CASTING

06/08/2018

Q.1. The plastic behaviour of a metal can be expressed as : $\sigma = 500\,\epsilon^{0.5}$ MPa.
Estimate the strength of a bar of this material if it is uniformly cold-worked to a reduction of $r = 0.3$. (reduct^n in area of c/s)

→ $r = \dfrac{A_0 - A}{A_0} = 0.3$, $\epsilon = \ln\left(\dfrac{l}{l_0}\right)$

$A_0 - A = 0.3 A_0$ $\quad = \ln\left(\dfrac{1}{1-r}\right)$

$A = 0.7 A_0$ $\quad = \ln\left(\dfrac{A_0}{A}\right)$

$\dfrac{A_0}{A} = \dfrac{10}{7}$

$\therefore \epsilon = \ln\left(\dfrac{10}{7}\right)$

Q.2 (a) Strain hardening behaviour of a low carbon steel is given by : $\sigma = 700\,\epsilon^{0.2}$ MPa
Estimate strenght of bar if it is cold-worked to 50% reduction.

(b) Suppose another bar of the same steel was cold-worked an unknown amount and then further cold-worked 15% more. and found to have Y.S. of 525 MPa.
Unknown amt. of cold work = ?

→ (a) $\dfrac{A_0 - A}{A_0} = 0.5$

$0.5 A_0 = A$

$\therefore \dfrac{A_0}{A} = 2 \Rightarrow \epsilon = \ln\left(\dfrac{A_0}{A}\right) = \ln 2 \rightarrow \sigma = 650$ M

(b) $525 = \epsilon_1 + \sigma\left\{\ln\left(\dfrac{1}{1-0.15}\right)\right\}$

$= \epsilon_1 + 700\left(\ln\dfrac{100}{85}\right)^{0.2}$ ✗

$\epsilon_{tot} = \left(\dfrac{\sigma}{k}\right)^{1/n} = 0.237$

$\epsilon_{know} = 0.1625$

Q.3. A cylindrical test specimen of dia = 10 mm and gauge lenght = 50 mm is extended to 65 mm. Determine true strain. If ultimate tensile strain occurs @ F = 25000 N and extension of 70 mm. Determine strain hardening exponent 'n' and UTS of material.

→ (A) True strain = $\epsilon = \ln\left(\frac{l_0}{l}\right)^{-1}$

$$= \ln\left(\frac{50}{65}\right)^{-1}$$

$$= 0.262$$

(B) $\cancel{\Delta} l = 70\text{mm}$

$$\epsilon = \ln\frac{l}{l_0} = \ln\frac{70}{50} = 0.336 = n$$

$$\sigma_{\text{engg}} = \frac{F}{A} = \frac{25000}{\pi r^2} = 318.47\ \text{MPa}$$

$$\sigma_{\cancel{\text{engg}}\ \text{true}} = \frac{25000}{\pi r^2}\left(1 + \overset{20/70}{\cancel{0.3364}}\right) = 445.2\ \text{MPa}$$

Q.4. The aluminium test specimen 100mm long, 20mm wide, 2mm thick is elongated to 130mm. If anisotropy ration 'r' value is 2. Determine $\epsilon_l, \epsilon_w, \epsilon_t$

→ $$\epsilon_l = \ln\frac{l}{l_0} = \ln\frac{130}{100} = 0.26$$

$$\frac{\epsilon_w}{\epsilon_t} = 2 \qquad \epsilon_l + \epsilon_w + \epsilon_t = 0$$

$$\epsilon_l = -3\epsilon_t$$

$$\epsilon_t = \frac{-1}{3}\epsilon_l = -0.0874$$

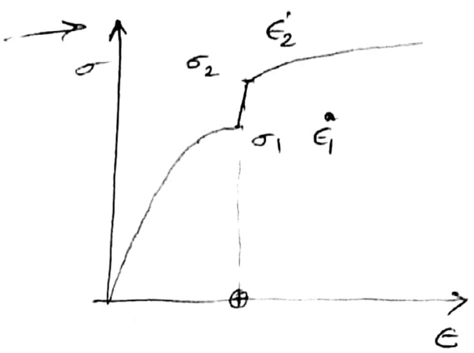
$$\epsilon_w = \frac{-2}{3}\epsilon_{\cancel{l}} = 0.175$$

Q.5 K, n, m value of stainless steel material

K → 1140 MPa, n → 0.35, m → 0.01

A test piece has initial width ~~of~~ thickness and gauge lenght are 12.5, 0.45, 50 mm resp.

Determine increasing load when extension is 10% and extension rate of guage lenght is ~~0.5~~ increased from 0.5 – 50 mm/min.



$$\sigma = K \cdot \epsilon^n \cdot \dot{\epsilon}^m$$

$$\dot{\epsilon}_1 = \frac{u_1}{l}$$

$$\frac{L-50}{50} = \frac{10.5}{100} \longrightarrow L = 55\,mm$$

$$\therefore \epsilon = \ln\frac{l}{l_0} = \ln\left(\frac{55}{50}\right) = 0.0953$$

$$\dot{\epsilon}_1 = \frac{0.5}{55\times 60} = 1.515\times 10^{-4}$$

$$\dot{\epsilon}_2 = \frac{50}{55\times 60} = 0.01515$$

$$\sigma_1 =$$

$$\sigma_2 =$$

$$\Delta\sigma = \sigma_2 - \sigma_1$$

$$\Delta P = \Delta\sigma \times \frac{A_0 l_0}{l}$$

FORMING ...

07/08/2018

Heat Treatment Process :-

① Annealing : Furnace cooling

② Normalising : Air cooling

③ Hardening : Water cooling / Oil

④ Case-Hardening : Only surface gets hardened.

- Heat Treatment
- Alloying

* Diffusion-based : wt % of phase = f (Temp, time)

* Non-diffusion : Austenite ⟶ Martensite
[Lower the temp., higher the prod. conc.]

- ① Flame-hardening
  ② Induction-hardening (Placed in mag. field)
  ③ Laser hardening

⑤ Tempering : [Hardness / Strenght / Ductility / impact strenght]

DEFORMATION :-

Temporary

$\epsilon = f(\sigma)$ [purely elastic] ⟶ Hooke's Law

~~(temporary)~~

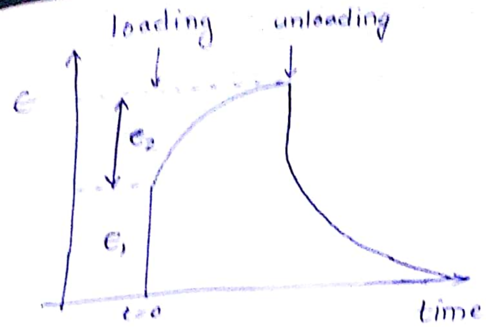
$\epsilon = f(\sigma, t)$
[comes back to original after some time]

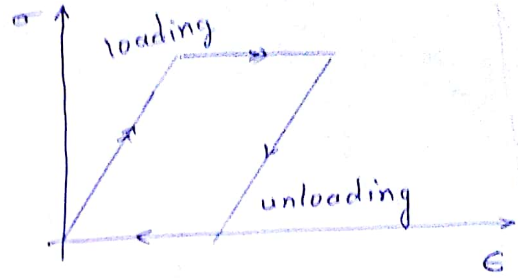
⟶ An-elastic deformation ...

Permanent

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

07/08/2018

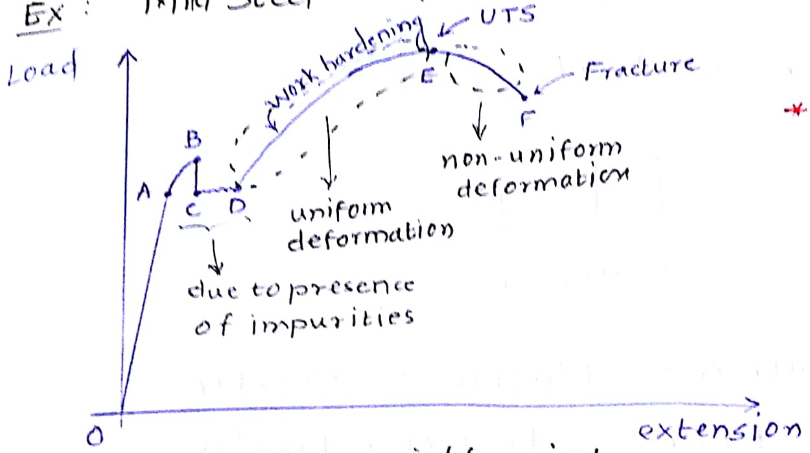




$$\epsilon_{max} = \epsilon_1 + \epsilon_2$$

$\boxed{\text{TEMPORARY}}$

Ex : Mild Steel (Permanent)



* Engg-stress-strain diagram . . .

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

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

B - upper yield point

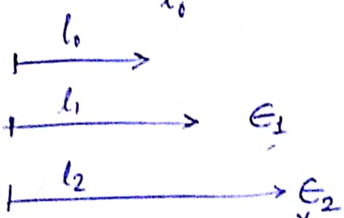
C - lower yield point

E - Ultimate tensile strenght

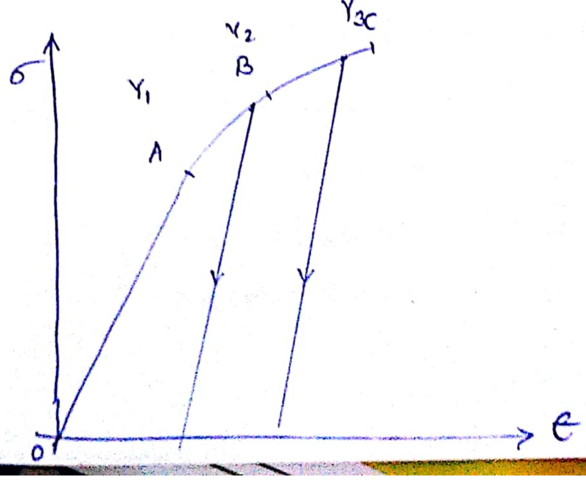
* True stress-strain diag.:-

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

*



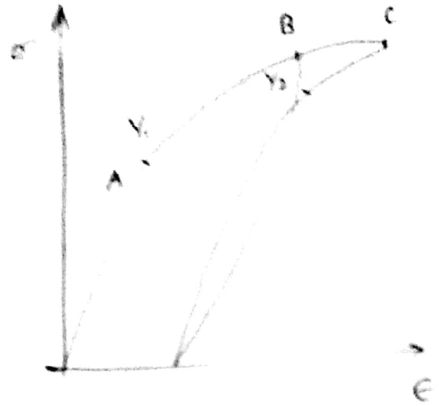
$$\epsilon_{12} = \ln\frac{l_1}{l_0} + \ln\frac{l_2}{l_1} = \ln\frac{l_2}{l_0}$$



OA : linear elastic

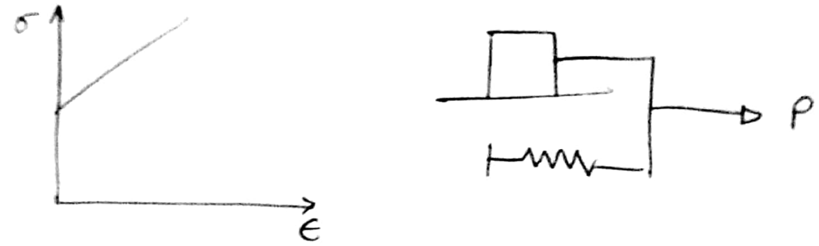
AB : Uniform plastic def.

BC : Non-uniform plastic def.



