: Material science :-

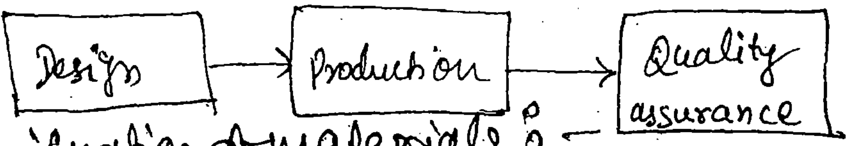
Date-27/5/12

Syllabus:-

Introduction- properties & testing methods, structure
Phase diagram/ steels & heat treatment of steels.
Plastic- Powder metallurgy.

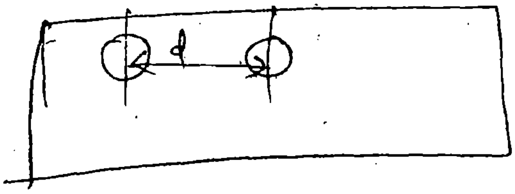
Ref: book,

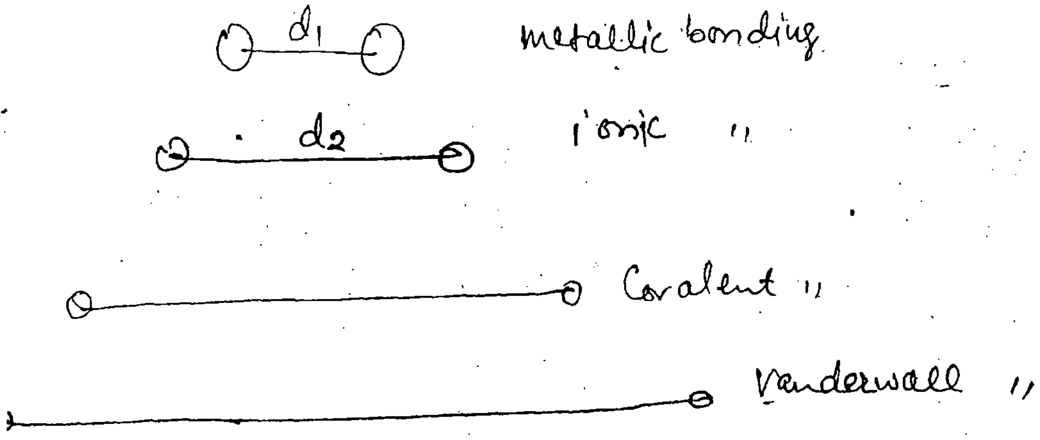
① Material science & metallurgy ⇒ Kodgere & Kodgere.



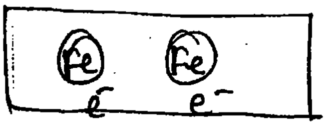
classification of materials :-

Metals	Polymer/ Plastics	Ceramics	Composite





* Metals :-

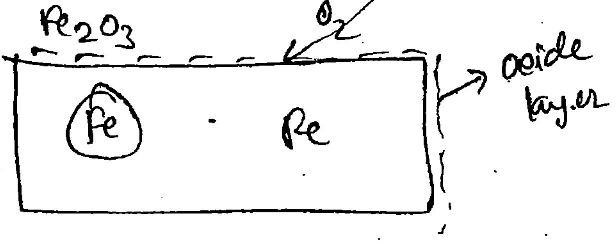


1. metallic bonding ⇒ d is less
⇒ B.E is high
V.V.I
① Strength is high

for mechanical properties

$$\boxed{\text{Strength} \propto \text{hardness} \propto \frac{1}{\text{Toughness}}}$$

* ② Ductility is good
③ Electrically good Conductors (free $\bar{e}$s)
④ Thermally good Conductors
⑤ density is high ⇒ weight is more.
⑥ Corrosive



⑦ Servicing temp = 800 – 1000°c
⑧ partially recylable
⑨ Environmentally friendly.

* polymer/plastics :-

C, H, O atoms only.

→ Covalent binding
① strength is less
② Ductility is high
③ Electrically bad Conductors
(no free $\bar{e}^s$)

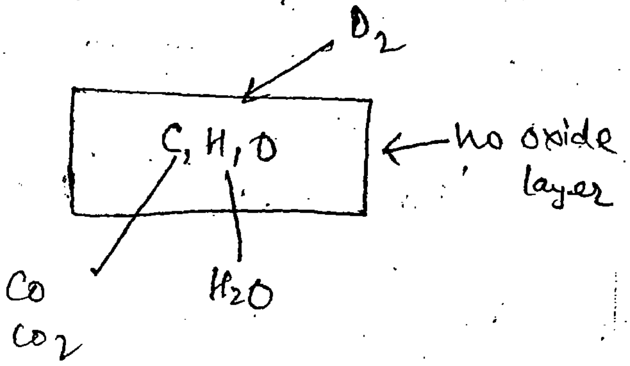
④ thermally bad conductors

⑤ low density ⇒ light weight

⑥ anti corrosive

↓

no oxide layer



⑦ Servicing temp = 300°C

⑧ Recylability

Plastics

Thermoplastic	Thermoset	Rubber
Recylable	non recylable	
e.g. plastic bottle	(helmet) e.g.	

⑨ Environmentally harazdous

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* Ceramics :-

→ mixture of metal oxide powders.

Al_2O_3, SiO_2, ZrO_2

$$\text{Powder form} \rightarrow \left(P_{Al_2O_3} + P_{SiO_2} + P_{ZrO_2}\right) = \text{ceramics}$$

→ ionic + covalent bondings

$d_m < d_{ceramics} < d_{polymers}$ ← distance

① $S_m > S_{ceramics} > S_{polymers}$ ← strength

②→ Brittle in nature

③→ electrically bad conductors (no free e's)

④ → thermally bad conductors

⑤ $\rho_{Metals} > \rho_{Cer} > \rho_{polymers}$

⑥ non-recylable

⑦ Servicing temp = 3000°C

⑧ Environmentally friendly.

⑨ Anti corrosive.

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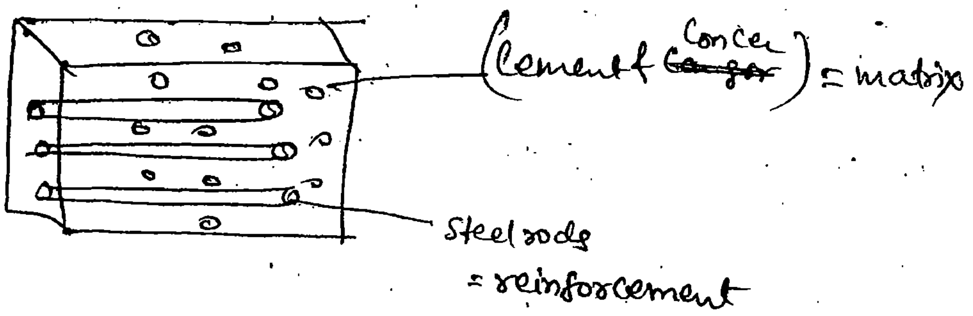
* **Composite material** :-

→ Physical mixing of more than two metals.



$M_1 + M_2 \Rightarrow C_1$

Eg!: Steel + (Cement + Concee) ⇒ R.C.S

R → Reinforce

Steel ⇓ High tensile strength

(Cement + Concee) ⇓ high Compressive strength

⇒ Both high Compressive & tensile strength

Ex 2: Steel + Plastic ⇒ FRP

Steel ⇓ High tensile strength

Plastic ⇓ light weight

FRP ⇓ ⇒ light weight & high strength.

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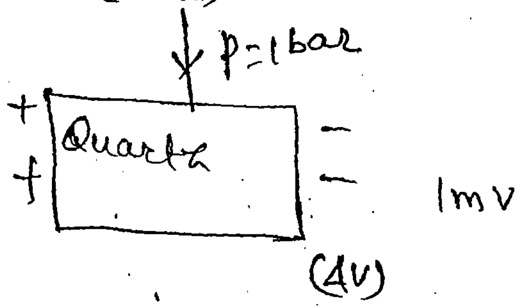
* Smart material :- (Advance material)

Ex: Quartz (SiO_2)

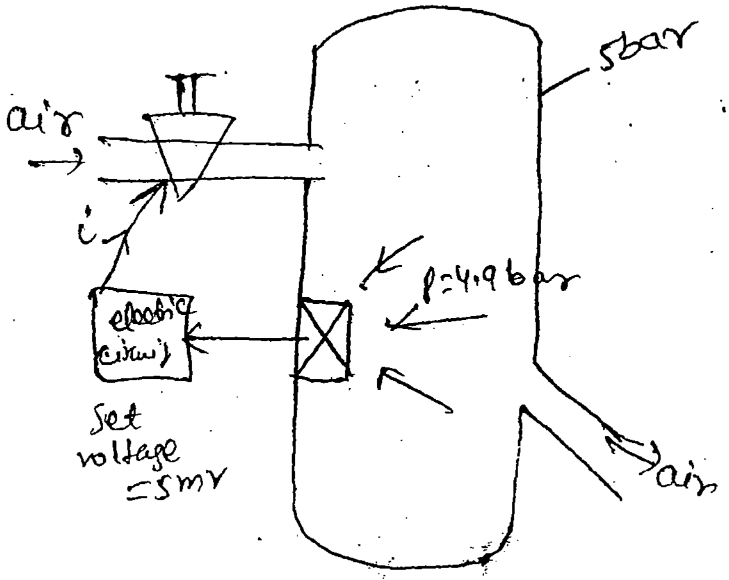


$\Delta V = f(\text{Pressure})$

→ If a material function based on its surrounding environments is known as a smart material.
for Ex:- Quartz (SiO_2)

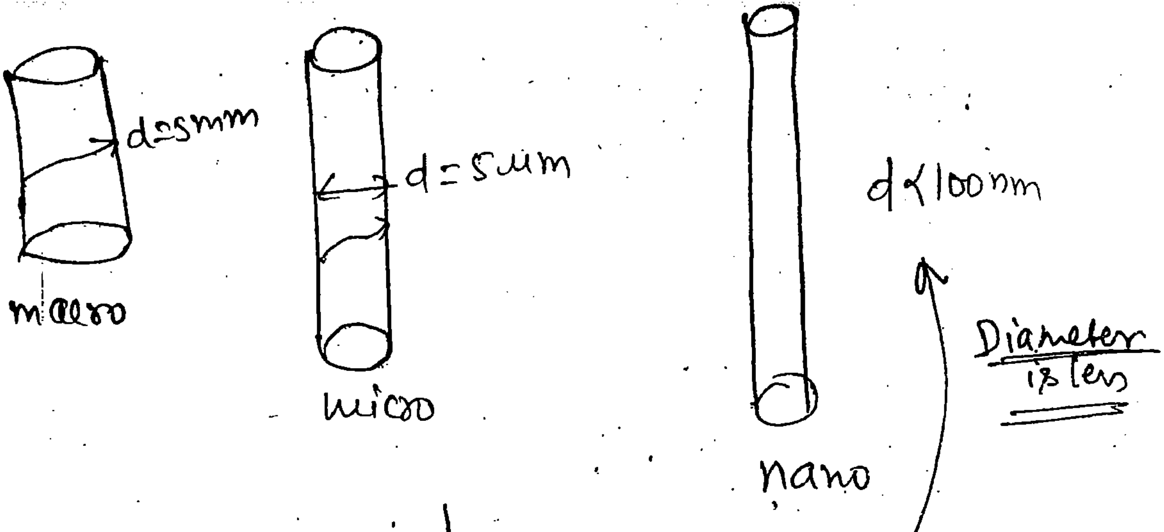
→ The voltage generated ~~over~~ across the Quartz sensor is the function of pressure acting on the sensor.

$$\boxed{\Delta V = f(\text{Pressure})}$$ #



bar	valve
4.9 →	open
5.1 →	close

* nanomaterial :-



$$\text{strength} \propto \frac{1}{\text{defect intensity}}$$

$$\boxed{S_{macro} < S_{micro} < S_{nano}}$$ V.V.I

→ If a material contains the grain size less than 100nm or, any one of the dimensions of a material (length, diameter, thickness etc.) is less than 100nm, is called as nano materials.

→ To produce nano materials, highly accurate production methods is required.

⇒ The defect size should be less.

⇒ strength is high.

Properties of material :-

① Physical

- Color
- density

② Mechanical

1) Strength
2) hardness
3) fracture toughness
4) Ductility
5) Stiffness
6) Brittleness
7) Creep
8) fatigue
9) Resilence

③ Thermal

1) melting point (servicing temp.)
2) thermal conductivity
3) Thermal diffusivity
4) Thermal emissivity

① **Strength :-** :-

→ ability of a material that can restained the mechanical load.

2) hardness

resistance offered by the material against mechanical deformation.

3) fracture toughness –

ability of a material that can observed energy at the time of failure.

④ ductility.

ability of a material can undergo plastic deformation before failure.

⑤ Stiffness

ability of a material that can resist mechanical deformation under stress.

⑥ **Brittleness:**

ability of a material than can resist mechanical load. without plastic deformation.

⑦ **creep :-**

Time vs strain behaviour of a material under constant mechanical load.

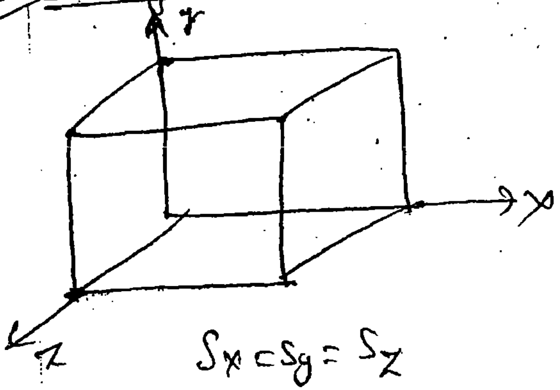
⑧ **fatigue :-**

Time vs strain behaviour of a material under oscillating mechanical load.

⑨ **Resilence :-**

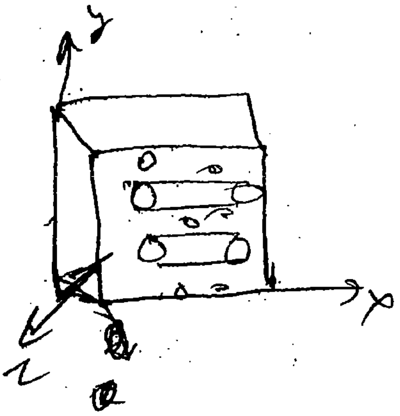
The ability of a material that can ~~resist shock or impact loads without shape changes.~~ absorb energy against shock or impact load without shape changes.

Ⓐ **Strength :-**



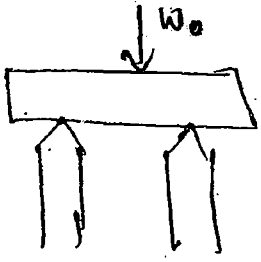
$S_x = S_y = S_z$

Isotropic / homogeneous

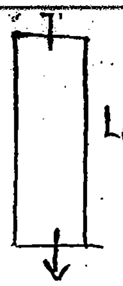


$S_x >> S_y = S_z$

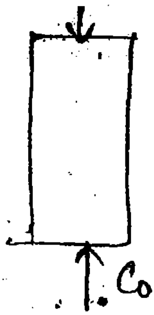
Anisotropic / non homogeneous



flexural/
bending



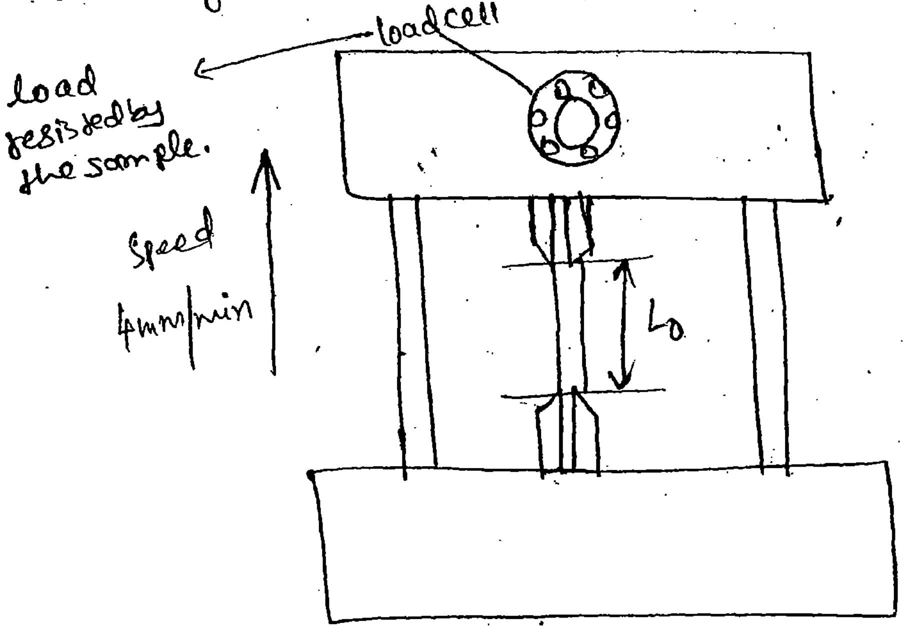
Tensile



Compressive

Tensile test :-

→ generally used universal testing machine.



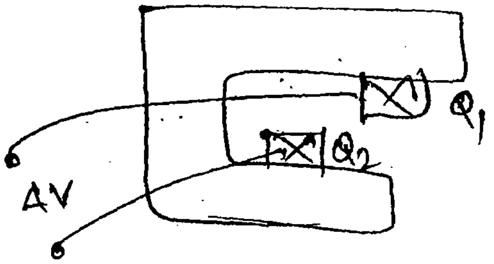
→ Shape change = M.D (mechanical deformation)

measured property of M.D = strain
(Δl, Δb, ΔV)

Strain

Temperory strain/ elastic	Permanent/ Plastic

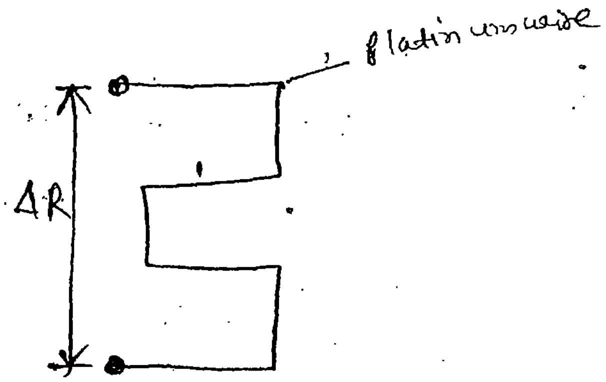
① extensometer (strain ~~meas~~ measuring device)

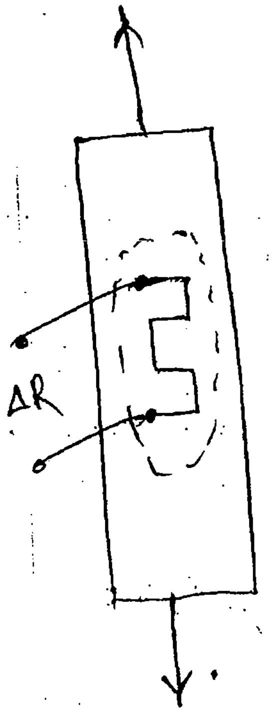


→ In extensometer, the voltage across the terminal (ΔV) is directly proportional to the strain produced in the sample.

$$\Rightarrow \quad \boxed{\Delta V \propto \text{strain}}$$

② Straingauge :-



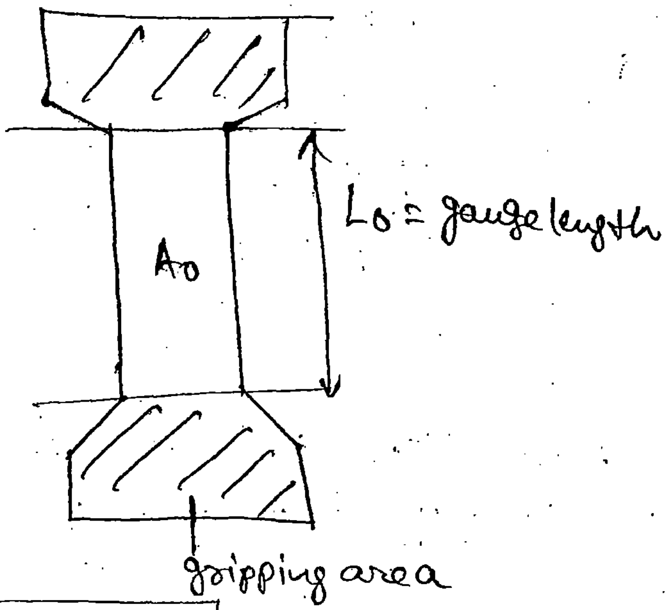


$$\boxed{\Delta R \propto \text{strain}}$$

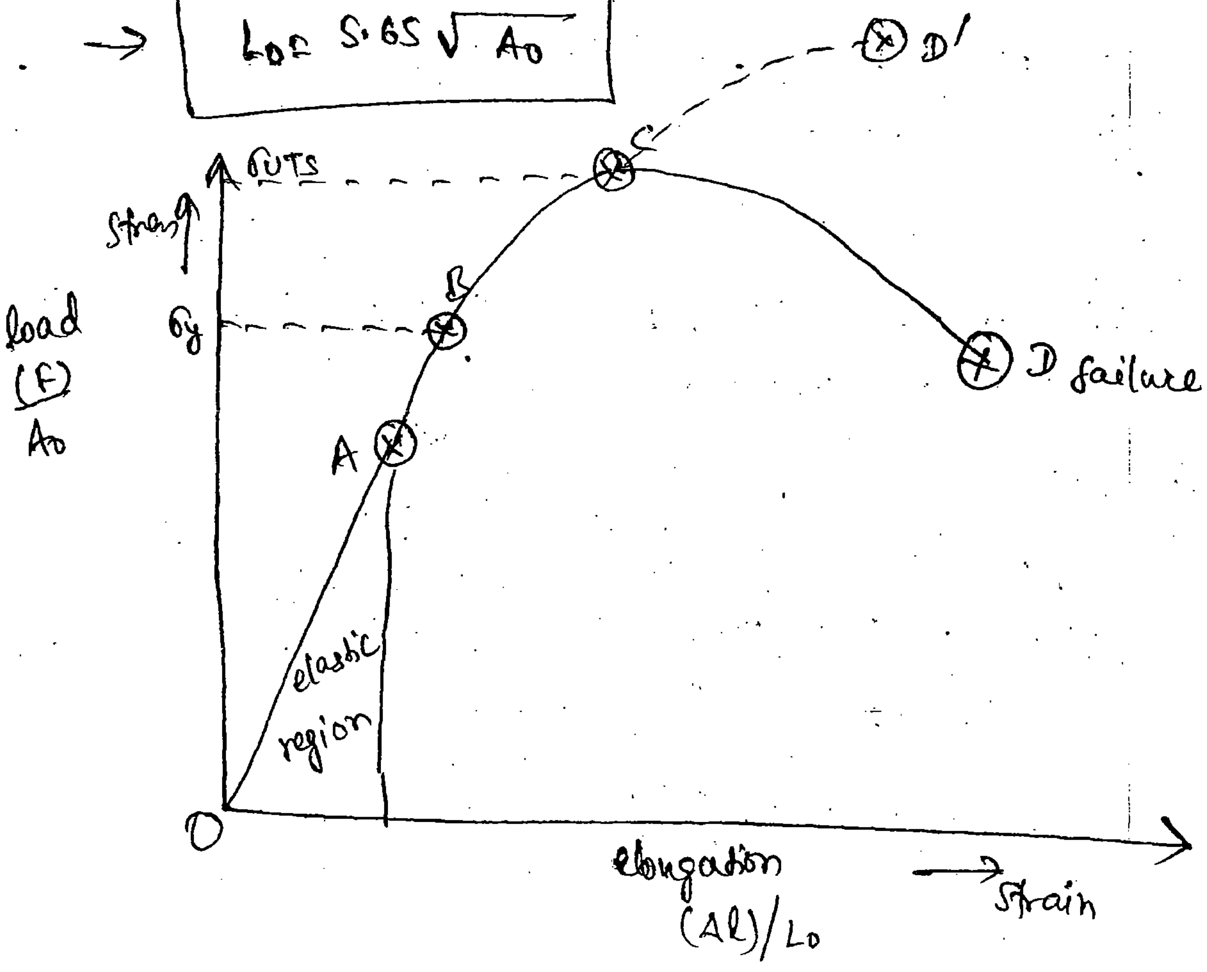
↑
resistance

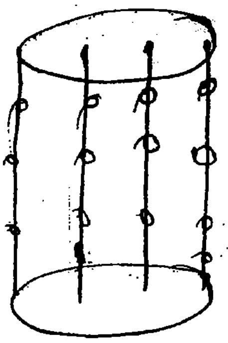
→ In strain gauge the change in electrical resistance (ΔR) is proportional to strain produced in the sample, Therefore,

$$\boxed{\Delta R \propto \text{strain}}$$



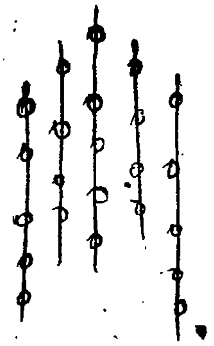
→ $$\boxed{L_0 = 5.65\sqrt{A_0}}$$





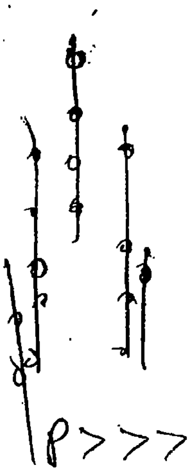
P<<<B.E

(OB)



P>>B.E

(BC) slow



P>>>B.E

(CD)

→ the sample is fixed between the grips of the UTM and the top ~~board~~ plate is moved upwards with certain speeds.

⇒ elongation is produced in the sample.

⇒. Strain is produced " " ".

⇒ But the sample will try to resist the elongation with a downward force F, which is measured with load cells connected to the sample.

Therefore,

elongation is produced in the sample and the load resisted in the sample ~~as~~ measured as load vs/ elongation curve, or stress vs strain curve as shown in fig. ①.

→ up to point 'A', stress is proportional to strain, and called proportional region OA.

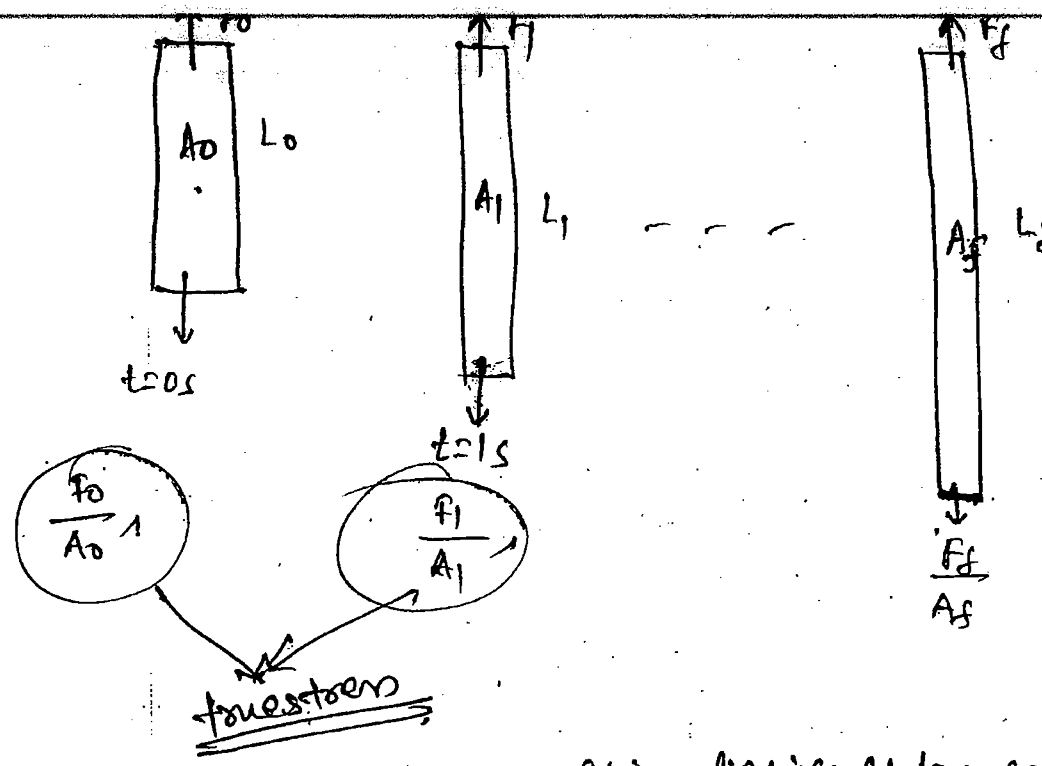
→ up to point B, stress is proportional to strain but by removal of the load, the sample will gain its original shape. ie. called elastic region OB.

