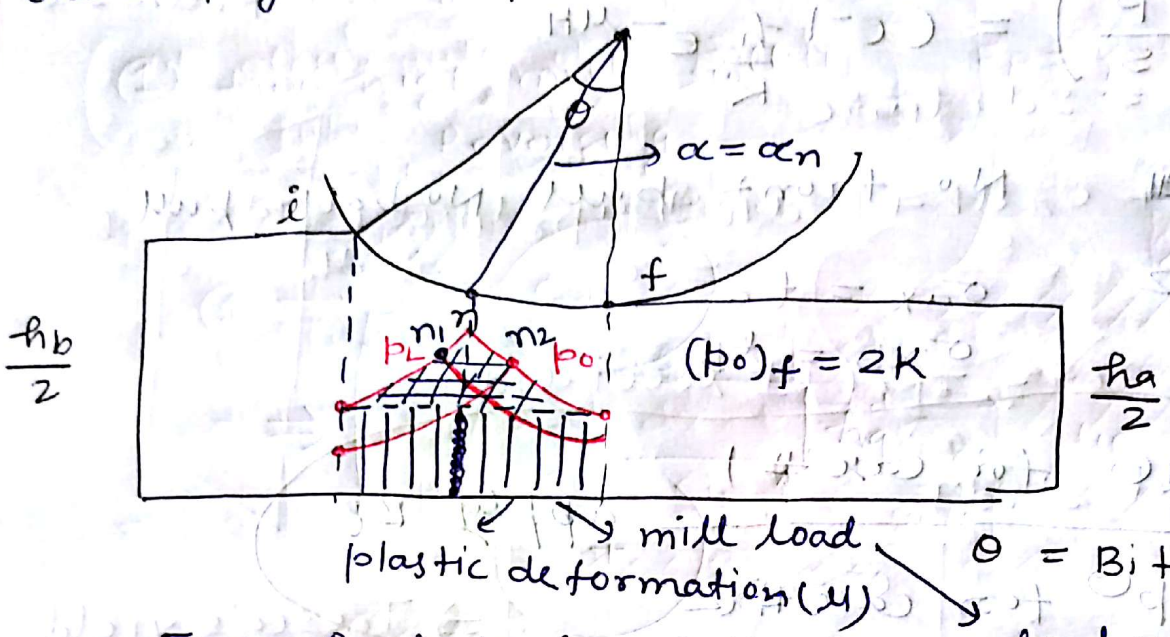
Scanned by CamScanner

08/09/2016

## Rolling Pressure distribution:

lagging zone ⇒ $p^+$

out striping zone ⇒ $p^-$




θ = Bite angle

load required to overcome friction + Plastic deformation

$\sigma_{xf} = 0 \rightarrow$ No front tension

$\sigma_{xi} = 0 \rightarrow$ No beam tension

$(p_L)_i \quad (p_L)_f$

$(p_L)_n = (p_o)_n$

Location of the neutral point

$\frac{\text{Front tension}}{\text{Back tension}}$ +

$n$ = No. front & no back pull

$n_1$ = front tension applied

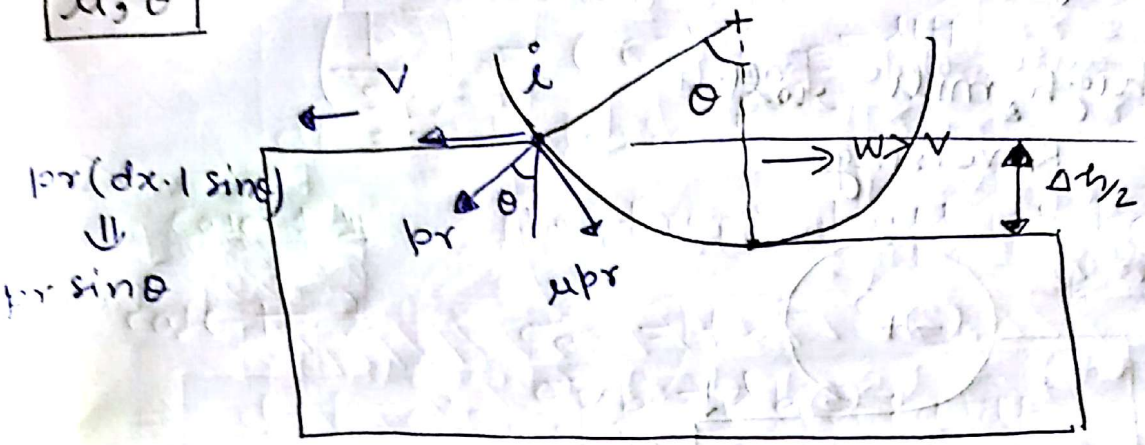
$n_2$ = only back tension is applied

$n_3$ = when both front & back tensions are applied

| $p\downarrow$ | Life of Rod ($\uparrow$) |
|---|---|

Limiting situation for $\mu$, no pully are applied

$\boxed{\mu, \theta}$




uniaided rolling

$\mu pr(A)\cos\theta \Rightarrow \boxed{\mu \geq \tan\theta}$

Draft $\equiv$ Reduction $\equiv h_b - h_a = \Delta h$

$\tan\theta = \Delta h = \mu$

$(\Delta h)_{max} \Rightarrow \boxed{\mu = \tan\theta}$

$\boxed{\mu\uparrow \Rightarrow \text{Rolling load } (\uparrow)}$

$R_1 > R_2$ mill load $\Rightarrow (\downarrow)$

$\tan\theta = \Delta h = \mu$

$$\mu = \sqrt{1 - \left(\frac{\Delta h}{R}\right)^2} - 1$$

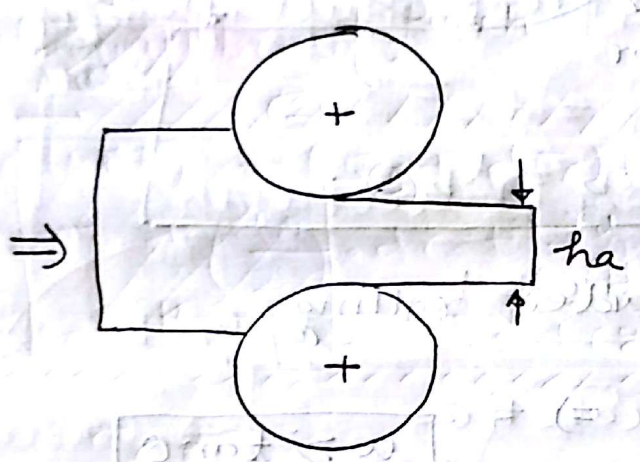
$\Delta h = f(\mu, R)$

Scanned by CamScanner

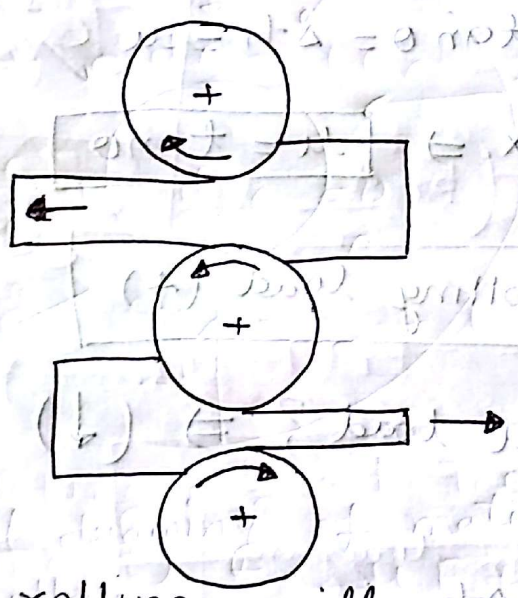
## Classification of Rolling mill:

No. of Rolls
+
arrangement

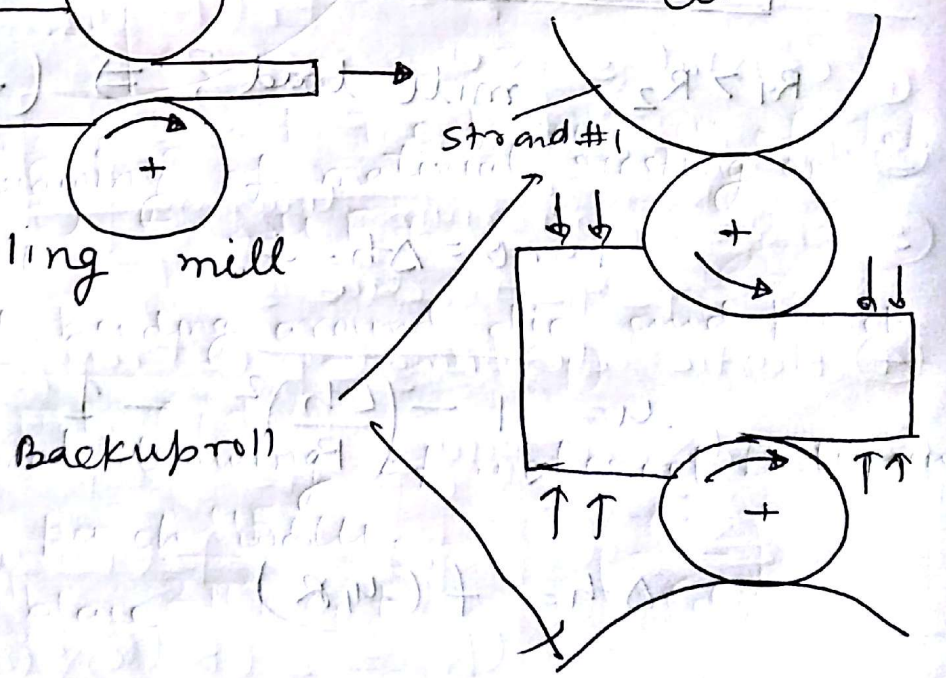
① two high mill roll
Reversing




② Three - high rolling milling



③ Four high rolling mill



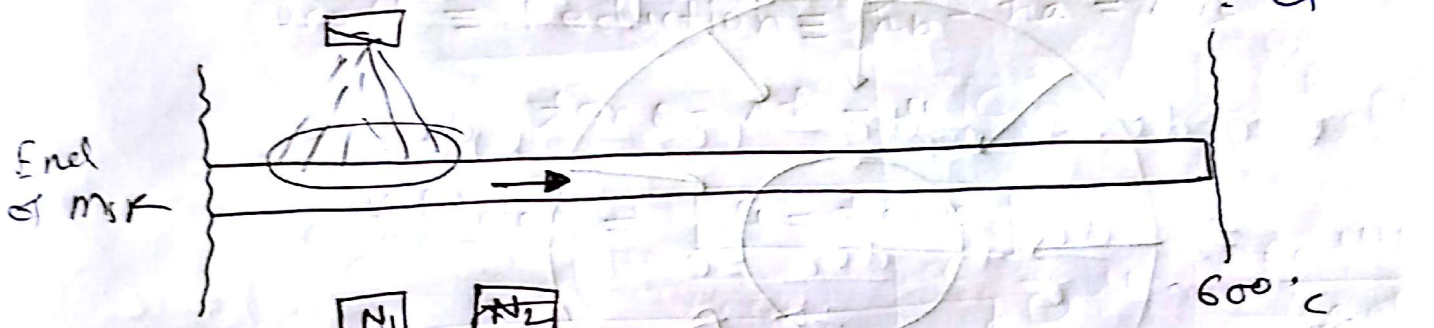

Scanned by CamScanner

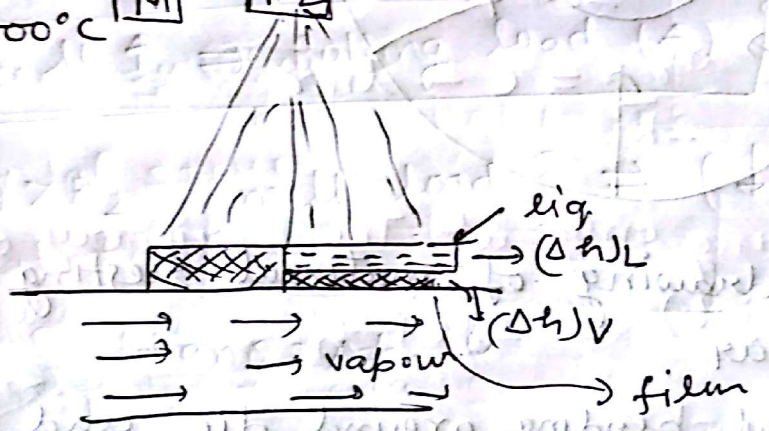
INGOT → BLOOM → Billet
sq C/S (sq C/S)
cross section
6inch square × 6inch
↓
SLAB