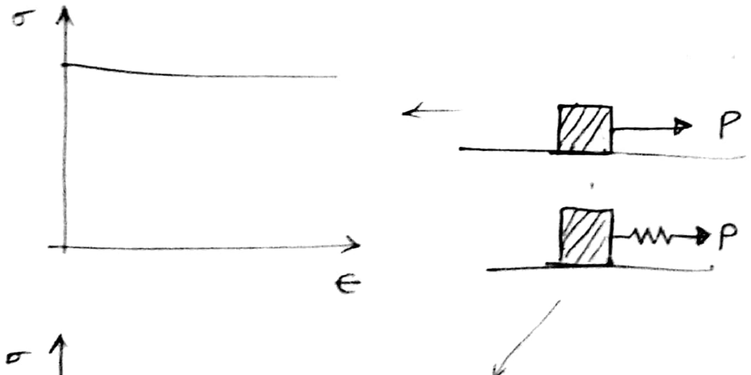
* Bauschinger effect:

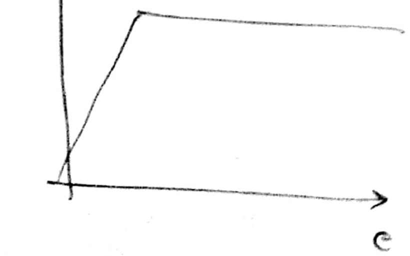
Rigid + Linear work-hardening:



Total deformation = Elastic + Plastic

Materials ⇒ Rigid + Perfectly plastic
+ elastic





Casting

13/08/18

Que. Following data were obtained from the plastic deformation part of load elongation test. The initial test width was 0.8 mm thickness / 12.5 mm width 50 mm guage lenght

Load (in kN)	Extension (mm)
	0.08
1.57	0.76
1.90	1.85
2.24	3.66
2.57	5.84
2.78	8.92
2.90	11.06
2.93	13.49
2.94	16.59
2.92	19.48
2.86	21.82
2.61	22.69
2.18	

(A) Plot engg. stress vs engg. strain

true stress vs true strain

log (" ") vs log (" ")

(B) Determine UTS and maximum load.

(C) " n & n value of material

if it follows Holloman power hardening law

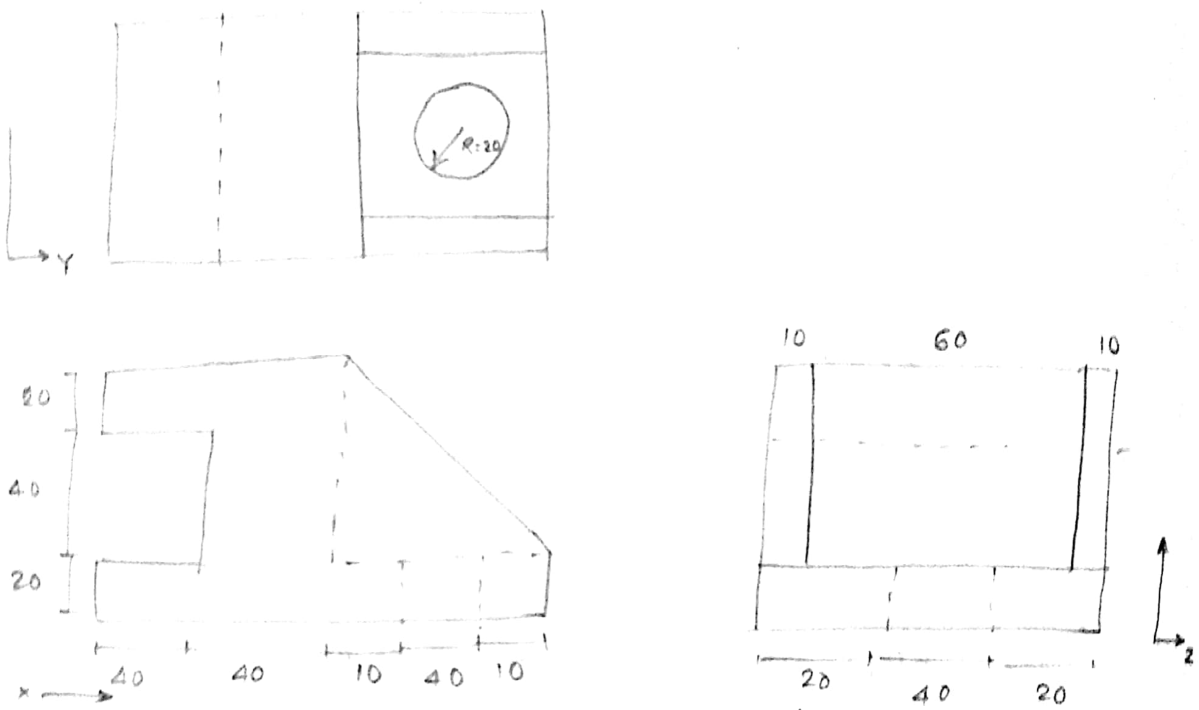
Que(D) Determine W.D if a bar of 10 mm dia. and 20 mm lenght is extended to 22 mm. The true stress - strain response of material is given as: $\sigma = 250\,\epsilon^{0.3}\ N/mm^2$

$$dW = \sigma A \cdot dl$$

$$= \sigma A \, l \frac{dl}{l} = \sigma A \, l \, (d\epsilon)$$

$$W = \int_0^{\epsilon} (Al) \, \sigma \cdot d\epsilon$$

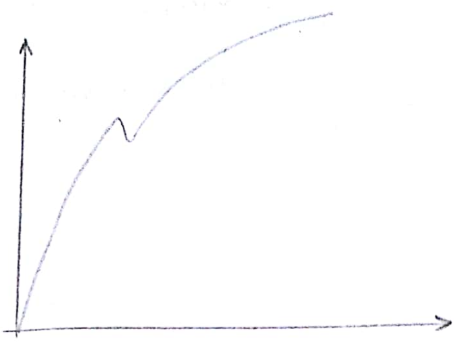
<u>Que</u>: For bracket casting shown, compare the 3 draw directions x, Y, z (with parting line @ x = 80mm, Y = 40mm, Z = 20mm) in terms of draw distance & undercut volume.



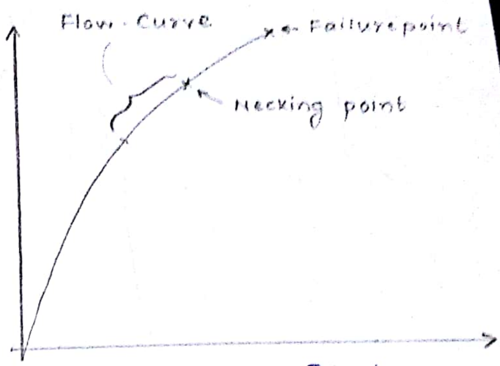
Parting pos.	No. of cores	Core Volume	Max. draw distance
X = 80mm	1		80mm
Y = 40mm	1		40mm
Z = 20mm	2		60mm

Forming

14/08/2018

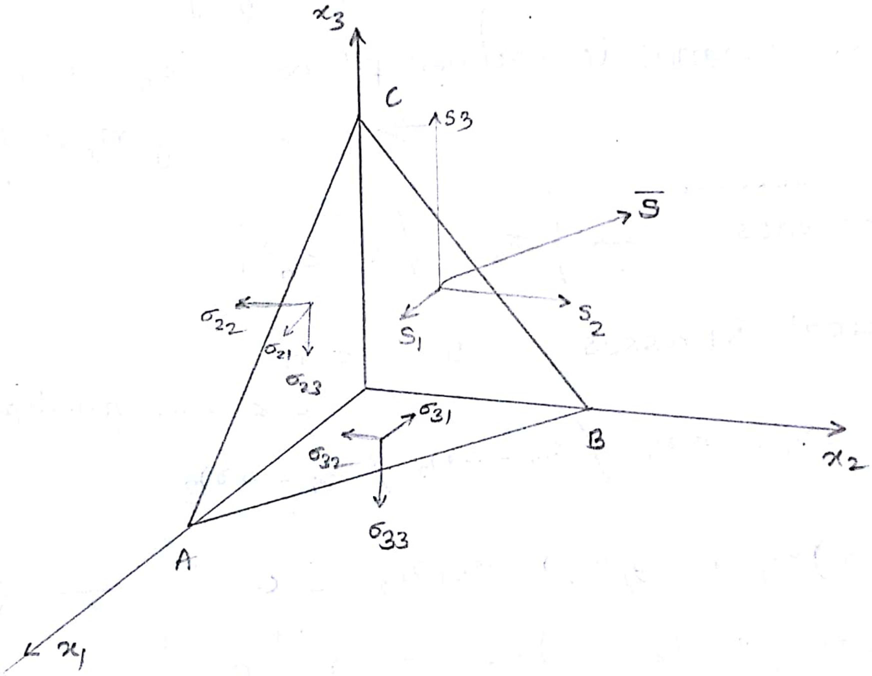


Engg. Stress Strain ...



True Stress Strain ...

* **Stress - Invariate:** (Yeild criteria)



$$\sum F_1 = \sum F_2 = \sum F_3 = 0 \quad [\sigma_{11} A_1 + \sigma_{22} A_2 + \sigma_{33} A_3 = 0]$$

* Normal stress acting on plane ABC :

$$\sigma_n = S \cdot n$$

* Principal stresses:

$$\underbrace{\begin{aligned} S_1 &= \sigma n_1 & S_1 A_s &= \ldots \\ S_2 &= \sigma n_2 & S_2 A_s &= \ldots \\ S_3 &= \sigma n_3 & S_3 A_s &= \ldots \end{aligned}}_{\text{Solve homogenous equation.}}$$

Total stress = Hydrostatic stress + ~~Derivative~~ Deviatoric stress

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

Deviatoric stress $\downarrow$ plastic shear

$$T = \begin{bmatrix} \sigma_{11} & \sigma_{12} & \sigma_{13} \\ \sigma_{21} & \sigma_{22} & \sigma_{23} \\ \sigma_{31} & \sigma_{32} & \sigma_{33} \end{bmatrix}$$

$$\boxed{\sigma_{ij} = \sigma_{ij}' + \frac{1}{3}\sigma_{xx}\,\delta_{ij}}$$

* From equil. stresses : $S_i = \sigma_{ij}\, n_j$

* Stress normal to inclined plane : $\sigma_n = \bar{S}\cdot\bar{n}$

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

* Shear stresses components $\rightarrow$ $\boxed{\sigma_s = \sqrt{S^2 . \sigma_n^2}}$

Principal Stresses : $\bar{S} = \sigma\bar{n}$

$\hookrightarrow$ Scalar multiple.

$\therefore$ $S_1 = \sigma n_1$ / $S_2 = \sigma n_2$ / $S_3 = \sigma n_3$

$$(\sigma_{11}-\sigma)\,n_1 + \sigma_{21}\,n_2 + \sigma_{31}\,n_3 = 0 \quad \text{—— (1)}$$

$$\sigma_{12}\,n_1 + (\sigma_{22}-\sigma)\,n_2 + \sigma_{33}\,n_3 = 0 \quad \text{—— (2)}$$

$$\sigma_{13}\,n_1 + \sigma_{23}\,n_2 + (\sigma_{33}-\sigma) = 0 \quad \text{—— (3)}$$

det() = 0

$$\begin{vmatrix} \sigma_{11}-\sigma & \sigma_{21} & \sigma_{31} \\ \sigma_{12} & \sigma_{22}-\sigma & \sigma_{32} \\ \sigma_{13} & \sigma_{23} & \sigma_{33}-\sigma \end{vmatrix} = 0$$

~~Derivative~~

Deviatoric stress

$\downarrow$

Plastic shear

$\sigma_n = \bar{S}\cdot\bar{n}$

$\boxed{ij\ n_J\ n_i}$

multiple.

—— ①

—— ②

—— ③

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

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

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

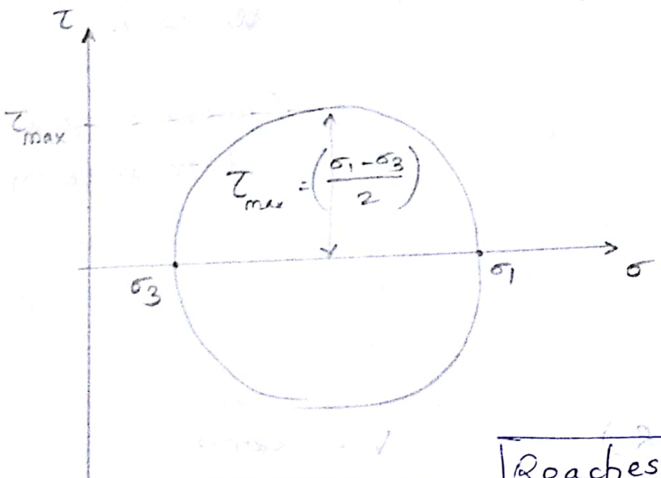
$I_3 = \sigma_{11}\sigma_{22}\sigma_{33} + 2\sigma_{12}\sigma_{23}\sigma_{31} - \sigma_{11}\sigma_{23}^2 - \sigma_{22}\sigma_{31}^2 - \sigma_{33}\sigma_{12}^2$

From deviatoria : $\underbrace{J_1 \quad J_2 \quad J_3}_{\sigma_{ij'} = \,/\!/}$

$\neq\ \sigma > Y \longrightarrow$ Yielding starts.