⇒ The corresponding stress at the point B is known as yield stress. (σ_y).

⇒ If the sample is loaded beyond the B, the displacement of atomic plane is slow implies, undergo plastic deformation, but it will be near the load up to point C. The corresponding stress value at point C is known as ultimate tensile stress. (σ_{UTS})

σ_{UTS} = tensile strength of the material.

⇒ Beyond the point C, the displacement of atomic plane is fast ⇒ undergo severe plastic deformation, implies severe increase in length and, decrease in cross-sectional area, and the sample will fail at point D.



→ During testing time, It is difficult to measure A_1, A_2, A_3, - ---- values.

∴ $A_1 = A_0$, $A_2 = A_0$, - - ---- is substituted.

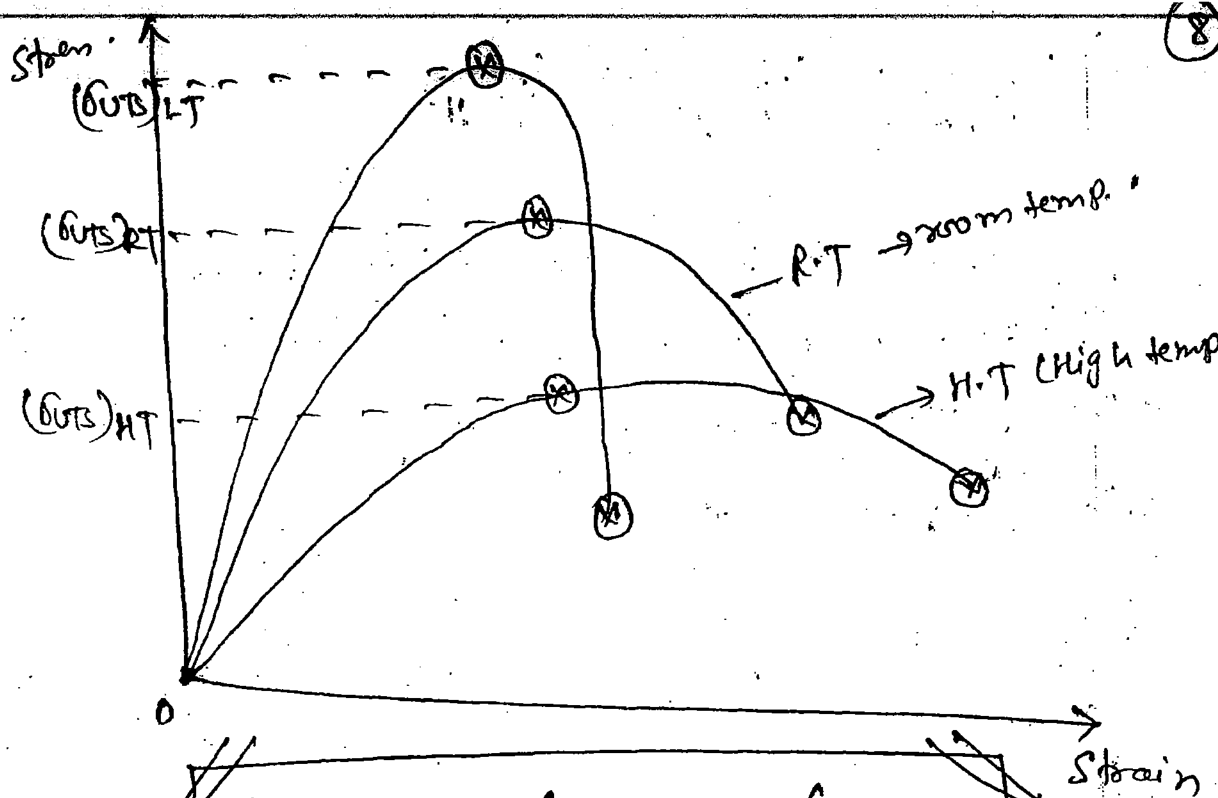
Hence, $\frac{F_0}{A_0}, \frac{F_1}{A_0}, \frac{F_2}{A_0}$ = Engg. stress

⇒ **Actually** $A_1 < A_0,\ A_2 < A_1,\ A_3 < A_2$ ------

Therefore, $\left(\frac{F}{A}\right)$ decreases from C point onwards.

⇒ Therefore the curve will fall down from C point onwards,

⇒ True stress vs true strain curve follow the path of (OABCD') whereas engg-stress vs engg-strain curve follow the path of (OABCD).

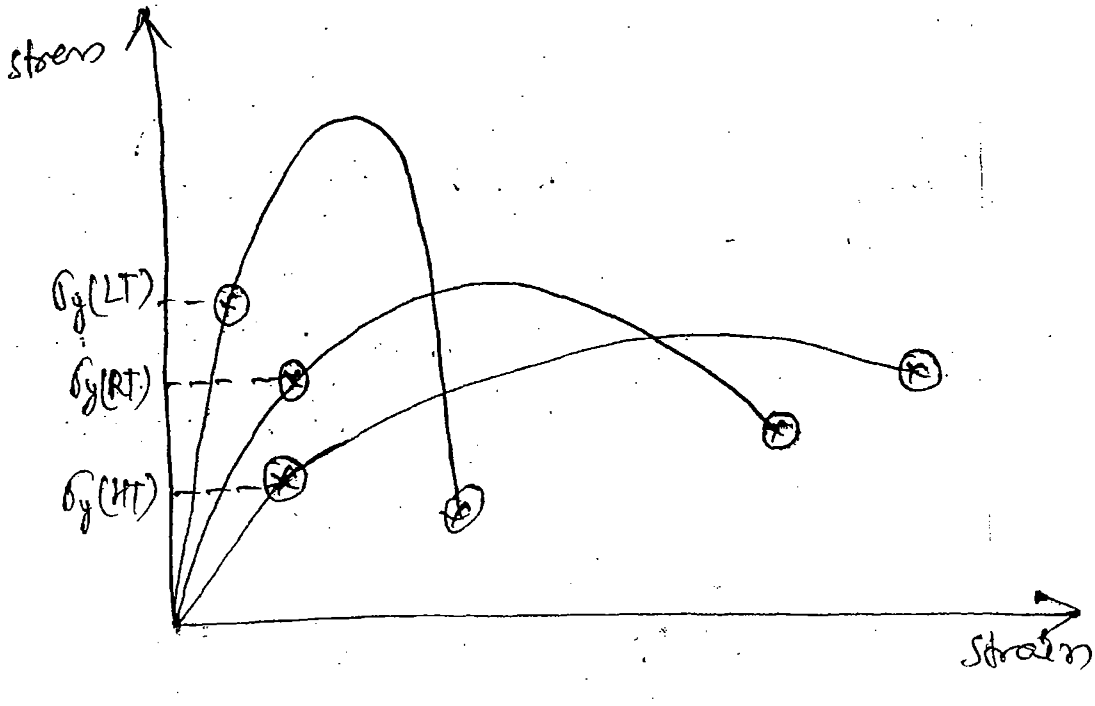


$$\boxed{(\sigma_{UTS})_{LT} > (\sigma_{UTS})_{RT} > (\sigma_{UTS})_{HT}}$$

⇒ If a material is tested at high temperature, the distance between the atoms increases,

⇔ Binding energy decreases

⇔ Strength decreases.



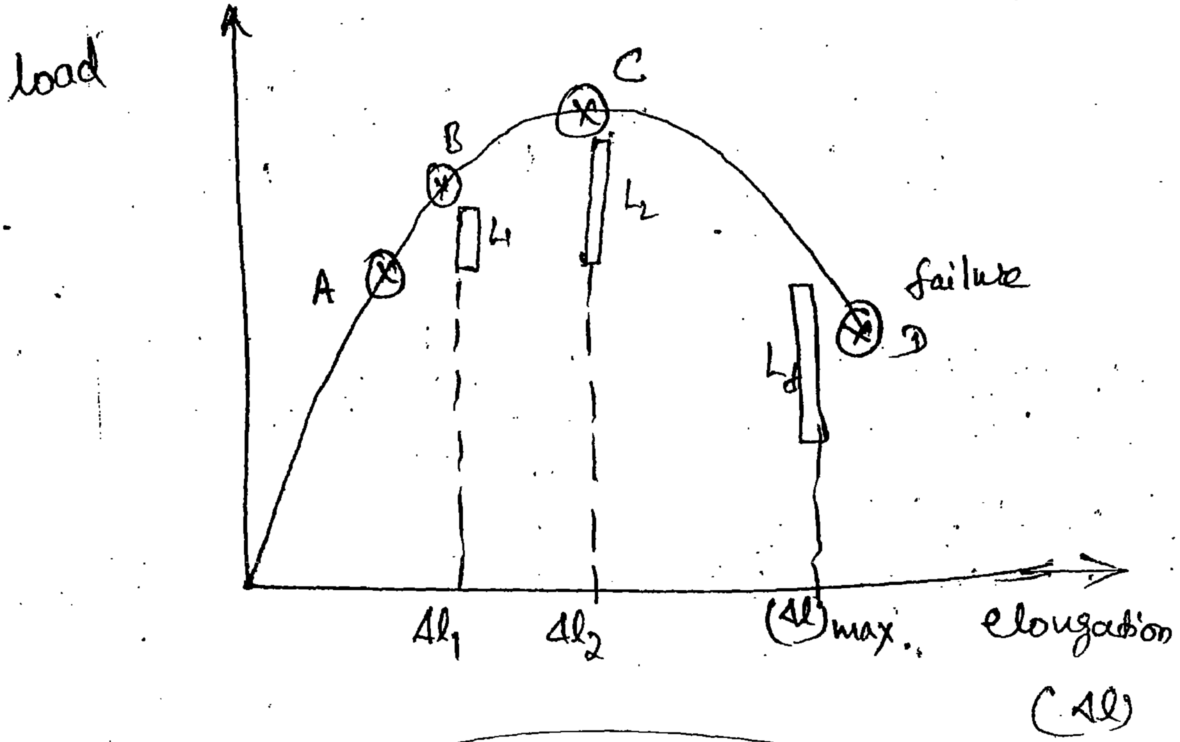
$$\boxed{(\sigma_y)_{LT} > (\sigma_y)_{RT} > (\sigma_y)_{HT}}$$

⇒ If a material is tested at a high temp, the displacement of atomic plane is easy

⇔ plastic deformation is easy.

⇔ yield stress decreases

Ⓑ Ductility measurement :—



Ductility = % of elongation in length

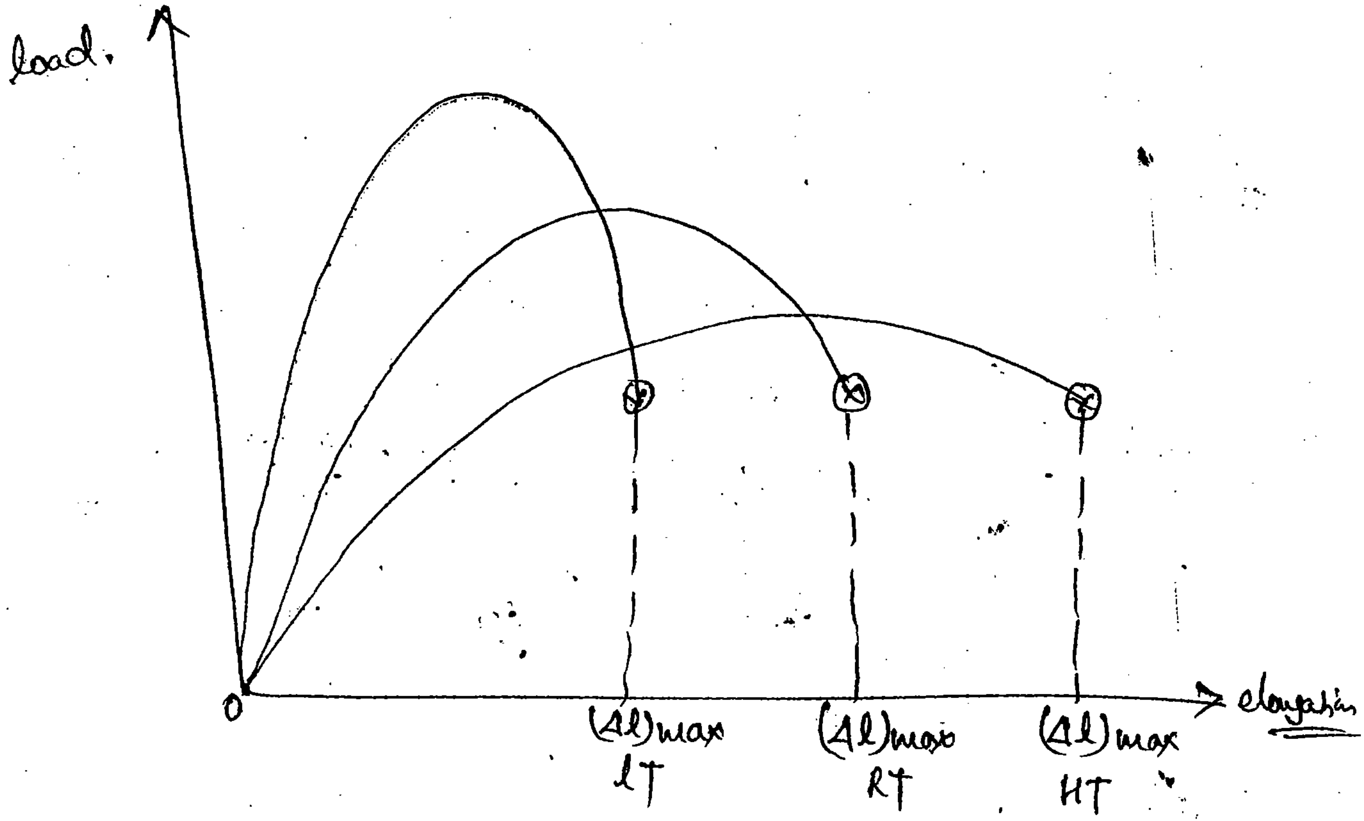
or

% of reduction in cross-sectional area on the failure point.

Ductility = % (Δl) max on the load vs elongation curve.

→ By calculating the percentage of elongation value in a sample at braking point, Ductility is measured.

→ The max^m elongation will be observed on a load vs elongation curve at the braking point i.e. (Δl)max.



$$\boxed{(\Delta l)_{max\,LT} < (\Delta l)_{max\,RT} < (\Delta l)_{max\,HT}}$$

$$\Downarrow$$

$$\text{Ductility} \rightarrow \boxed{D_{L.T} < D_{R.T} < D_{H.T}}$$

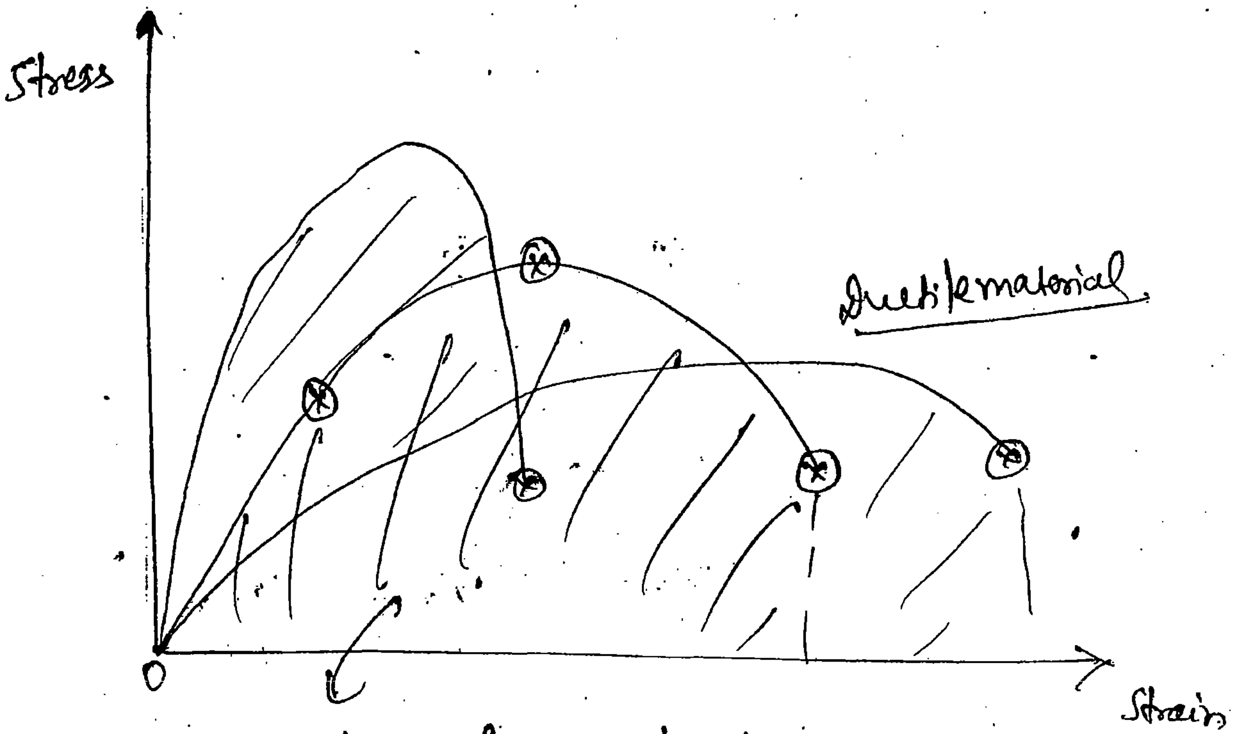
⇒ If a material is tested at high temperature undergo easy Plastic deformation

⇒ undergo more strain

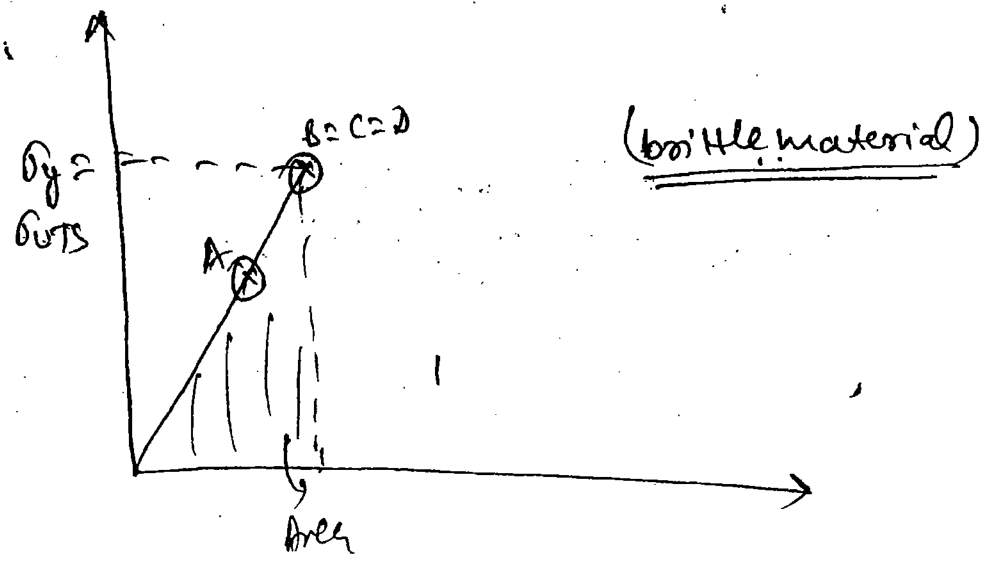
⇒ $(\Delta l)_{max.}$ is more.

⇒ Ductility is high.

ⓒ fracture toughness measurements :—



Area = fracture toughness.



⇒ By calculating the area under the stress vs strain curve upto failure point, the fracture toughness of a material will be calculated, Therefore,

$$\boxed{A_{ductile} > A_{Brittle}}$$

$$\Downarrow$$

⇒ $$\boxed{F.T_{ductile} > F.T_{Brittle}}$$

fracture toughness

⇒ A brittle material does not undergo plastic deformation.

→ A ductile material can absorb more energy against failure.

$$\boxed{A_{L.T} < A_{R.T} < A_{H.T}}$$

$$\Downarrow$$

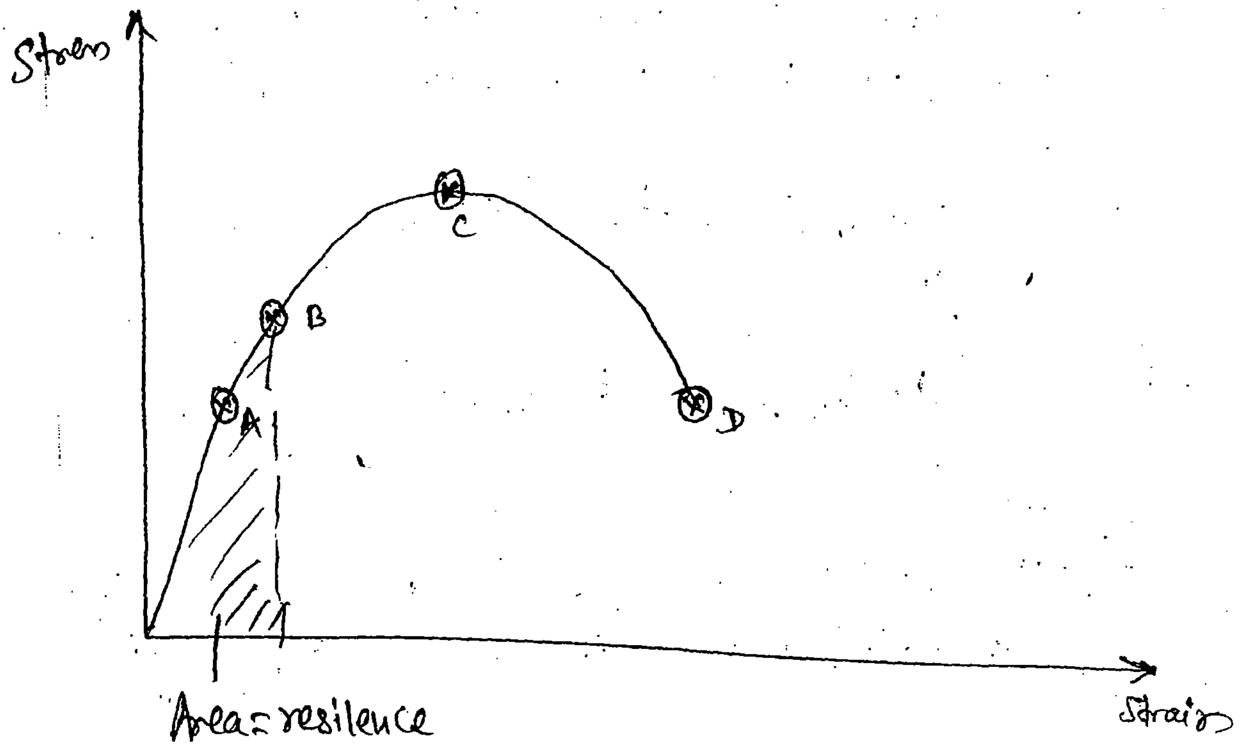
$$\boxed{(F.T)_{L.T} < (F.T)_{R.T} < (F.T)_{H.T}}$$

⇒ If a material is tested at high temperature, undergo easy / more plastic strain

⟺ Area under the curve increases

⟺ fracture toughness increases.

ⓓ Resilence measurement :—



⇒ By calculating the area under the stress vs strain curve up to elastic point, resilence is determined.

⇒ Resilence says about the rigidity and the ductility of a material.

⇒ If a material possess high resilence means It will absorb shock and impact loads most effectively without undergoing shape change of the Component.

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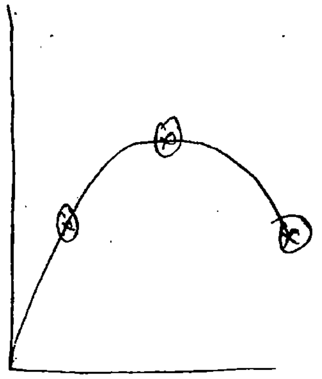
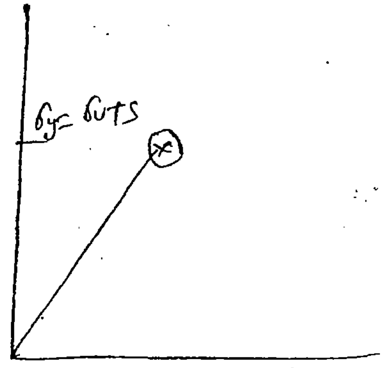
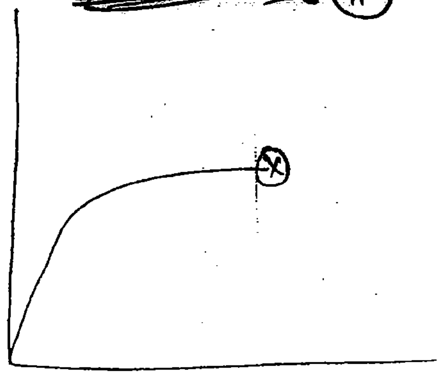






Ductile
(high work hardening)

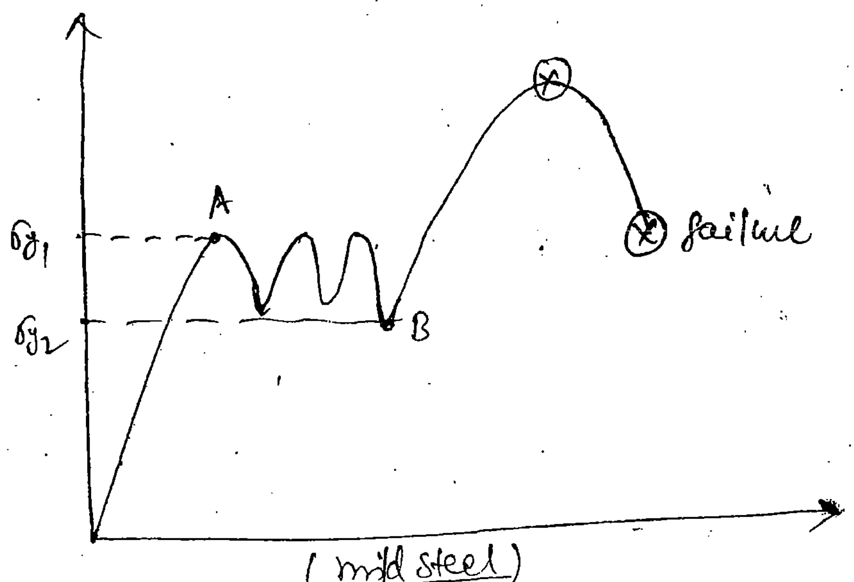
$0 - 0.15\% C$ ⇒ mildsteel

$0 - 0.25\% C$ ⇒ L.C.S (low

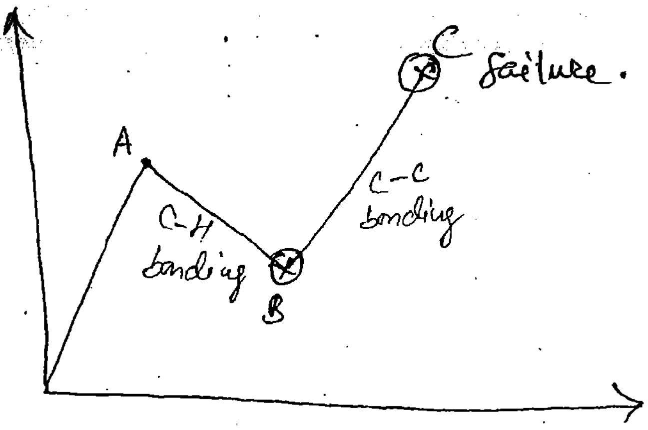
$0.25 - 0.45\% C$ ⇒ MCS (medium

$0.45 - 2.11\% C$ ⇒ HCS (high

$2.11 - 6.67\% C$ = cast iron



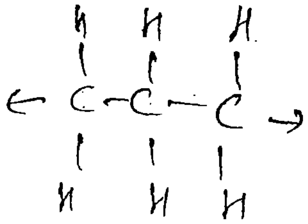
(mild steel)

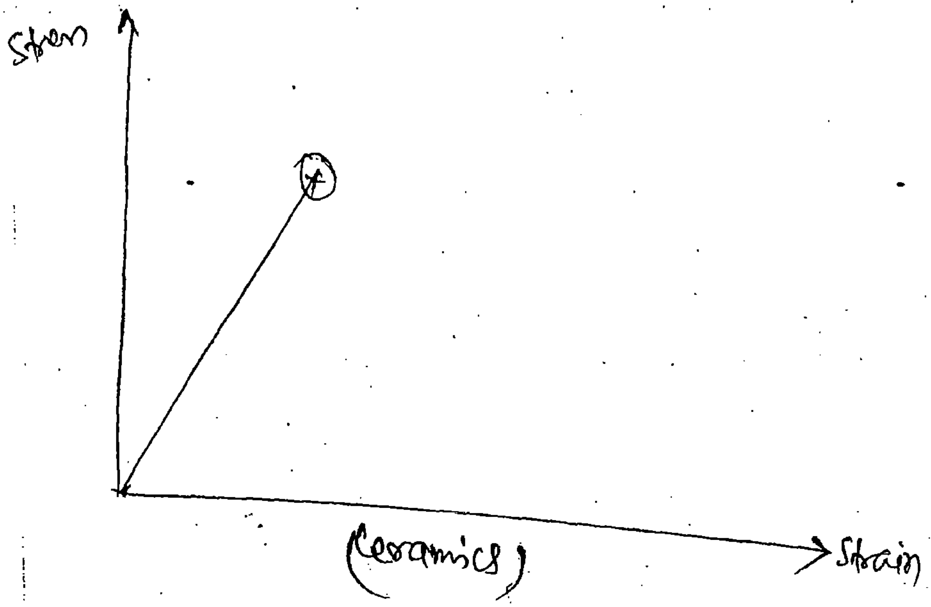


Plastic

C-H ⇒ weak

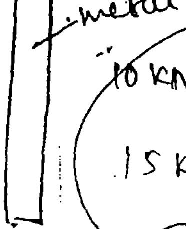
C-C ⇒ strong





(Ceramics)

NOTE:-

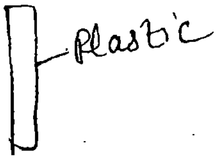


10 KN/min → 1000 MPa

15 KN/min → 1000 mpa

whatever strainrate

strength remains same



1 KN/min ⇒ 100mpa

5 " ⇒ 80mpa

15 KN/min ⇒ 70 mpa

⇒ In case of metals the strength value is independent on the strain rate at which it is tested but in case of plastics it is dependent. Higher the strain rate will give lower the strength to the plastic material.