BLOOM / BILLET / SLAB ⇒ Plate → > 6mm
sheet → < 6mm
strip → < 6mm
$W_{sheet} > W_{strip}$

Rectangular

Ingot → slab → strip → cooling →
MSR
T ≈ 1000°C
≈ 600°C




forced convection zone

mech properties = f (α, β, γ, δ, d)

Scanned by CamScanner

27/09/2016

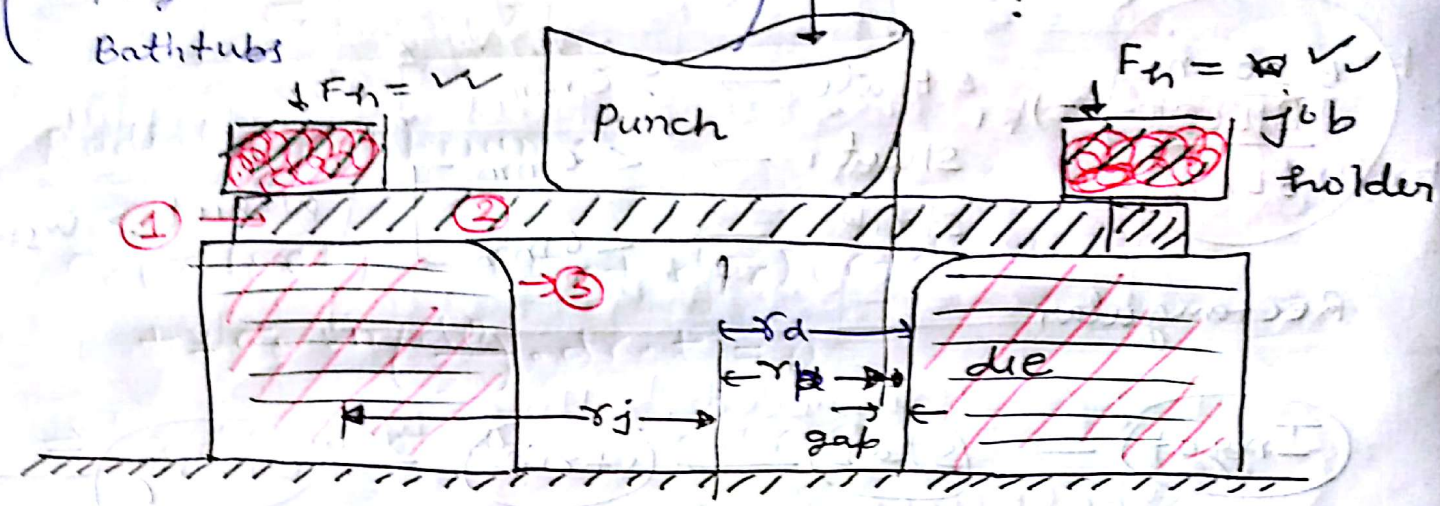
**Deep drawing:** Sheet metal forming operation

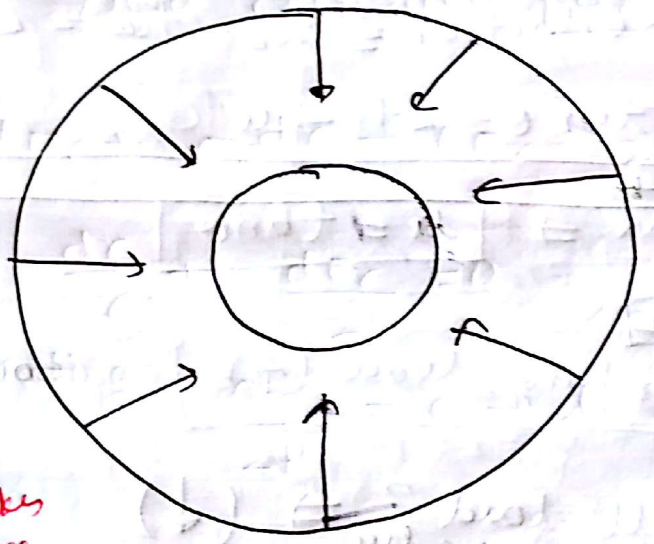
↓ depth of the shape

⇓ Die & Punch

(cup, glass, automobile panels, Bathtubs)

$F_p = ?$



thickening takes place

1 → Radial drawing of material resting on die collar

2 ⇒ material bending around die and punch corners

3 ⇒ longitudinal drawing of material between die and punch walls.

⇓

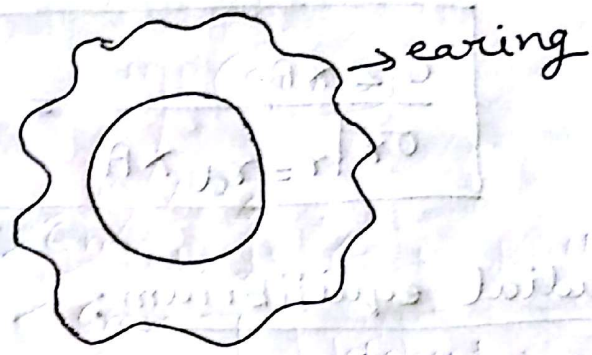
~~thinning~~ takes place

Thining

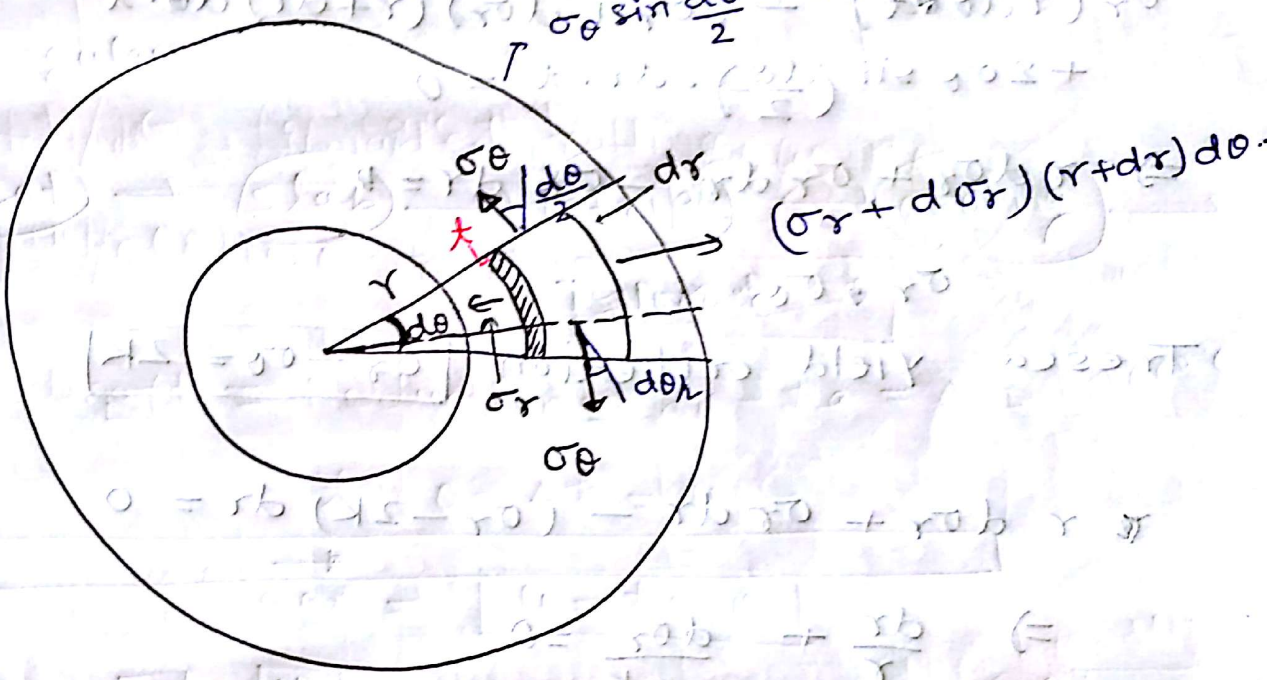
Scanned by CamScanner

⇒ Ironing:

⇒ wrinkling Ironing ⇒ earing




$gap = (r_d - r_p) < (t_0)$

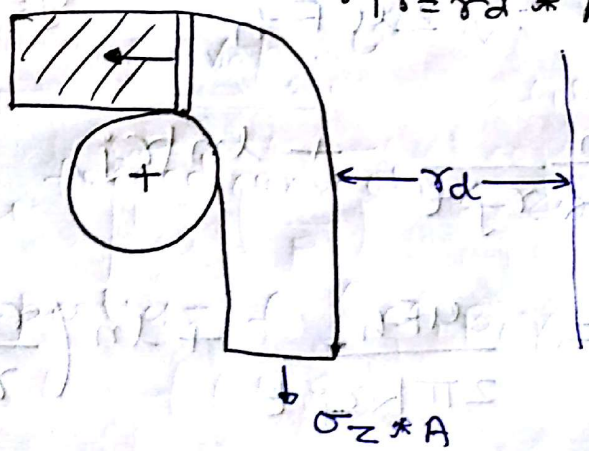



$\Sigma F_R = 0$

① ⇒ $\sigma_r$

$\sigma_r|_{r=r_d} =$ ✓

$\sigma_r|_{r=r_d} * A$




Scanned by CamScanner

$\theta = \frac{\pi}{2}$ , $F_p = \sigma_z \cdot A_p$

$$\frac{T_1}{T_2} = e^{\mu\theta}$$

$$\boxed{\frac{\sigma_z \times A}{\sigma_r|_{r=r_d} \times A} = e^{\frac{\mu\pi}{2}}}$$

<u>Radial equilibrium:</u>

$$\sigma_r(r\,d\theta\, t) - (\sigma_r + d\sigma_r)(r+dr)\,d\theta \cdot t + 2\sigma_\theta \sin\left(\frac{d\theta}{2}\right) \cdot dr \cdot t = 0$$

$$\Rightarrow r\,d\sigma_r + \sigma_r\,dr - \sigma_\theta\,dr = 0$$

$\sigma_r$, $\sigma_\theta$

Tresca yield criterion $\boxed{\sigma_r - \sigma_\theta = 2K}$

$$r\,d\sigma_r + \sigma_r\,dr - (\sigma_r - 2K)\,dr = 0$$

$$\Rightarrow \frac{dr}{r} + \frac{d\sigma_r}{2K} = 0$$

Integrating $\frac{\sigma_r}{2K} = c - \ln r$

$F_h$ is acting only at the periphery of job

$\sigma_r(2\pi r_j t) = 2\mu F_h$ $r_j$ = full radius

$r_j$

$$\Rightarrow c = \frac{\mu F_h}{2\pi K r_j t} + \ln(r_j)$$

$$\Rightarrow \left(\frac{\sigma_r}{2K}\right)_{r=r_d} = \frac{\mu F_h}{2\pi K r_j t} + \ln\left(\frac{r_j}{r_d}\right)$$