$\boxed{\text{TRESCA}}$ } Max. shear stress reaches a critical value $\Downarrow$ Yielding Starts

$\boxed{\text{Von-mises}}$



$Y \approx K$

$\sigma_1 - \sigma_3 = 2k$

$\boxed{\text{Shear strain energy per unit volume}} \rightarrow \boxed{\text{Reaches a critical value}} \rightarrow \boxed{\text{Yielding}}$

$(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 =$ const $\equiv A$

(1) $\sigma_1 = Y, \quad \sigma_2 = 0 = \sigma_3$ } uniaxial loading.

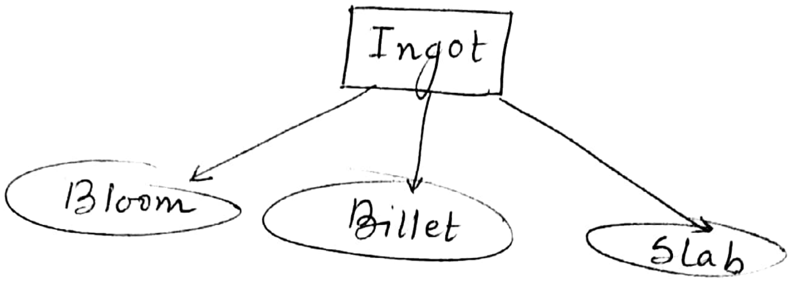
(2) Pure torsion, $\sigma_1 = K$, $\sigma_2 = 0$

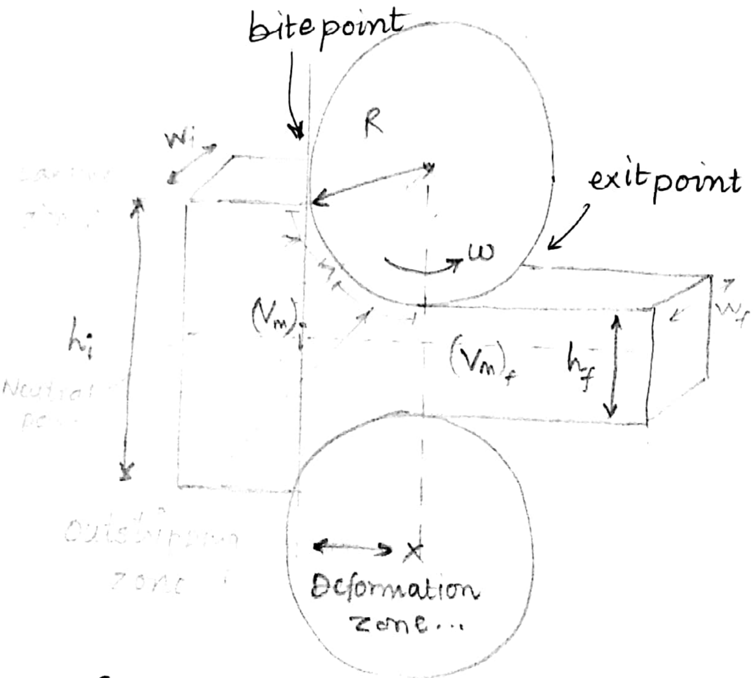
$\sigma_3 = -K$

* ROLLING :

- Slab
- Plate
- Sheet
- Strip

below 6mm thickness





$$V = \omega * R$$

$$\omega >> h$$

Plane-strain deformation.

$$(V_m)_i < V_R \; (\equiv \omega R)$$

$$w_i \sim w_f$$

$$V = \text{const.}$$

$$l \cdot w \cdot h = \text{const}$$

$$d\epsilon_1 + \cancel{d\epsilon_2} + d\epsilon_3 = 0$$

$$\therefore \; d\epsilon_l = -\, d\epsilon_h$$

14/08/2018

Casting

* In an alloy, eutectic composition is such that liquidus temp. is minimum and freezing range is zero.

Q. Write briefly on:
(1) Draft allowances
(2) Machining allowances
(3) Distortion allowances (why residual stresses generate ...)

Q. Brass chaplets are used to support sand core inside a sand mold cavity. The projected core print area is $13\ cm^2$ for each end of the cylindrical sand core which support at both ends. The design of the chaplets and the manner in which they are placed in the mold cavity surface allows each chaplet to sustain a force of 45N. If vol. of the core = $7.5\times10^3\ cm^3$ and the metal poured is brass, determine the min. no. of chaplets that should be placed
(a) beneath the core.
(b) above the core
(Density of sand core & brass = 1.6 & 8.67 gm/cm^3
green sand strenght = $6.9\times10^3\ N/m^2$)

→ Wt. of core = 117.6 = W

Support provided by core print at bothends = 17.94 = S

∴ No. of chaplet at bottom = $\frac{W-S}{45}$

ω * R

h

strain

mation.

o

* AFS grain fitness number : —
* Lifting properties of pattern : —

Q.1. A laddle with circular c/s (dia. = 2 m) contains 70×10^3 kg molten steel. The steel is teemed through circular hole (dia 3cm) calculate time required to empty the laddle

→ $V_1 = \left(\frac{A_2}{A_1}\right) V_2$

$$= \frac{\pi (0.015)^2}{\pi (2/2)^2} \times V_2 = 2.25 \times 10^{-4} V_2$$

Neglecting V_1 compared to V_2 in Bernoulli,

$$V_2 = \sqrt{2gh} = \left(\frac{A_1}{A_2}\right) V_1$$

$$\sqrt{2gh} = \left(\frac{A_1}{A_2}\right) \frac{-dh}{dt}$$

$$\frac{A_1}{A_2} \int_{h_0}^{h} \frac{-dh}{\sqrt{2gh}} = \int_0^t dt$$

$$\frac{-A_1}{A_2 \sqrt{2g}} \int_{h_0}^{h} \frac{dh}{\sqrt{h}} = t$$

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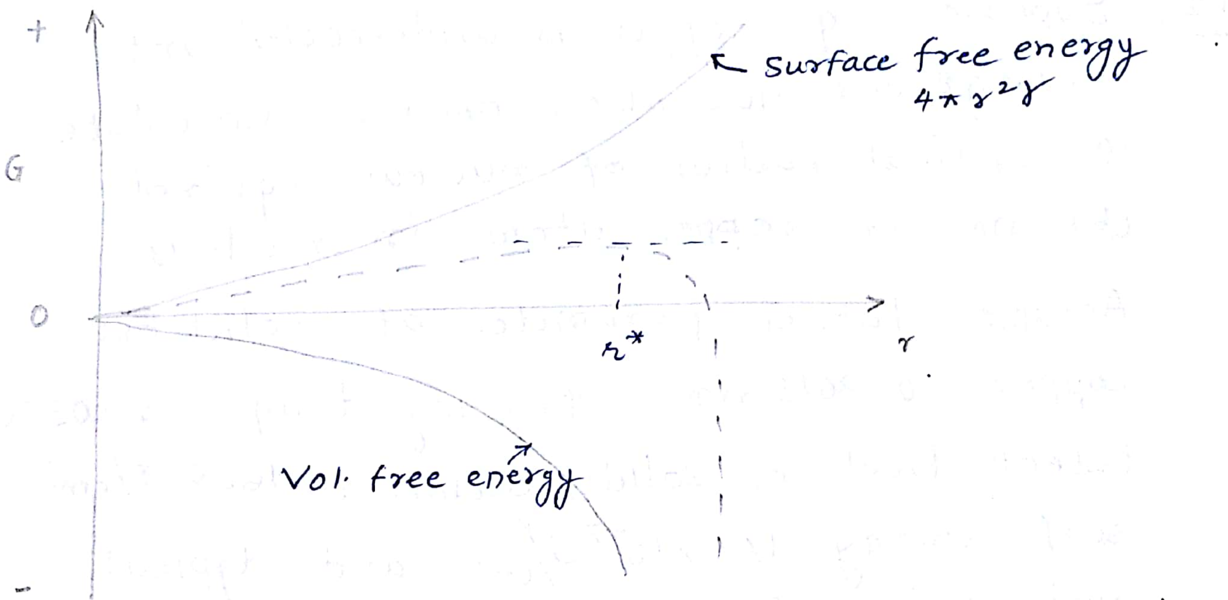
* Let us assume that few atoms arrange themselves to a small nucleus/embryo of a spherical shape.

Let ΔG_v be the free energy per unit volume and γ is interfacial surface energy.

Nucleation of crystalline solid:

- Change in vol. free energy $= \frac{4}{3}\pi r^3 \Delta G_v$
- Energy req. to create new solid liquid interface $= 4\pi r^2 \gamma$
- Net change in total free energy associated with formation of embryo $= \frac{4}{3}\pi r^3 \Delta G_v + 4\pi r^2 \gamma$.



There exists critical radius where barrier of solidification is maximum. (r^*)

$$\frac{d(\Delta G_T)}{dr} = 4\pi r^2 \cdot \Delta G_v + 8\pi r \gamma = 0$$

$$r = r^* = \frac{-2\gamma}{\Delta G_v}$$

$$\Delta G_T = \Delta G^* = \frac{16\pi \gamma^3}{3\,\Delta G_v^{\,2}}$$

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There is a critical size of new phase (embryo) to become stable and grow. Hence there exists an energy barrier. to solidifica

$$\Delta G_V = \frac{-2\gamma}{r^*} = -L\frac{\Delta T}{T_E}$$

$$\Delta T = T_E - T = \frac{2\gamma T_E}{L r^*}$$

$$\boxed{T = T_E\left(1 - \frac{2\gamma}{L r^*}\right)}$$ → Gibbs Thompson Equation.

Q.1 $T_1 < T_2 < T_E$

then draw $G_{T\,(total)}$ w.r.t r

Q.2. Suppose liq. copper is undercooled until homogenous nucleation occurs. Calculate
(a) critical radius of nucleus required,
(b) no. of copper atoms in nucleus.