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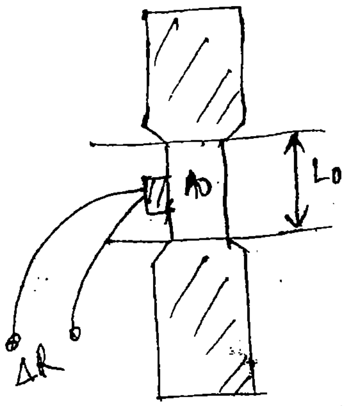
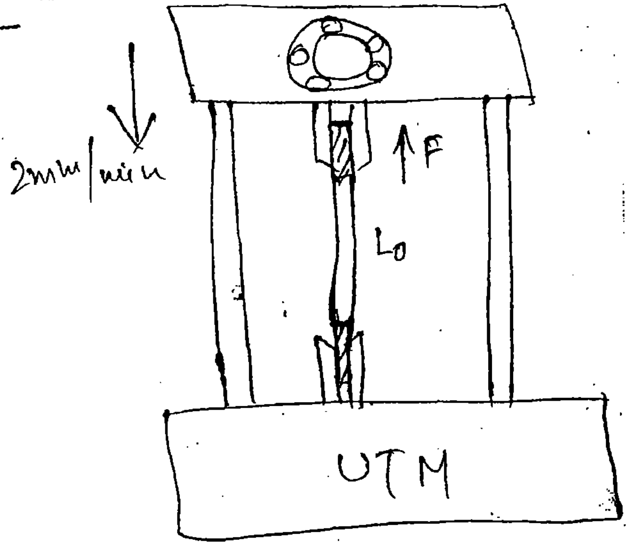
* Compression Test :-

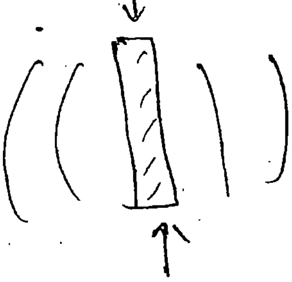


$L_0 < 2d_0$



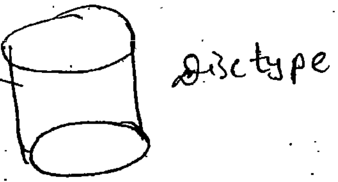
Case-1, if $L_0 >>> d_0$

undergo buckling



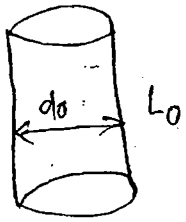
Case-2 If $L_0 <<< d_0$

Strains are small

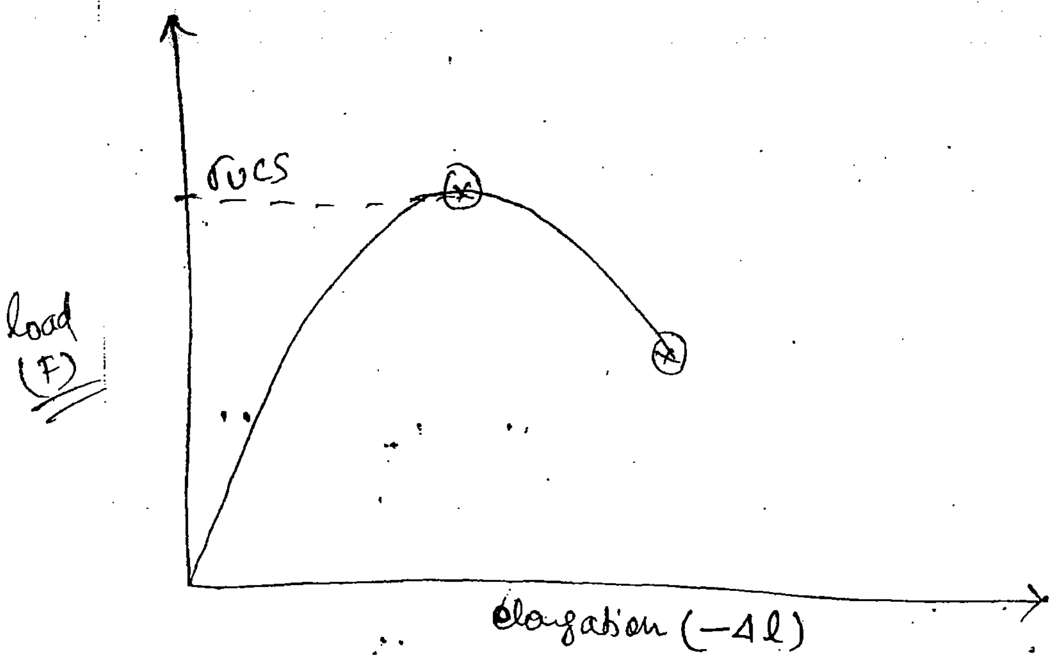


difficult to determine with the strain gauge also.

Case-3 $L_0 < 2d_0$



Then, Compressive load can be apply effectively at the same time the strain produced can be measurable with the help of strain gauge.



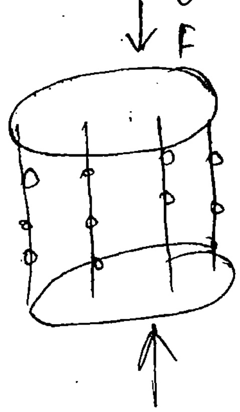
→ The sample is fixed between the grips of UTM and top plate is moved downwards with the certain speeds but the sample will resist the elongation in upward direction with a force F. Therefore,

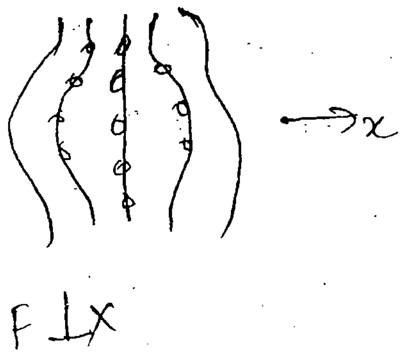
load vs elongation or stress vs strain curve can be obtained as shown in above fig.

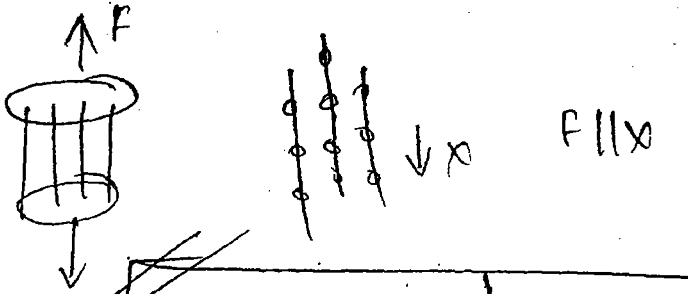
→ In case of compression test, Strain ~~produced is~~ very small compare with Tensile Test.

Hence a high sensitive strain gauge should be used to measured the strain in the sample.

→ The max^m load resisted by the sample under Compression is known as ultimate Compressive stress (σ_{UCS} = Compressive strength of the material.







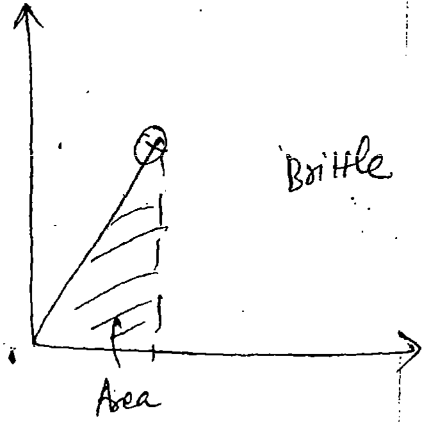
Tensile F‖X	Compression F⊥X

→ In case of Compression test, the displacement of atomic plane (X) is ⊥r to the direction of F. but in tensile condition It is parallel to F.

→ Powder made material posses high Compressive strength but low tensile strength ex- Chock

→ Powder metallurgical component posses high Compressive strength and whereas metal & alloys posses high tensile strength.

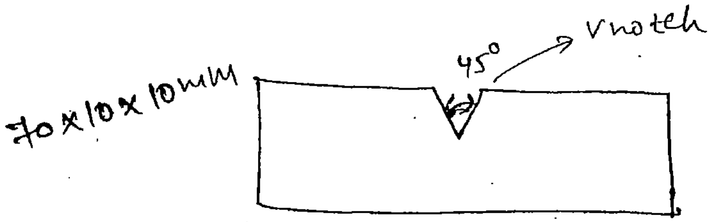
* fracture toughness measurements for brittle material :-



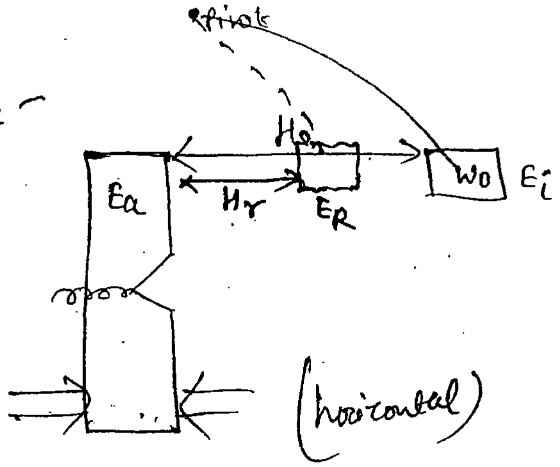
⇒ In case of ductile materials, the fracture toughness is measured by calculating the area under the curve in stress vs strain curve.

⇒ In case of brittle material the area under the stress vs strain curve is less. ⇔ difficult to measure accurately without error and therefore I-Zod & charpy test will be used.

Izod or charpy test :-



Izod test :-



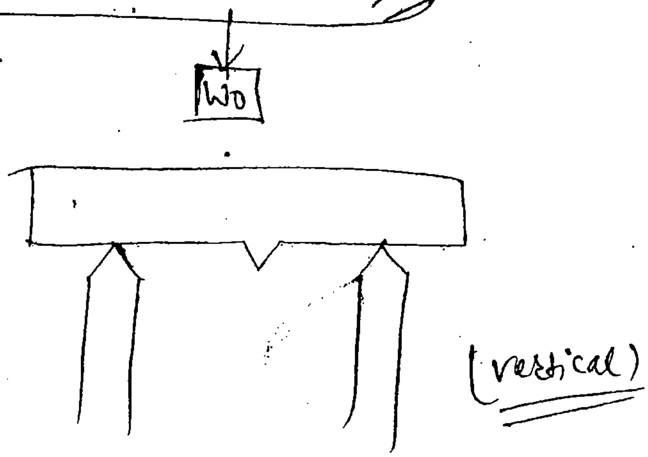
energy absorbed

$$E_a = \underset{\substack{\uparrow \\ \text{initial}}}{E_i} - \underset{\substack{\uparrow \\ \text{rebound}}}{E_R}$$

$$= \left(\begin{array}{c}\text{initial} \\ \text{energy} \\ \text{of hammer}\end{array}\right) - \left(\begin{array}{c}\text{Rebound} \\ \text{energy of} \\ \text{hammer}\end{array}\right)$$

$$\boxed{f.T = E_a = H_o W_o - H_r W_r}$$

charpy test :-



⇒ The sample is fixed as a cantilever beam in the instrument and it is subjected to failure by heating the sample with a weight of W_0.

⇒ when the load is heating the sample it acts as the notch point and It will be failed. Therefore energy absorbed by the sample(E_a) is measured at the time of failure.

⇒ V-notch is made in the sample to obtain easy failure in the sample with less weight of the hammer W_0, but It does not affect the fracture toughness measurements.

⇒ In Izod test one end of the sample is fixed and the other end is free

⇔ sample is under non uniform stress.

⇔ fails earlier than the actual value.

⇔ measured fracture toughness is slightly error value.

⇒ To overcome this drawback in charpy instrumentation the sample is kept on two point supported beam and subjected to failure, Therefore the sample is under stress free.

⇔ measured fracture toughness is highly accurate.

Note!-

⇒ in case of ductile material the measured of f. T. this method is invalid because the sample undergo bending instead of failure.

Q) How to measure H_r.

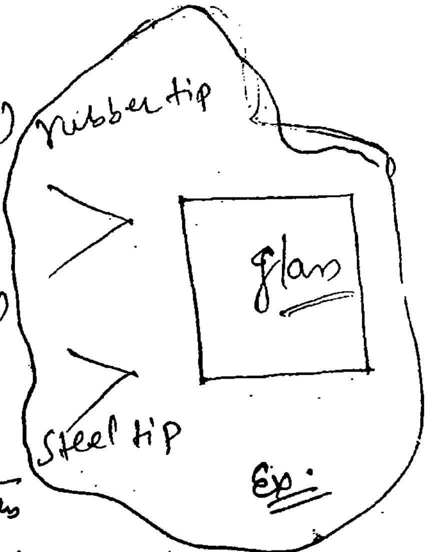
→ The device LVDT is used to measure the distance of moving object.

✻ Hardness measurements :-

① Mho test / Scratch test :-

Diamond ← High hard
SiC ① Rockwell (R_C)
Topaz
Quartz ← medium hard
feldspar ① Rockwell (R_B)
Apedite ② Brenel
fluorite ③ vicker
Calcite ← low hardness
Gypsum ① knoop test
Talc ② Rockwell (R_A)

hardness ↑

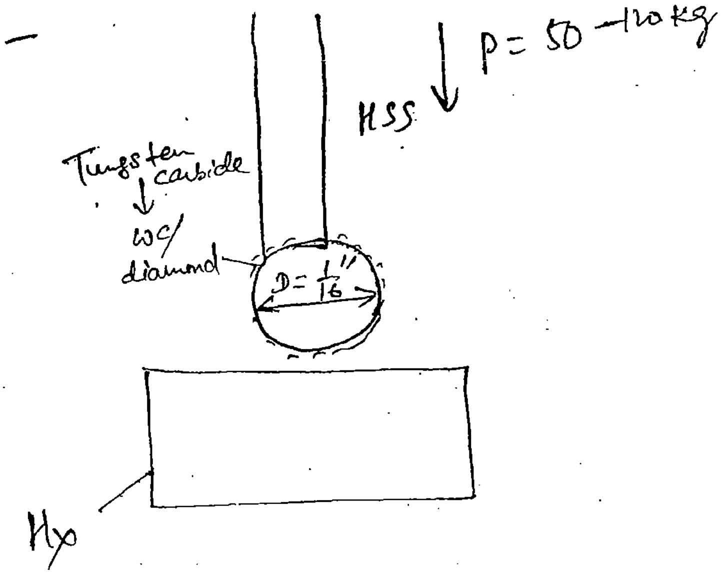


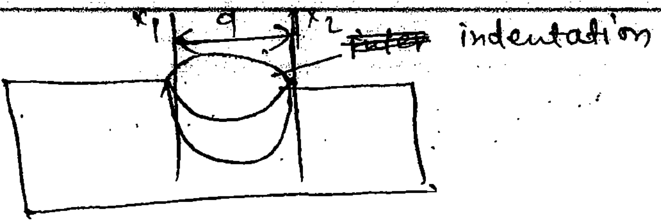
$$\text{If, } \boxed{H_{tip} > H_{surface} \Rightarrow \text{Scratch forms}}$$

→ Mho test is Qualitative method.

✻ Brenel test :-

Spherical base Indenter





$$\rightarrow \boxed{\text{Hardness} \propto \frac{1}{d}}$$

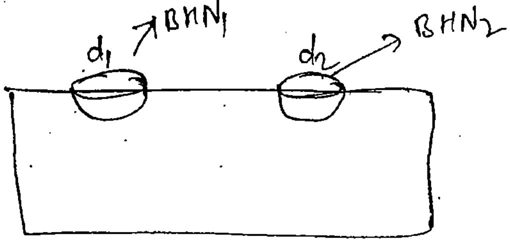
$$\Rightarrow \boxed{B.H.N = \frac{2P}{\pi D\left[D - \sqrt{D^2 - d^2}\right]}}$$

D = indenter dia.

P = load used to form indentation.

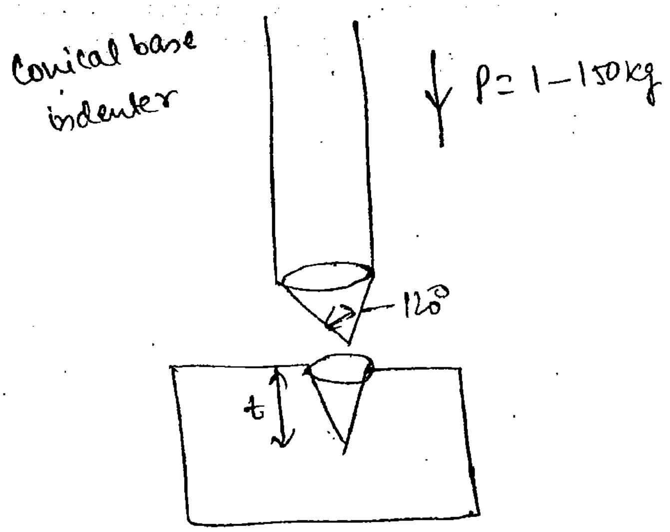
d = indentation dia $(x_2 - x_1)$ from microscope.

$$\boxed{\sigma_{UTS} \propto B.H.N}$$

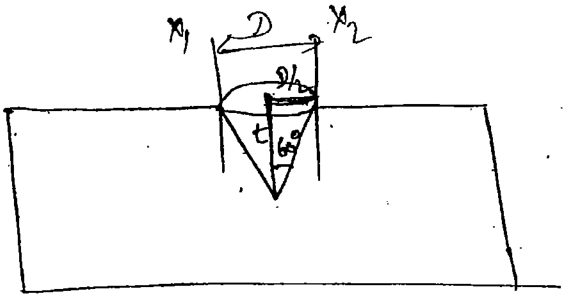


$$\left[\text{avg. BHN} = \frac{BHN_1 + BHN_2 + ----- + BHN_{10}}{10}\right]$$

② Rockwell :-



→ $$\boxed{\text{Hardness} \propto \frac{1}{t}}$$

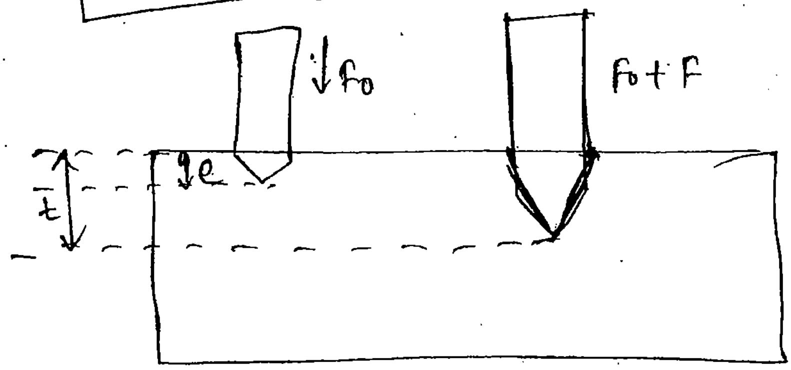


$$\tan 60° = \frac{D/2}{t} \Rightarrow t = \frac{D/2}{\sqrt{3}}$$

→ $$\boxed{t = \frac{(x_2 - x_1)}{2\sqrt{3}}} \xrightarrow{} \text{from microscope}$$

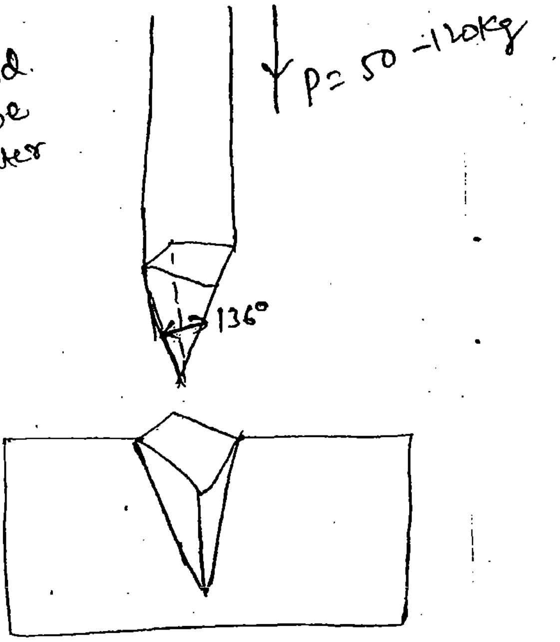
activation energy

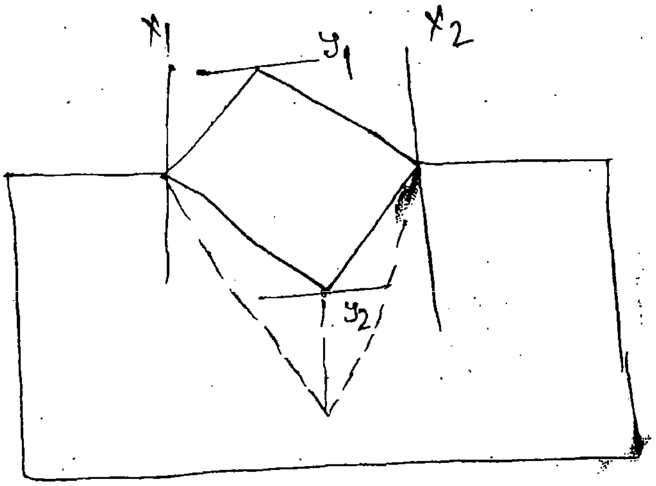
→ $$\boxed{R.H.N = e - 500t}$$



RA	RB	RC	
1-50 Kg	50-100 Kg	100-150 kg	
low hard ⇓	medium hard ⇓	high hard ⇓	
Al, Au, Ag, Cu, Sb, etc.	Fe, Fe alloys Mg ", Al " Ni ", etc.	MCS, HCS, C.I Powder made material, ceramics,	SiC, WC, Fe3C etc. tools steel

③ Vicker test :-



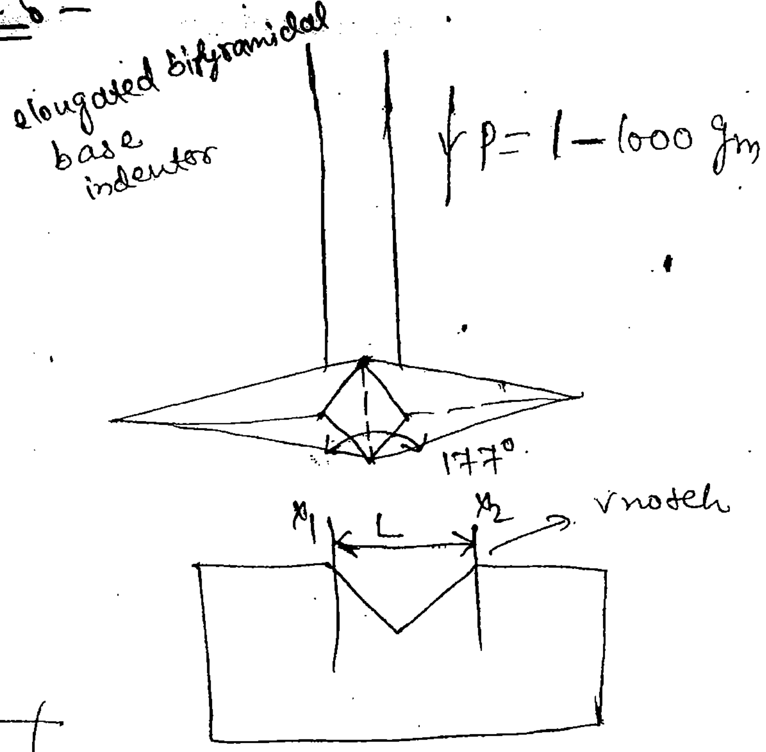


$$\rightarrow \quad d_{avg} = \frac{d_1+d_2}{2} = \frac{(x_2-x_1) + (y_2-y_1)}{2}$$

$$\rightarrow \quad \boxed{V.H.N = \frac{1.854\, P}{(d_{avg})^2}}$$

④ Knoop test :-

or microhardness test

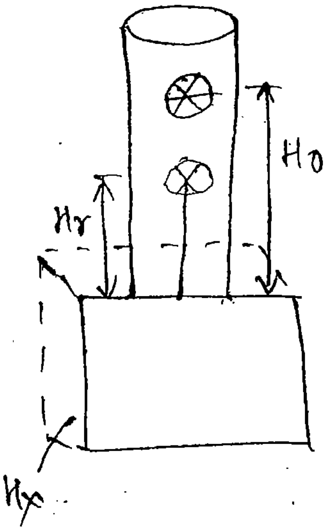


$$\rightarrow \boxed{K.H.N = \frac{14.22\,P}{L^2}}$$, L = notch length

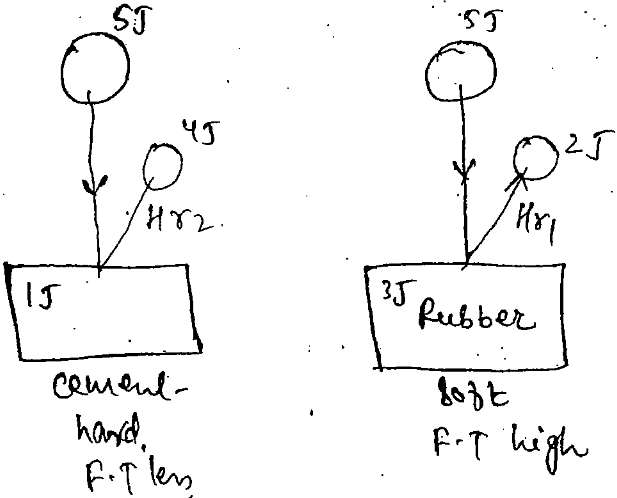
→ Knoop test is used for low hard materials and highly sensitive to indentation for ex- silicon, germanium, galium etc.