Scanned by CamScanner

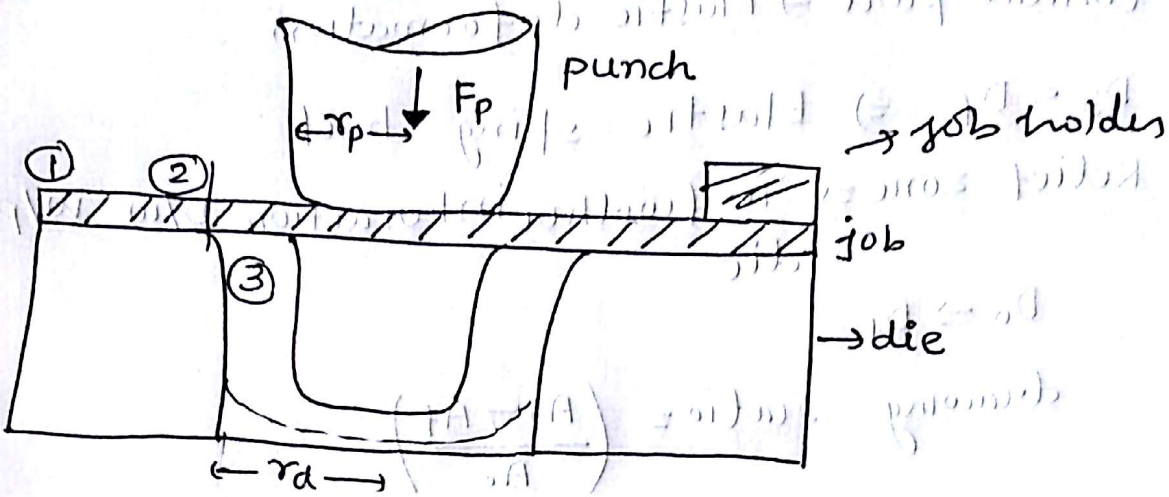
Ques: A cold rolled steel cup with an inside radius 30mm and a thickness 3mm is to be drawn from a blank of radius 40mm. The shear yield stress and a maximum allowable stress of the material are 210 N/mm2 and 600 N/mm2 respectively

$\mu = 0.1$

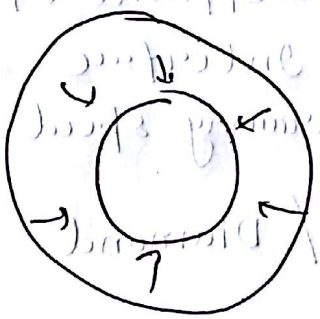
$F_h = 50$ KN find out the drawing force $F_p$.

Scanned by CamScanner

## Deep drawing:

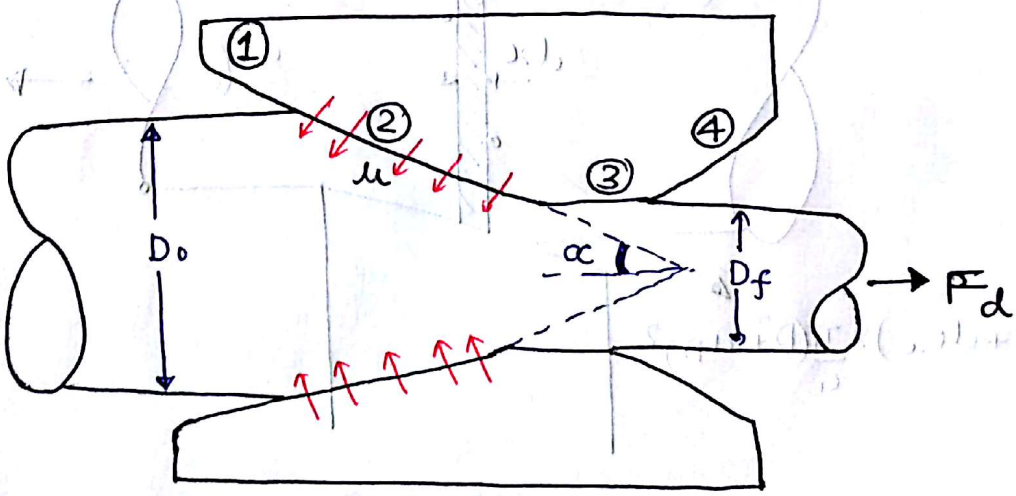



$$F_p = \sigma_z * A$$



**DRAWING:**
- → Bulk metal forming (cold working)
- → Bar, Rod, wire
- → strip

$\boxed{\sigma_d \neq Y}$




multipass drawing

Scanned by CamScanner

① Bulk shape → easy insertion of the job

② Conical part → Plastic deformation

③ $D_3 < D_f$ ⇒ Elastic spring back

④ Relief zone ⇒ To further interaction b/w W/P and die

$D_0 \rightarrow D_f$

drawing ratio $= \left(\frac{A_0 - A_f}{A_0}\right)$

Important factors: ⇒ ① Drawing Ratio

② Semi die angle ($\alpha$)

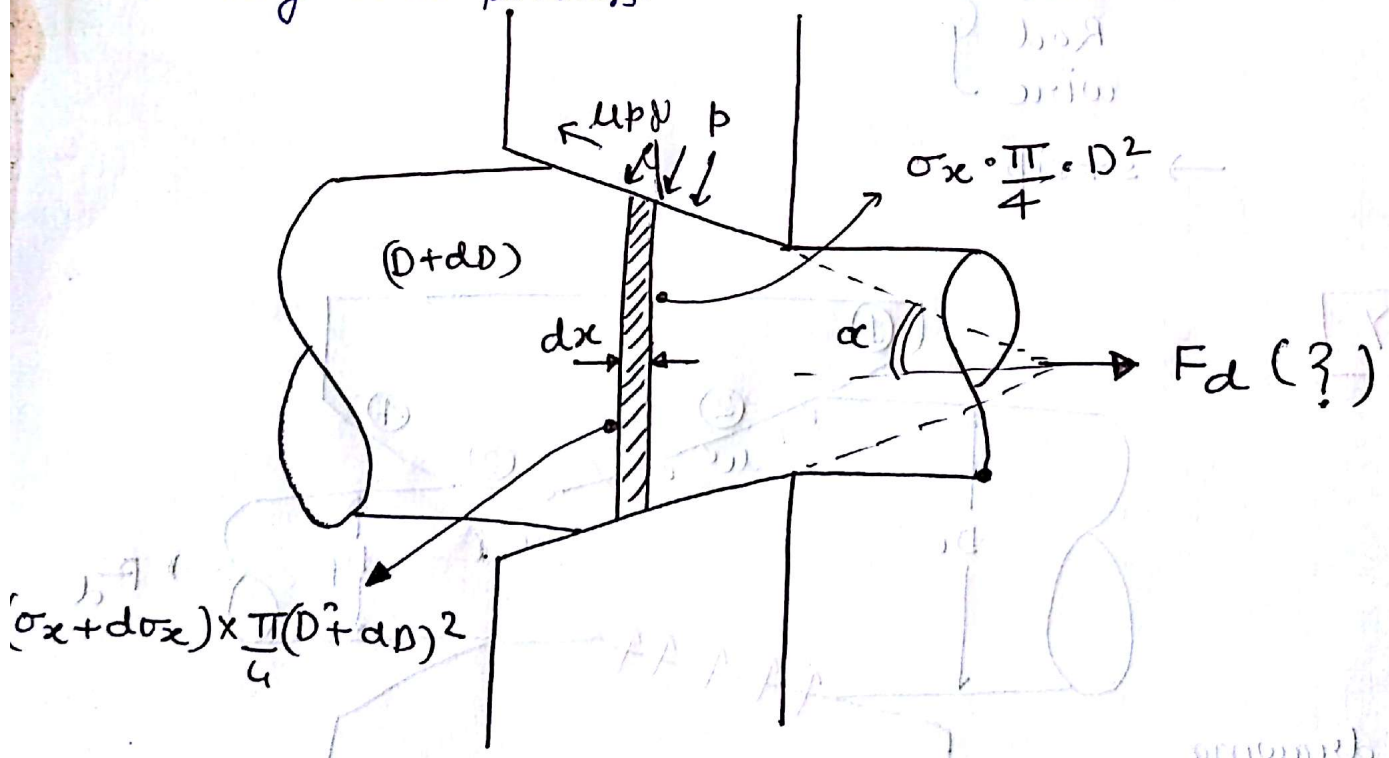
③ coefficient of friction at the Interface

④ drawing speed

<u>Die material</u> ⇒ WC / Diamond

Lubrication ⇒ sold / wet

used to absorbe the heat generated during the process.




Scanned by CamScanner

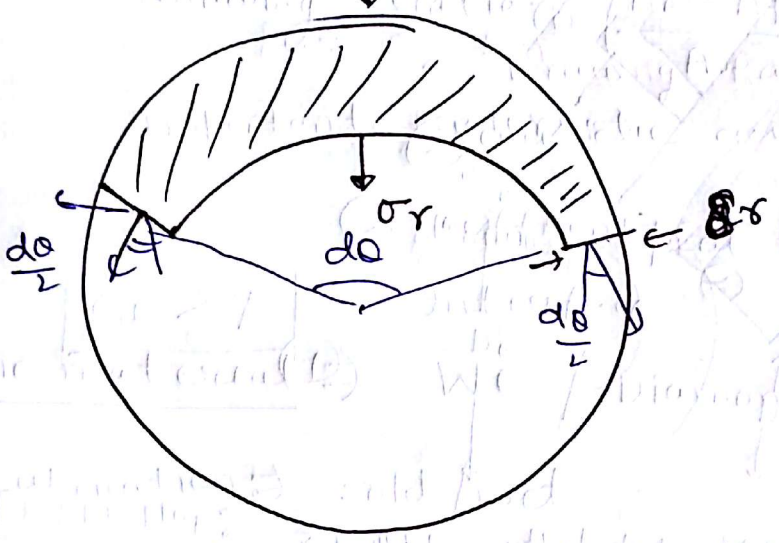
$$p\left(\pi D \cdot \frac{dx}{\cos\alpha}\right)\sin\alpha$$