Assume lattice parameter of solid FCC copper 0.3615 nm, freezing temp. is 1085°C Latent heat of solidification is 1628 J/cm³ surf. energy 177×10^{-7} J/cm² and typical undercooling for homogenous nucleation is 236°C

→ $\Delta T = 236°C$

$T_E = 1085 + 273 = 1358$

$L = 1628$ J/cm³

$\gamma = 177 \times 10^{-7}$ J/cm² $\Rightarrow r^* = \frac{-2\gamma}{\Delta G_v} = \frac{-2 \times 177 \times 10^{-7}}{282.92} = -1.25 \times 10^{-7}$ cm

$$\Delta G_v = \frac{-2\gamma}{r^*} = -L\frac{\Delta T}{T_E} = -1628 \times \frac{236}{1358} = 282.92 \text{ J/cm}^3$$

Forming

21/08/2018

1. Tresca Yield Criteria $\rightarrow \tau_{max} = K$
2. Von-mises " " $\rightarrow \left[\frac{\sigma_1 - \sigma_3}{2}\right] = K$

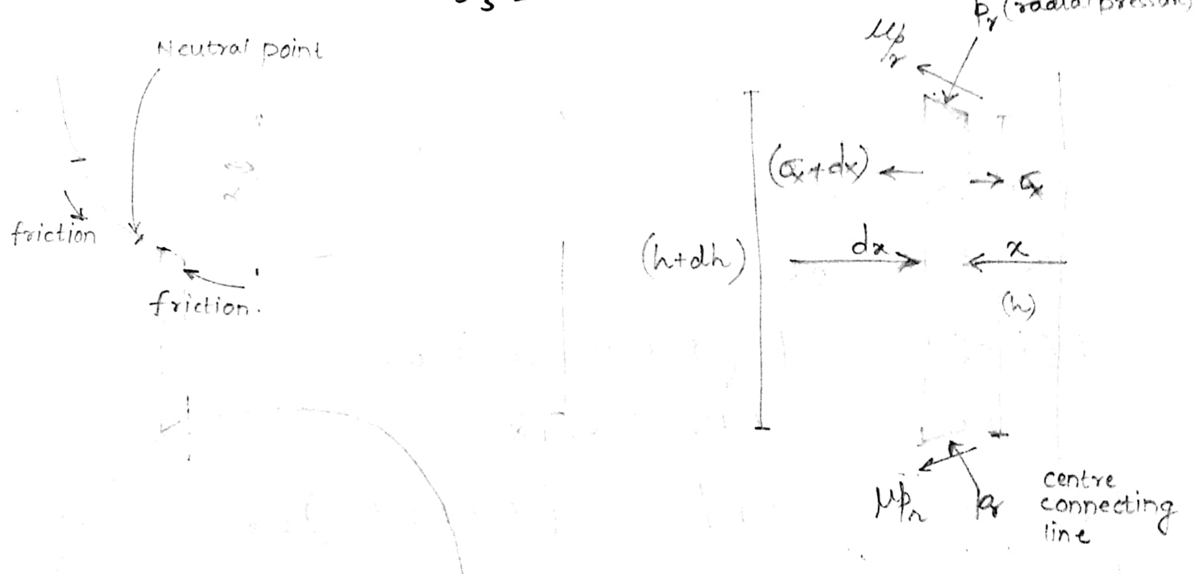
$\downarrow$

Shear strain energy per unit volume $\longrightarrow$

$$(\sigma_1 - \sigma_3)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 = A$$

3. Uni-axial loading : $\sigma_1 = Y$
$\sigma_2 = 0$
$\sigma_3 = 0$

4. Pure torsion : $\sigma_1 = K$
$\sigma_2 = 0$
$\sigma_3 = -K$



- Due to longitudnal stress : $(\sigma_x + d\sigma_x)(h+dh)$
- Due to radial pressure : $2 p_r \left(\frac{dx}{\cos\alpha}\right) \sin\alpha$
- Due to frictional force : $2 \mu p_r \left(\frac{dx}{\cos\alpha}\right) \cos\alpha$

$\sigma_1 = \sigma_x$

$\sigma_3 = \sigma_y = -p$

* $\Sigma F_x = 0$

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

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

$\rightarrow$ $\sigma_1 = \sigma_x$

$\sigma_3 = \sigma_y = -p$ [vertical pr.]

* Normal to the direction of rotting $\Rightarrow$

$$\sigma_y\,dx = -p_r\frac{dx}{\cos\alpha} + \mu p_r\frac{dx}{\cos\alpha}\sin\alpha$$

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

$$\sigma_y = -p_r$$

$$\Rightarrow \sigma_3 = \sigma_y = -p = -p_r$$

Tresca Yield Criteria:

$$\boxed{\sigma_x + p = 2k}$$

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

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

$$d(h_s - h_p) = -2Rp\sin\alpha(1\pm\mu\cot\alpha)\,d\alpha$$

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

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

$$h = h_a + (2R)\frac{\alpha^2}{2}$$

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

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

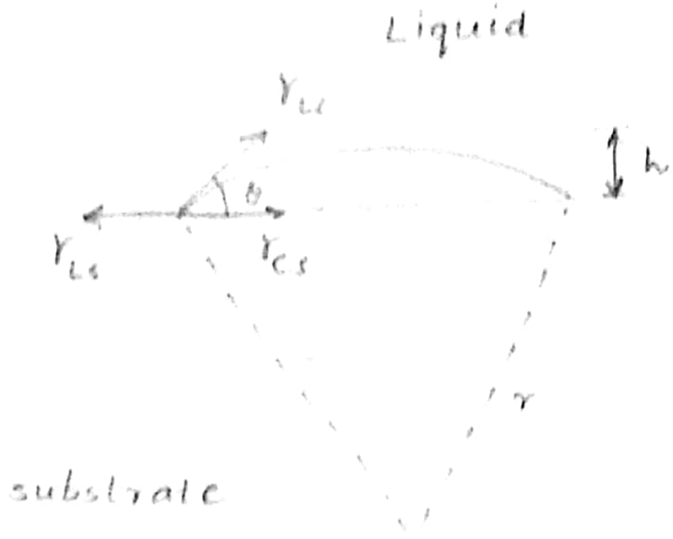
$$\Rightarrow \boxed{\frac{p^+}{s} = c^+\left(\frac{h}{R}\right) e^{\mu H}} \quad \{\text{on exit side}\}$$

$$\Rightarrow \boxed{\frac{p^-}{s} = \bar{c}\left(\frac{h}{R}\right) e^{-\mu H}} \quad \{\text{on entry side}\}$$

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

Casting

* (problem solving)
* Nucleation due to nucleating agents:



$$\cos\theta = \frac{\gamma_{LS} - \gamma_{CS}}{\gamma_{LC}}$$

$$\therefore\ V = \frac{1}{3}\pi h^2 (3r - h)$$

$$= \frac{1}{3}\pi r^3 (2 - 3\cos\theta + \cos^3\theta)$$

$$\therefore\ A = 2\pi r h = 2\pi r^2 (1 - \cos\theta)$$

$$\therefore\ \Delta G_T = \gamma_{LC} \cdot 2\pi r^2 (1 - \cos\theta) + \frac{1}{3}\pi r^3 (2 - 3\cos\theta + \cos^3\theta)\Delta G$$
$$+ (\gamma_{CS} - \gamma_{SL})\pi r^2 (1 - \cos^2\theta)$$

$$\therefore\ r^* = \frac{2\gamma_{LC}}{\Delta G_V}$$

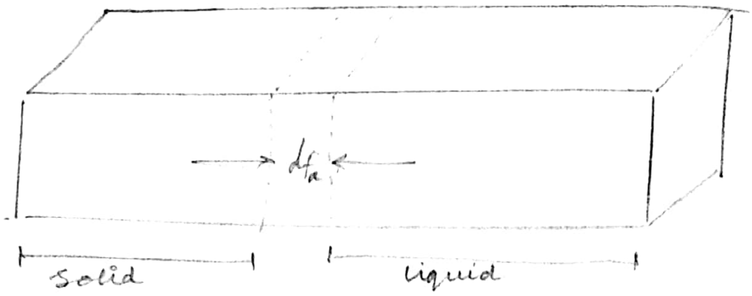
$$\therefore\ \Delta G^* = 4\pi\gamma_{LC}^3 (2 - 3\cos\theta + \cos^3\theta)$$

Segregation during solidification:

$$k_0 = \frac{C_s}{C_L} \rightarrow \text{partition coeff.}$$

$\hookrightarrow$ composition of solid / liq.

- composition of solid @ advancing solid-liq. interface -



A liq. metal of initial composition C_0 is solidifying within the rectangle.

Solidification point is propogating from left to right

Let f_x be fraction solidified.

Now, composition of Liq. is C_L

At any small instant of time, volume fraction of df_s suppose solidifies.

Let conc. of the small elemental front is C_s^*

$$(C_L - C_s^*)\,df_s = (1-f_s)\,dC_L$$

$$\therefore (C_L - k_0 C_L)\,df_s = (1-f_s)\,dC_L$$

$$\therefore \int_0^{f_s} \frac{df_s}{1-f_s} = \int_{C_0}^{C_L} \frac{dC_L}{C_L(1-k_0)}$$

$$C_L = C_0 (1-f_s)^{k_0 - 1}$$

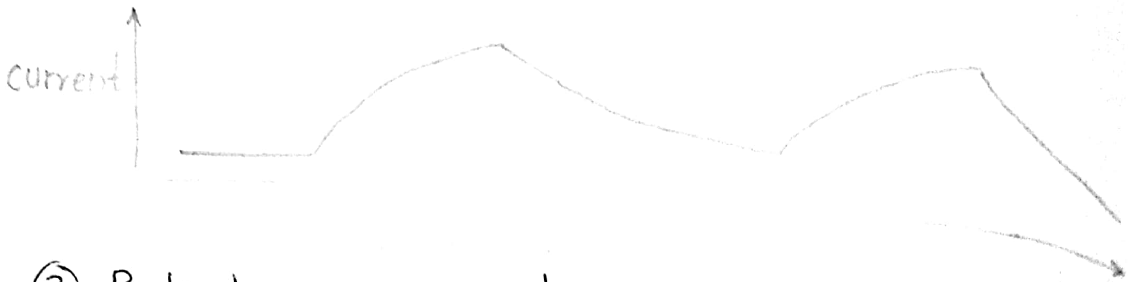
$$\underbrace{C_s^* = k_0 C_L = k_0 C_0 (1-f_s)^{k_0-1}}$$

Scheil Equation...

Welding 23/08/2017

* Material Transfer types -

1. Free flight · Globular-projected transfer:
   - Effect of increasing current.
2. Bridging or short circuit tranfer:
   - Sequence of above process



3. Pulsed arc or pulsed current transfer:

* Difference b/w normal spray mode and pulsed transfer type of metal transfer -

4. Slag protected metal transfer:

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FORMING ...

Tuesday
Aug. 28.2018

* Pressure distribution during rolling :-
[discussed in previous class]

- Boundary conditions :

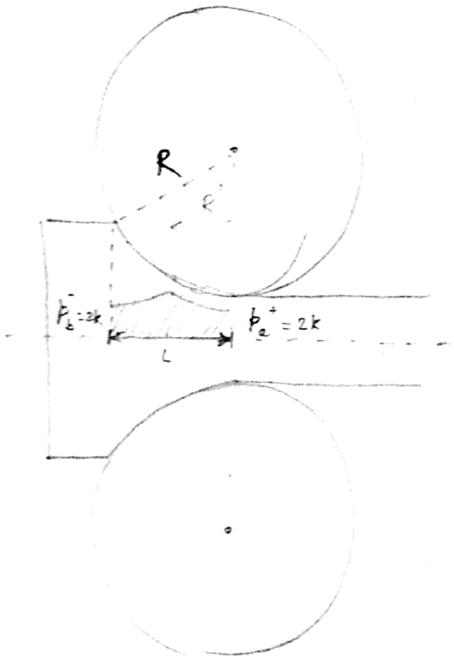
(1) No pull at front and back ends.

i.e $\sigma_{xa} = 0 \longrightarrow H_a = 0$ (at exit point)

Exit point $\Rightarrow p_a^+ = 2k \Rightarrow c^+ = \frac{R}{h_a}$

Bite point $\Rightarrow p_b^- = 2k$ $\quad * \left(\frac{p^+}{s}\right) = \left(\frac{h}{h_a}\right) e^{\mu H}$

$* \left(\frac{p^-}{s}\right) = \left(\frac{h}{h_a}\right) e^{\mu (H_0 - H)}$



Front pull $\Rightarrow F_a$ ✓

$\underbrace{\sigma_{xa}}$ ✓

$\sigma_x + p = 2k$

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

$(p_a^+) < (p_a^+)$
With pull — No front pull

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

$(p_b^-) < (p_b^-)$
No back pull — with pull

(2) Roller radius : $R' < R$ preferable as it decreases the 'L'

(3) Rolling Load : $F = \int_{\alpha_n}^{\theta} p_r () + \int_{0}^{\alpha_n} p_r ()$

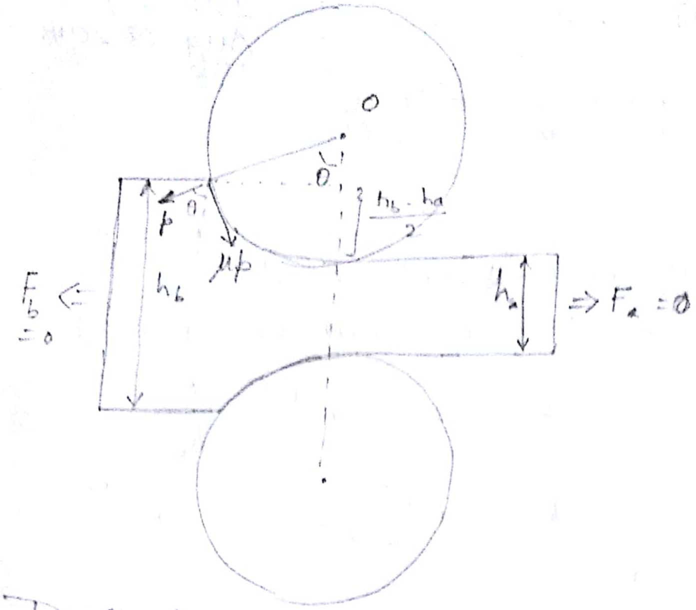
Torque $= \int \mu p_r () + \int \mu p_r ()$

Power $= T \omega$

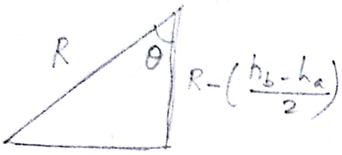
Scanned by CamScanner

$\mu \geq \tan\theta$

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



Draft for unaided rolling ...



$$\cos\theta = \frac{R - \frac{\Delta h}{2}}{R}$$

$$\Rightarrow \cos\theta = 1 - \frac{\Delta h}{2R}$$

$$\therefore \frac{\Delta h}{2R} = 1 - \cos\theta$$

$$\therefore \frac{\sqrt{R^2 - \left(R - \frac{\Delta h}{2}\right)^2}}{R} = \tan\theta$$

$$\Rightarrow \sqrt{\frac{\Delta h}{R}} = \mu \longrightarrow \Delta h = \mu^2 R$$

Casting...