⇒ Since, the loads used to get indentation is the order of grams hence It is called as microhardness test.

* Shore method :-



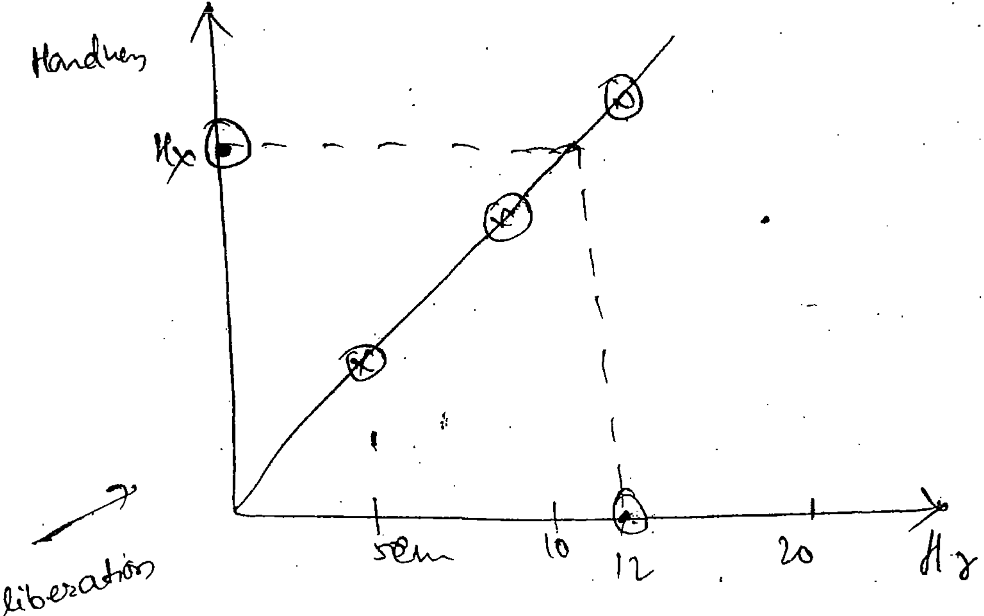
Shore's scolariscope



$\boxed{H_r \propto \text{Hardnes}}$

↑ rebound height

material	Hr value	Hardnes
( ) Ace	5cm	50
(silver) Ag	10 cm	100
(copper) Cu	20 cm	200
Rubber	12cm	Hx



caliberation curve

⇒ In shore method for known materials for hardnes, the H_R values are determined and a calibration curve is plotted as shown in figure.

→ now by keeping a rubber sheet, the H_R value is determined.

→ By taking the corresponding intercepts on the hardnes axis to the H_r value, the hardnes of the rubber material H_x will be determined.

⇒ This method applicable to <u>soft plastic</u>, thermo plastic materials & rubber.

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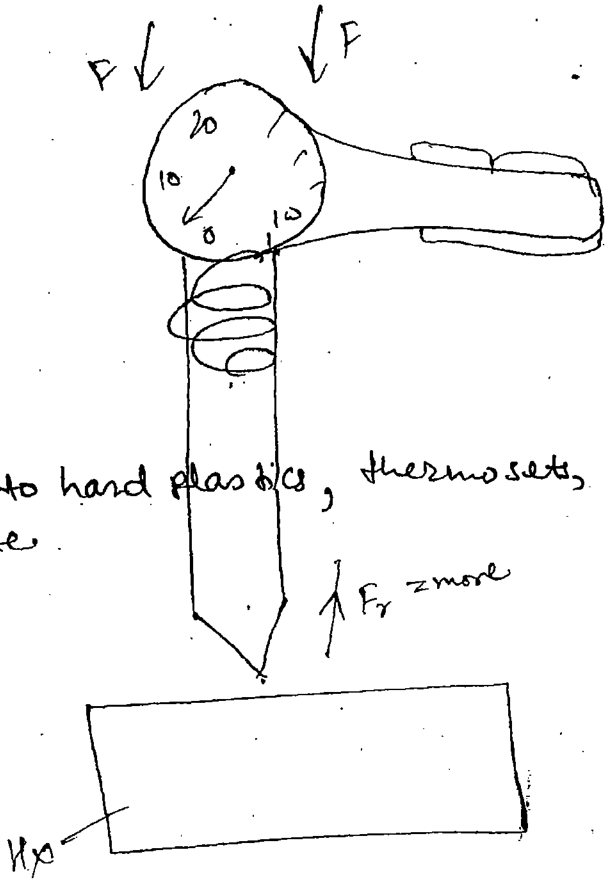
* Barcol test :-



→ applicable to hard plastics, thermosets, Composite material etc.

$f_R \propto -x$

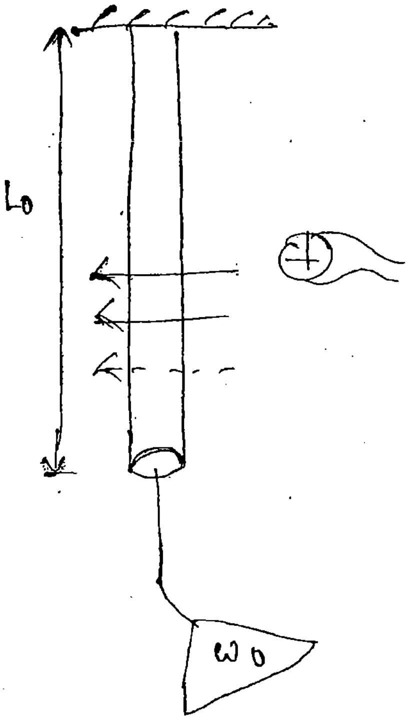
$$\boxed{f_R = -kx}$$

ired.

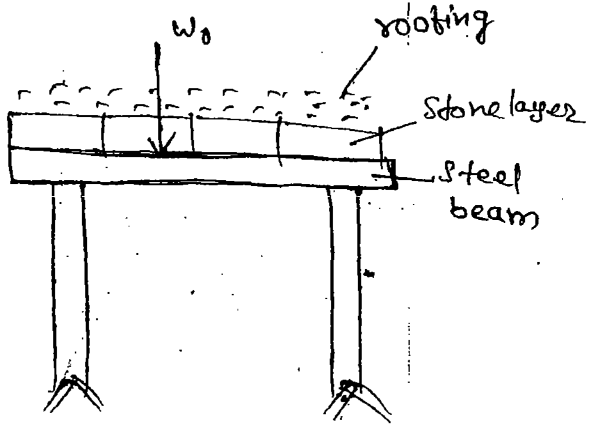
→ If material is hard, Penetration is difficult,
⟺ reverse force generated (f_R) is more
⟺ spring will be compressed more
⟺ needle show higher value of hardness.

→ If material is soft, penetration is easy,
⟺ f_r is less
⟹ spring will be compressed less
⟹ needle show low value of hardness.

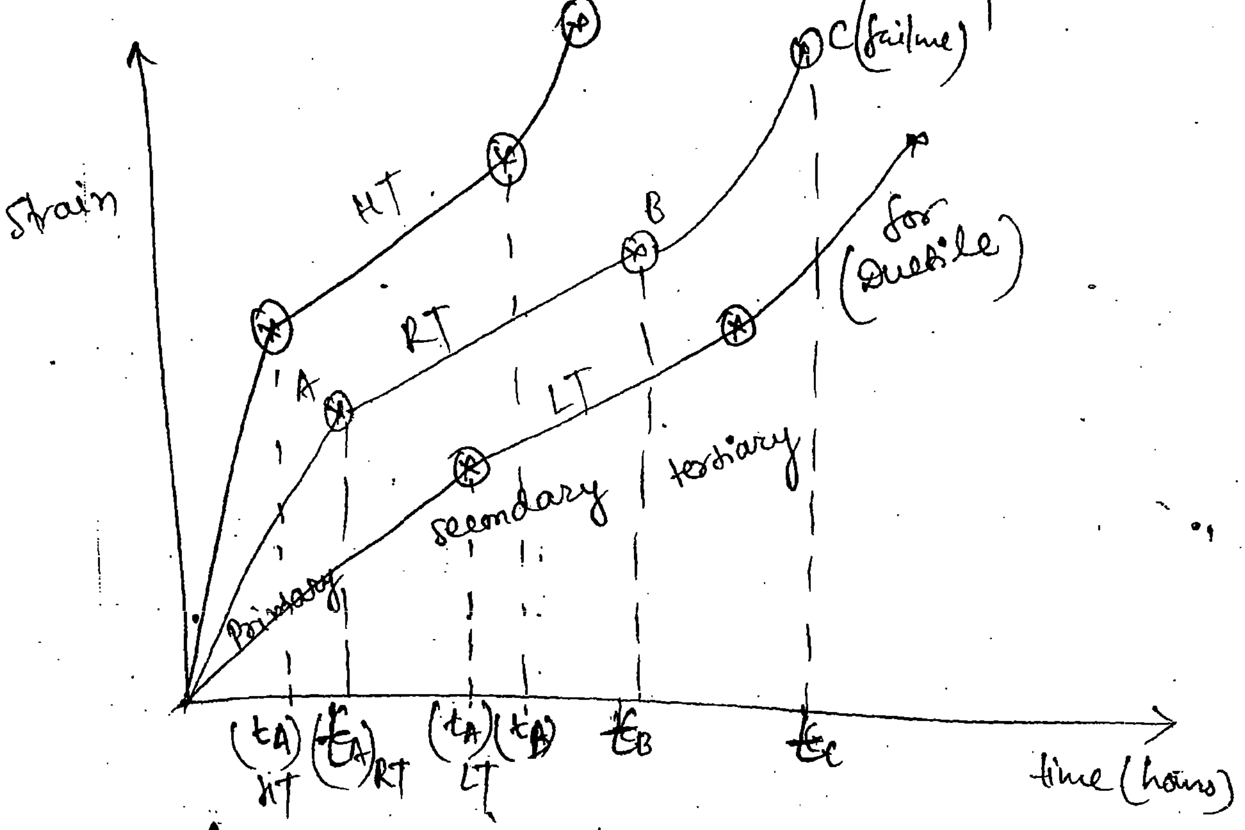
* Creep behaviour in ductile material :-

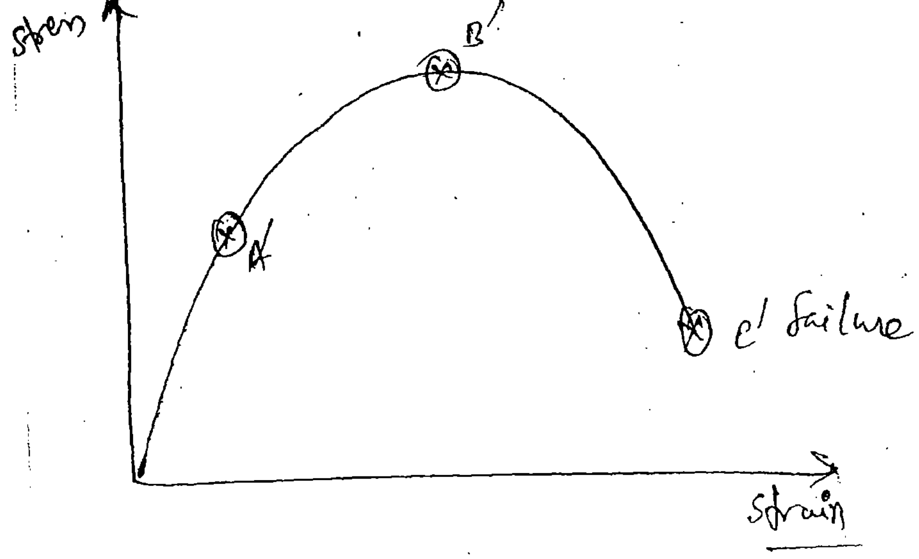


x_0 t = 0
x_1 t = 1 hr
x_2 t = 2 hr

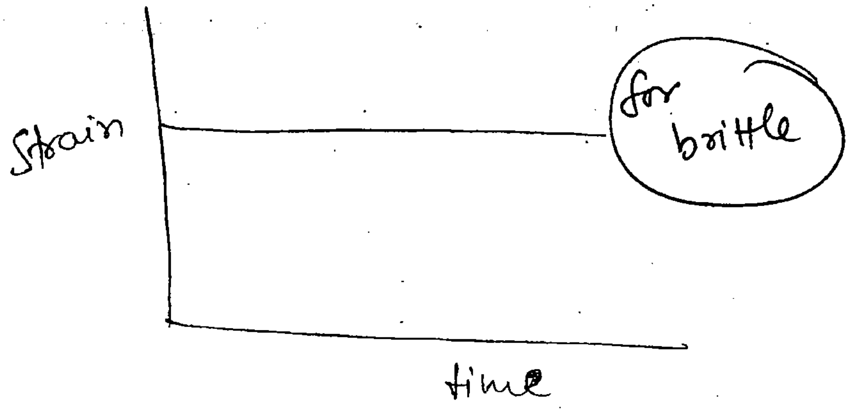


time	Position	elongation	strain
0	x_0	—	ϵ_0
1	x_1	$\Delta l_1 = x_1 - x_0$	$\frac{\Delta l_1}{l_0} = \epsilon_1$
2	x_2	$\Delta l_2 = x_2 - x_0$	$\frac{\Delta l_2}{l_0} = \epsilon_2$
⋮			
t=n			ϵ_n





⇒



⇒ If a material is loaded up to time t_A, strain will increase with time but by removing the load before t_A time, It will gains its original shape.

⇒ represents elastic region (O$\underline{A'}$). in fig.

⇒ If a material is loaded beyond the time t_A, the displacement of atomic plane is slow and undergo plastic deformation up to time (t_B)..

⇒ If the load is removed, the sample does not gains its original shape. In this region the sample will wear the load. by undergoing shape change

⇒ which represents A'B' region in figure.

⇒ If the sample is loaded beyond the point B undergo <u>seever</u> plastic deformation

⇒ within short time the strain will increase more and fails at the point C. (time t_C)

⇒ which represent B'C' region in fig.

⇒ To maintain the dimensional accuracy of component, the load should be removed before t_A.

⇒ Small dimensional changes are allowed in the Component, then the load should be removed before time t_B.

→ At any cost the load should not act beyond t_B time because the Component will undergo severe shape change and fails ..

Therefore
Creep curve will give life of the Component under Constant mechanical load.

→ Creep doesnot exist in brittle material because it does not undergo plastic deformation.

⇒ Stress vs Strain curve explains the failure behaviour of material w.r.t load, and whereas creep curve explain the failure behaviour with time.

$$\Rightarrow \boxed{(t_A)_{H.T} < (t_A)_{R.T} < (t_A)_{L.T}}$$

→ If a material is tested at high temperature, more strain will produced but fails within short time, Therefore,

$$(t_A)_{H.T} < (t_A)_{R.T} < (t_A)_{L.T}$$

NOTE :-

⇒ It is always preferrable to operate a component at as low surrounding temp. as possible to improve the life of the component without shape change.

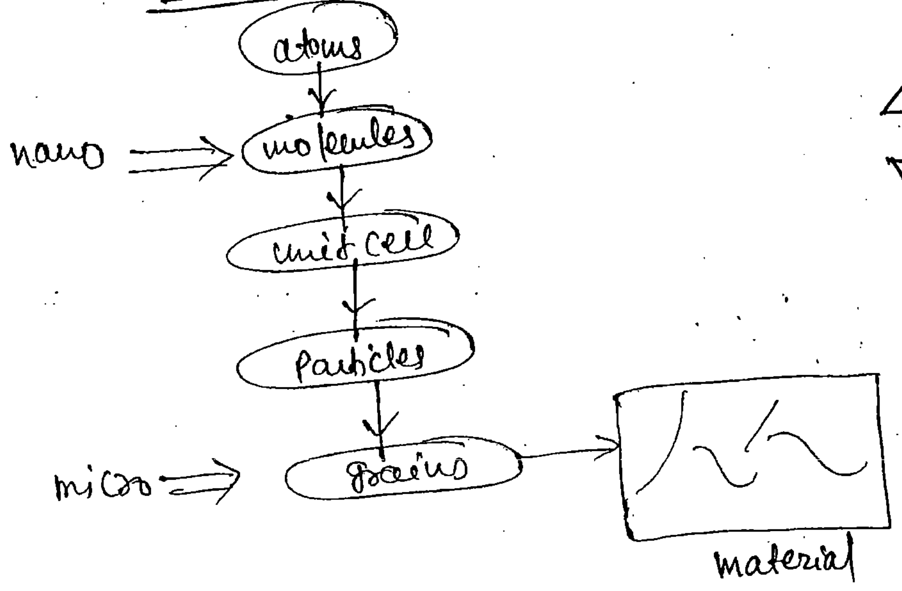
⇒ Therefore design of component at high temp. environment is complex and difficult.

⇒ Strength of a material depends on –

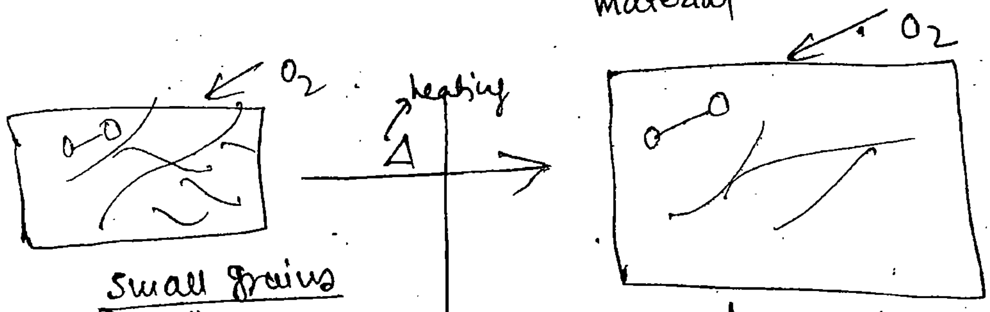
① Structure
② Defects
③ Composition

---

① **Structure :-**

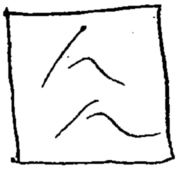


Δ → heating
∇ → cooling

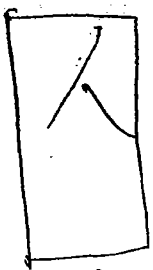


small grains
⇓
Definitely
① strength is high
② Ductility is low
⇓
may or may not
1. density is high
2. Anticorrosive

large grains
⇓
1. Strength is low
2. Ductility is high
⇓
1. low density
2. Corrosive



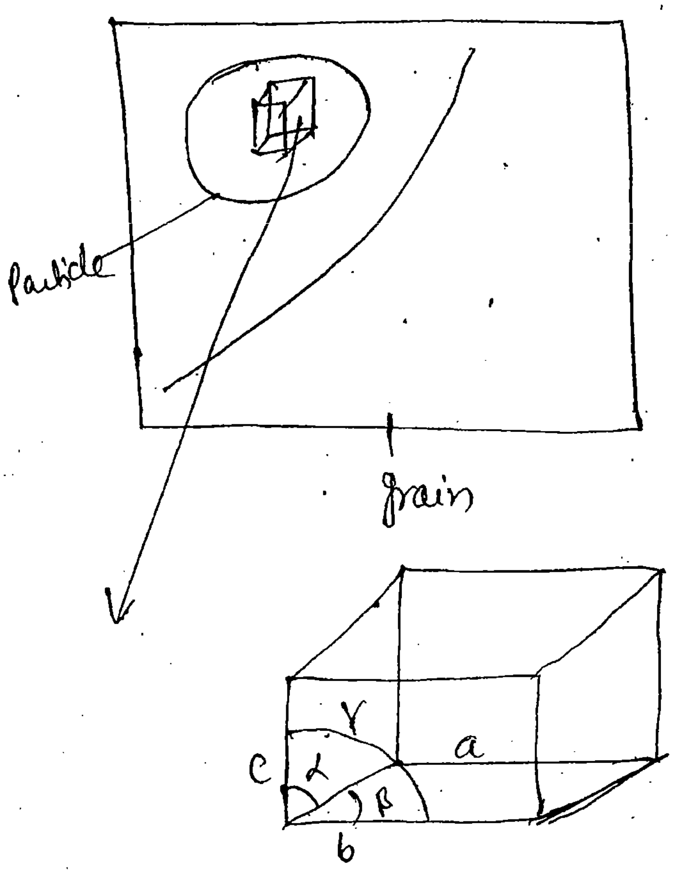
Al
(Small grain)



Al
(large grain)

⇒ If a material possess with small grain is heated to high temperature followed by slow cooling process
   ⇒ Small grains will combined and form larger grains
   ⇒ hardness decreases

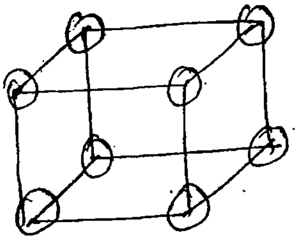
⇒ A material with large grain is heated to high temp. followed by rapid cooling process.
   ⇒ large grains will break into small grains
   ⇒ hardness increases.



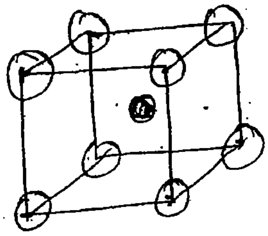
$\left.\begin{matrix} a, b, c, \\ \alpha, \beta, \gamma \end{matrix}\right\} \rightarrow$ lattice

Structure of unit cell = Structure of material

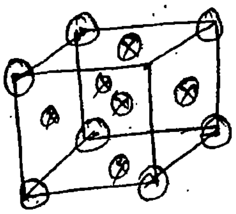
→ The minm volume of material which explain the whole structure of the material.
Therefore by knowing the structure of unit cell, structure of material can be determined.



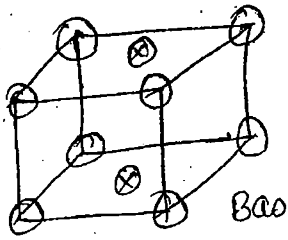
Simple structure ⓐ



body centre structure ⓑ



face centred structure ⓒ



Base centred structure ⓓ

⇒ ~~A~~ unit cell contains a, b, c, α, β, γ ~~parameter~~ dimensions, called as lattice parameter.

⇒ By changing the unit cell dimensions If the strength of the material is changed, called as structural change.

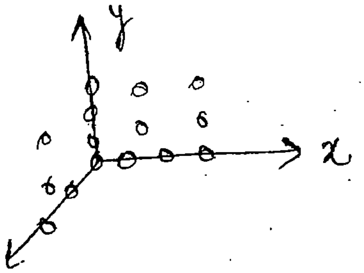
⇒ After fixing the unit cell dimensions, If the atomic orientation is changed, known as substructural change.

lattice parameter	Structure	Substructure	Material
① ~~Cub~~ $a=b=c$ $\alpha=\beta=\gamma=90^\circ$	Cubic →	→ S.C → b.c.c → f.c.c	→ NaCl → α Fe, δ Fe → γ_{Fe} ← austenite (γ-iron) → gate 2012
② $a=b\neq c$ $\alpha=\beta=\gamma=90^\circ$	Tetragonal →	→ S.T → B.C.T ~~→ f.C.T~~	 → Radium
③ $a\neq b\neq c$ $\alpha=\beta=\gamma=90^\circ$	orthorhombic	→ S.O → B.C.O → f.C.O → ba.C.O	 → γ_{mn} → U, Ga
④ $a=b=c$ $\alpha=\beta=90^\circ, \gamma\neq 90^\circ$	Rombohedral →	S.R	→ Bi (Bismuth)
⑤ $a=b\neq c$ $\alpha=\beta=90^\circ, \gamma=120^\circ$	Hexagonal →	S.H.	→ Cd, Zn.
⑥ $a\neq b\neq c$ $\alpha=\beta=90^\circ, \gamma\neq 90^\circ$	monoclinic	→ S.M → ba.C.M	→ γ_{mn} → Plutonium ← Radioactive atom
⑦ $a\neq b\neq c$ $\alpha\neq\beta\neq 90^\circ$	triclinic →	S.Tri	→ $CuSO_4$

→ 7 structure & 14 substructure ⇒ Bravais lattice

→ classification of material based on structural point of view :-

Crystalline

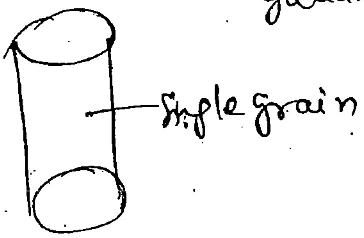


→ atomic orientation is systematic in 3-D in lattice.

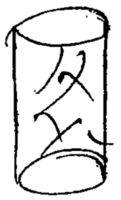
Types

Ⓐ Single crystalline

- If entire volume of material contains a single grain is called as single crystalline.
Ex- silicon, Ge, GaAs
↑ galium austenite

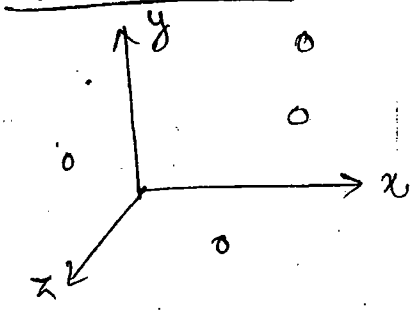


Ⓑ Polycrystalline



→ If many grains are there in a material called as polycrystalline
Ex- metals.

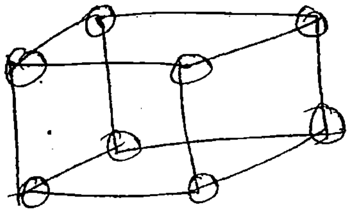
Amorphous



→ If atomic orientation is random in 3-D, called amorphous material
Ex- powder made material.

NOTE :-

⇒ The crystalline material in the nature will be one of the 14 substructures.



→ Strength of unit cell is high if i) no. of atoms in unit cell are more

$$\boxed{N = \frac{N_c}{8} + \frac{N_f}{2} + \frac{N_b}{1} + \frac{N_{ba}}{2}}$$

(ii) packing factor is high

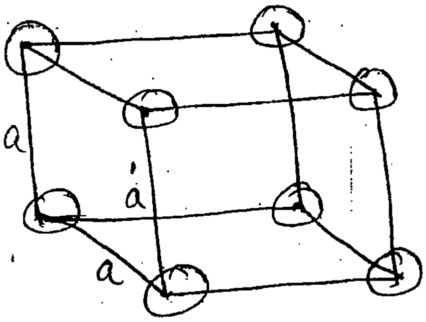
$$P.f = \frac{\text{volume occupied by the atoms in unit cell}}{\text{volume of unit cell}}$$

$$\boxed{P.f = \frac{\text{no. of atoms} \times \frac{4}{3}\pi R^3}{\text{Vol. of U.C}}}$$

⇒ In a unit cell if the no. of atoms are more and the packing factor is high then that structure exhibits high strain.