$$\mu p\left(\pi D \times \frac{dx}{\cos\alpha}\right)\cos\alpha$$

$$\sum F_x = 0$$

$\boxed{\sigma_r,\ \sigma_x,\ \sigma_\theta}$ $\Rightarrow$ yielding

$$-(p\cos\alpha - \mu p\sin\alpha)(r+\delta r)(d\theta\, dx)$$




$$\epsilon_\theta = \epsilon_r \Rightarrow \sigma_\theta = \sigma_r$$

$$\sigma_1 = \sigma_x$$
$$\sigma_2 = \sigma_3 = \sigma_r = \sigma_\theta$$

$\Downarrow$

yielding take place at the value of Y

$$+\ \sigma_r \cdot r\, d\theta\, dx$$

$$+\ 2\sigma_\theta\ \delta r\, dx \sin\frac{d\theta}{2}$$

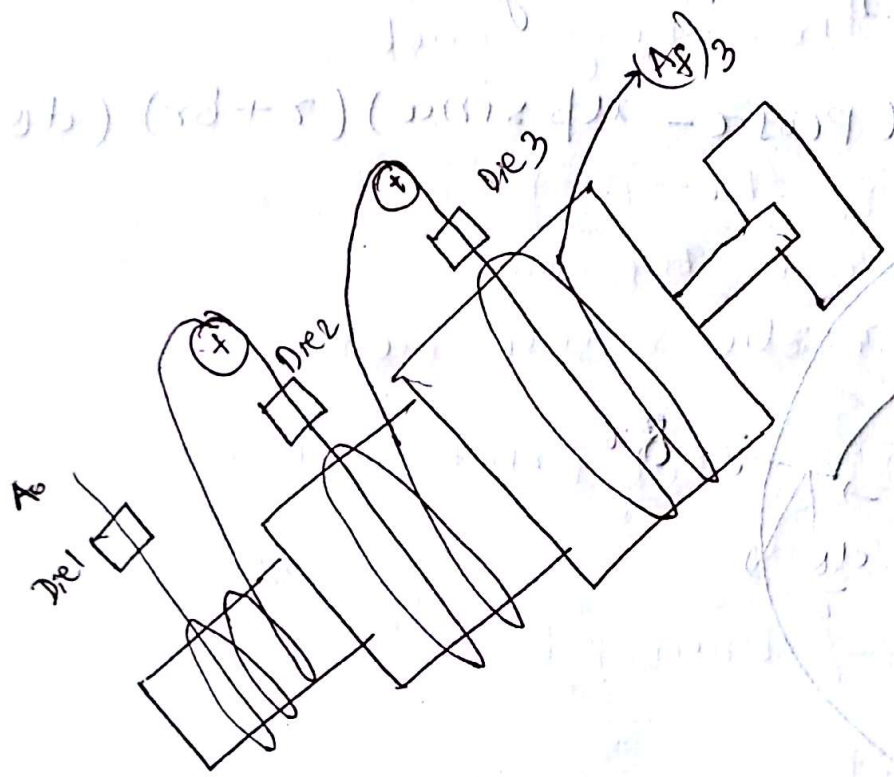
Scanned by CamScanner

## applying the boundary conduction

No bulk pull $\Rightarrow F_b = 0$

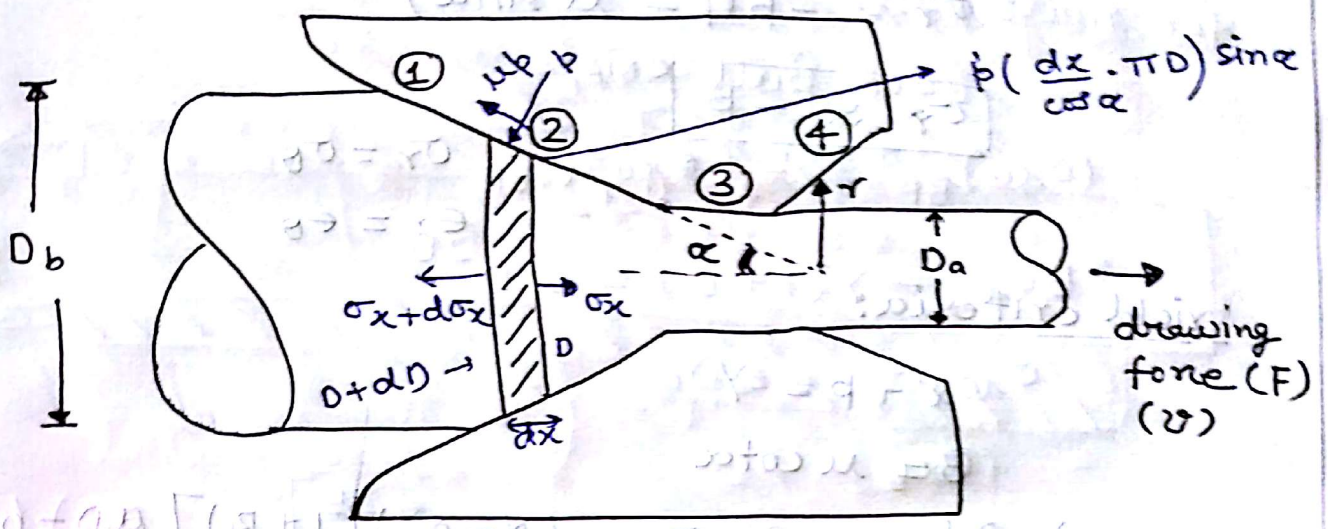
$$\text{Power} = v \times F_d = \sigma_d * A_f$$

wire $\Rightarrow$ to much reduction



06/10

# drawing process




$$r = \frac{A_b - A_a}{A_b}$$

wire $\longrightarrow$ multipass drawing process
Bar/rod

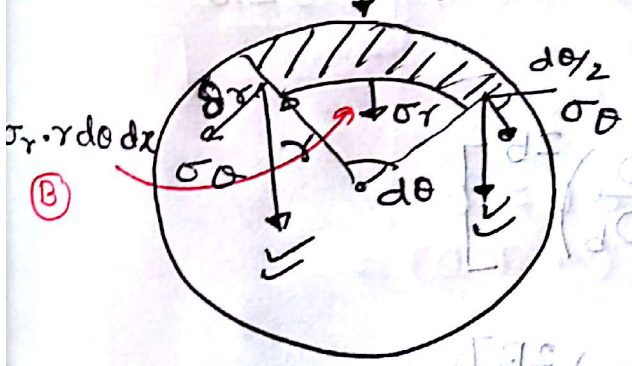
$$\sigma_x\left(\frac{\pi}{4}D^2\right) \;\|\; (\sigma_x + d\sigma_x)\frac{\pi}{4}(D+dD)^2$$

$$\mu p\left(\frac{dx}{\cos\alpha}\pi D\right)\cos\alpha$$

$\sum F_x = 0 \longrightarrow$ equation ①

$\sum F_R = 0$

$$\downarrow (p\cos\alpha - \mu p\sin\alpha)(r+\delta r)\, d\theta\, dx \downarrow \quad (A)$$




$$2\sigma_\theta\cdot(\delta r\, dx)\sin\frac{d\theta}{2}(\downarrow) \quad (C)$$

$$\Rightarrow -(A) - (B) - (C) = 0$$

$\sum F_x = 0 \Rightarrow$

$$D\, d\sigma_x + 2\left[\sigma_x + p(1+\mu\cot\alpha)\right] dD = 0$$

Scanned by CamScanner

$$\Sigma F_R = 0 \Rightarrow [p(1-\mu \sin\alpha) + \sigma_r]\, r\, d\theta\, dx = 0$$

$$\sigma_r = -p(1-\mu \sin\alpha)$$

$$\boxed{\sigma_r \simeq -p}$$

$$\sigma_r = \sigma_\theta$$

$$\epsilon_r = \epsilon_\theta$$

Yield criteria:

$$\sigma_x + p = Y$$

$$B = \mu \cot\alpha$$

$$\Rightarrow D\, d\sigma_x + 2[\sigma_x + (Y-\sigma_x)(1+B)]\, dD = 0$$

$$\frac{d\sigma_x}{B\sigma_x - Y(1+B)} = 2\frac{dD}{D}$$

Integrating

$$\boxed{B\sigma_x - Y(1+B) = C D^{2B}}$$

Int const.

No back end pull

At $D = D_b$ $\quad \sigma_{xb} = 0$

$$C = \frac{-Y(1+B)}{D_b^{2B}}$$

$$\Rightarrow \frac{\sigma_x}{Y} = \left(\frac{1+B}{B}\right)\left[1 - \left(\frac{D}{D_b}\right)^{2B}\right]$$

drawing stress

$$\frac{\sigma_{xa}}{Y} = \left(\frac{1+B}{B}\right)\left[1 - \left(\frac{D_a}{D_b}\right)^{2B}\right]$$

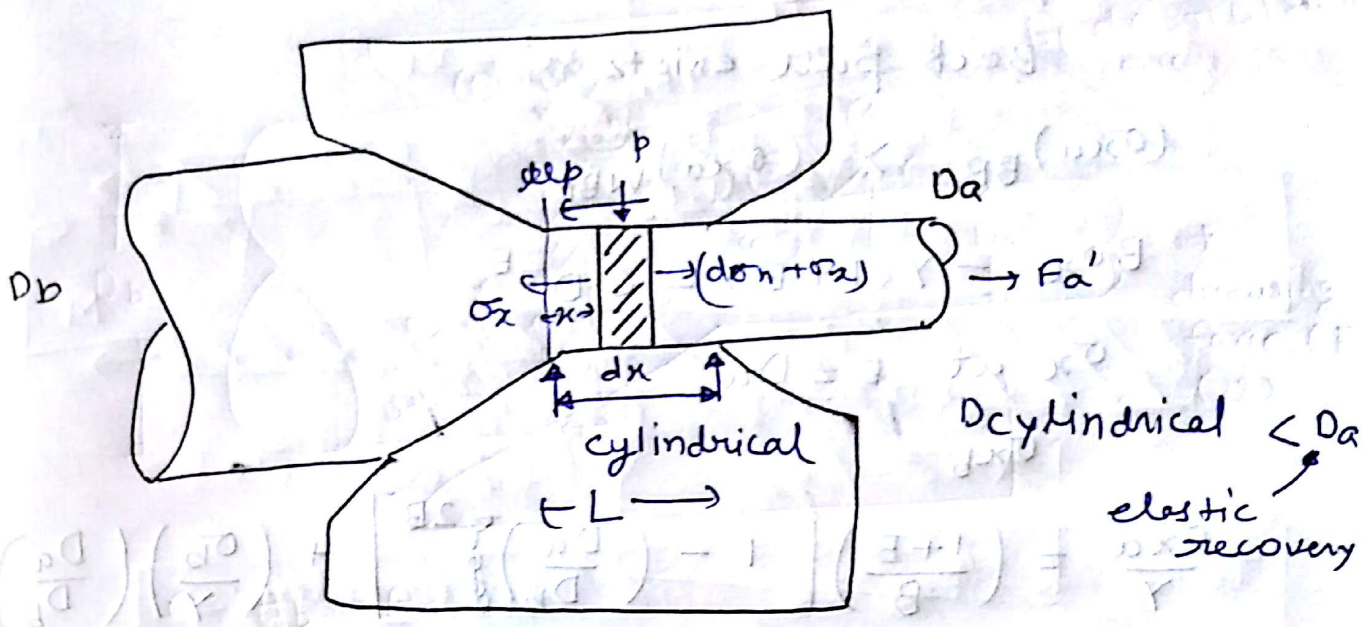
$$\sigma_{xa} = \checkmark\checkmark$$

$$F = (\sigma_{xa} \times A_a)$$

Scanned by CamScanner

drawing ~~Force~~ Power

$$P = (F_a \times v)$$




$\sigma_x = \sigma_{xa} =$

$x = 0 \quad \sigma_x = \sigma_{xa} \rightarrow$ Integration const $C$

$\sigma_{xa}' =$

$$F_a' \cdot v = \text{Power}$$

$$F_a' = (\sigma_x + d\sigma_x) \cdot A_a$$

die having land portion:

$$(\sigma_x + d\sigma_x)\pi R_a^2 - \sigma_x \pi R_a^2 - \mu p (2\pi R_a dx) = 0$$

$$\frac{d\sigma_x}{\sigma_x - Y} = -\frac{2\mu dx}{R_a}$$

Integrating

$$\ln(\sigma_x - Y) = -\frac{2\mu x}{R_a} + \text{const.}$$

At $x = 0$, $\sigma_x = \sigma_{xa}$

$$C = \ln(\sigma_{xa} - Y)$$

$R_a$ → Radius of a

$$\sigma_x = Y - (Y - \sigma_{xa}) e^{-\left(\frac{2\mu x}{R_a}\right)}$$

Scanned by CamScanner

$$\sigma_{xa}' = \sigma_x\big|_{x=L} = Y - (Y - \sigma_{xa}) \cdot e^{-\frac{2\mu L}{R_a}}$$

for multi pass:

Back pull exists

$$(\sigma_{xa})_{BP} > (\sigma_{xa})_{WBP}$$

$$B\sigma_x - Y(1+B) = C D^{2B}$$

$\sigma_x$ at $D = D_a$

$\sigma_{x_b}$

$$\frac{\sigma_{xa}}{Y} = \left(\frac{1+B}{B}\right)\left[1 - \left(\frac{D_a}{D_b}\right)^{2B}\right] + \left(\frac{\sigma_b}{Y}\right)\left(\frac{D_a}{D_b}\right)^{2B}$$

$$\boxed{\sigma_x + p = Y}$$

die life

Friction less Drawing:

$\rightarrow F_a =$

$\rightarrow B = \mu \cot\alpha$

$= 0$

$$D\,d\sigma_x + 2[\sigma_x + p(1 + \cancel{\mu}^{\,0} \cot\alpha)]\,dD = 0$$

$$p = Y - \sigma_x$$

$$D\,d\sigma_x + 2[\sigma_x + Y - \sigma_x]\,dD = 0$$

$$d\sigma_x = -\frac{2Y\,dD}{D}$$

$$\Rightarrow \ln D = \frac{-\sigma_x}{2Y} + C \Rightarrow \frac{\sigma_x}{2Y} = \ln\frac{D_b}{D}$$

$D = D_b$, $\sigma_x = 0$

$$\Rightarrow C = \ln D_b$$

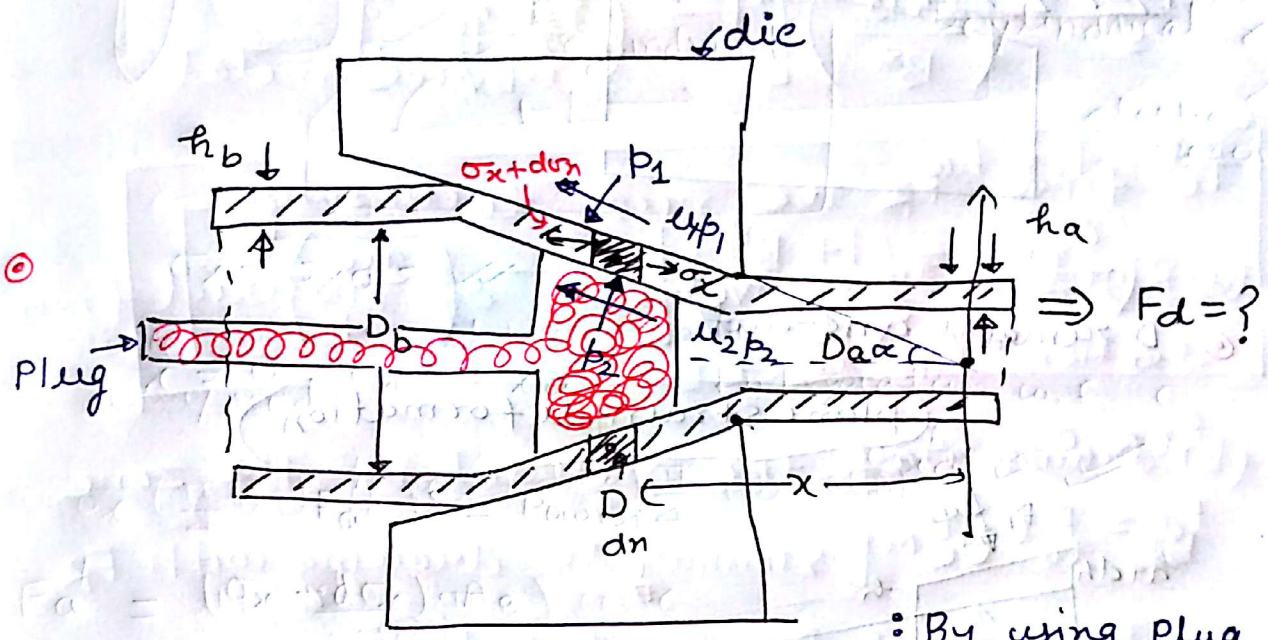
Scanned by CamScanner

20/10/16

Bar/wire drawing : with/without land of (die)

Tube drawing → solid bar
(Seam less) → Hollow member

draw bench → outer dia
Thickness
Int dia




: By using Plug

outer dia ≠ Die

No control of internal die/wall thickness

⇓

Tube sinking

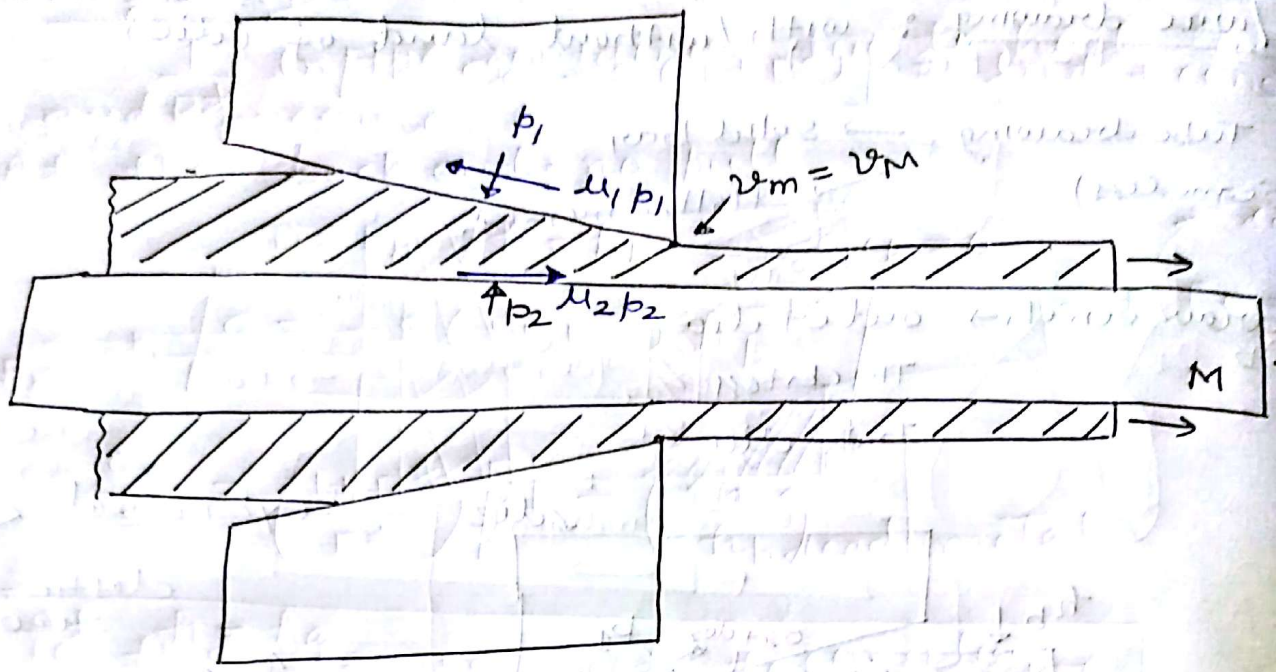
Tube drawing: → only change of outer dia
⇒ tube ~~drawing~~ sinking

→ outer dia, int dia & wall thickness

Stationary member (Plug)

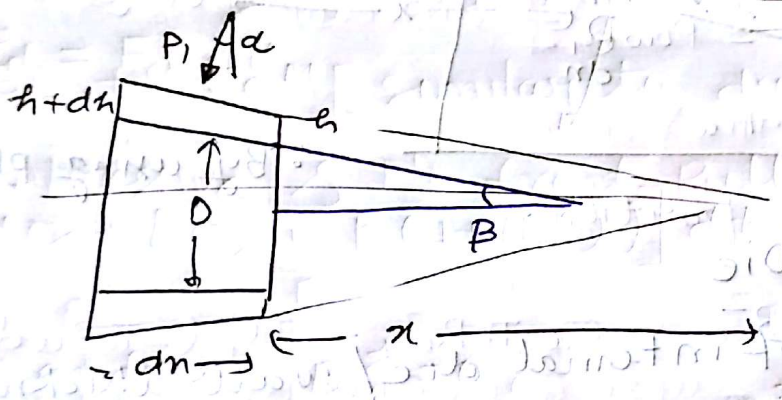
Moving member (Mandrel)

Scanned by CamScanner




- D remains constant

plane strain deformation




For element inside the deformation zone: $\boxed{p_1 = p_2}$

① due to longitudinal stress

$$(\sigma_x + d\sigma_x)\pi D(h+dh) - \sigma_x(h\pi D) =$$

$$(\sigma_x dh + h d\sigma_x)\pi D$$

② due to die pressure

$$p\left(\frac{dx}{\cos\alpha}\cdot \pi D\right)\sin\alpha = p\cdot \pi D \tan\alpha \cdot dx$$

Scanned by CamScanner

③ due to plug pressure $= -p\pi D \tan\beta \, dx$

④ due to die friction

$$\mu_1 p\left(\pi D \cdot \frac{dx}{\cos\alpha}\right)\cos\alpha$$

⑤ due to plug friction

$$\Rightarrow \mu_2 p \pi D \, dx$$

$$\Sigma F_x = 0$$

$$(\sigma_x + dh + h\,d\sigma_x)\pi D + p\pi D(\tan\alpha - \tan\beta)\,dx$$
$$+ p\pi D(\mu_1 + \mu_2)\,dx = 0$$

$$\Rightarrow \quad dh = dx\tan\alpha - dx\tan\beta$$

$$\Rightarrow (\sigma_x\,dh + h\,d\sigma_x) + p\,dh\left(1 + \frac{\mu_1 + \mu_2}{\tan\alpha - \tan\beta}\right) = 0$$

$$\Rightarrow h\,d\sigma_x + [\sigma_x + p(1 + (B^*))]\,dh = 0$$

where $B^* = \dfrac{\mu_1 + \mu_2}{\tan\alpha - \tan\beta}$

$$B = \frac{\mu}{\tan\alpha}$$

Cylindrical plug $\Rightarrow$ $B^*_p = \dfrac{\mu_1 + \mu_2}{\tan\alpha}$

Mandrel $\Rightarrow$ $B^*_m = \left(\dfrac{\mu_1 - \mu_2}{\tan\alpha}\right)$

Cylindrical plug (No hoop strain)

$$\sigma_x + p = 2K = S$$

$$\frac{d\sigma_x}{B^*\sigma_x - S(1 + B^*)} = \frac{dh}{h}$$

Scanned by CamScanner

Integrating

$$\frac{1}{B^*} \ln\left[B^* \sigma_x - s(1+B^*)\right] = \ln h + \text{const.}$$

At the back end, no pull

$$D = D_b \;/\; h = h_b \Rightarrow \sigma_{xb} = 0$$

$$\boxed{C = -s(1+B^*)\, h_b^{-B^*}}$$

$$\frac{\sigma_x}{s} = \left(\frac{1+B^*}{B^*}\right)\left[1 - \left(\frac{h}{h_b}\right)^{B^*}\right]$$

At $h = h_a$

$$\boxed{\left(\frac{\sigma_{xa}}{s}\right) = \left(\frac{1+B^*}{B^*}\right)\left[1 - \left(\frac{h_a}{h_b}\right)^{B^*}\right]}$$

$$F_d = \sigma_{xa} \cdot A_a$$

$$P_d = F_d \cdot v_M$$

$$h\, d\sigma_x + \left[\sigma_x + p(1+(B^*))\right] dh = 0$$

mandre $\Rightarrow$ $B_m^* = 0$

$$B_m^* = \frac{\mu_1 - \mu_2}{\tan\alpha}$$

if $\mu_1 = \mu_2$

$\downarrow$

$$F_d = ?$$

$B_m^* = 0$ when $\mu_1 = \mu_2$

$$\sigma_{xa} = \lim_{B_m^* \to 0} \left(\frac{1+B_m^*}{B_m^*}\right)\left(1 - \left(\frac{h_a}{h_b}\right)^{B_m^*}\right)$$

$$\sigma_{xa} = -(1+B_m^*)\left[\left(\frac{h_a}{h_b}\right)^{B_m^*} - 1\right]$$