Tuesday
Aug. 28. 2018

Riser :-

- Completes the mould filling.
- Compromise liquid and solidification shrinkage
- Venting entrapped gases.

Feeder design :

- Location, type and dimensions of feeder need to be defined / decided.
- 7 feeding rules :

1. Unnecessary feeder dereases casting yield.
2. Time of solidification of riser should be higher than that of the casting.

[# Caine's method : Vol. ratio vs. freezing ratio]

3. Feeder should contain sufficient liquid metal to feed the contraction requirement of casting and itself.
4. There must be a path to reach the feed metal to req. region. This is achieved if there is directional solidification of casting as a whole towards riser.

[$M_r \sim 1.2$ or $1.1\ M_c$: Modulus of riser/casting]

5. Junction requirement :[side riser]
6. pressure requirement :
7. Temperature gradient :

* No. of risers = $\dfrac{100 - 2EE}{2RE + d}$

Riser : $d = 4.95''$, $h = 9.9''$ | $RE = 1.5t$, $EE = 2t$ | t = some time after pouring.

Location of hotspot using MATLAB :

① Divide the body into several section

② Imagine a point within the section. Join the the end points to the point in order to discretize the section.

③ Evaluate the volume and surface area of each discretized element.

④ Draw the vector whose magnitude is V/A and direction is bisecting internal angle made @ the imaginary point.

⑤ Addition of vector of all discretized element

⑥ Resultant vector should be the next imaginary point.

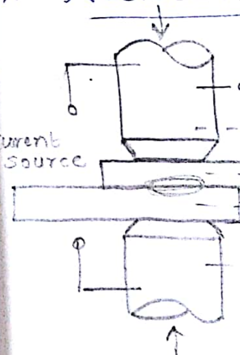
⑦ Loop continues until we reach hotspot area.

* Arc Weldin
- Constant
- Constant
  - 'self R
    lenght
    rate.
- Combined

* Thermite
- Metal ox
- Heat fo
  superhea

Ex: 2A

* Resistan



Q = Pt =

ΔT =

m

- Coppe
  no r
- Soli

Welding

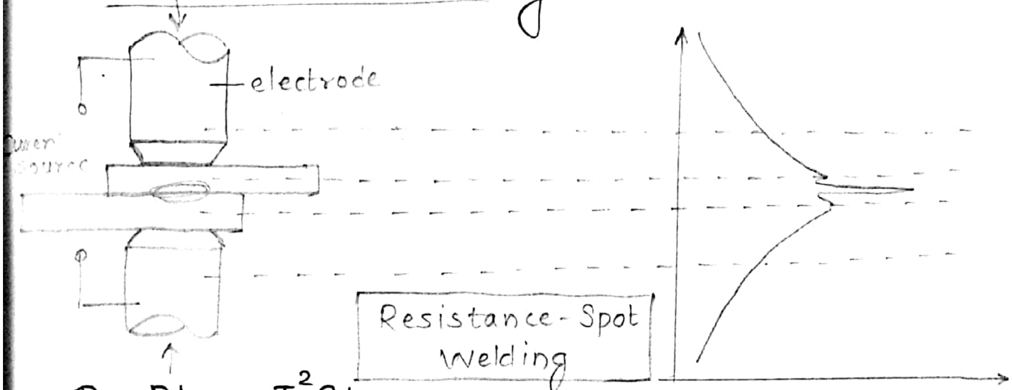
Thursday
30 - 08 - 2018

* Arc Welding :
- Constant current power source.
- Constant voltage power source.
  - 'Self Regulation' - Tries to maintain arc lenght by changing the metal consumptior rate.
- Combined charachteristic sources.

* Thermite Mixture :
- Metal oxide + Aluminium → Metal + Al oxide + hea
- Heat for coalescence is produced by the superheated molten metal.

Ex: $2Al + Fe_2O_3 \longrightarrow 2Fe + Al_2O_3 + Heat$

* Resistance Welding :



$$Q = Pt = I^2Rt$$

$$\Delta T = \frac{Q}{mC_p} = \frac{I^2Rt}{mC_p}$$

- Copper electrode → Highly conductive : There is no melting @ electrode - plate junction.
- Solid state ↔ Fusion {combination of both}

Casting - Forming - Welding ①

Prof. S.K Panda (Monday) — 7 marks ⇓ STC (Foundry)

S.k Pal (Tuesday) — 7 marks ⇓ Inside STC

J. Paul. (Thursday) — 6 marks → TA ⇓ ME dpt. ground floor + Friction stir welding (STC)

R A W Mate.

* Syllabus [Forming]:

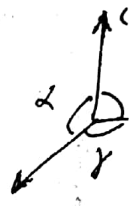
1. Crystal Structure
2. Phase Diagram
3. T-T-T diagram.
4. Heat treatment process
5. Deformation Processes.
6. Yield criteria [Tresca + von-mises yeild criteria]
7. Bulk metal forming process.
   ⓐ Rolling
   ⓑ Drawing → Rod / Bar
      → Tube drawing.
   ⓒ Extrusion
   ⓓ Forging
8. Sheet metal forming [Deep drawing process]
9. Non-conventional forming → Electromagn.
   → Explosive
   → Electrohydraulic.
10. Powder metallurgy
11. Misc process

① FSW Lab (Dept.)
② CoE in Adv. M. Tech.
③ HMC (13 Sept. 2018)

* CRYSTAL

① 3D s

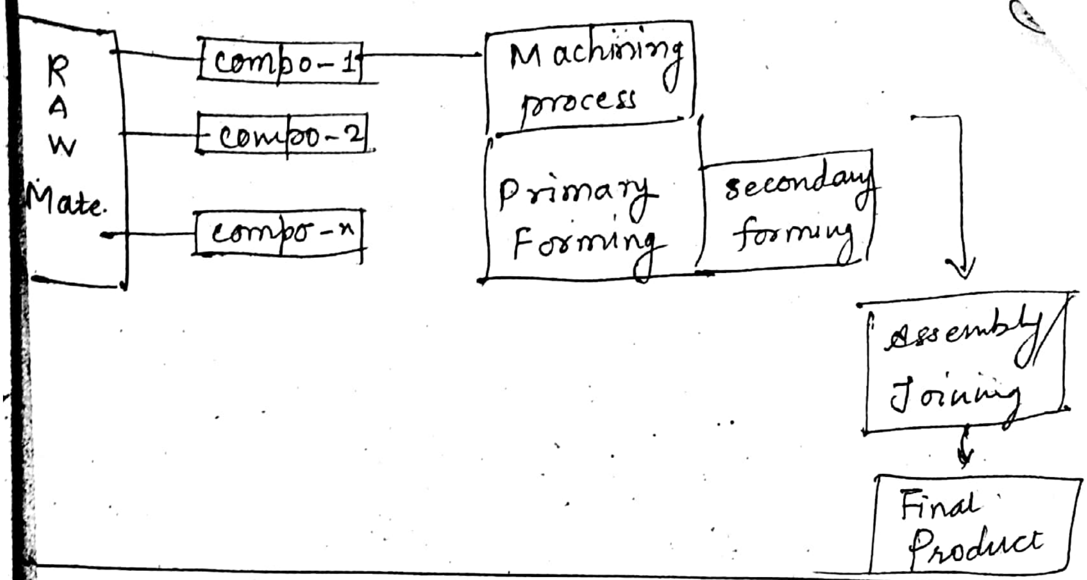
② sima



③ (1) Triclin
(2) Mono-c
(3) Ortho
(4) Rhom
(5) Tetra
(6) Hexag
(7) cubic

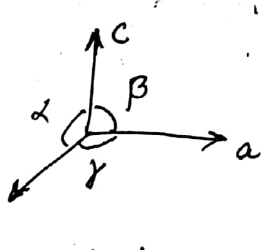
④ Depend

⑤ Cubic



CRYSTAL STRUCTURE :-

1) 3D structure - space lattice
2) smallest unit - unit cell.



a, b, c

α, β, γ

(1) Triclinic
(2) Mono-clinic
(3) Ortho rhombic
(4) Rhombohedral
(5) Tetragonal
(6) Hexagonal
(7) Cubic

} Crystal system

) Depends on: no. of atoms present in a particular crystal sys.

) Cubic — 1) $\boxed{\text{Simple cubic [SC]}}$

8 corners $\left[\frac{1}{8} \times 8 = 1\right]$ = E.N.A (effective no. of atom)

- Packing efficiency = $\frac{\text{Vol. of atoms}}{\text{Total Vol.}}$
- $P.F = \frac{\frac{4}{3}\pi r_a^3}{a^3}$
- $a = 2r_a$

2) Body centred cubic:

$$E.N.A = 1 + \left(\frac{1}{8} \times 8\right) = 2$$

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

$$\sqrt{3}a = 4r$$

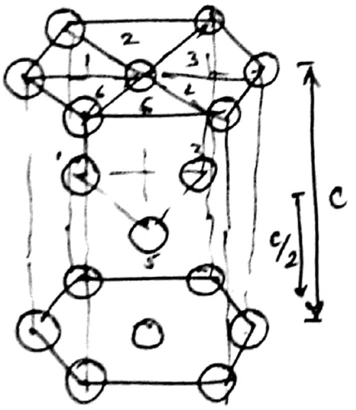
3) Face centred cubic:

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

$$P.F = \frac{4 \times \frac{4}{3}\pi r_a^3}{a^3}$$

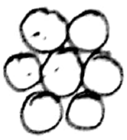
$$\sqrt{2}a = 4r$$

6 Hexagonal – $a = b \neq c$ (HCP - hexagonal closed packed)



Base plane #1

Top



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

$$= 6$$

Vol. of unit cell = $(6 \times eq.\Delta^{le}) \times c$

Rel. b/w r_a and c

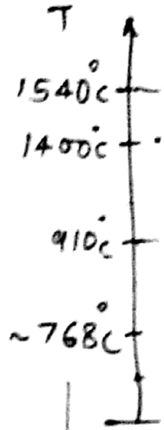
$$P.F = \frac{6 \times \frac{4}{3}\pi r_a^3}{6 \times eq\Delta^{le} \times c}$$

7 Al/

Fe ·

Ti

8 Iron



Goody

9 Allo

Carbo

10 Depe

(1) Te

(2) %

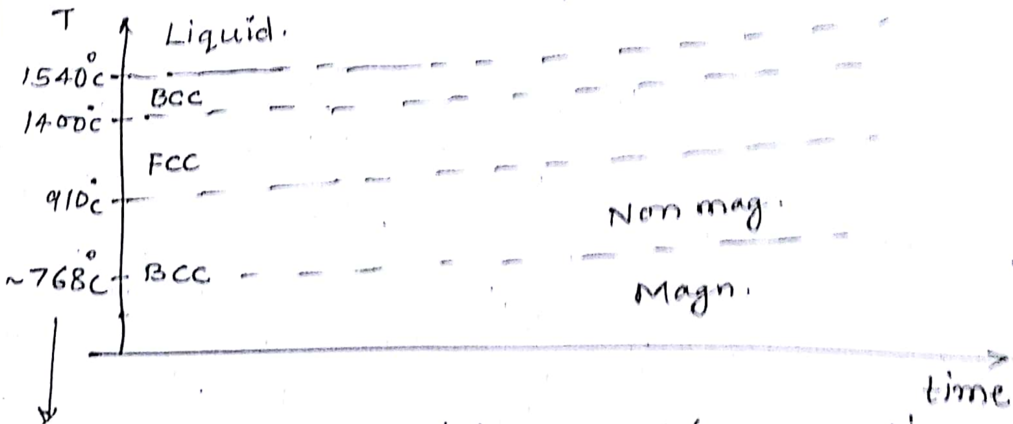
- Pha

(7) Al/Cu → FCC

Fe → FCC, BCC } Depends on temp. (Allotrophic)

Ti → HCP

(8) Iron → Melt. Pt. → 1540°C



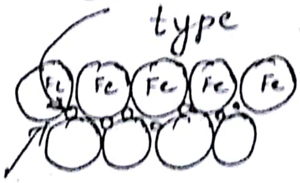
Goody point - Transition pt. b/w magnetic and non-magnetic.