* packing factor calculation of simple cubic :-

$a = b = c$
$\alpha = \beta = \gamma = 90^\circ$



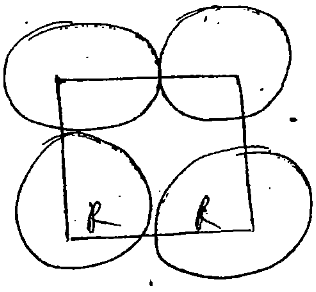
no. of atoms = N

$$= \frac{\overset{\to \text{corner}}{N_c}}{8} + \frac{\overset{\to \text{face}}{N_f}}{2} + \frac{\overset{\to \text{body}}{N_b}}{2} + \frac{\overset{\to \text{base}}{N_{ba}}}{2}$$

$$= \frac{8}{8} + 0 + 0 + 0$$

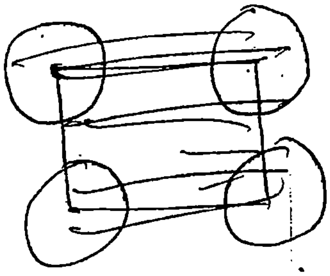
$$\boxed{N = 1}$$

$$\text{now, } P.f = \frac{N \times \frac{4}{3}\pi R^3}{\text{vol. of u.c}} = \frac{1 \times \frac{4}{3}\pi R^3}{a \times a \times a} \quad \text{— (i)}$$



$$\boxed{a = 2R}$$

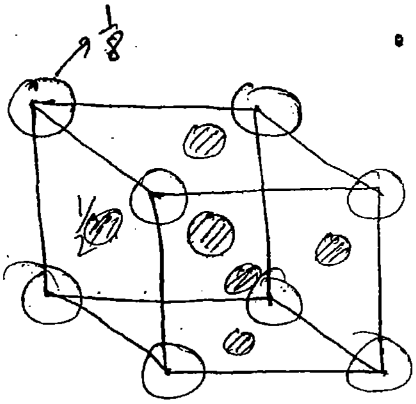
$$\boxed{R = \frac{a}{2}}$$



$$P.f = \frac{1 \times \frac{4}{3}\pi R^3}{a^3} = \frac{\frac{4}{3}\pi \cancel{R^3}}{8\cancel{R^3}} = \frac{4\pi}{24}$$

$$\boxed{P.f = 0.52 = 52\%}$$

✳ Packing factor for F.C.C :-

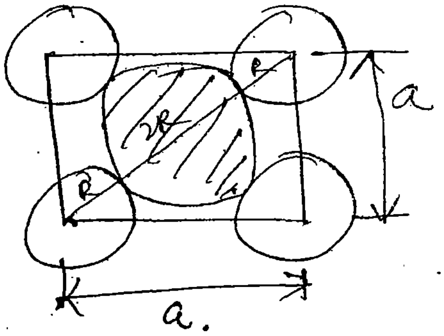


$$N = \frac{N_c}{8} + \frac{N_f}{2} + \frac{N_b}{1} + \frac{N_{ba}}{2}$$

$$= \frac{8}{8} + \frac{6}{2} + 0 + 0$$

$$\boxed{N = 4}$$

$$P.f = \frac{N \times \frac{4}{3}\pi R^3}{a \times a \times a}$$



$$(4R)^2 = a^2 + a^2 = 2a^2$$

$$\Rightarrow 16R^2 = 2a^2$$

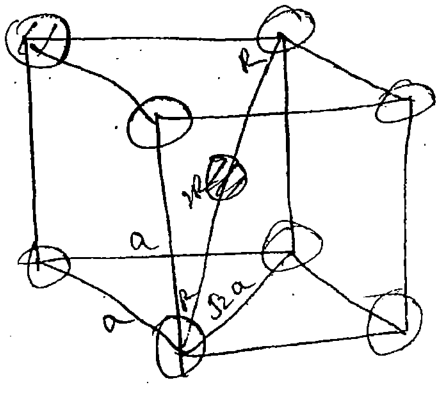
$$8R^2 = a^2 \Rightarrow \boxed{R = \frac{\sqrt{2}\,a}{4}}$$

$$\boxed{P.f = 0.74 = 74\%}$$

✳ Packing factor for B.C.C

$$N = \frac{8}{8} + 0 + \frac{1}{1} + 0$$

$$\boxed{N = 2}$$



$$P.f = \frac{N \times \frac{4}{3}\pi R^3}{a^3}$$

$$(4R)^2 = (\sqrt{2}a)^2 + a^2$$

$$16R^2 = 3a^2$$

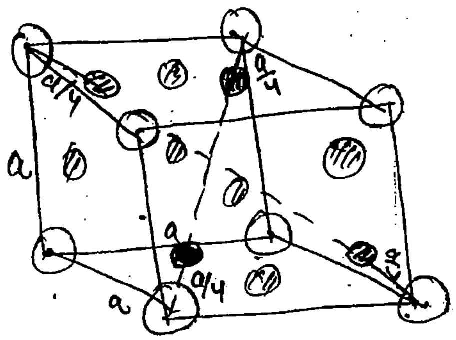
$$\boxed{R^{\cancel{2}} = \frac{\sqrt{3}a}{4}}$$

now, $P.f = 2 \times \frac{4}{3}\pi\left(\frac{\sqrt{3}a}{4}\right)^3 \Big/ a^3 = 0.68$

$$\boxed{P.f = 68\%}$$

Packing factor for diamond structure:—

⇒ A face centred cubic structure with four body atoms at a distance of $\frac{a}{4}$ from the opposite corners of the two opposite body diagonals is known as diamond structure.



Put, $R = \frac{\sqrt{3}a}{8}$

$$N = \frac{8}{8} + \frac{6}{2} + \frac{4}{1} + 0 = 8$$

$$P.f = \frac{N \times \frac{4}{3}\pi R^3}{a^3}$$

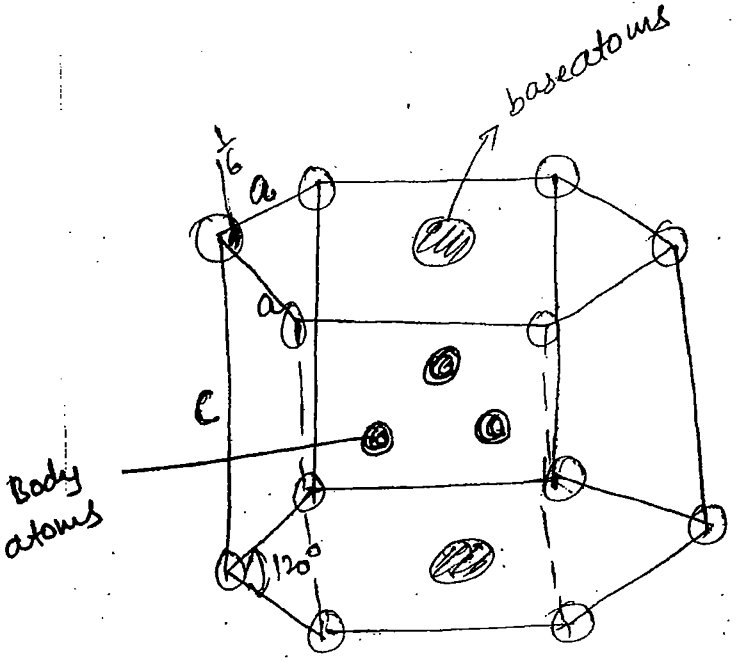
$$= \frac{8 \times \frac{4}{3}\pi\left(\frac{\sqrt{3}a}{8}\right)^3}{a^3}$$

$$\boxed{P.f = 0.34 \text{ or } 34\%}$$

* Packing factor for hexagonal Closed packed structure –

$a = b \neq c$

$\alpha = \beta = 90^\circ, \gamma = 120^\circ$



$N = \frac{12}{6} + 0 + \frac{3}{1} + \frac{2}{2}$

keep remember not 8

$= 2 + 3 + 1 \quad \boxed{N = 6}$

$\boxed{P.f = 0.74 \text{ or } 74\%}$

Structure	N	Pf (%)
S.C.	1	52
B.C.C	2	68
F.C.C	4	74
H.C.P	6	74
diamond	8	34

Case 1): If a material forms with simple cubic, & B.C.C structures then,

strength → $\boxed{S_{B.C.C} > S_{S.C}}$

because,
B.C.C contains more no. of atoms in the unit cell
⇒ no. of bonding will be more
⇒ strength will be high.

also, B.C.C contains high packing factor.
⇒ Binding energy among the atoms is high
⇒ strength is high.

$$\Rightarrow \boxed{\rho_{B.C.C} > \rho_{S.C}}$$

because B.C.C contains more no. of atoms in the unit cells
⇔ density is high
⇒ weight is more.

Case 2: If a material forms with s.c, B.C.C and f.c.c structures then

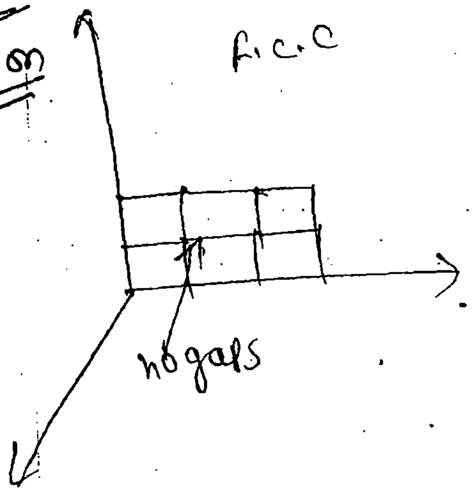
$$\boxed{S_{F.C.C} > S_{B.C.C} > S_{S.C}}$$

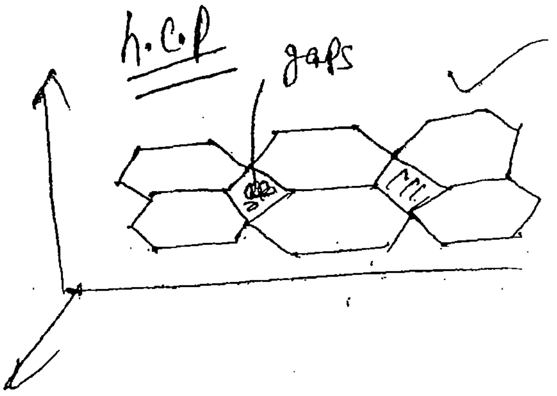
$$\Downarrow$$

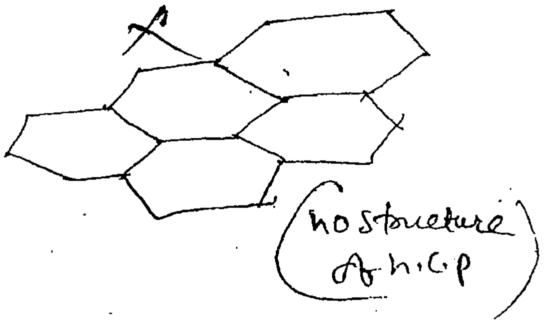
$$\boxed{\rho_{F.C.C} > \rho_{B.C.C} > \rho_{S.C}}$$

Case 3: If a material forms with f.c.c and h.c.p then

V.V.I.P Exception







So,

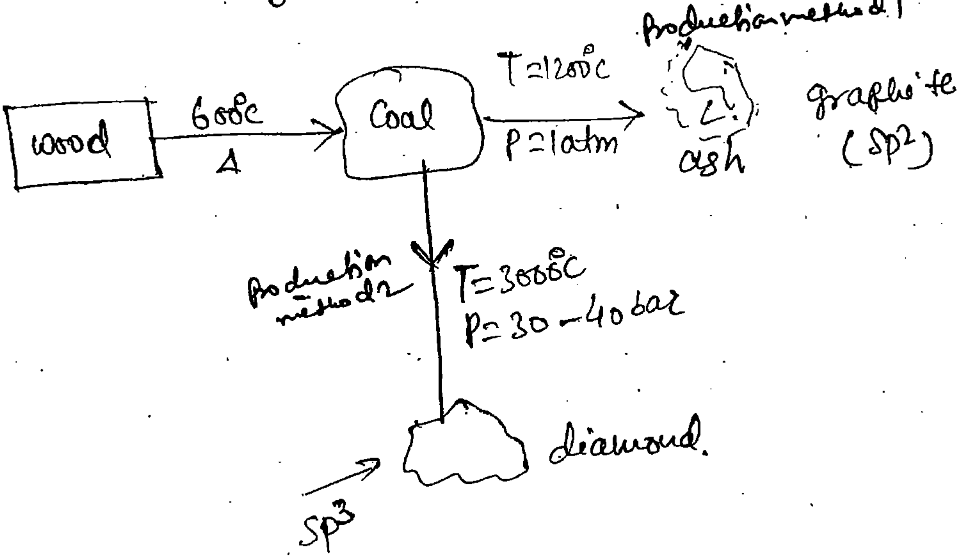
$$\boxed{\begin{array}{l} S_{F.C.C} > S_{h.c.p} \\ \rho_{F.C.C} > \rho_{h.c.p} \end{array}}$$

⇒ During formation of h.c.p structures gaps will formed among the lattice atoms
- → binding energy decreases
- → strength is less.

→ During formation of f.c.c lattice, no gaps will formed among the lattice atoms

⇒ strength is high.

Case-4 :- Diamond structure exhibits more hardness and strength even though it has low packing factor



→ In diamond carbon atoms will formed bondings with carbon atom itself with sp^3 bonding, which possess highest binding energy among the atoms.

Therefore

⇒ It has high hardness & strength.

NOTE :-

⇒ Production method changes the grain size of the material

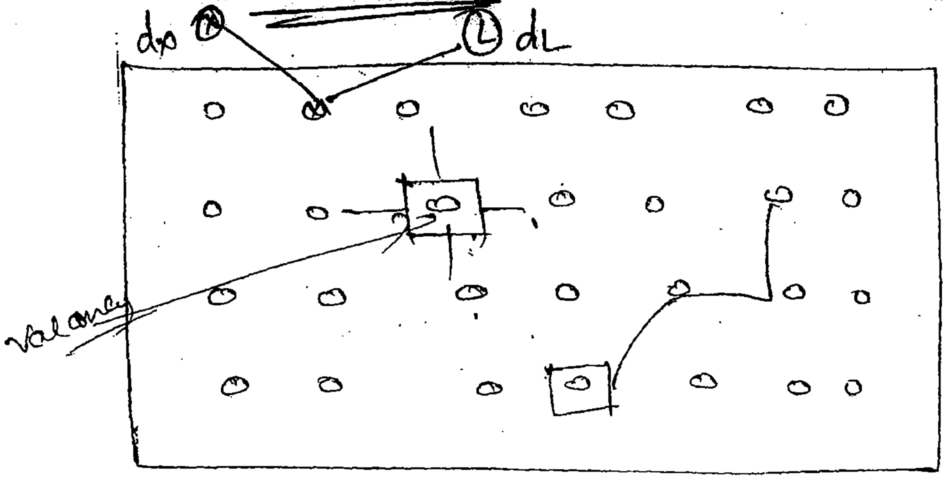
⇒ grainsizes changes the atomic orientation

⇒ change of atomic orientation gives change in structures

⇒ change of structure changes the ~~shape~~ Strength of materials.

Date-30/8/2012

DEFECTS :-



→ Physical discontinuties that is present in a lattice of atoms is known as defects.

(A) POINT Defects :-

If the defect is confined through a single atoms in the lattice.

i) vacancy :

→ ~~vac~~ missing of atom from the regular lattice site

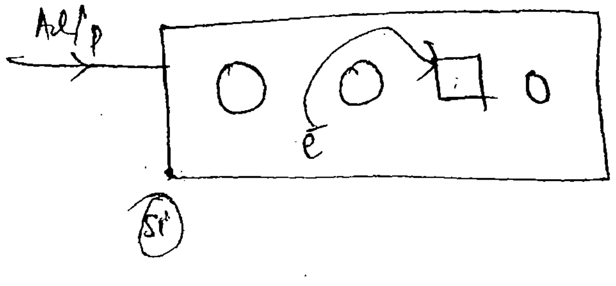
→ vacancies creates defficiency of bondings.
↳ strength of the material decreases.

(ii) displacement of atoms -

→ moment of atom from one lattice site to another lattice side within the lattice.

→ displacement of atoms does not change the no. of bondings within the lattice.
↳ strength remains same but it may change either electrical, thermal or other properties of the material.

Expl:-



eg.:- In pure form (Si) is electrically bad conductor, but by addition of al/p . It creates electron in the lattice.

(phosphorus)

This electrons will travel through the vacancies.

↳ current will flow

↳ becomes as electrically good conductor.

③ **Inclusion :-**

→ Addition of foreign atoms to the lattice of atoms is known as inclusion.

Two types

- Substitutional inclusion
- interstitial inclusion

Ⓐ **Substitutional inclusion :-**

→ The foreign atom occupies the position of lattice atom by removing lattice atom.

→ The no. of bondings remains same in the lattice.

↳ Strength remains same but it may changed either electrical or chemical properties of the material.

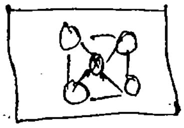
Ex:- Addition of chromium to steel as substitutional inclusion improve the corrosion resistance of steel but strength remains same.

* **Condition for S.I :-**

(i) $\underset{\substack{\uparrow \\ \text{dia. of foreign atom}}}{d_x} = d_L \leftarrow$ dia. of lattice atom

(ii) valency of x = valency of L

Ⓑ **Interstitial inclusion :-**



→ The foreign atom will occupy the empty space available within the lattice, without disturbing the position of lattice atoms.

→ Interstitial inclusion increases the no. of bondings →
with surrounding atoms.
↳ Strength increases.

→ addition of carbon to iron as interstitial inclusion, improve the strength of iron and forms as steel.

* Condition for I.I :-

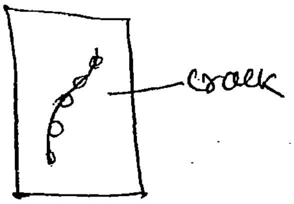
(i) $d_x < d_L$

(ii) valency of x > valency of L

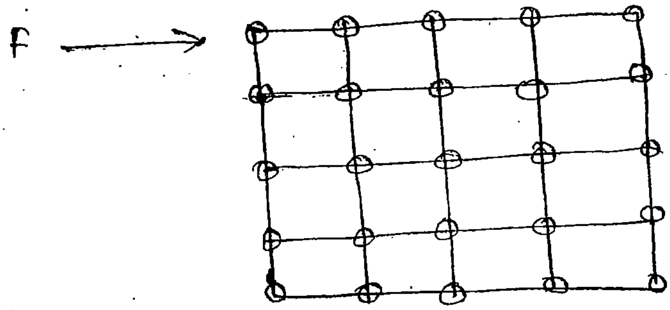
(B) LINE DEFECTS :- (Dislocation)

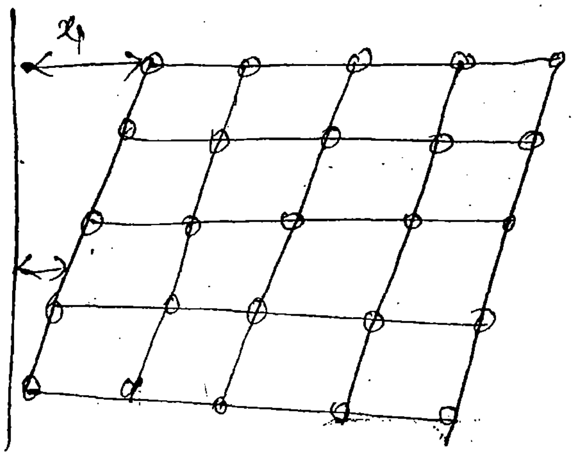
→ If the defect is confined to more than one no. of atoms, called as line defects.

Ex (i) crack :



(ii) Slip phenomena :-





→ If a shear force is applied on a lattice, the top atomic plane will move with respect to bottom atomic plane. moment of atomic planes one on another is known as <u>slip phenomena.</u>

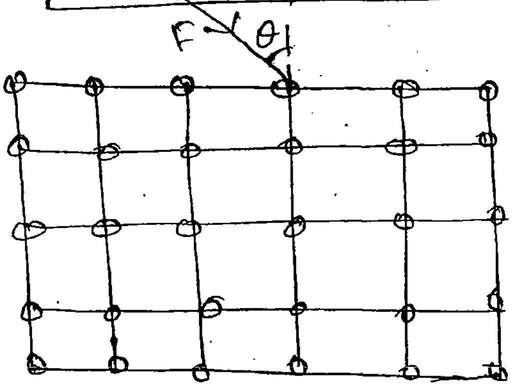
→ Here the entire plane of atoms are moving, Hence It is called as a line defects.

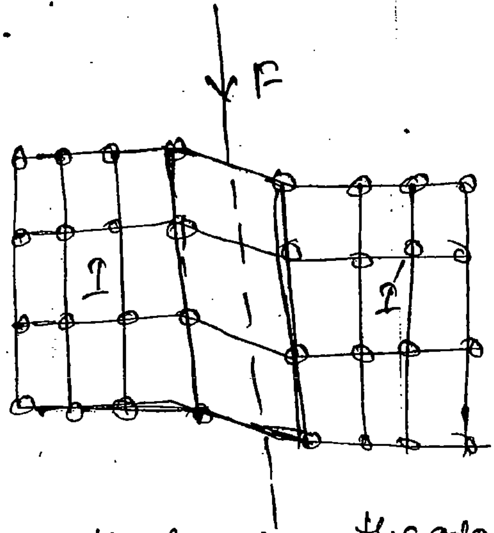
→ Slip phenomena causes plastic deformation in ductile materials.
↳ which exhibits ductility, creep, behaviour of a material.

→ Ex: forging

→ Slip phenomenon is difficult at low temp. because the displacement of atomic plane is difficult.

② Twinning phenomena :-



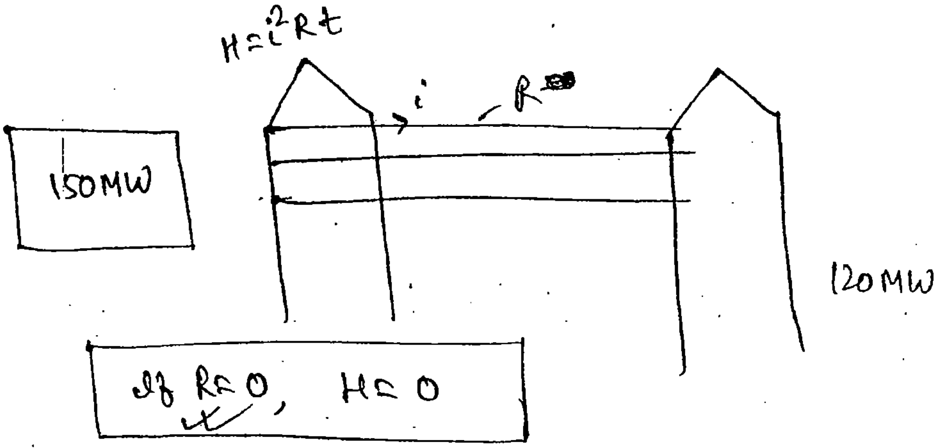


→ If an angled force is applied on the lattice, the atoms will displaced along the line of force only. with respect the plane of force, I and I' are the mirror images (fins).

Therefore,
A lattice splits into two identical sublattices I & I' known as twinning phenomenon.

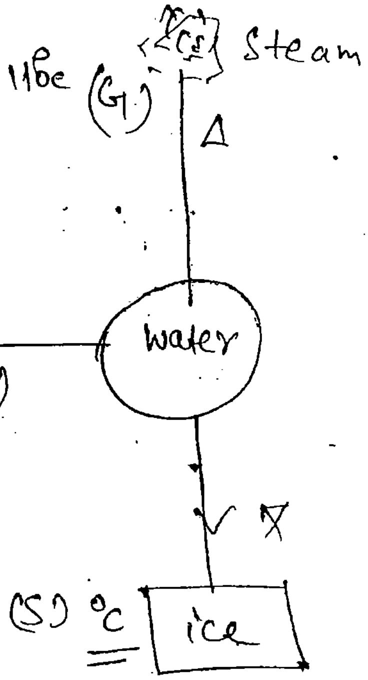
→ Super Conductivity in materials

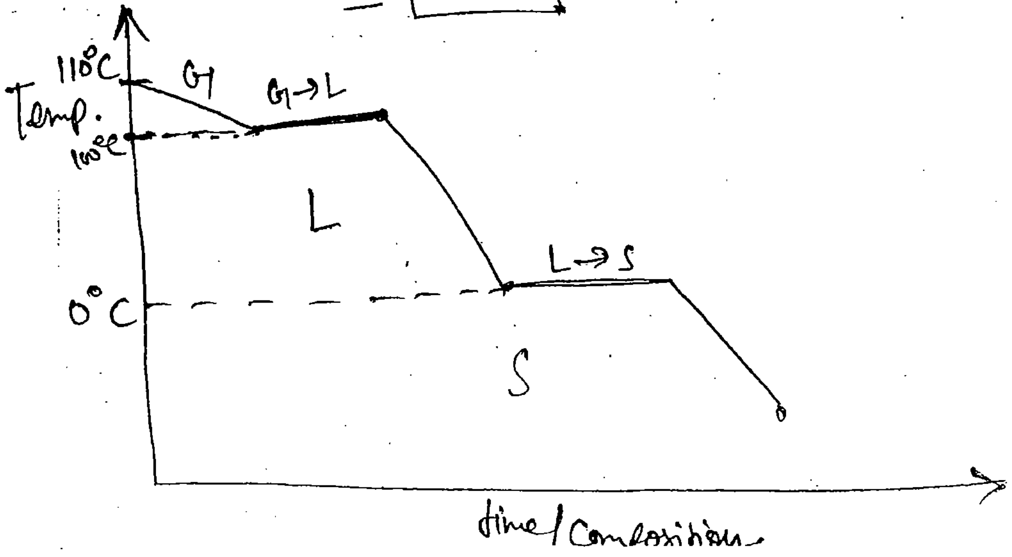
(Zero electrical resistance)



V.Imp
→ Thermal properties of metal does not depend on defects.
(M.P, B.P).

PHASE DIAGRAM





① **Phase :-** Physical state of a material.

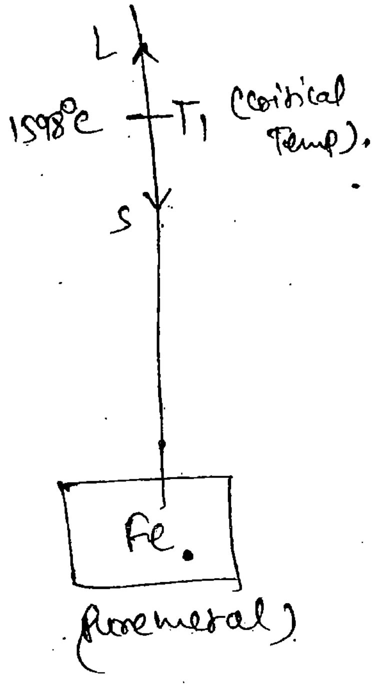
② **Phase transformation :-** Conversion of one phase into - another phase either by heating or cooling process.

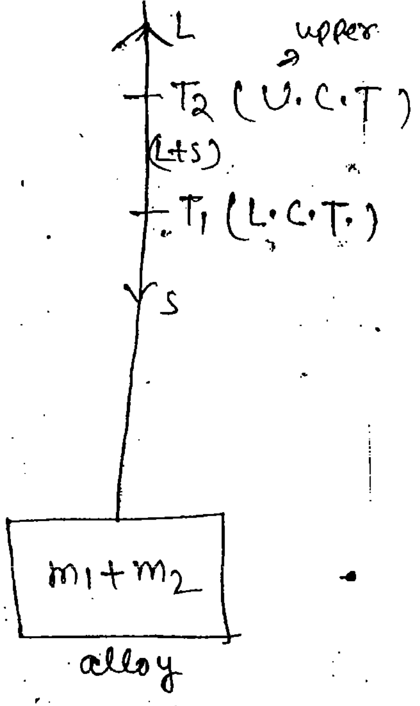
③ **Phase diagram :-**
The diagram which represents phase transformation of a material.

④ **Phase diagram are two types :-**

(i) Temp. - Composition P.D (eq^b P.D)

(ii) Temp - time P.D (non eq^b P.D)





→ In case of a pure metal, the phase transition temp. is a point of temp. (T_1), called as critical temperature.