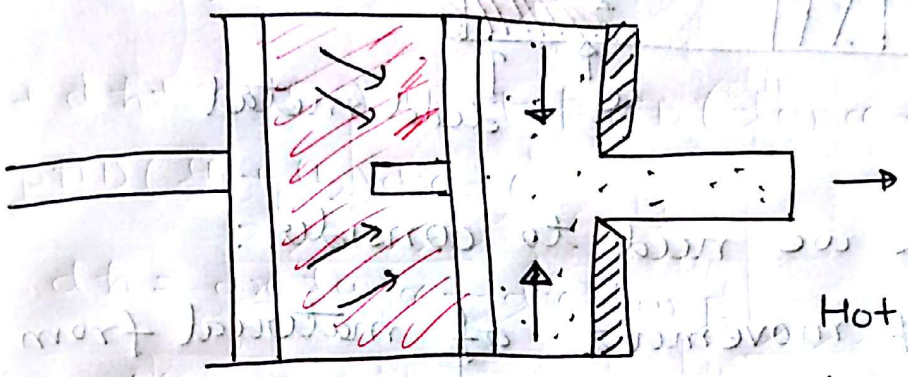
Scanned by CamScanner

$$= -S(1+B_m^{*}) - \ln \frac{h_a}{h_b}$$

$$= -S \ln \frac{h_a}{h_b} = S \ln \frac{h_b}{h_a}$$

27/10/16

## Extrusion :



Al, Mg, Cu

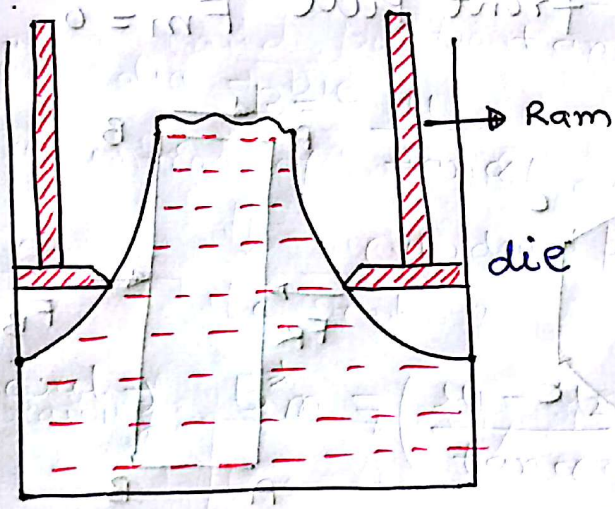
Low yield strength

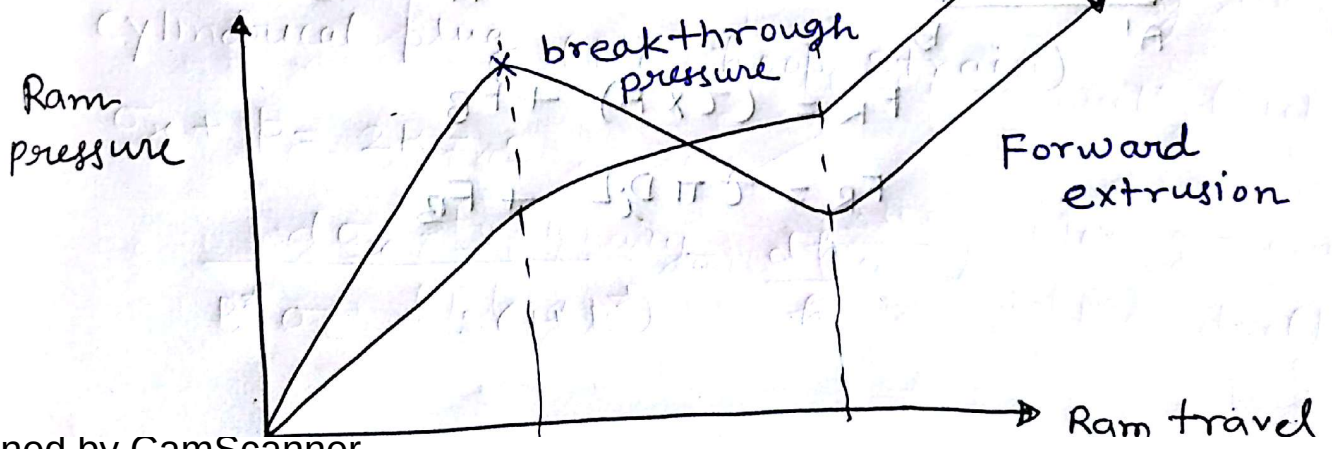
Hot working process

dead metal

(a) forward extrusion or direct extrusion

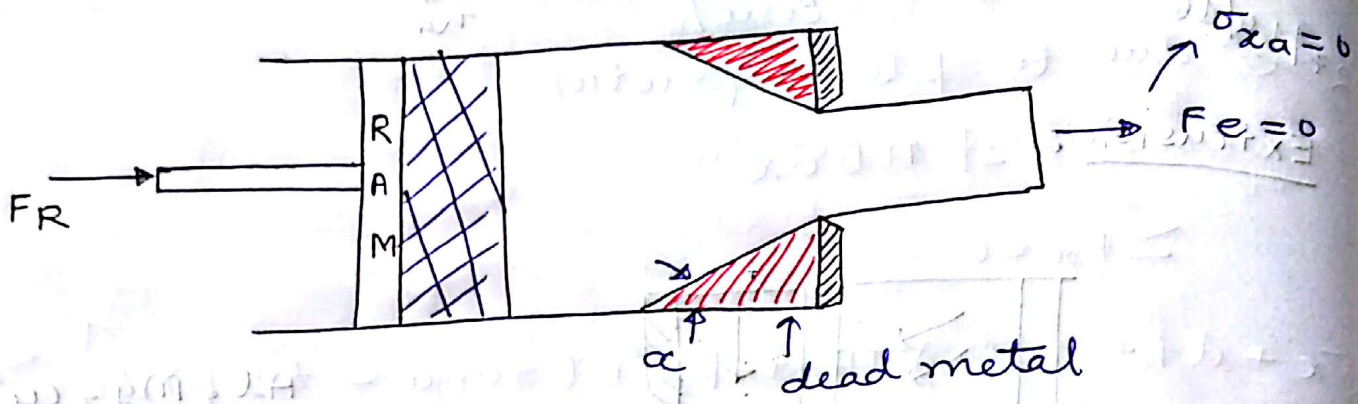
(b) Backward or Indirect extrusion




Scanned by CamScanner

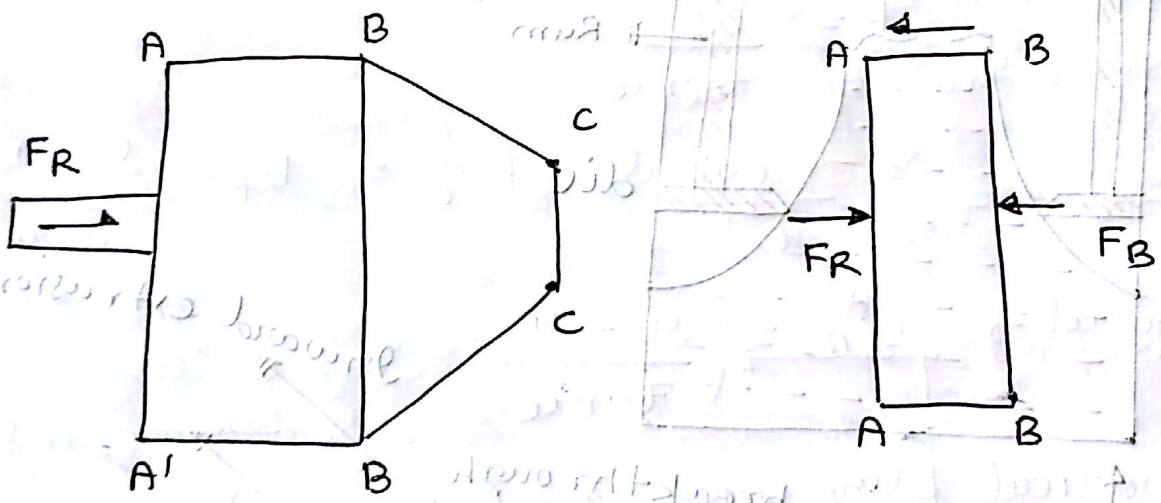
**Dead metal:** metal welded to the surface of the container due to high temp. and pressure.




To find $F_R$ we need to consider:

(a) Rigid body movement of material from section AA to BB

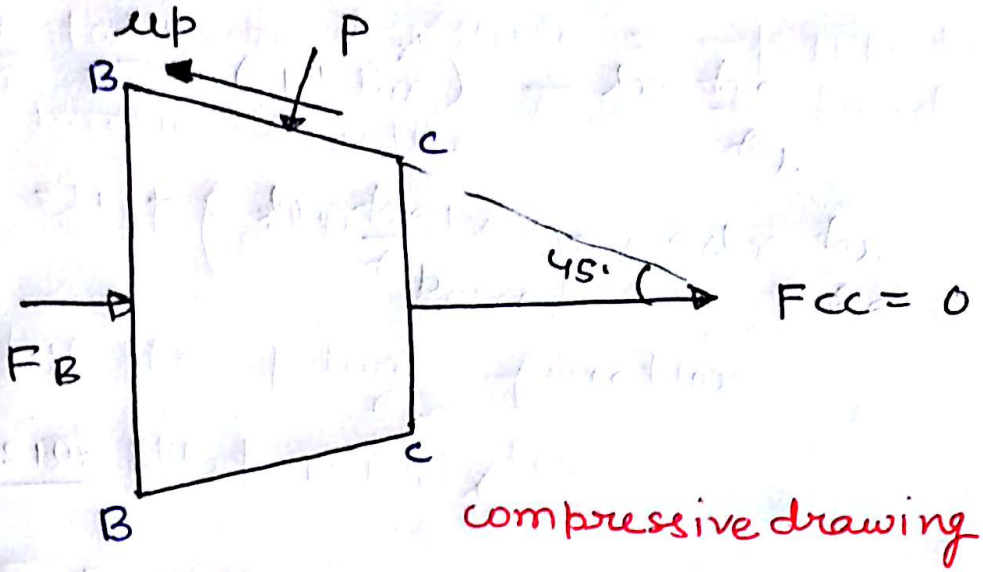
(b) drawing of the material in the zone BB to CC [similar to drawing with $F_R$ compressive & No front pull $F_m = 0$.




$$F_R = (\tau \times A) + F_B$$

$$F_R = \tau \pi D_i L + F_B$$

Scanned by CamScanner




$\alpha = 45°$

compressive drawing

for drawing

$$\left(\frac{\sigma_{xa}}{Y}\right) = \frac{1+B}{B}\left(1 - \left(\frac{D_a}{D_b}\right)^{2B}\right) + \text{Backpull}$$

$$\sigma_{xa} = 0$$

$$0 = \frac{1+B}{B}\left(1 - \left(\frac{D_a}{D_b}\right)^{2B}\right) + F_B$$

$$F_B = \frac{1+B}{B}\left[\left(\frac{D_a}{D_b}\right)^{2B} - 1\right]$$

$$B = \mu \cot\alpha = \mu \quad (\alpha = 45°)$$

Scanned by CamScanner

03/11/2016

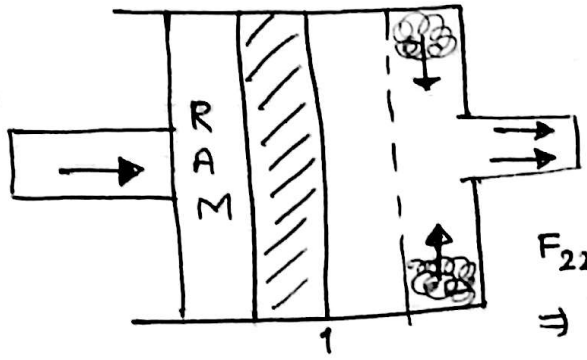
2nd class test → 8th Nov
Tuesday @ 10 am
NR321 and NR421