(9) Alloy - $\boxed{\text{Solid Solution}}$

Interestial type

Substitution type

$\boxed{\text{Cu-Zn}}$



Carbon

(10) Dependency of crystal structure on—

(1) Temp.

(2) % of solute in the alloy.

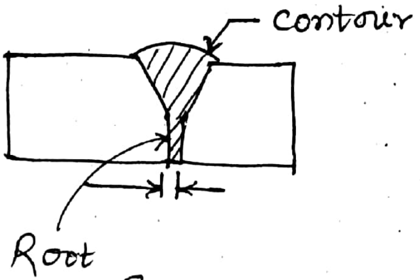
- Phase equil. diag.

Welding

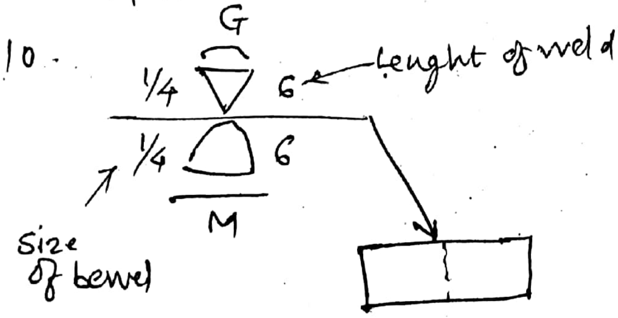
19/07/2018

(5)

1. Principles of Welding, Robert Messler
2. Joining → Welding
   → Brazing
   → Soldering
   → Adhesive Bonding
   → Threaded fastners, etc.
3. 2 thin sheets → Nut-Bolt
   Botton plate is thick → Screw
4. Localised coalescence achieved by appropriate combination of temp. & pressure.
5. Fusion Welding - Melting the base material.
6. Solid State welding - The temp. is maintained below the m.p. of the base material.
7. Types of Joint -
8. Fillet Weld & Groove Weld
9. Weld Symbols →



10.

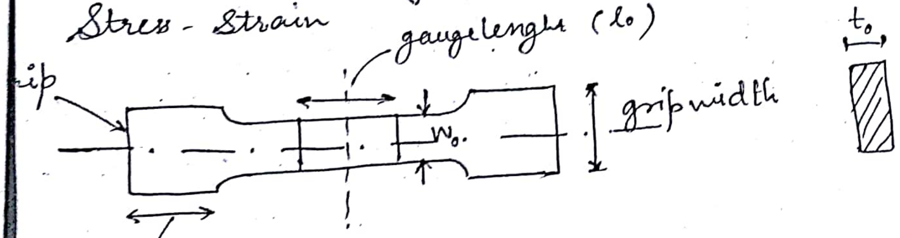


1. Rubinfeld

G.A. Steiner

Casting

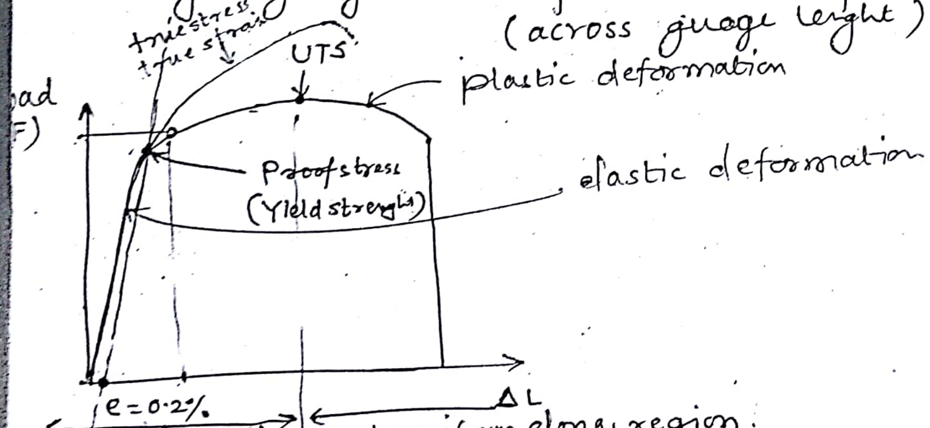
Stress - Strain



[ASTM, tensile specimen]

ensors :

- Load sensor (Load cell) - Load on specimen.
- Strenght guage - displacement in specimen (across guage lenght)



uniform elongation | post uniform elong. region.

nitial area of c/s = $A_0 = w_0 \times t_0$

ngg. stress (S) = $\dfrac{F}{A_0}$

ngg. strain (e) = $\dfrac{\Delta l}{l_0}$

* Hooke's Law : $\sigma = E \epsilon$

* Yeild str : @ e = 0.2% draw line ‖ to graph.

* UTS :: Ultimate Tensile Strenght.

* During Tensile Test 2 phenomena takeplace

(1) Decr. in load bearing cap. of specimen due to decr. in area of c/s

(i) [vol. remains const.]

(2) Load bearing capacity of specimen incr. due to strain hardening.

* UTS - instability point
(Onset of necking)

* True stress and true strain:-

⇓

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

A → instantaneous area of c/s $\Rightarrow \sigma = \frac{F}{A_0} \times \frac{A_0}{A}$

(vol.)

As, $A_0 l_0 = A l$

$$\therefore \frac{A_0}{A} = \frac{l}{l_0}$$

$$\therefore \sigma = \left(\frac{F}{A_0}\right)\left(\frac{l}{l_0}\right) = \underbrace{S}_{\text{engg stress}}\,(1+\underbrace{e}_{\text{engg strain}})$$

* True strain:

l → instanteneous lenght

dl → change in lenght

$$d\epsilon = \frac{dl}{l}$$

$$\therefore \epsilon = \int_{l_0}^{l} \frac{dl}{l} = \ln\left(\frac{l}{l_0}\right) = \ln(1+e)$$

1. A bar of lenght l_0 is uniformly extended until its lenght $l = 2l_0$ (3)

(1) Compute engg. strain and true strain

(2) To what final lenght must a bar of lenght l_0 be compressed if strains are to be same except the sign in part A.

→ (1) Engg. strain $= 1 = e$

True strain $= \ln 2 = 0.693$

(2) $e = -1$, Not possible. → engg. strain

$e = -0.693$ → $1 - 0.693 = \frac{l}{l_0}$

$\Rightarrow l = 0.$

For equivalent amt. of tension → 0.693 (True strain)

compression → −0.693

True strain for eq. amt. of tension and compression are same except sign.

Q.2 A bar of 10cm elongated to 20cm in 3 steps: 10 cm → 12cm → 15cm → 20cm

(1) Calc. engg. strain for each step, compare sum with overall strain.

(2) Repeat for true strain.

$(1 + e)$

→ 1) $e_1 = \frac{2}{10} = 0.2$ $\qquad e = 1$

$e_2 = \frac{3}{12} = 0.25$

$e_3 = \frac{5}{15} = 0.33$

2) $\varepsilon_1 = \ln(1.2)$ $\qquad \varepsilon = \ln(2) = 0.693$

$\varepsilon_2 = \ln(1.25)$

$\varepsilon_3 = \ln(1.33)$

True strains are additive in nature.

* $l_0 \times w_0 \times t_0 = l \times w \times t$

$$\frac{l_0}{l_0} \times \frac{w}{w_0} \times \frac{l}{l_0} = 1$$

$$\therefore \ln\left(\frac{l}{l_0}\right) + \ln\left(\frac{w}{w_0}\right) + \ln\left(\frac{t}{t_0}\right) = 0$$

$$\therefore \epsilon_l + \epsilon_w + \epsilon_t = 0$$

* Vol. constancy cond. can be expressed using simple mathematical cond. in terms of true strain.

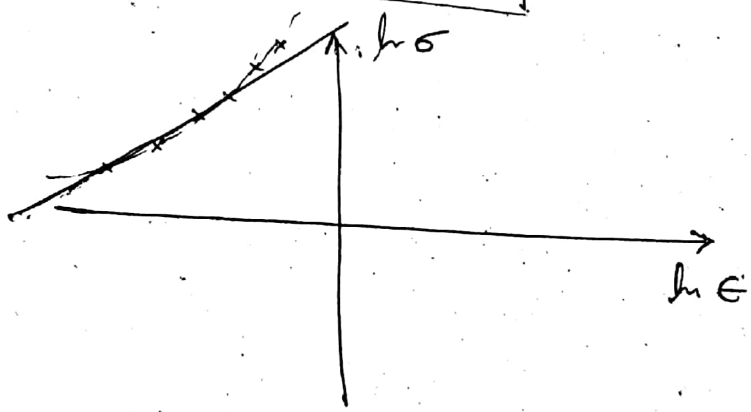
Hollomon Power hardening Law:-

$\boxed{\sigma = K\epsilon^n}$ ~~[during post elongation region]~~

K = Strenght coefficient.

n = strain hardening exponent.....

$\boxed{\ln\sigma = n\ln\epsilon + \ln K}$



° Yield Strenght — UTS (applicable)

Metal Forming

24/07/2018

(10)

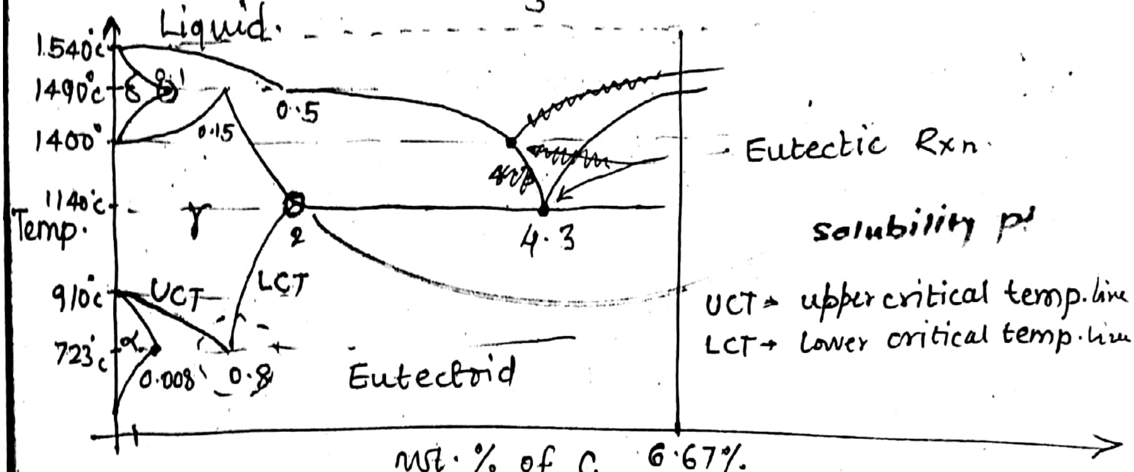
Crystal Structure of Metal :-

[Alloy of Fe] = Fe + C/N/ ...