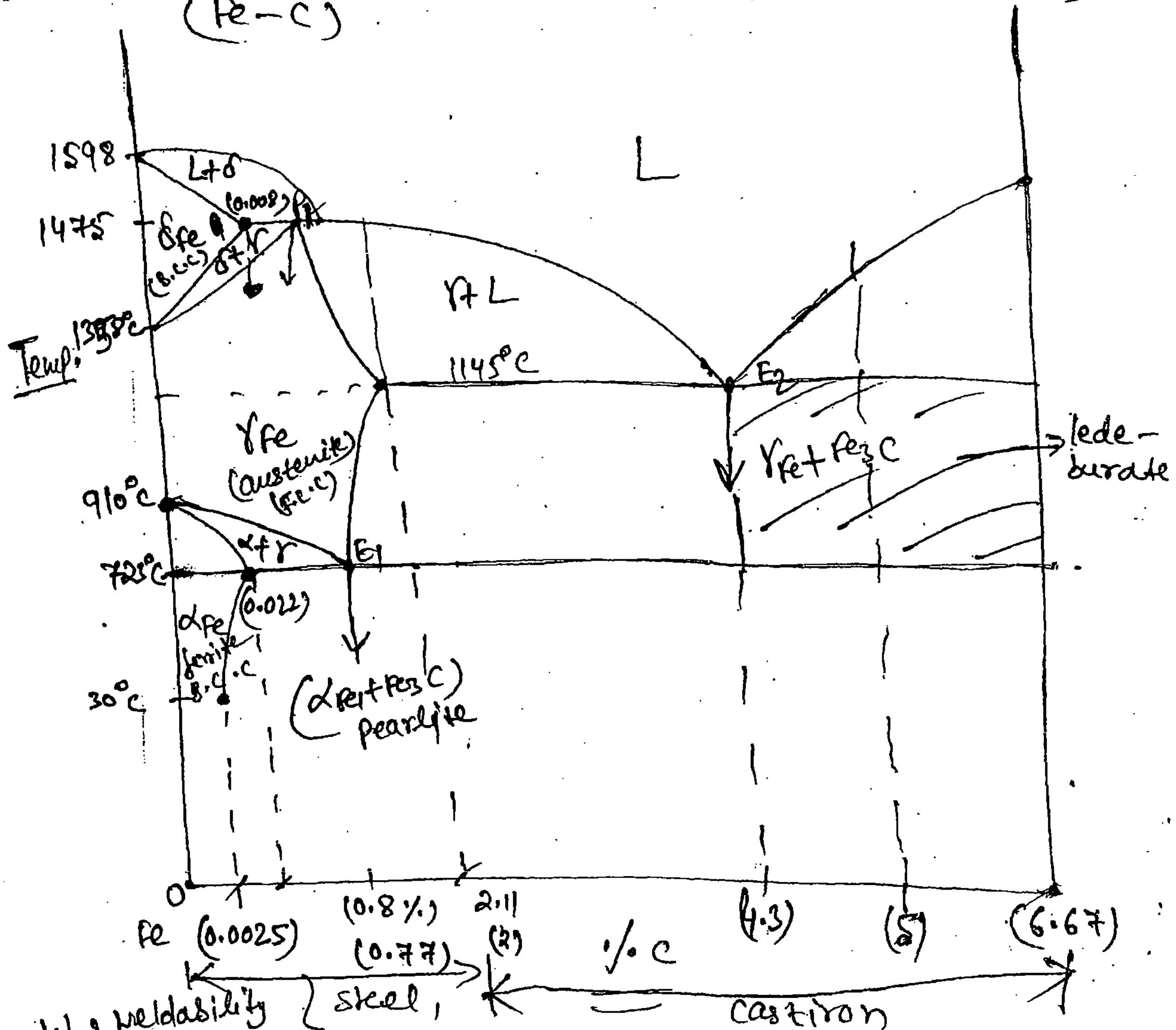
→ In case of an alloy the phase transition temp. is a range of temp. between T_1 and T_2.

→ The Temp. below which it remains in the same phase is known as lower critical Temp. (T_1)

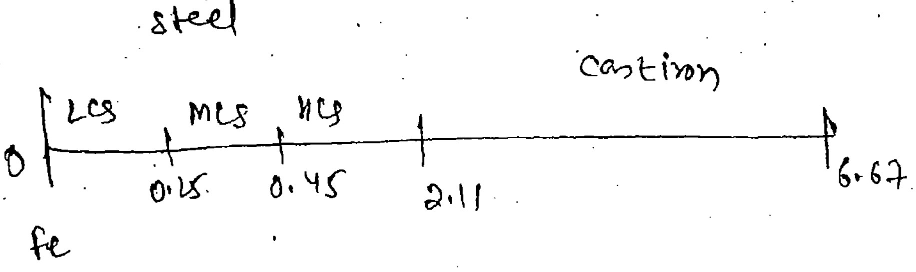
→ The temp. above which It changes the phase is known as upper critical Temp. (T_2)

→ In between T_1 and T_2 it possess a mixed phase.

* IRON- CARBON PHASE DIAGRAM :- (V.V.I) (Fe-C)



Wl → weldability
H → hardness
M → missibility
} steel



→ Fe3C

C ↑ ↑ free Fe ↓

⇒ carbon is added to iron to improve the strength of iron.

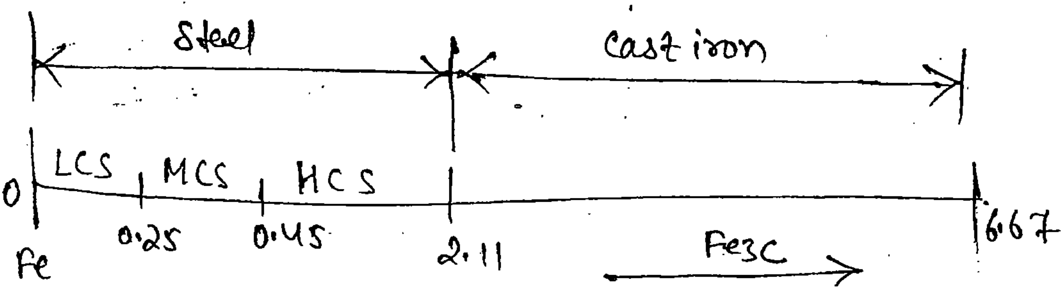
→ If carbon is added to iron, it forms iron carbide (Fe_3C) which is hard & brittle in nature, also known as, <u>cementite</u>.

→ If carbon is added to iron, the max^{m} solubility of carbon in iron is 6.67 %, known as critical concentration.

→ If % of carbon is 0 to 2.11 % ⇒ steel

→ If % of carbon is 2.11 to 6.67 % ⇒ cast iron

v.v.I → If any phase contains high carbon content, it possess <u>high iron carbide volume</u>.
⇒ It exhibits high hardness & Brittleness.



∴ $$\boxed{H_{Fe} < H_{steel} < H_{C.I}}$$

Similarly, $$\boxed{H_{Fe} < H_{LCS} < H_{MCS} < H_{HCS} < H_{C.I}}$$

→ If any phase is more hard ⇒ ~~machinability~~ machinability is difficult.

$$\boxed{M_{Fe} > M_{LCS} > M_{MCS} > M_{HCS} > M_{CI}}$$

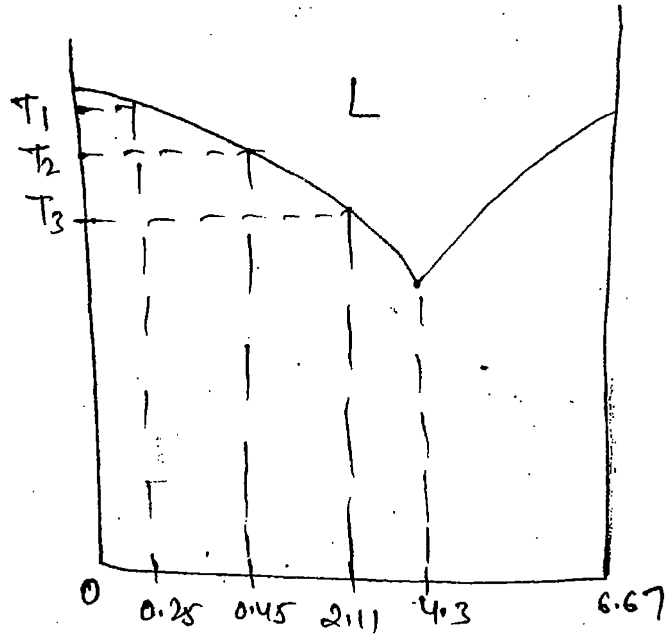
→ If any phase contains high carbon content (free iron is less) ⇒ difficult to weld,

$$\boxed{W_{Fe} > W_{LCS} > W_{MCS} > W_{HCS} > W_{C.I}}$$

→ If any phase contains high carbon content (free iron is less), corrosion resistance will be high.

∴ $\boxed{C.R_{Fe} < C.R_{LCS} < CR_{MCS} < CR_{HCS} < CR_{C.I}}$

→ The melting form :-



→ as the corner content increases, the melting point decreases up to (4.3 %) and again it rises up to (6.67%)

Therefore,

$\boxed{M.P_{Fe} > M.P_{LCS} > MP_{HCS}}$

melting point

→ Low carbon steels are difficult to produce because
① melting temp. is high
② difficult to mixed minute carbon content at very high temp.

∴ LCS are eppensive, but possess high servicing temperature.

→ High carbon steels can be produced easily and cheaper because
(i) Melting point is low.
(ii) more carbon can be added easily.

ABOUT δ-Iron :-

→ The max^{m} solubility of carbon is 0.008 % at 1475°C.

→ Since It possess low carbon content, highly ductile in nature.

→ It exhibits similar properties of pure iron.

→ difficult to produce because production temp. is high.

→ δ-iron contains large grain ⇒ ductile in nature.

→ Structure is B.C.C

ABOUT (γ-Iron) :- (austenite)

→ The max^{m} solubility of carbon is 2.11 % at 1145°C.

→ The min^{m} temp. at which γ-iron ~~exhibits~~ exits 723°C at 0.8 % of carbon.

→ Structure is F.C.C.

→ The strength of austenite depends on the % of carbon inside.

→ By either heating or cooling process, the grain size can be changed.

ABOUT (α-iron) :- (ferrite)

→ The max^{m} solubility of carbon is (0.022 %) at 723°C.

→ The min^{m} % of carbon can be dissolved at room temp. is 0.0025 %.

→ Structure is B.C.C.

→ α-iron will exhibit similar properties of pure iron with little improved hardness.

→ magnetic in nature.

* strength of steel can be changed by →

① by varying carbon content

② by varying grain size (heat-treatment process)

→ steels are used in design of components where,

(i) small dimensional changes are allowed in the component at beyond designs load.

(ii) fails gradually

(iii) under shock, impact & vibrational environments it works most efficiently.

→ strength of cast iron can be changed by:-

ⓐ by varying carbon content only.

② not by heat treatment.

→ cast iron are used in design of components where

① high dimensional accuracy of the component is required at beyond design load.

② fails suddenly (unsafe)

③ can't be used under shock, impact, and vibration environment.

→ If the % of carbon is 2.11 to 5% then Melting point is min^M.

↳ called as easily castable range of carbon content.

↳ called as cast iron.

① **At E_1 point (eutectoid point) :-**

$\gamma_{Fe} \xrightarrow{\nabla} (\alpha_{Fe} + Fe_3C)$ at 0.8%. at 723°C

$\underset{(solid)}{S_1} \xrightarrow{\nabla} \underset{solid.}{(S_2 + S_3)}$

→ Eutectoid phase transformation.

② **At E_2 point** (eutectic point)

$L(Fe+C) \xrightarrow{\nabla} (\gamma_{Fe} + Fe_3C)$ at 1145°c at 4.3 %.

$L \xrightarrow{\nabla} S_1 + S_2$

→ Eutectic phase transformation

③ **at P_1 point** (peritectic point)

$(L + \delta_{Fe}) \xrightarrow{\nabla} \gamma_{Fe}$

$L + S_1 \longrightarrow S_2$

(peritectic phase transformatic)

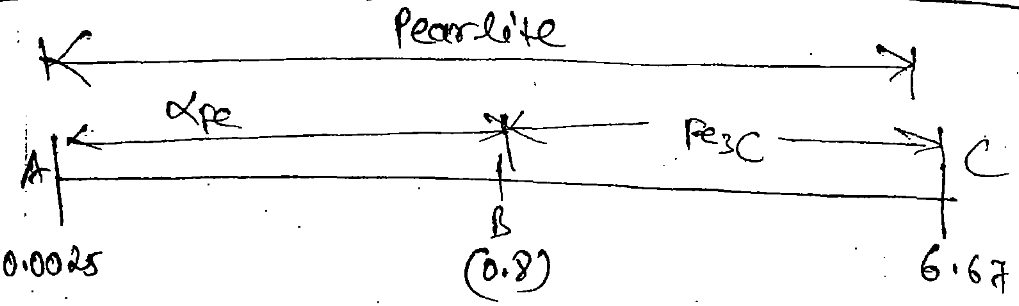
④ $(S_1+S_2) \xrightarrow{\nabla} S_3$

peritectoid phase transformation.

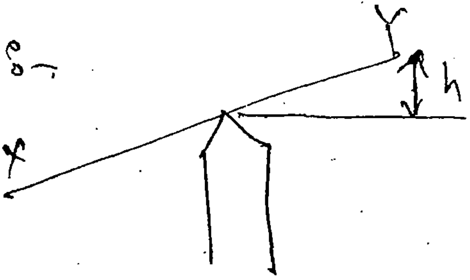
remember
solid → oid
liquid → tic

→ A mixed phase of $(\gamma_{Fe} + Fe_3C)$ existing b/w 4.3 — 6.67 % and 723—1145°c is known as **Ledeburate phase.**

Q) Determine % α_{Fe} and % Fe_3C in pearlite phase at 0.8 % C ?



Rule: Lever rule :-



$$\% A.X = \frac{\% AY}{\% XY}$$

$$\% Y = \frac{\% X}{\% XY}$$

$$\% \alpha_{Fe} = \frac{BC}{AC} = \frac{6.67 - 0.8}{6.67 - 0.0025}$$

$$\boxed{\% \alpha_{Fe} = 88 \%}$$

$$\% Fe_3C = \frac{AB}{AC} = \frac{0.8 - 0.0025}{6.67 - 0.0025}$$

$$\boxed{\% Fe_3C = 12 \%}$$

1/6/2012
Friday

* Types of steel :-

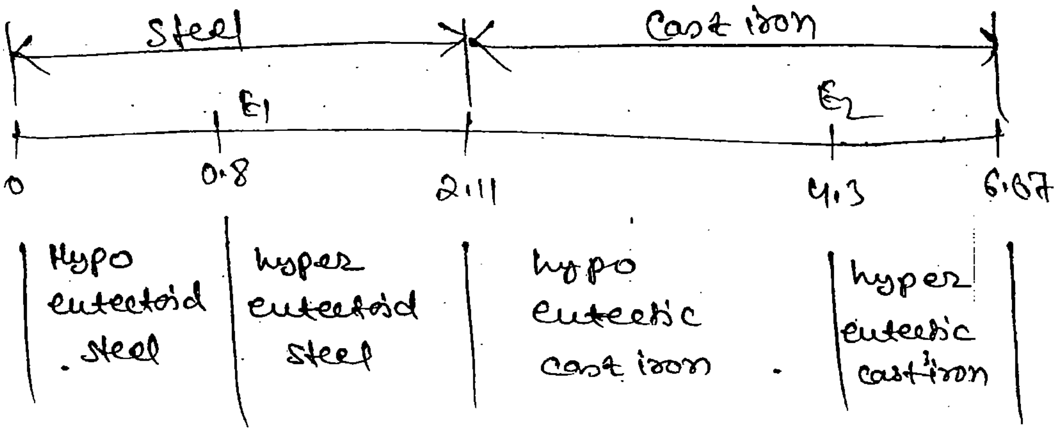
0 — 0.15 % C ⇒ mildsteel

0 — 0.25 % C → LCS

0.25 — 0.45% C → MCS

0.45 — 2.11 % C → HCS
(1.5%)

2.11 — 6.67 % C → C.I
(5%)



→ any steel + Cr → stainless steel

any steel + alloying element → Alloyed steel

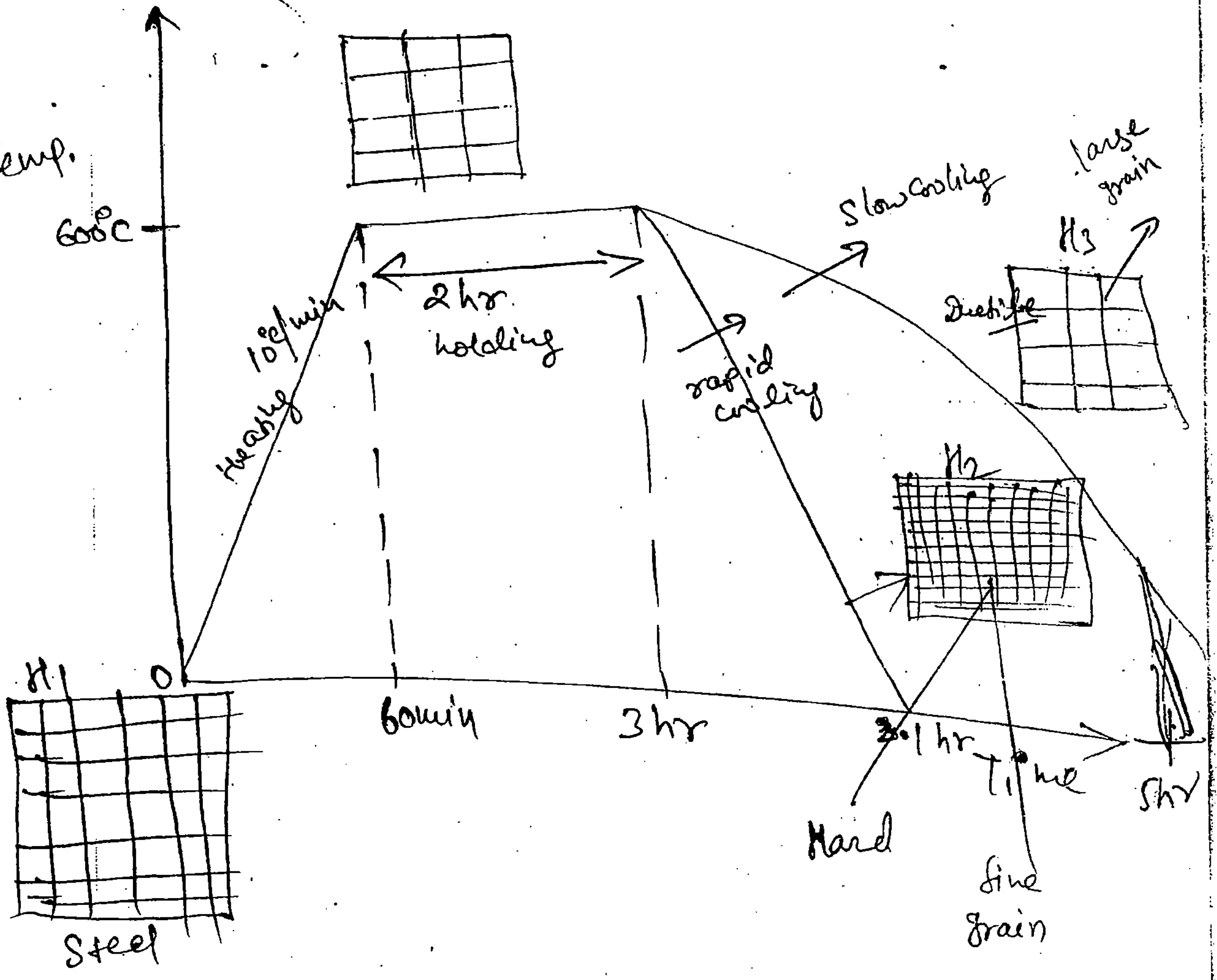
→ V.V.I

Alloying element	Purpose
Cr	improve corrosion resistance and abrassion resistance. ↓ friction free
Si	improve hardenability and formablity
Mg	Toughness & machinability
S	machinability
Mn	hardenability
tungsten → (W/V) → vanadium	improve high temp. hardness & strength
Al	improve toughness

(Cobalt) Co → Mo molybdenum	→ hardenability
→ Ni Nickel	improve toughnes
(lead) Pb →	→ improve hardenability
→ Ti Titanium	→ improve wear resistance and abrasion resistance.

* Heat treatment of steel :-

→ modification of grain size of a steel component by either heating or cooling proces so that the strength of steel can be changed, known as heat treatment proces of steel.



→ Every heat treatmet contains three steps →

① Heating.
↳ small grains will turn into large grains.

② Holding
↳ All grains will turn into uniform shape & size.

③ Cooling
↳ which decides the final grain size of the components.

NOTE :-

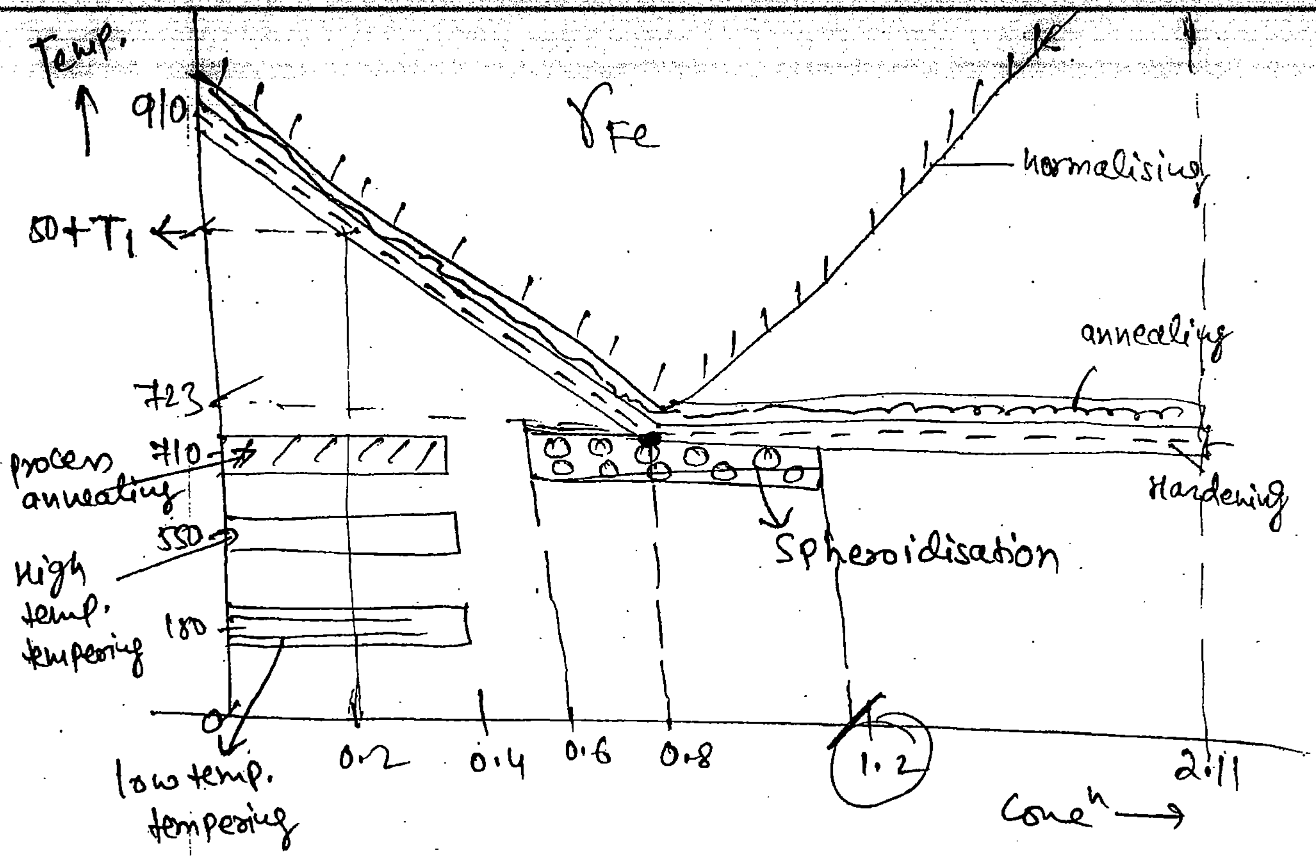
① If the Component is heated to high temperature followed by rapid cooling process
↳ large grains will break into small grains
↳ hardness increases.

② If a Component is heated to high temp. followed by slow cooling process,
↳ smaller grains will combine and forms larger grains.
↳ ductility will increases.

---

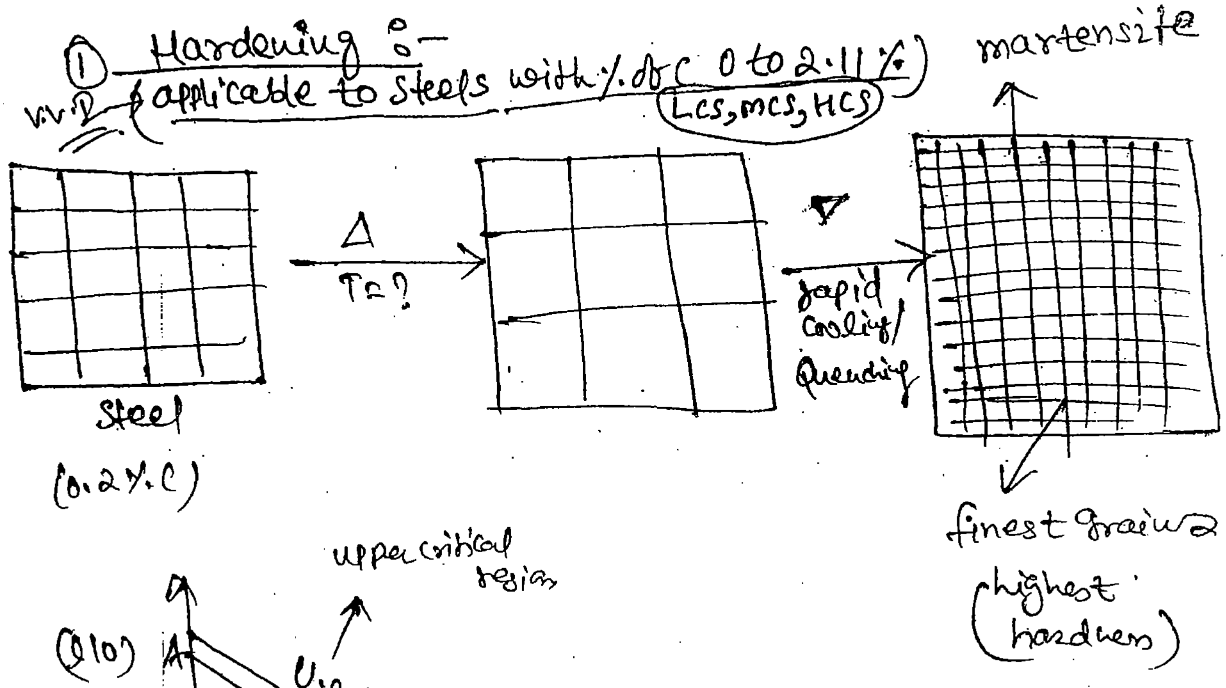
* Types of heat treatment :-

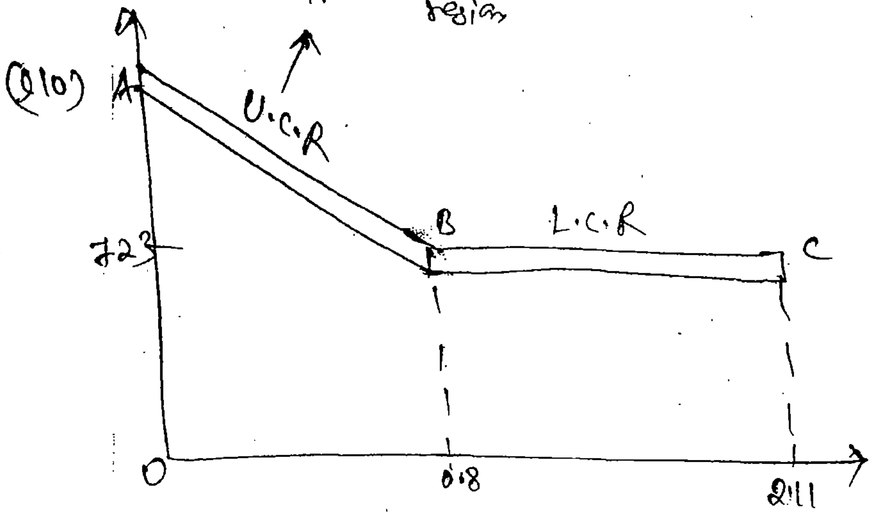
① hardening
② annealing
③ normalising
④ Tempering
⑤ mar tempering
⑥ Aus tempering
⑦ case hardening
⑧ surface hardening.



① **Hardening :-**

v.v.I (applicable to steels with % of C 0 to 2.11%)
(LCS, MCS, HCS)





→ T = ?