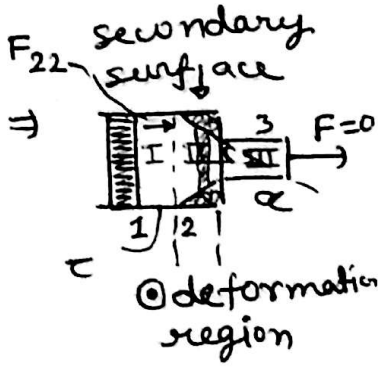
## Forging process:

extrusion Process
Powder metallurgy
+ Non conv. forming Process

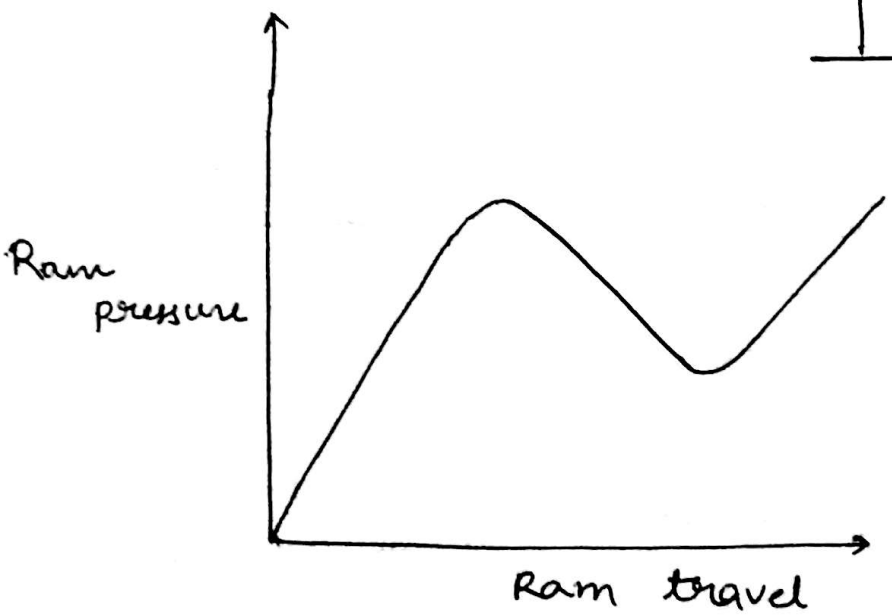
## Extrusion Process:

Direct extrusion
Indirect "



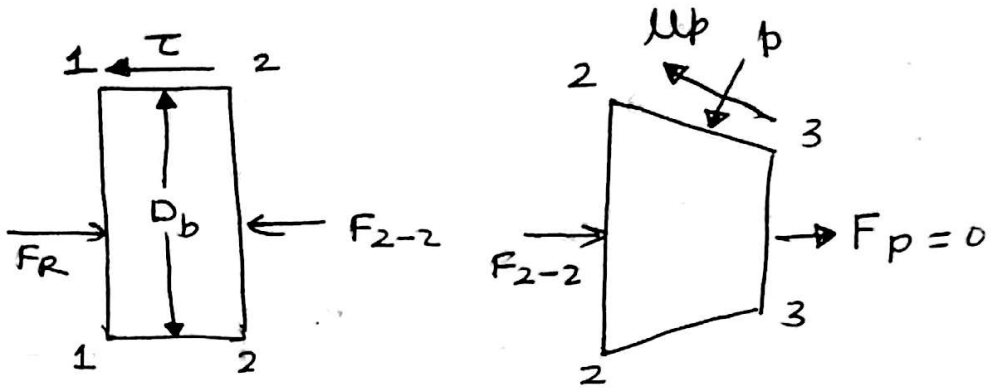




α = semi dia angle




I ⇒ Rigid body movement of billet (1-1 to 2-2)
II ⇒ Plastic deformation takes place
III ⇒

Scanned by CamScanner




$$\frac{F_{2-2}}{A_{2-2}} = \sigma_x \Big|_{2-2}$$

$$F_R = (\tau \times A) + F_{2-2}$$

In case of drawing with bulk tension

$$\left(\frac{\sigma_{xa}}{Y}\right) = \left(\frac{F_b}{Y A_b}\right)\left(\frac{D_a}{D_b}\right)^{2B} + \frac{1+B}{B}\left[1 - \left(\frac{D_a}{D_b}\right)^{2B}\right]$$

$B = \mu \cot\alpha$

extrusion Process, $\sigma_{xx} = 0$

$F_b$ compressive

$$\left(\frac{\sigma_x|_{2-2}}{Y}\right) = \frac{1+B}{B}\left[\left(\frac{D_b}{D_a}\right)^{2B} - 1\right]$$

<u>Forging:</u>

compression test

Force → Hot working → Impact → by hand → by hammer

Force → Squeezing ⊙ gradual

Hot working → grain structure → mechanical prop. Impro

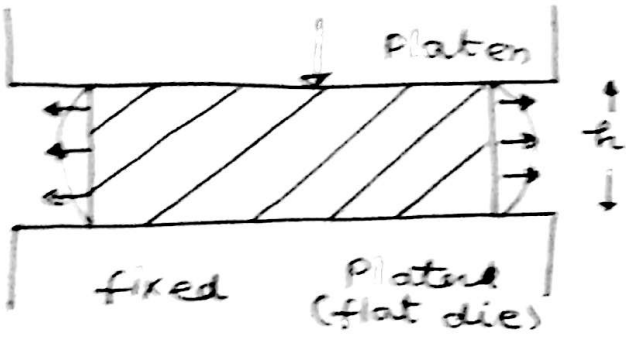
skill

⊙ → through the use of die

open die forging

close " " (Hot working)

Scanned by CamScanner




Plain strain ~~paraboli~~ deformation

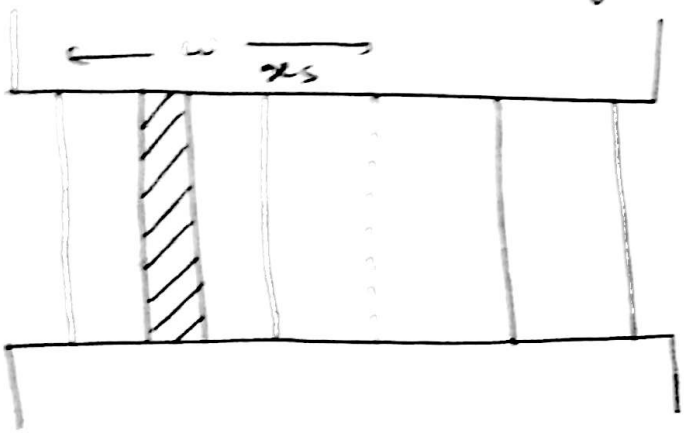
$\boxed{R, \theta, z}$ cylindrical coordinates

strip $\Rightarrow$ $h << (L, W)$

Disc ✓✓

$\tau_1 = k$ (sticking friction

$\tau_2 = \mu p$ (sliding yield)




$0 \le x \le x_s$

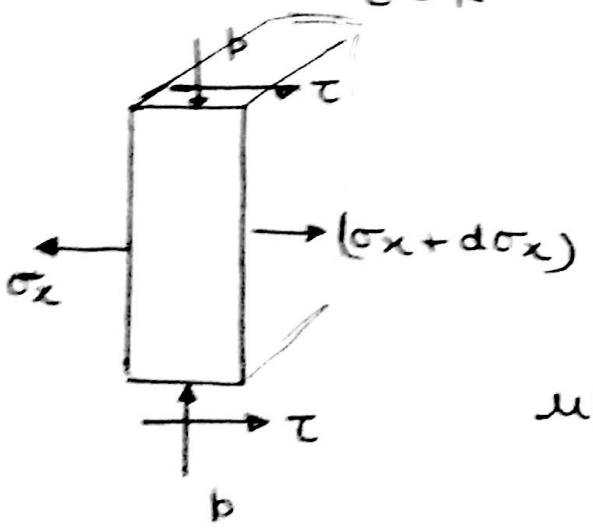
$p_1 \Leftarrow$ sliding zone

$\tau = \mu p$

$x_s \le x \le w$

$p_2 \Leftarrow$ sticking zone

$\tau = k$




at $x = x_s$

$$\boxed{(p_1)_{\text{at } x = x_s} = (p_2)}$$

$\mu p_s = k$

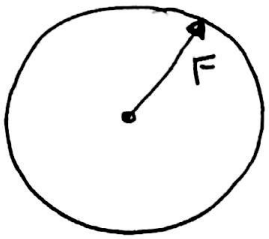
Scanned by CamScanner

$$\boxed{F_F = \int p_1\,dx + \int p_2\,dx}$$

$(\sigma_x + d\sigma_x)(h \cdot 1)$

Boundary condition At $x = 0$ $\sigma_x = 0$

$R, \theta, z$




$\boxed{\sigma_\theta \simeq \sigma_r}$

$\boxed{-p, \sigma_\theta}$

$$\Rightarrow \quad F_F = \int_0^{x_s} p_1\,dx + \int_{x_s}^{W} p_2\,dx$$

$$(\sigma_x + d\sigma_x)(h \cdot 1) + (\tau \cdot dx \times 1) = \sigma_x \times h \times 1$$

$$h\,d\sigma_x + 2\tau\,dx = 0 \quad \text{—①}$$

$$\sigma_x + p = 2K$$

$$\boxed{dp = \frac{2\tau}{K} \cdot dx}$$

$0 \le x \le x_s \Rightarrow \tau = \mu p$

$x_s \le x \le W \Rightarrow \tau = K$

sliding zone:

$$\int \frac{dp}{p} = \frac{2\mu}{h} \int dx + c_1$$

$$\ln p = \frac{2\mu x}{h} + c_1$$

at $x = 0$, $\sigma_x = 0$

$\sigma_x + p = 2K \Rightarrow \boxed{p = 2K}$

$\Rightarrow \quad c_1 = \ln(2K)$

Scanned by CamScanner

$$p_1 = 2k\, e^{\left(\frac{2\mu x}{h}\right)}$$

For sticking zone

$$\int dp = \frac{2k}{h}\int dx + C_2$$

$$p = \frac{2kx}{h} + C_2$$

At $x = x_s$, $p = p_s$

$$C_2 = \left(p_s - \frac{2kx_s}{h}\right)$$

$$(p - p_s) = \frac{2k}{h}\cdot(x - x_s)$$

$$p_s = 2k\exp\left(\frac{2\mu x_s}{h}\right) \leftarrow \text{sliding zone}$$

$$\Rightarrow p = 2k\left[\exp\left(\frac{2\mu x_s}{h}\right) + \frac{1}{h}(x - x_s)\right]$$

at $x = x_s$, ~~at~~ $\tau = \mu p_s = k$

$$\mu\, 2k\exp\left(\frac{2\mu x_s}{h}\right) = k$$

$$\Rightarrow x_s = \frac{h}{2\mu}\cdot\ln\left(\frac{1}{2\mu}\right)$$

$$P = 2k\left[\frac{1}{2\mu}\cdot\left\{1 - \ln\left(\frac{1}{2\mu}\right)\right\} + \frac{x}{h}\right]$$