Solution Solvent Solute

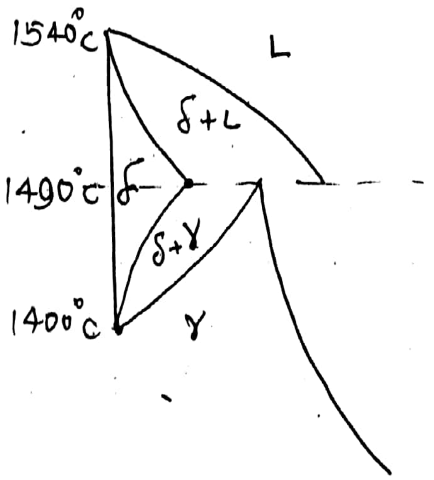
- Solid solution
- solubility of C/N in Fe lattice depends on the temperature.

wt. % of C in Fe_3C : (Iron Carbide)



Phase diag. of Fe and Fe_3C.

- Cementite – Orthorhombic structure (6.67% C)
  - Max. solubility of C.
- α, δ – BCC
- γ – FCC



① @ 1490°c & wt.%C = 0.15

$$\delta + L \underset{\text{Heat}}{\overset{\text{cool.}}{\rightleftarrows}} \gamma$$

1490°c

Peritectic Reaction

② Eutectic Reaction 1140°c

$$L \underset{\text{Heat}}{\overset{@1140°c}{\underset{4.3}{\rightleftarrows}}} \underbrace{\gamma + Fe_3C}_{\text{LEDEBURITE}}$$

③ $\boxed{\text{Eutectoid Reaction}}$

$$\gamma \xrightarrow[\underset{\text{heat}}{0.8}]{723^\circ C} \underbrace{\alpha + Fe_3C}_{\text{PEARLITE}}$$

Austenite (γ)

Ferrite (softest) (α)

* Important metal forming reaction.

[Tensile Strenght / Yield Strenght

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

1. $\boxed{\text{Cast Iron}}$ – Brittle (more amt of C). above 2% wt.
2. $\boxed{\text{Steel}}$ – below 2% wt. C.
3. $\boxed{\text{Hypo-eutetic cast iron}}$ – bet^n 2% – 4.3%
4. Hyper " " " > 4.3%.
5. Hypo-eutectoid steel < 0.8%
6. Hyper – " " : 0.8% – 2%
7. Low carbon steel = upto 0.3%
8. Medium carbon " = 0.3 → 0.6%
9. High carbon " = 0.6 → 1%
10. Tool steel = 1 → 2%

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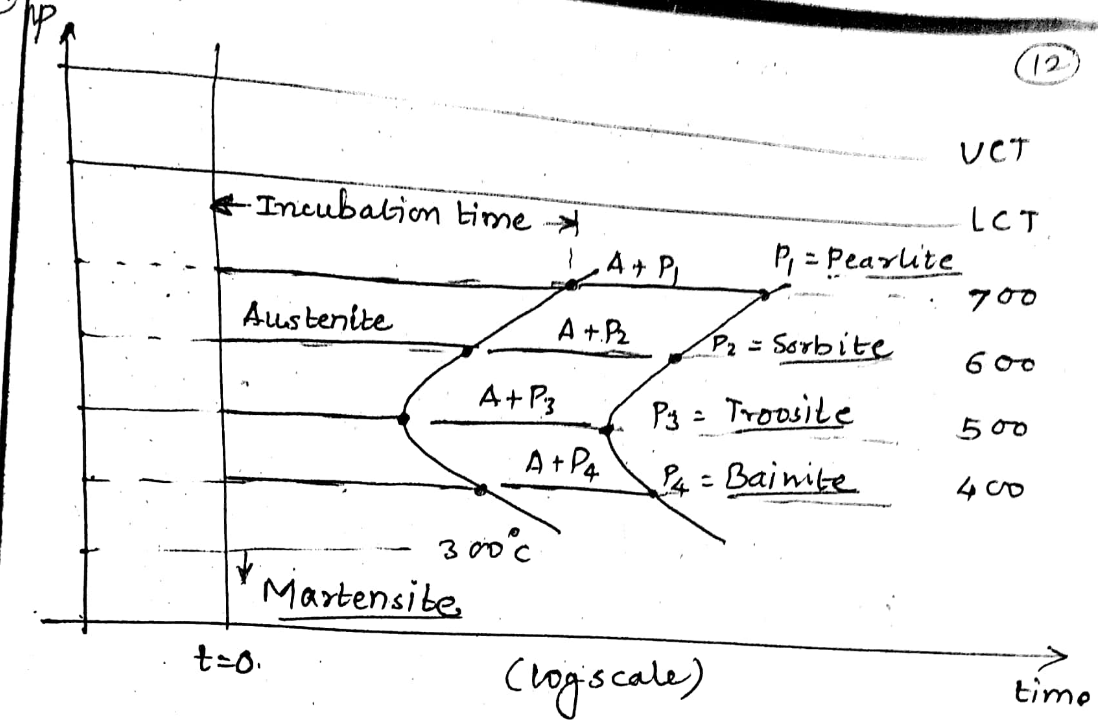


Diffusional transformation : f (temp., time)

Austenite $\longleftrightarrow$ Martensite : f (temp.)

[Non-diffused : A doesnot fully transform to M.]

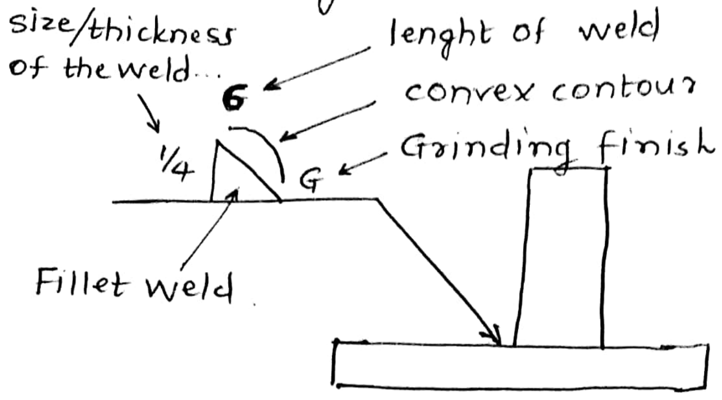
$$\left.\begin{matrix} TS \\ YS \end{matrix}\right\rangle f(\alpha, \beta, \gamma, \delta, d)$$

26/07/2018

Welding

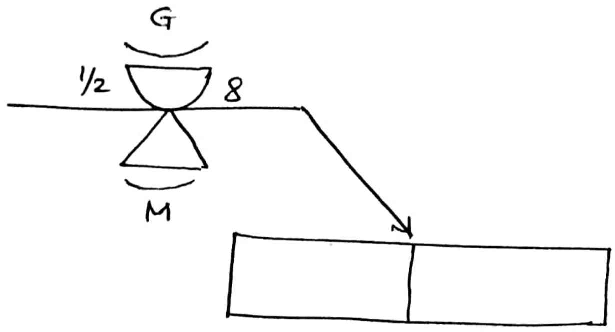
- # Type of Weld
- # Contour
- # Finishing

} Weld Specification.



] Weld Representation.

(Ex)



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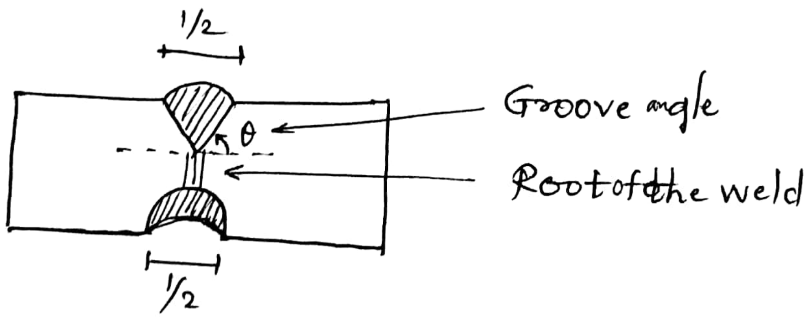


1. Elements of welding Setup -
   - Energy Source
   - Removal of surface contaminants.
   - Atmospheric contaminants.
   - Weld Metallurgy
2. Fusion Welding - Temp. above m.pt.
3. Solid-state welding - Temp. below m.pt.

Casting

30/07/2018

(14)

n- value :-

$$\boxed{\sigma = K\epsilon^n}$$

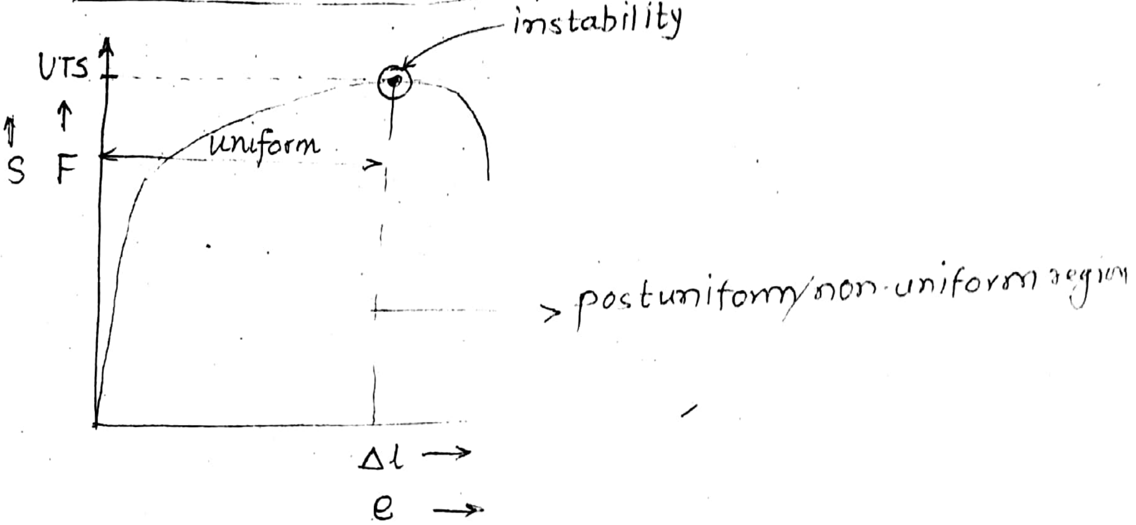
strain coeff.