Statement (i) If %C = 0–0.8% ⇒ 50°C above U.C.T (AB)

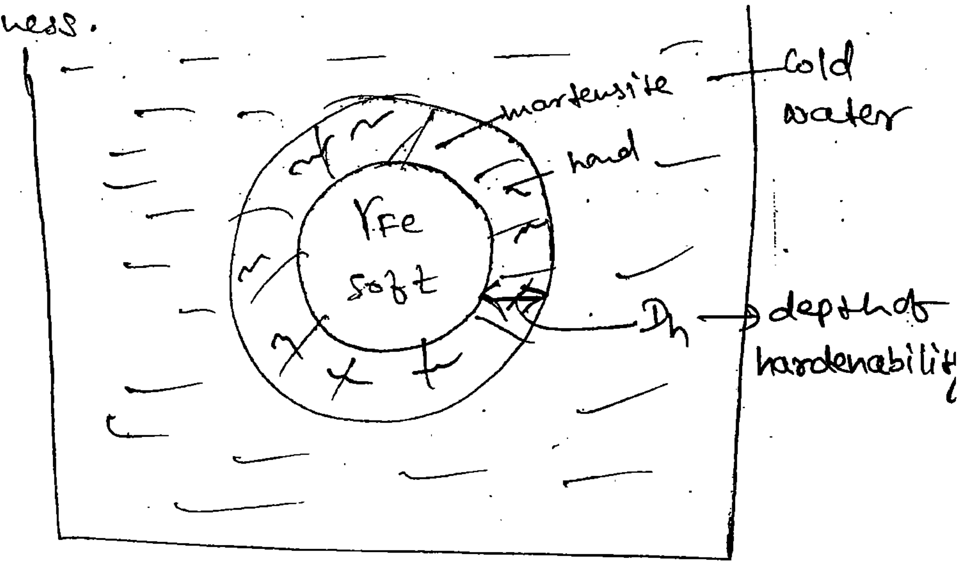
(ii) If %C = 0.8–2.11% ⇒ 50°C above L.C.T (BC)

⇒ obtaining hardness in a steel component by heating followed by rapid cooling process or obtaining martensite phase in a steel by heating followed by rapid cooling process.

→ If a component is subjected to rapid cooling or Quenching It produces smallest size of the grains

↳ It achieves highest hardness, that phase is called as martensite.

→ If any steel of martensite is produced, It exhibits more hardness and brittleness.



→ If a steel component is subjected to hardening in Quench medium then the outer surface will undergo cooling effect and core remains in hot condition

↳ outer surface turned hard due to martensite phase.

↳ and whereas the core remains in soft condition due to γ- iron phase.

→ The depth up to which from the surface of the component has been hardened is known as depth of hardenability.

→ Due to hardening process, the outer surface is in contraction, whereas the core remains in expansion state.

↳ Surface residual stresses will form on the component

↳ A hardened component can't be used in any applications without removing the residual stresses.

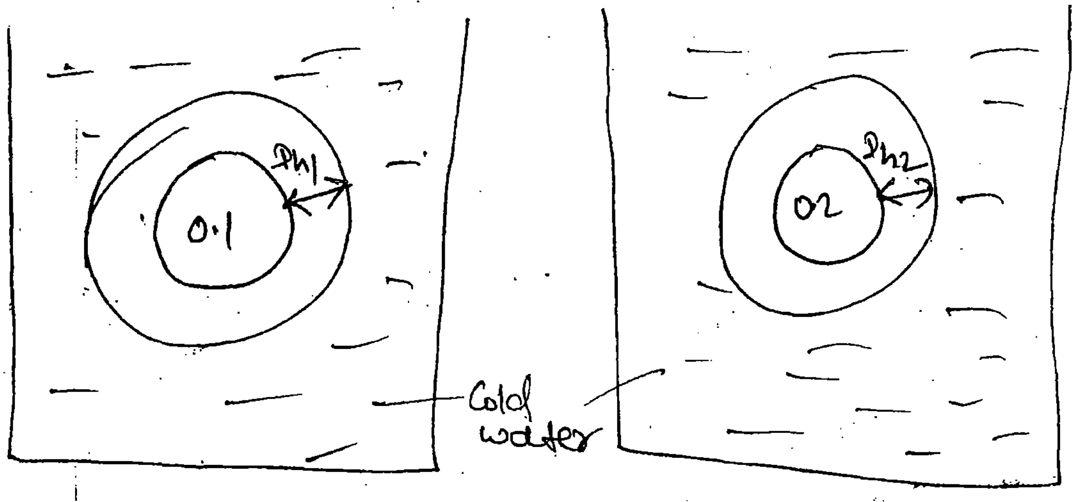
→ ~~A~~ hardened component process, extreme hardness on the outer surface, due to martensite phase,

↳ difficult to perform mechanical operations to shape change the component.

↳ due to severe residual stresses, intensity of cracks will form on the surface.

Case-II.

→ If two steel components with different % of carbon has been hardened in the same quenching medium



→ $\boxed{D_{h2} > D_{h1}}$ because of carbon content is high,

↳ iron carbide volume is high

↳ easily converts into martensite

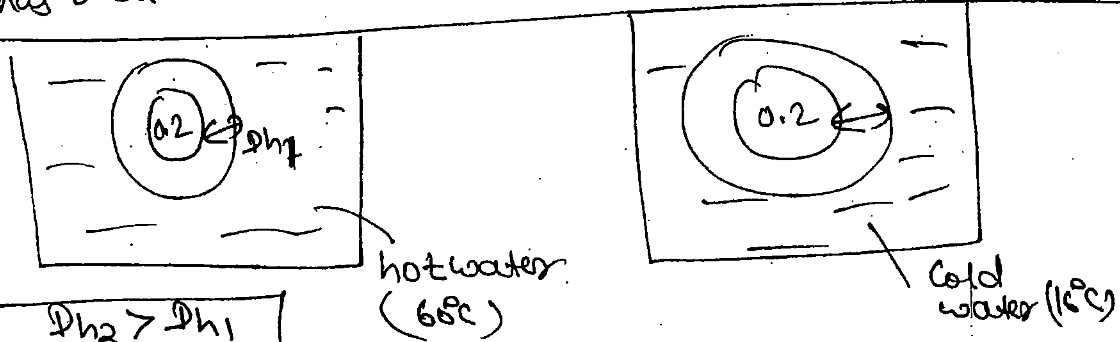
↳ depth of hardenability is high

Note :→

→ H.C.S are easily hardenable than L.C.S

V.V.I

case-2 :- Two steel components with same % of carbon has been hardened in different Quench media.



$\boxed{D_{h2} > D_{h1}}$

because, as the Quenching medium Temp. is low,

ΔT is more,

↳ heat transfer will be fast

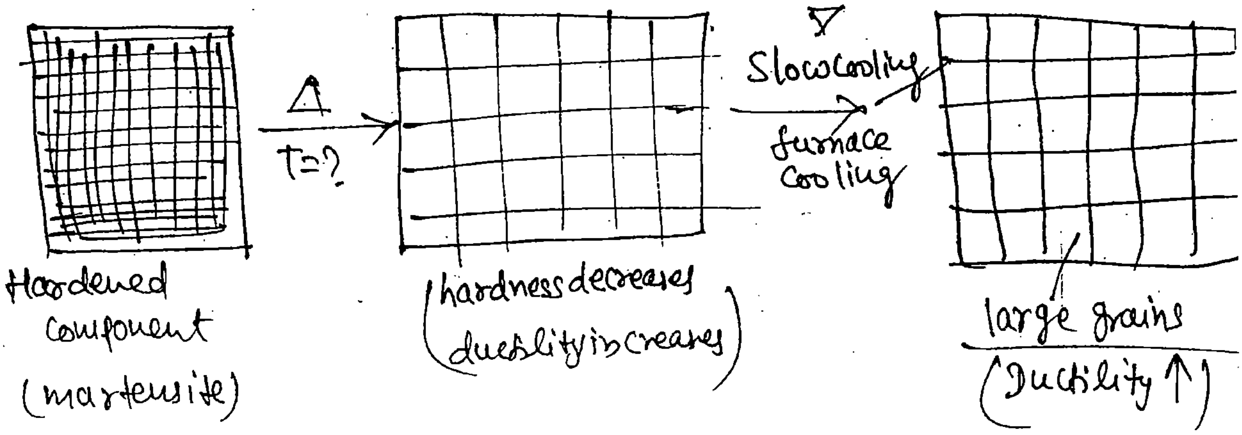
↳ more the vol. converts into martensite

↳ Dh is more.

② full Annealing :-

Ⓐ ↳ applicable to steels with %C = 0 − 2.11% (LCS, MCS, HCS)

→ The method of removal of residual stresses or obtaining ductility in a hardened Component by heating followed by slow cooling process.



$$\boxed{\text{hardness} \propto \frac{1}{\text{ductility}}}$$

T = ?

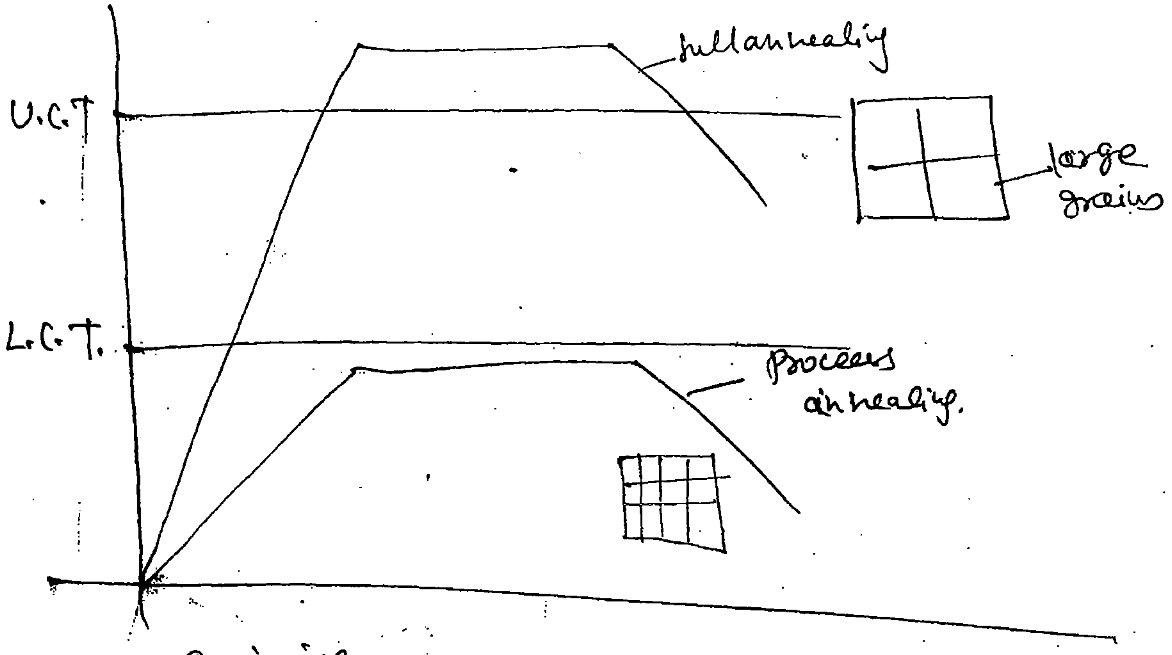
1) If % of C = 0 – 0.8 % → 50°C above U.C.T (AB)

2) If % C = 0.8 – 2.11 % → 50°C above L.C.T (BC)

→ In annealing due to slow cooling process the residual stresses will be relieved. but due to formation of large grains. The component will obtained ductility (hardness reduces).

(B) Process annealing :-

→ applicable to steel with % C = 0 – 0.4 %
(LCS & MCS only)



grain size

$G.S_{F.A.C} > G.S_{P.A.C} > G.S_{H}$ → hardness

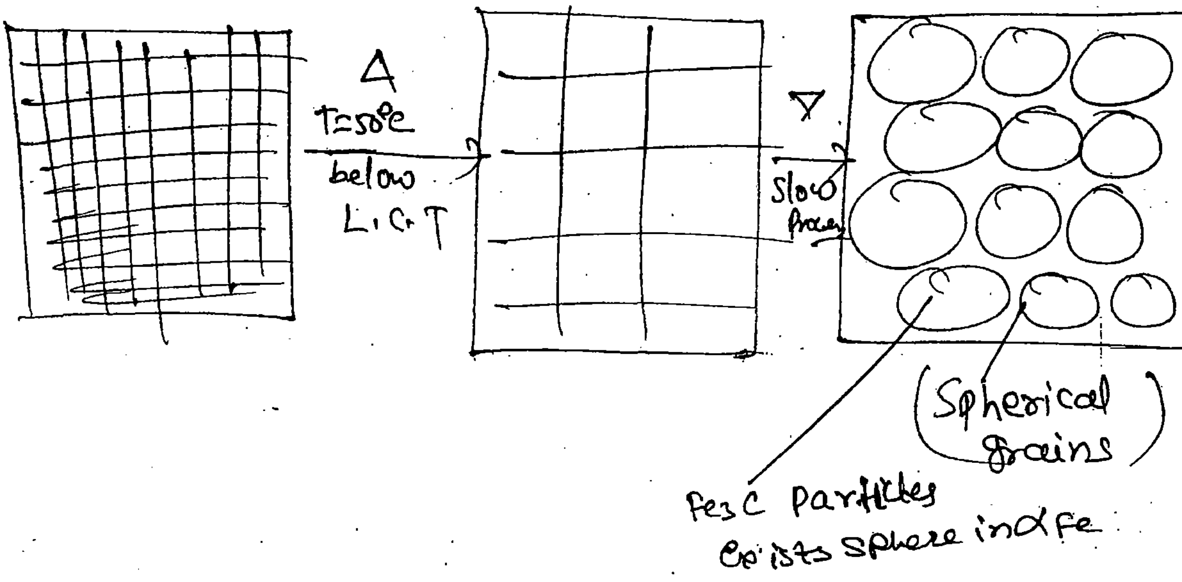
full annealing.

hardness → $H_{FAC} < H_{P.A.C} < H_{H}$

Ductility → $D_{F.A.C} > D_{P.A.C} > D_{H}$

© Spheroidisation annealing :-

→ applicable to steels with % C = 0.6 – 1.2% C (HCS only)



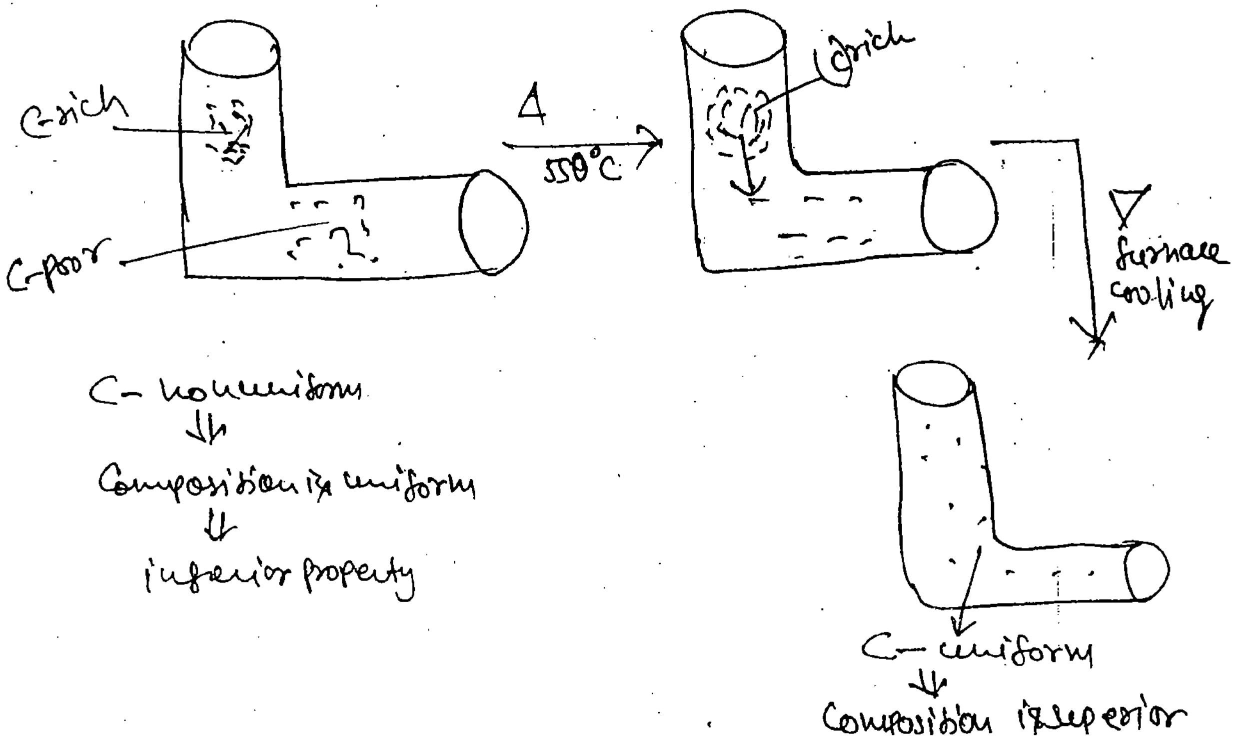
→ spherical grains offer uniform resistive force against the moment of the tool width with roll friction,

↳ machinability will be easy.

(D) Diffusion annealing :-

→ applicable to steel ⇒ [HCS + made by casting + in hardened state]

$\rho_{Fe} > \rho_C$



→ During casting process of high carbon steel, carbon rich and carbon poor zone will formed in the Component, because,

density → $\boxed{\rho_{Fe} > \rho_C}$

↳ Carbon residues non uniformly.

↳ composition is non uniform.

↳ exhibit inferior property.

∴ By heating the Component to 550°C, the carbon particles will achieves velocity and travels from c-rich to c-poor zones (diffusion)

↳ Carbon distributes uniformly

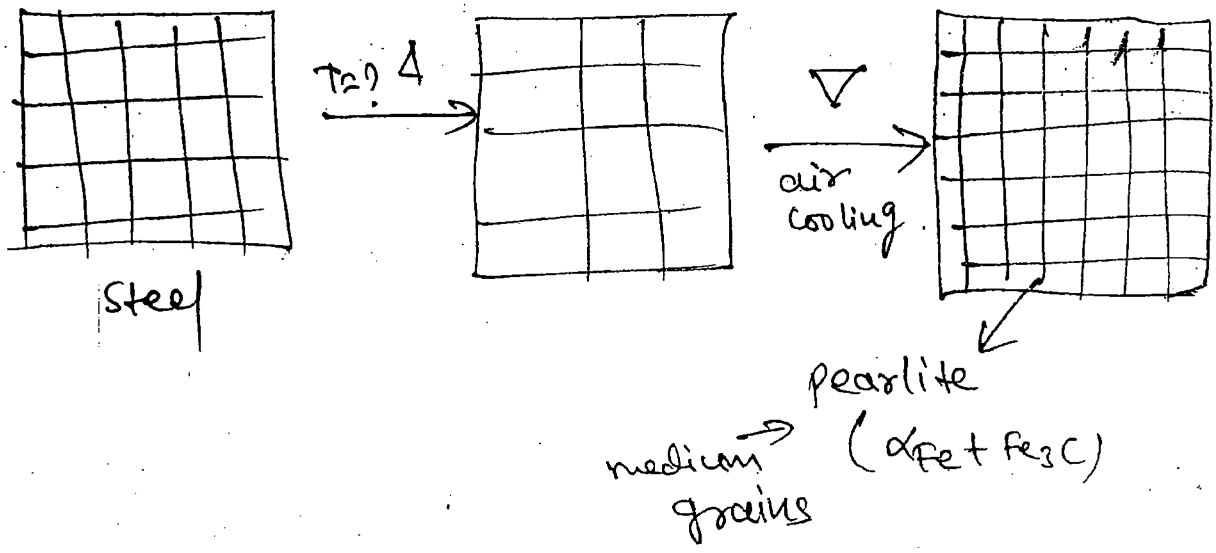
↳ exhibit superior property.

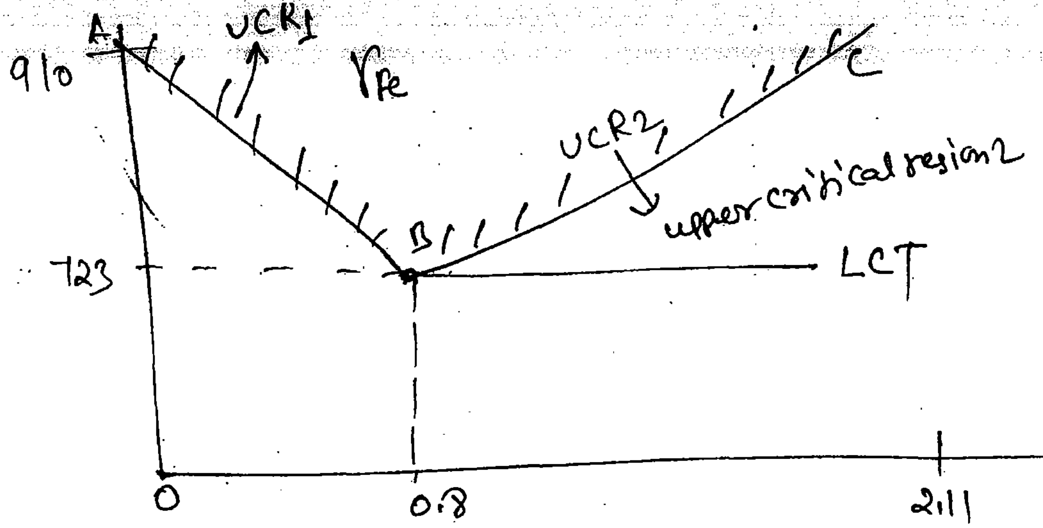
---

③ Normalizing :-

→ applicable to steels with $\% C = 0 - 2.11\%$ (LCS, MCS, HCS).

→ obtained pearlite phase in a steel component by heating followed by atmospheric cooling.





→ T=?

i) If % of C = 0 – 0.8 ⇒ 50°c above U.C.T (AB)

(ii) If % of C = 0.8 – 2.11 ⇒ 50°c above U.C.T (BC)

(iii) If % of C = 0.8 ⇒ 50°c above L.C.T (B)

→ **Pearlite** is the phase possess similar property of martensite with little improved ductility. Therefore normalised steel possess good strain along with considerable ductility.

→ Due to atmospheric cooling of the component. It will be oxidised partially.

↳ Corrosion resistance will be very high.

↳ used under, under water application like submarines & ship structures.

Hardening	Normalising	Annealing
↳ rapid cooling	↳ air cooling	↳ furnace cooling
↳ small grains	↳ medium grains	↳ large grains
↳ martensite	↳ pearlite	↳ amyphone
↳ with residual stress	↳ Partially R.S	↳ No R.S

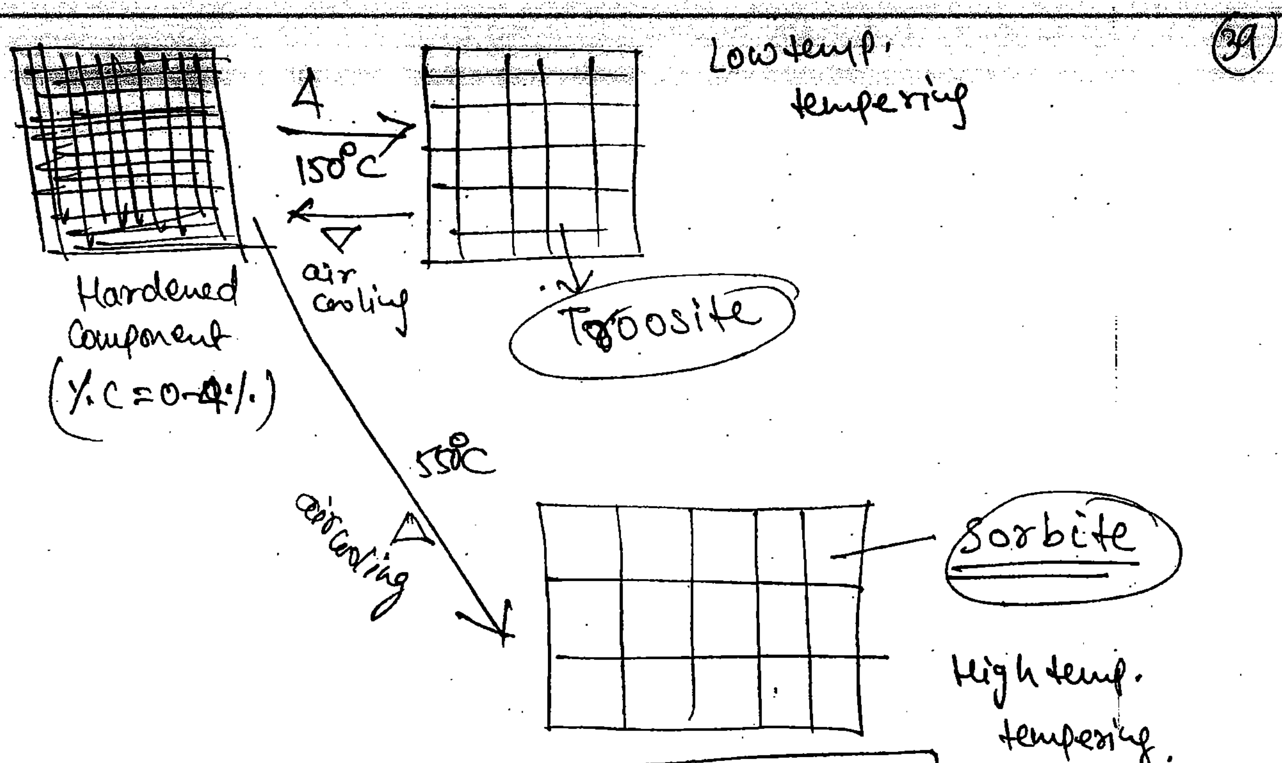
$$\boxed{\begin{array}{c} G.S_H < G.S_N < G.S_A \\ \hline H_H > H_N > H_A \end{array}}$$

H → hardening
N → normalising
A → annealing

④ Tempering :-

→ applicable to steel with % C = 0 — 0.4 %
(LCS, MCS) only

→ Obtaining ductility in a steel component by heating followed by atmospheric cooling



$G.S_{H} < G.S_{L.T.T} < G.S_{H.T.T}$

$H_{H} > H_{L.T.T} > H_{H.T.T} \longrightarrow$ High temp. tempering.

$H_{martensite} > H_{Troosite} > H_{Sorbite}$

* ⑤ case hardening :-

→ low carbon steels are difficult to harden by hardening process, because they posses low carbon contents
- ↳ iron carbide volume is less
- ↳ difficult to produce martensite.

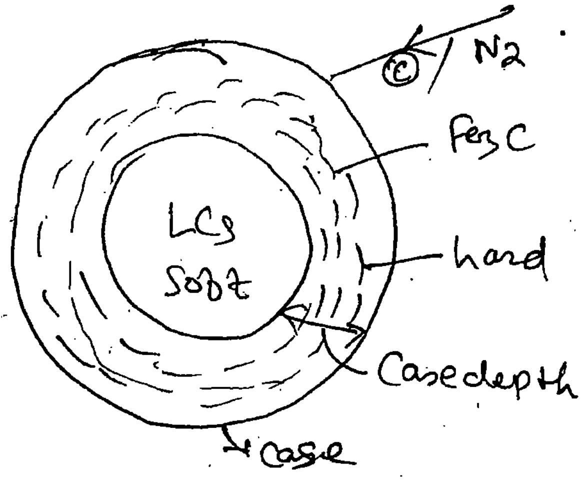
→ even though to achieve hardness, the hardening should be done, at a quenching medium of very low temp. but at that temp. the residual stresses will be greater than the strength of the material.

$$\boxed{\underset{\uparrow}{\sigma_{R.S}} > \sigma_{UTS}}$$

Residual stress

↳ Component will break into pieces.