for $x_s \le x \le W$

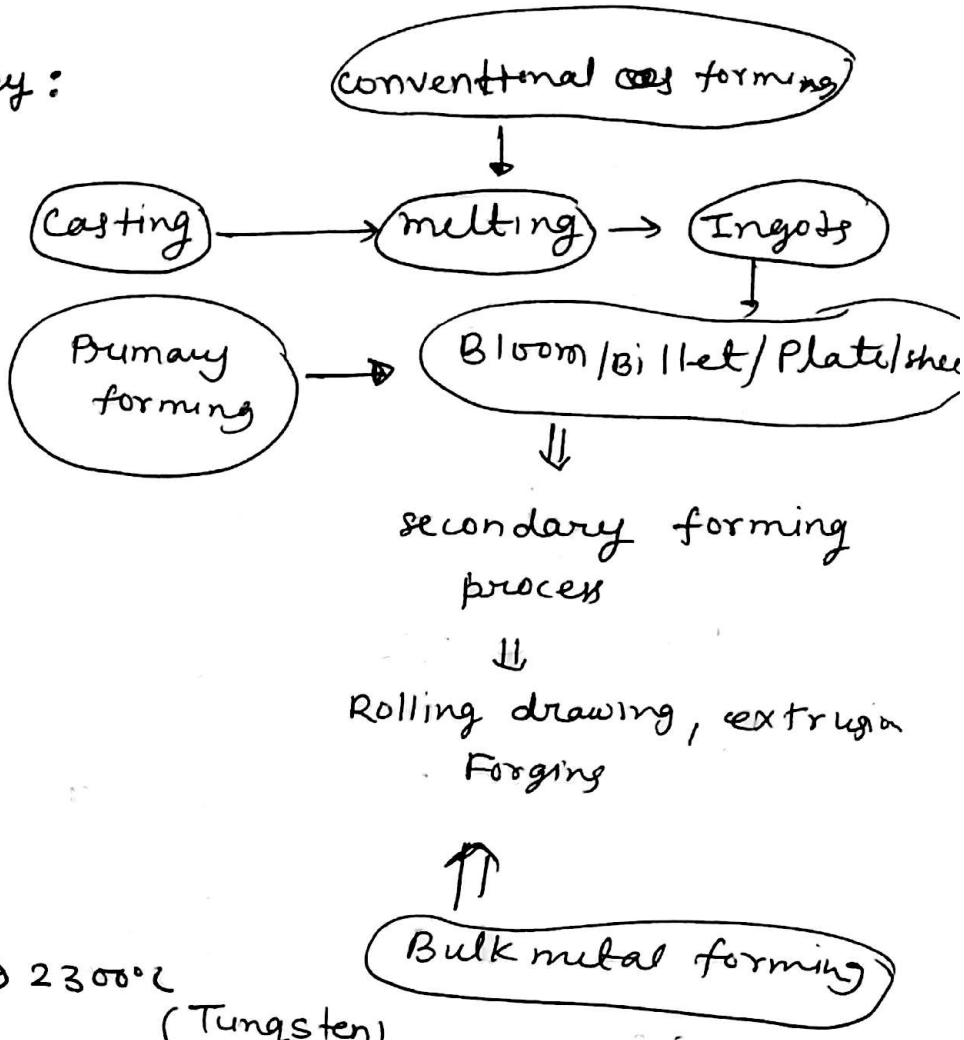
$$F_F = 2\left[\int_0^{x_s} p_1\, dx + \int_{x_s}^{W} p_2\, dx\right]$$

Scanned by CamScanner

10/11/2016

## Powder metallurgy:

HERF Process




Melting point ⇒ 2300°C (Tungsten)

(MP)mould > (MP)tungsten
↳ Refractory mold

PM → characteristics → shape
size
size distribution
Purity
Flowability

PM → work
↳ compact

## Steps Involved in powder metallurgy:

1. Manufacturing of Powder
2. Mixing of powder
3. compaction → green solid

Loose

Scanned by CamScanner

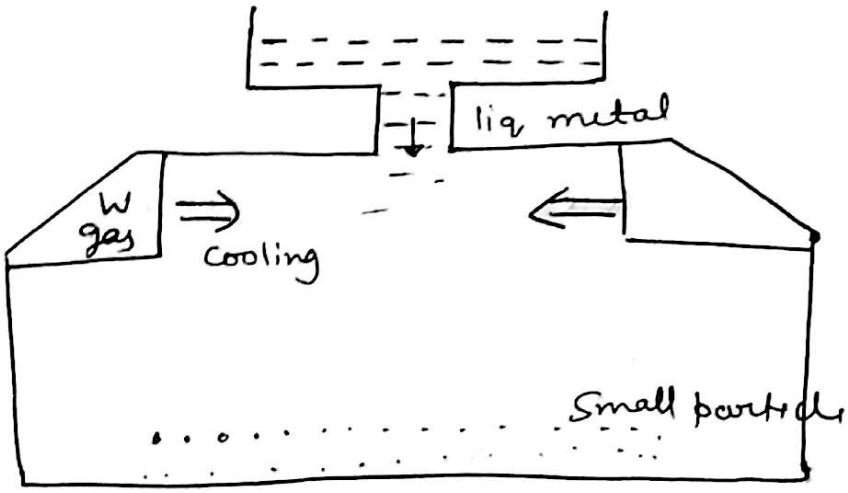
|| ④ Sintering (Heating) (heat the sample so proper mixing occurs)

⑤ Finishing (size of the product

① Manufacturing : Machining, (grinding) ] No, MP problem

#2 Crushing

#3 Atomisation (MP needed)




#4 Reduction (Remove metal oxides)

#5 Electroplating

Mixing / Blending :

→ Mech properties

→ ⊕ Binder

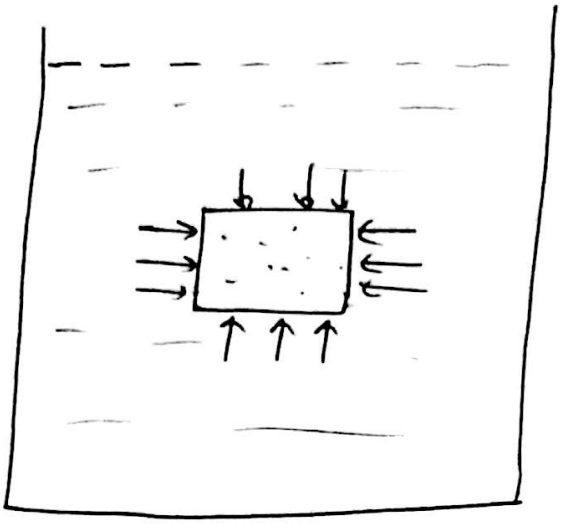
Compaction : #1 Pressing

#2 centrifugal casting

#3 slip casting (mixed with water slurry Poured in plaster of Paris so POP absorb water)

Scanned by CamScanner

## #4 Isostatic compaction



uniform compaction through hydraulic pressure

**Advantages:**

1. High MP are easily tackling
2. desired mech prop. can be achieved
3. Less defects
4. Near net shape - No loss of material
5. Good surface finish
6. No skill labour is required

**Disadvantages:**

1. Smaller objects
2. For change of geometry specific die

**HERF** high energy rate forming

different forms of energy

↓

for short duration → size of the produc

## # chemical energy

→ Explosive forming

Scanned by CamScanner

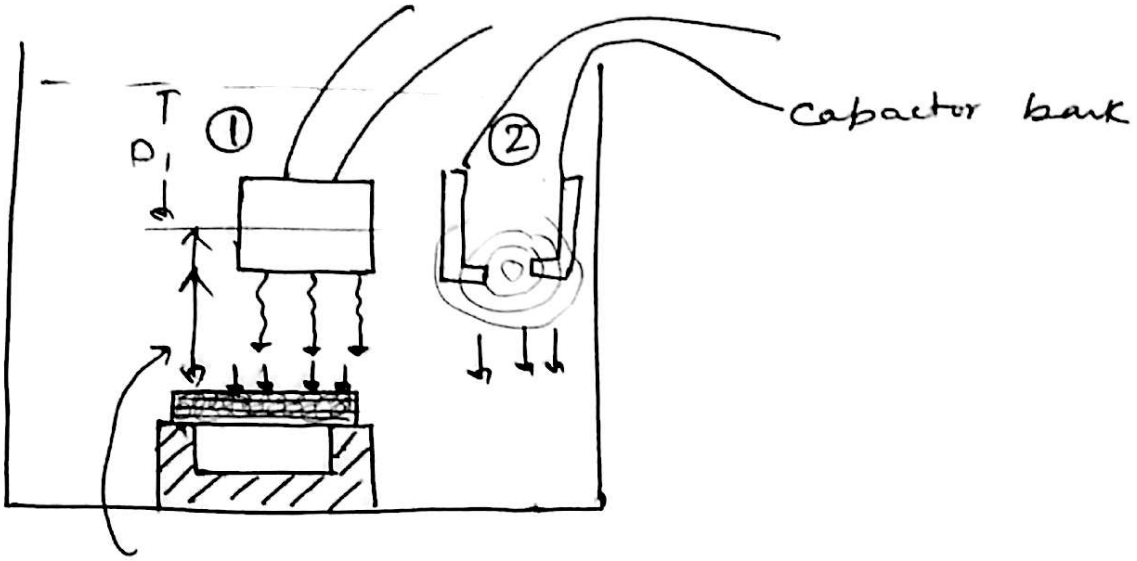
# Electric discharge

→ electro hydraulic forming

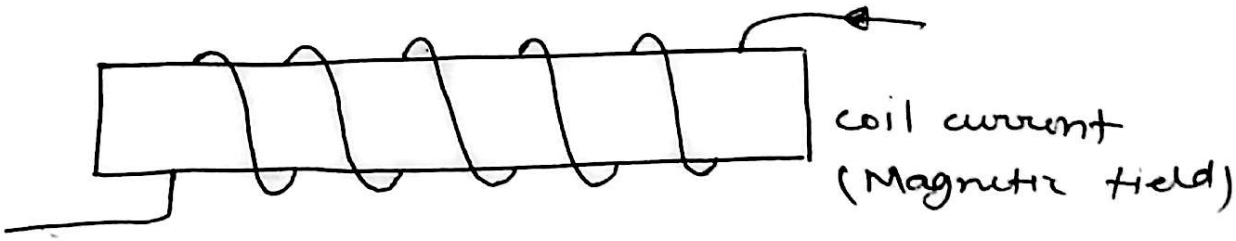
# Magnetic energy

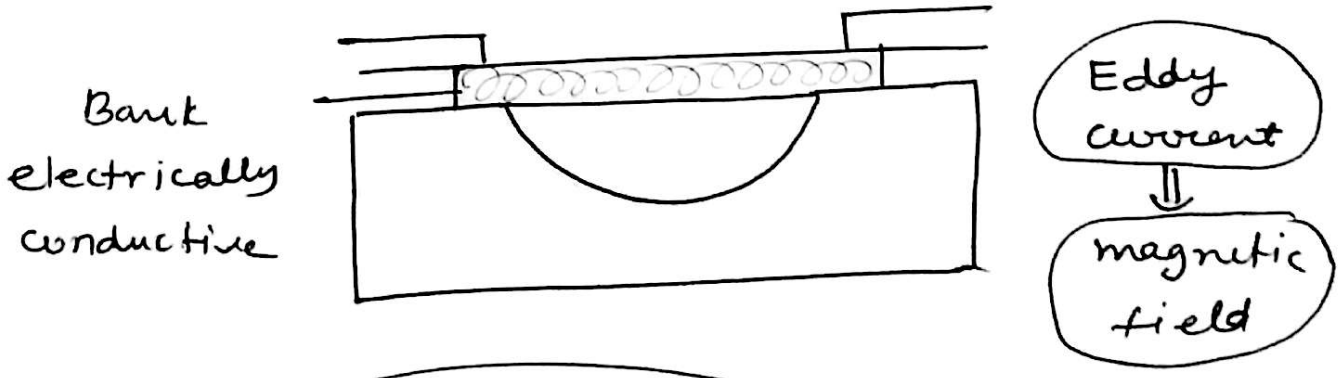
↳ electro magnetic forming

electromagnetic Induction




$D_1 = 2D_2$




EP > EHF > EMF

↑ explosive

Scanned by CamScanner