- Physical significance:

$$F = \sigma A.$$

$$dF = \sigma dA + A d\sigma$$

$$\boxed{\therefore \frac{dF}{F} = \frac{dA}{A} + \frac{d\sigma}{\sigma}} \quad \text{—— (1)}$$



At UTS, (1) : $\frac{d\sigma}{\sigma} + \frac{dA}{A} = 0$ —— (2)

$$\frac{d\sigma}{\sigma} = \frac{-dA}{A} \quad \text{—— (3)}$$

As, V is constant : $V = Al$

$$\frac{dV}{V} = \frac{dA}{A} + \frac{dl}{l}$$

$$\therefore \frac{dA}{A} = -\frac{dl}{l} \quad \text{—— (4)}$$

Substituting in (3),

$$\frac{d\sigma}{\sigma} = \frac{dl}{l} = d\epsilon$$

$$\therefore \frac{d\sigma}{d\epsilon} = \sigma \Big|_{at\ UTS}$$

$$\therefore \frac{d(K\epsilon^n)}{d\epsilon}\Bigg|_{\substack{at\ UTS \\ \epsilon = \epsilon_u}} = K\epsilon^n\Big|_{\epsilon = \epsilon_u}$$

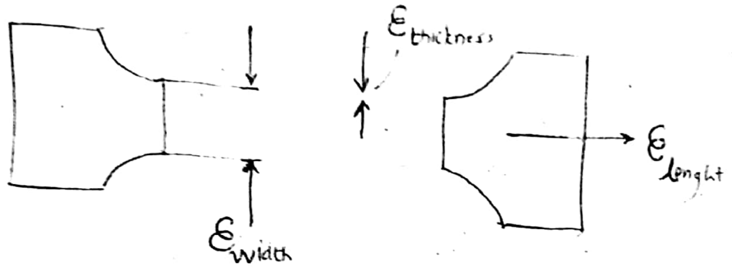
$$\boxed{n = \epsilon_u}$$

n value of materials = Uniform strenght of materials
(Given material follows holloman hardening law)

$(n)\uparrow$ (strain (uniform)) $\uparrow$ (ductility) $\uparrow$
(Uniform elongation) $\uparrow$

* ANISOTROPY

Different properties in one direction



- Isotropic: $\varepsilon_w = \epsilon_t$
- Volume constancy : $\epsilon_l + \epsilon_w + \epsilon_t = 0$

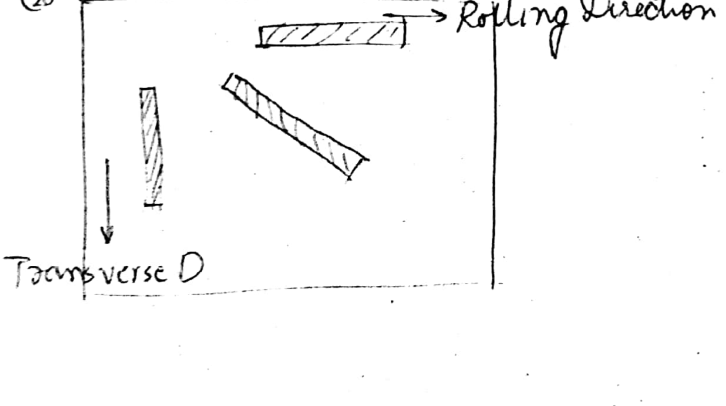
$$\Rightarrow \quad \epsilon_l = -2\epsilon_w = -2\epsilon_t$$

$$\epsilon_w = \ln \frac{w}{w_0}$$

$$\epsilon_t = \ln \frac{t}{t_0}$$

* Lankford Anisotropy paralueter = $R = \dfrac{\epsilon_w}{\epsilon_t}$

$$= \frac{\epsilon_w}{-(\epsilon_w + \epsilon_l)}$$

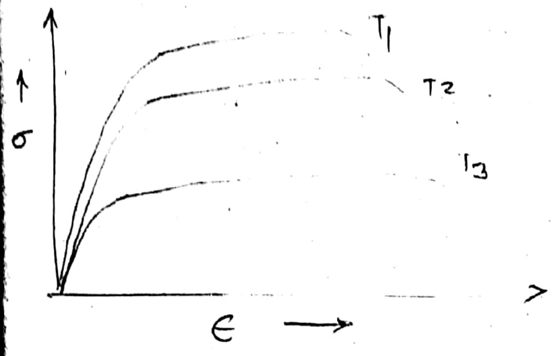


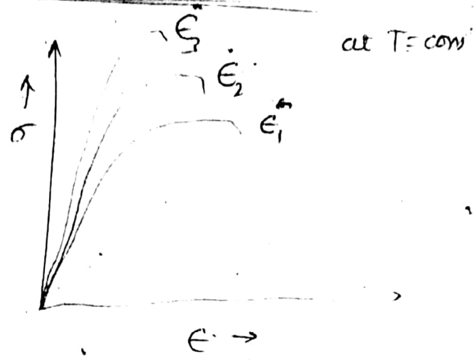
⇒ Lankford Anisotropy parameter R value determined along R_0, R_{90}, R_{45} along rolling, transverse & 45° dir. respectively.

$\bar{R}$ = Avg. Normal Anisotropy = $\frac{R_0 + 2R_{45} + R_{90}}{4}$

ΔR = Planar Anisotropy = $\frac{R_0 - 2R_{45} + R_{90}}{2}$

Effect of temperature & strain rate:





$\dot{\epsilon}_3 > \dot{\epsilon}_2 > \dot{\epsilon}_1$

$$\dot{\epsilon} = \frac{d\epsilon}{dt} = \frac{dl/l}{dt}$$

$$= \frac{1}{l}\left(\frac{dl}{dt}\right) = \frac{u}{l}$$

ramp speed

UTM → constant ramp speed machine
↳ constant strain rate machine

If a material strain changes w.r.t strain rate sensitive material.

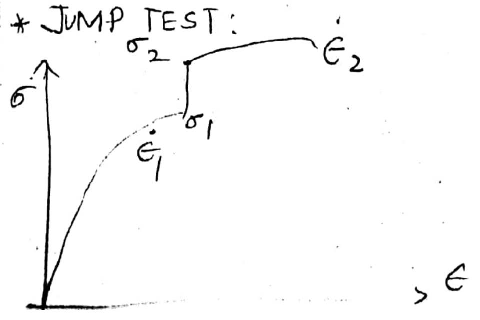
$$\boxed{\sigma = C \cdot \dot{\epsilon}^m}$$

where C = strain coeff

m = strain rate sensitivity index.

$$m = \frac{\ln\left(\frac{\sigma_2}{\sigma_1}\right)}{\ln\left(\frac{\dot{\epsilon}_2}{\dot{\epsilon}_1}\right)}$$

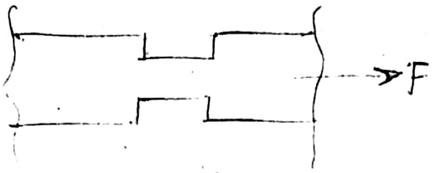
* JUMP TEST:



* Let us consider a specimen which has been already necked.

A_n = Area of c/s of neck

A_u = Area of c/s outside neck



$F = \sigma_u A_u = \sigma_n A_n$

$$\Rightarrow \frac{\sigma_u}{\sigma_n} = \frac{A_n}{A_u} \qquad \left[\text{As, } \sigma = C\dot{\epsilon}^m\right]$$

$$\therefore \left(\frac{\dot{\epsilon}_u}{\dot{\epsilon}_n}\right) = \left(\frac{\sigma_u}{\sigma_m}\right)^{1/m} = \left(\frac{A_n}{A_m}\right)^{1/m}$$

Que. $A_n = 90\% \, A_u$

$\boxed{\text{Case 1}}$: $m = 0.02$

$$\frac{\dot{\epsilon}_u}{\dot{\epsilon}_n} = (0.9)^{1/0.02} = 5\times10^{-3}$$

$\boxed{\text{Case 2}}$ $\Rightarrow$ $m = 0.5$

$$\frac{\dot{\epsilon}_u}{\dot{\epsilon}_n} = (0.9)^2 = 0.81$$

m = strain rate sensitivity index

m↑ (post elongation (uniform)) ↑

FORMING...

31/07/2018

(18)

Hypo eutectic

Hyper eutectic

Castiron vs Steel

Hypo eutectoid

Hyper eutectoid

LCS

MCS

HCS

Austenite → P, S, T, B	Austenite → Martensite
① f(temp, time)	① f(temp.)
② Complete transformat^n observed.	② complete transformation n'ot possible. some amt. of A remains

INGOT → 1st product obtained.

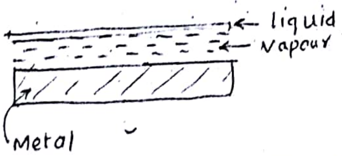
Casting ⇒ INGOT → Bloom / Billet /

primary forming - - - Rolling process

secondary forming - - - Slab {Temp ~ 1000°c}

Slab → sheet → Coiled [~600°c]

* Sudden cooling : 1000°c → 600°c (use of water jets)



Run-out Table {cooling phenomenon}

* Heat Treatment Process :-

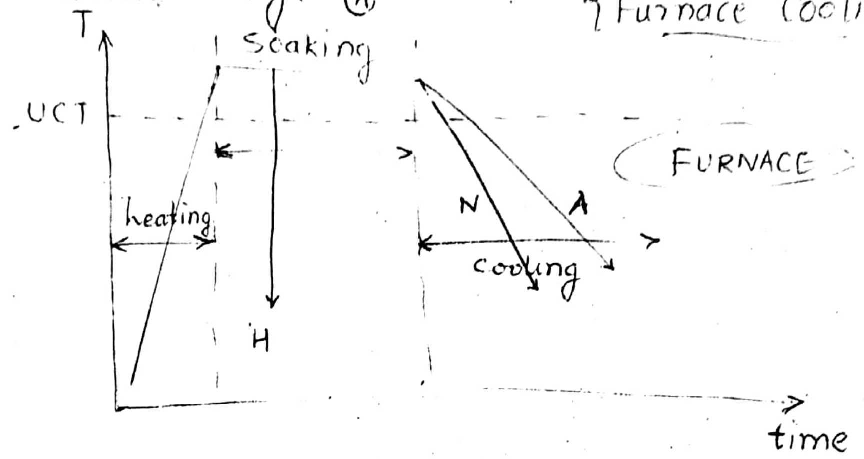
Solid → Heating, Cooling

mechanical properties

Heat Treatment.
- → Reduce internal stress
- → Refine grain structure
- → Hardness, toughness, ductility.

Methods. more related.

1. Annealing (A) { Furnace Cooling }



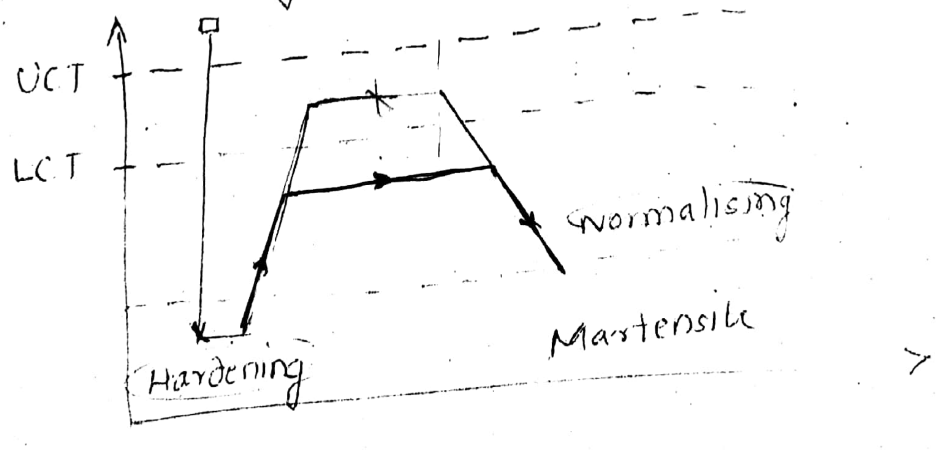
2. Normalizing (N) { Air Cooling }

- Cooling Rate (C.R)
  Annealing < Normalising
- Product Hardness
  Annealing < Normalising

3. Hardening (H) { Water cooling }
   → Only incr. hardness, strenght.
4. Tempering → Hardness + strenght + Ductility + Tempering

↓

Hardness + Ductility
Hardening Normalising



(19) Surface Property : ⟶ Case Hardening (20)

[BOOKS :

1. Physical Metallurgy – S.H AVNER.
2. Manufacturing Science – GHOSH & MALLIK
3. Principles of Metal Working – G.W. ROWE]

CASE HARDENING :—

Change of Surface Property,

Alloying (low carbon steel)

(1) carburising @ 800°C – 900°C

(2) Nitriding @ ~600°C

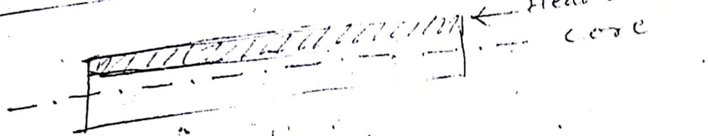
(presence of NH_3)

(3) Cyaniding ~ 900°C

(dip in cyanide soln)

Heat treatment (medium carbon steel)

Flame - Hardening – use of oxyacetylene flame.



Induction Hardening –

Laser Hardening

* Classification of Metal Working :—

$\boxed{\text{Hot Working}}$ | $\boxed{\text{Cold Working}}$

$T_{Working} > T_{recrystallisation} > T_W$

$T_{recr.} \sim \frac{1}{3}$ or $\frac{1}{2}$ of m.pt.

(1)