2. To obtain hardness in a low carbon steel, case hardening is employed.



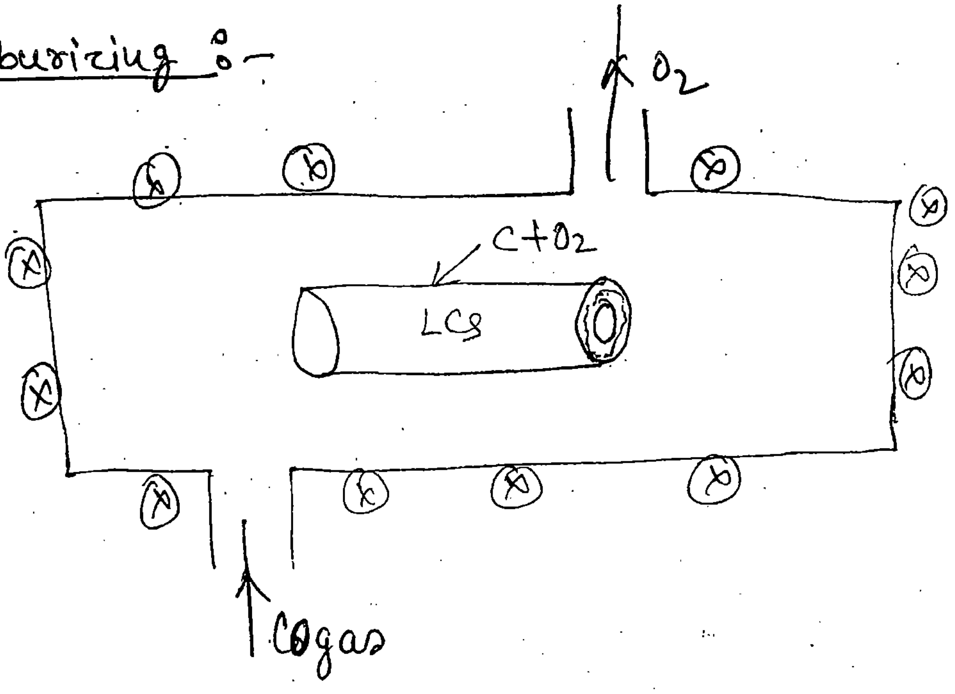
→ By incorporating C/ N_2 atoms on to the outer envelop (case of the components) iron carbide or iron nitride phases will be formed. and hence it will be termed as hard.

→ The depth up to which from the surface of the component has been hardened is called case depth (CD)

→ case hardening is composition modification process but not grain size modification.

① Carburizing :-

→



T = 850–900 C

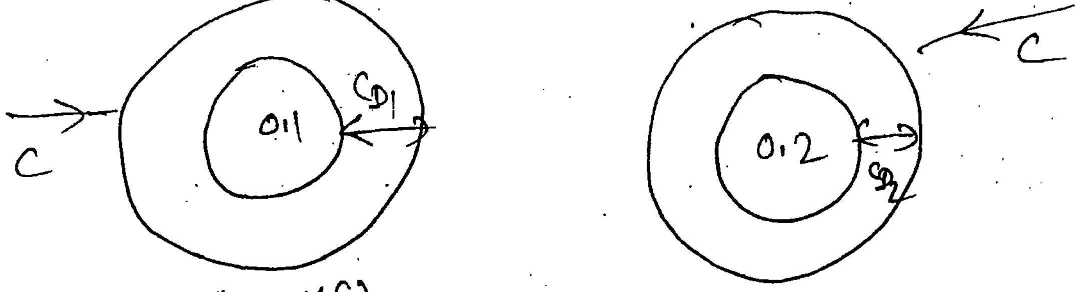
medium = CO gas, $CO \rightarrow C + O_2$

→ casedepth = 0.5mm / 5hr

→ By heating the component to 900°C, carbon monoxide gas will be circulated in the heated envelop.

→ CO gas break into carbon & oxygen, carbon atoms will penetrate into the component and oxygen atoms come out.

Case 1, Two low carbon steel component with different % of carbon has been carburized



(low % C)

Casedepth → $\boxed{CD_1 > CD_2}$ because if the component contains low carbon component it is easy to add external carbon atoms.

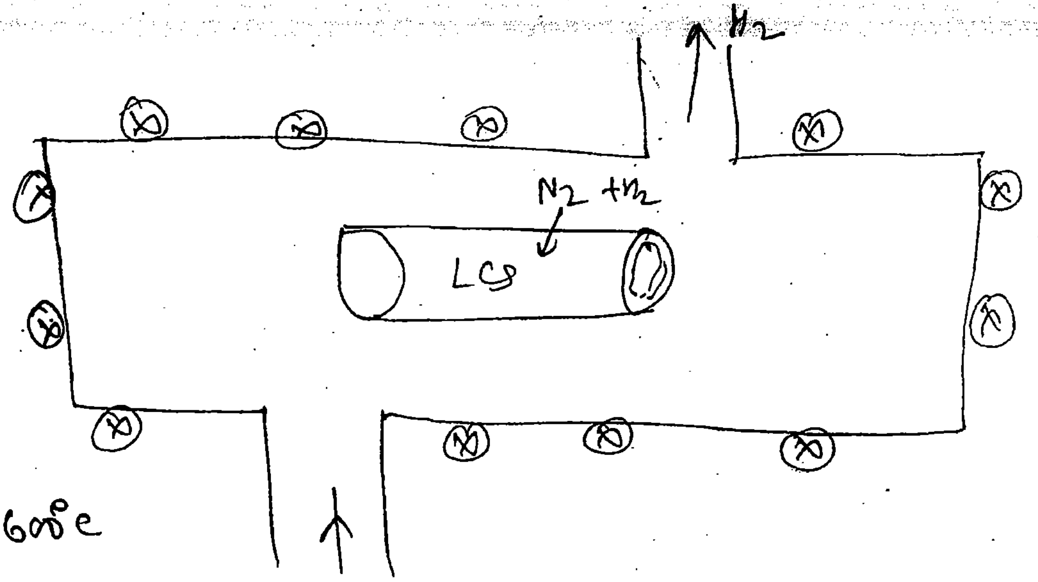
↳ high case depth

NOTE :-

→ To achieve more case depth in case hardening process, the component should posses low carbon content.

Ⓑ **Nitriding :-**

→ By incorporating N_2 atoms on to the outer envelop of the component, it will be termed as a hard by forming [illegible] (Fe_3N)



T = 550 - 600°C

medium = NH_3

$NH_3 \rightarrow N_2 + H_2$

casedepth = 0.5mm / 100 hr

→ melting point of LCS = 1500°C

→ Nitride steel posses more hardness on the surface and softness in the core.

→ Due to formation of iron nitride phase at the outer envelop it possess high temp. sensibility up to 2500°C.

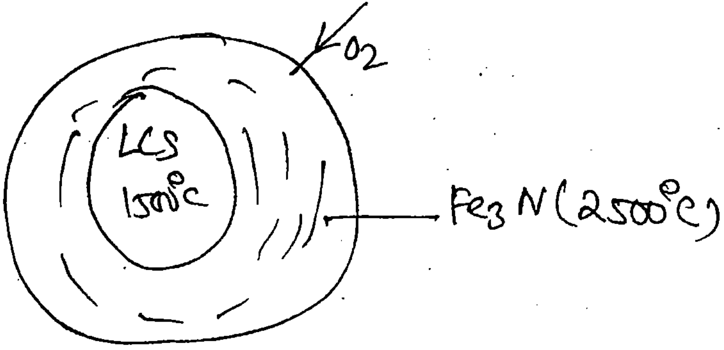
→ low carbon steels are corrosive in nature, but after nitriding process, the corrosion resistance increases tremendously due to iron nitride phase on the surface.

→ Nitride steel possess more hardness on the surface.
↳ errossion of material is less
↳ wear resistance is high.

→ Nitride steel possess good surface finish,

↳ friction will be less

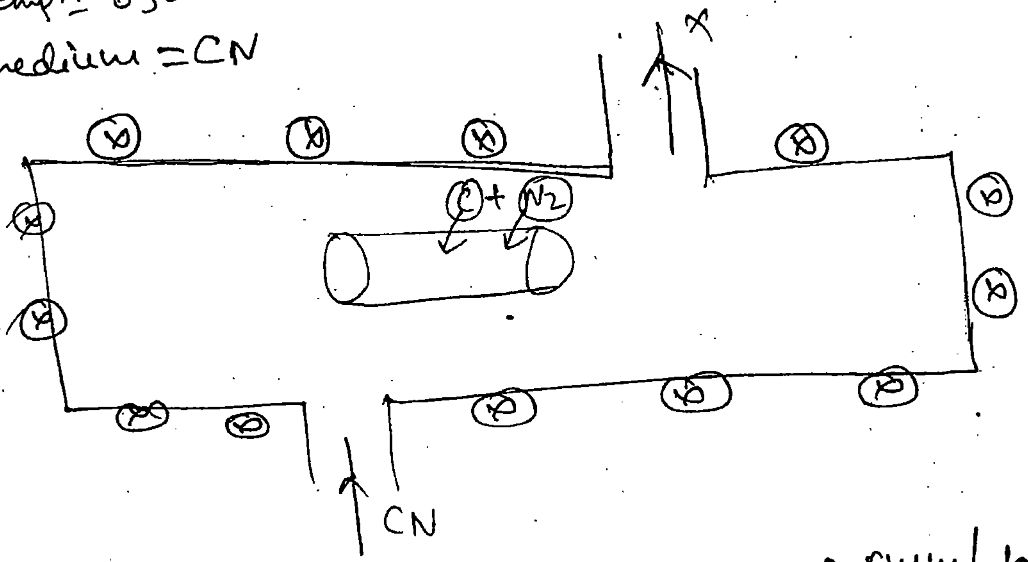
↳ abrasion resistance is high.



(C) cyaniding :-

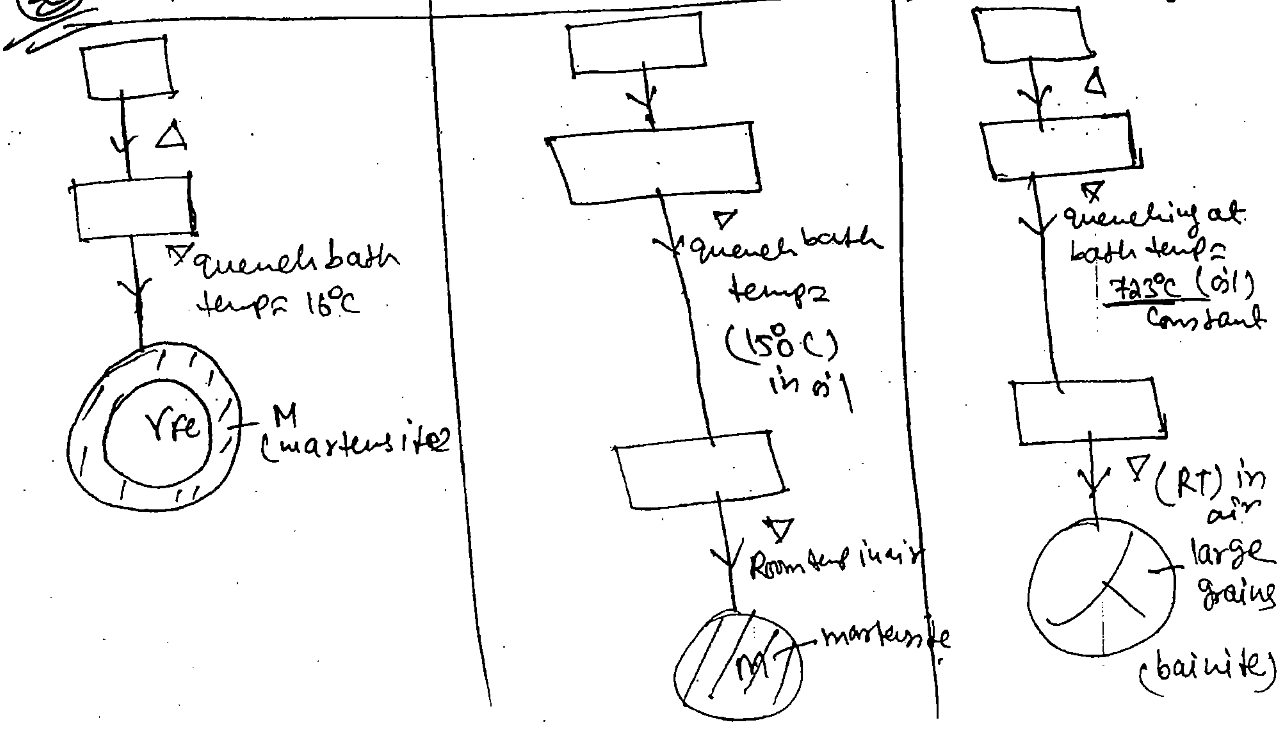
Temp = 650–700°C

medium = CN



$CN \rightarrow C + N_2$ case depth = 0.5mm / 10 hrs

(6) Hardening | martempering | Austempering



⇒ ~~Applicable~~

Hardening

- applicable to steels with % of carbon 0 – 2.11 % C
- residual stresses are more
- Intensity of cracks
- rapid Quenching.
- Partial volume converts into martensite.

martempering :-

- applicable to steels with % of C = 0 – 0.4 %
- Partial residual stress
- less intensity cracks
- Interrupted Quenching
- whole vol. converts into martensite

Austempering :-

- Steel with % of C = 0.8 %
- No stress.
- No intensity of cracks.
- Iso thermal Quenching
- Converts into <u>bainite</u> phase.

NOTE :=

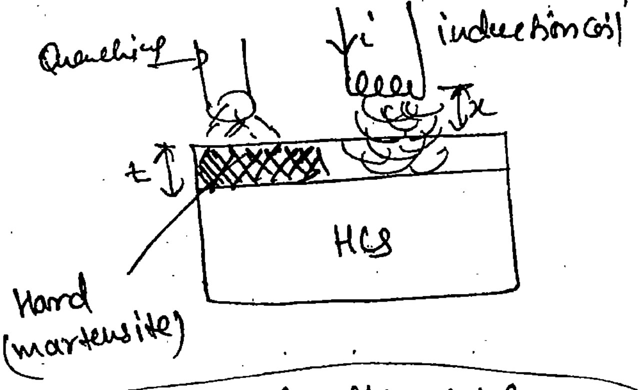
In aus tempering if the % of C is = 0.8 % and subjected to Quenching at a quenching medium of temp = 723°c then bainite will formed. During Quenching of the quenching medium temp is more than Ms, then austenite will formed insteadof bainite.

→ Hence Quench bath temp. should be maintained constan

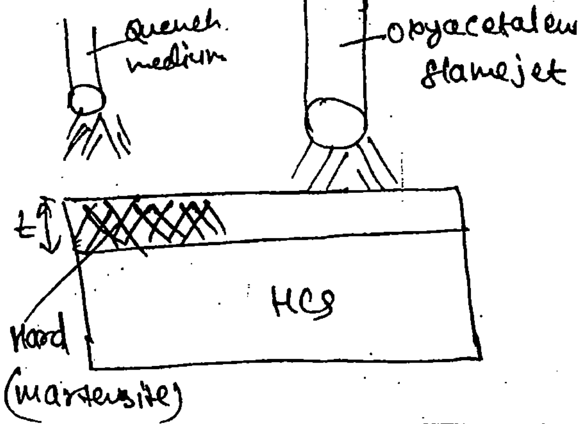
* surface hardening :-

→ applicable to HCS only.

→ · Induction hardening



Flame hardening



→ By using induction coil or oxyacetelence flame jet, the top surface of the component will be heated up to certain depth (t) by pouring the quench medium on the hot surface, the depth up to which it is heated will be termed as hard by forming martensite phase.

⟹ The distance from the coil to the surface of the component (x) and the temp. of the coil (t) should be constant, otherwise non uniform depth of heating takes place,

- ↳ which forms, non uniform depth of hardness
- ↳ undergo non uniform residual stress
- ↳ more intense cracks will form.

→ applicable to steel components with large surface area, eg - steel plates & sheets.

1 * plastics :-

C, H, O atoms only

① non corrosive ② light weight ③ low strength
④ serive temp ≃ 300°C

Thermoplastics (T.P)	Thermosets	Rubber/elastomers
① polymer terms as soft by heating.	① polymer form as hard by heating	① polymer form as hard by heating but the hardness achieved is a function of temp. to which it is heated $\boxed{\text{Hardness} \propto T}$
② At room temp available in the form of solid.	② At room temp. ⇒ liquids	② at room temp. ⇒ liquids
③ $\underset{(S)(R.T)}{T.P} \underset{\nabla}{\overset{\Delta}{\rightleftharpoons}} \underset{(L)(H.T)}{T.P}$	③ $\underset{(L)\,R.T}{T.S} \underset{\cancel{\leftarrow}}{\overset{\Delta}{\rightarrow}} \underset{(S)\,H.T}{T.S}$	③ $\underset{(L)\,R.T}{R} \underset{\cancel{\leftarrow}}{\overset{\Delta}{\rightarrow}} \underset{H.T}{R_{(S)}}$
④ Recylable	④ non recylable e.g- Helmet	④ non recylable
⑤ serricing temp = 150°C (max)	⑤ serricing temp = 300°C	⑤ serricing temp ≃ 300°C
⑥ By heating ⇒ losses strength By cooling ⇒ gains strength	⑥ By heating ⇒ gains strength By cooling ⇒ no change	⑥ By heating → gains strength by cooling → no change
⑦ shaping ⇒ during cooling	⑦ shaping ⇒ during heating	⑦ shaping → during heating
⑧ environmentally hazardous	⑧ environmentally hazardous than thermoplastics	Ex-
⑨ Ex- polyethelene, polystyrene, tefflon, PVC (Polyvinyl chloride)	⑨ Ex- epoxy regin, phenolic regin, vinyl ester (liquid)	

Note :- $R_{R.T} \xrightarrow{\Delta (50°C)} R_{50}$ (soft rubber)
(L)

$R_{R.T} \xrightarrow[150°C]{\Delta} R_{150}$ (Hard rubber)

Hardnes $\propto f$(Temp.)

→ $\boxed{H \propto Temp.}$

Ep :- ① butyl rubber ⇒ soft rubber ⇒ car tubes

② Nitrile rubber ⇒ high temp. sustainable
Ep- gascade

③ styrene butadiene rubber (SBR)

→ $\boxed{T.P/T.S/R + additive = plastic}$

* **Additives :-**

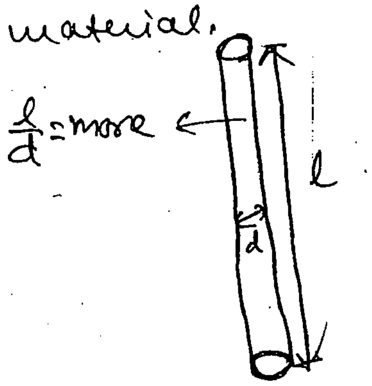
→ compound use to improve mechanical or thermal or any property of polymer.

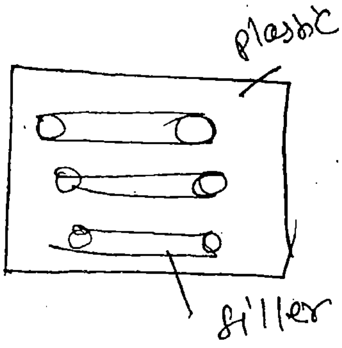
① **Asbestos** -
gives moldability and heat resistance.

② **Mica** -
Improve thermal conductivity & electrical resistance.

③ **filler.**
improve mechanical strength of material.

Steel : Steel fibre
Carbon "
Glass "
Graphite "
Aramid/kevlar "





⟹ F.R.P
fibre reinforcement plastics

$M_1 + M_2 \Rightarrow C_1 \rightarrow$ composite

→ as it is condition, polymer possess low strength but by incorporting high strength fibres, (reinforcements) in the polymer materials, the strength of plastic can be increase tremendously, known as fibre reinforced plastics (FRP).

→ FRP possess lightweight high strength property.

Ex:- $\underset{\text{material}}{M_1} + M_2 \Rightarrow$ FRP

$$\boxed{\underset{\text{lightwt}}{\text{plastic}} + \underset{\text{highstrength}}{\text{fibre}} \Rightarrow \text{FRP}} \rightarrow \text{lightwt \& high strength}$$

* CFRP:-

+ If carbon fibre is embeeded in a plastic part, known as CFRP.

$$\boxed{\underset{\text{strength}}{S_{CFRP}} = 100(\overset{\text{strength}}{S_{steel}})}$$

$$\boxed{\underset{\text{weight}}{W_{CFRP}} = \frac{W_{steel}}{8}}$$

CFRP properties

1) Light weight
2) high strength
3) servicing temp = 300°C

applications of CFRP :-

- → aerospace structure
- → aircraft components
- → rocket motor casing etc,

15)

* Glass fibre R.P :- (GFRP)

→ If glass fibre is embedded in the plastic part, called as glass FRP.

- → highly anti corrosive
- → light weight,
- → $S_{GFRP} < S_{CFRP}$

applications

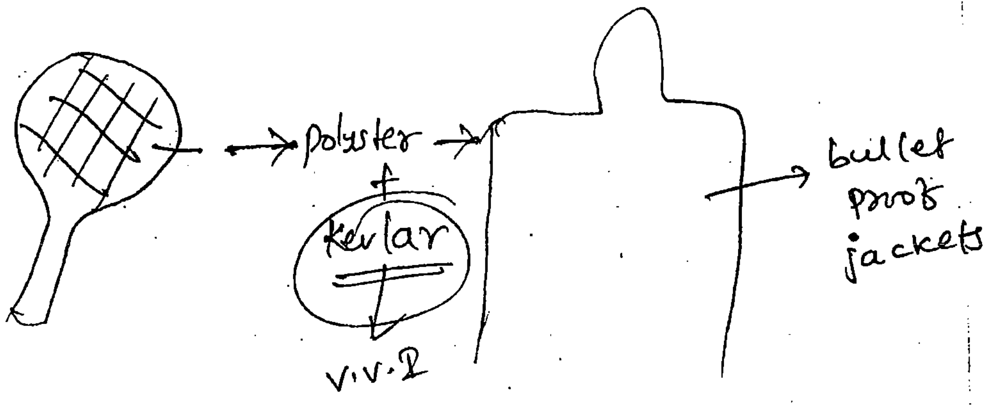
- → under water applications
- → (submarines
- → outer envelop)
- → ship structures

* graphite FRP :-

→ If graphite fibre is embedded in a ~~glass~~ plastic part, is called Gr FRP.

8th

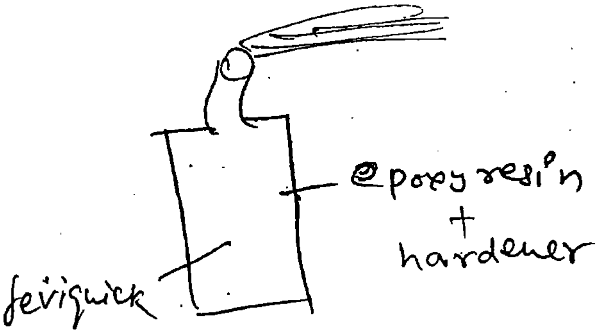
- → high temp. sustainable
- → strength high < CFRP
- → light weight



* Dyes and Pigments :-

① Hardener :-

→ which improves hardness of polymer



② plasticizer -

- improve toughness of the polymer.

③ UV-stabilizer -

→ Improve stability of plastic, against sun radiation exposure.

---

* Production methods of plastic part :-

① moulding/casting	② forming	③ laminating
Ⓐ Compression moulding (TS&TP)	Ⓐ Thermoforming (TP)	(TP & TS)
Ⓑ Transfer " (TS)	Ⓑ Roll forming (TP)	
Ⓒ Injection " (TP)	Ⓒ Extrusion " (TP)	
ⓓ Blow " (TP)		

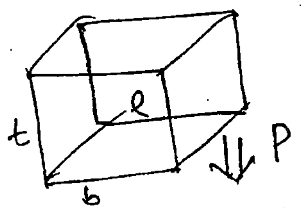
TP → Thermoplastics

TS → Thermosets

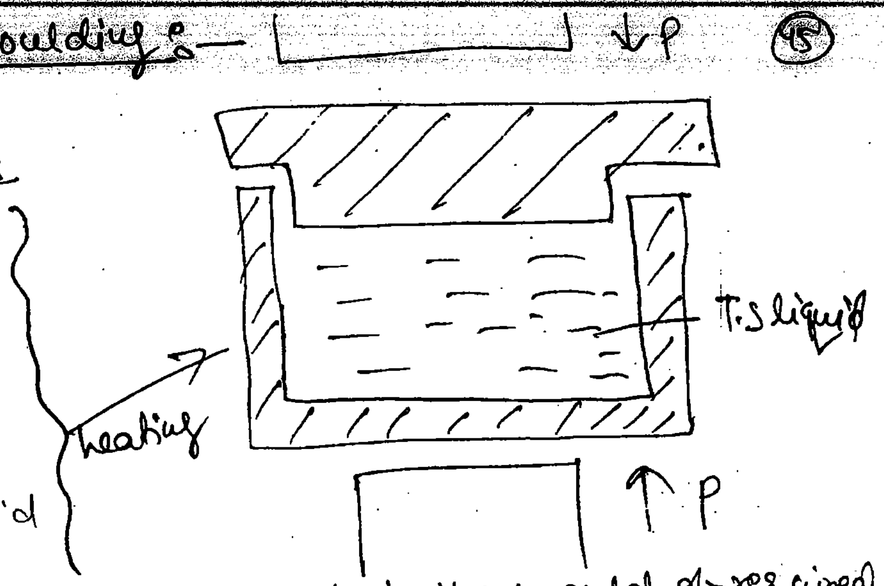
① Compression moulding :-

→ T.P & T.S

case-2 thermosets



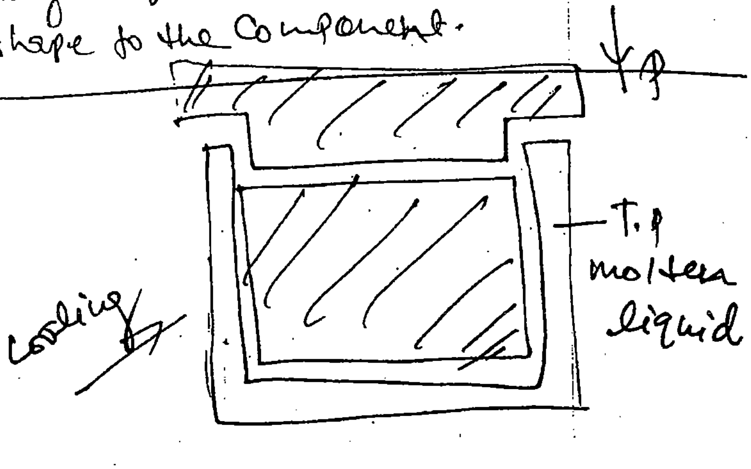
liq → gel → solid



→ A thermoset liquid is kept in the mould of required shape of the component and subjected to heating under pres. during heating process. The liquid will undergo the following changes.

→ during gel time, the compression load is applied on the mould so that, shaping of the component can be done. Heating liquid into hard whereas compression gives shape to the component.

Case-A T.P



→ Thermoplastic molten liquid is kept on the mould and subjected to compression load. followed by cooling process.

Compression gives the required shape of the component and whereas the cooling converts the molten liquid into solid.

① thickness, density and the strength of the plastic can be controlled by varying the compression load p.

$$\boxed{\rightarrow p \propto \frac{1}{t} \propto \rho_{plastic} \propto S_{plastic}}$$

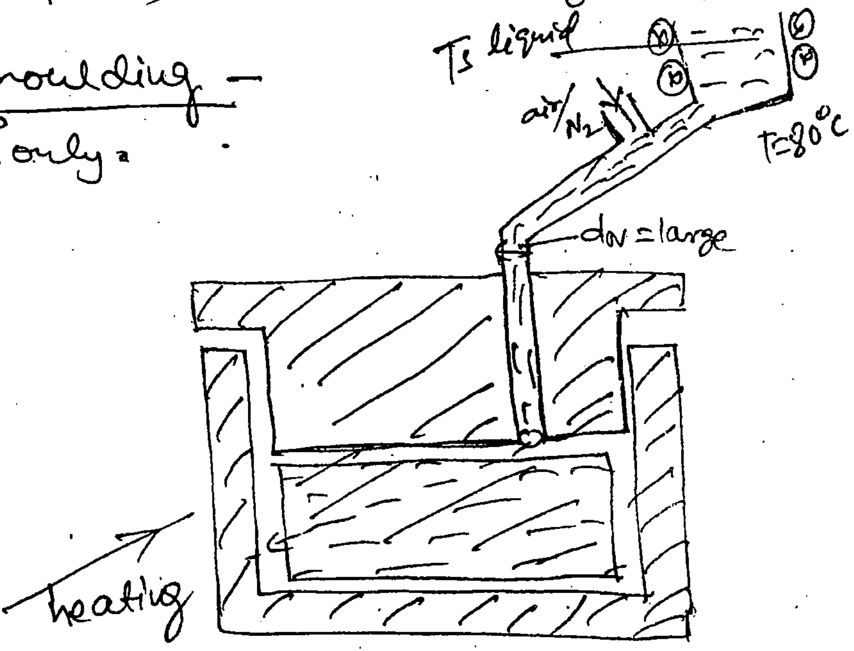
② nonuniform density of the plastic part will be produced if the component shape is complex.

③ difficult to insert metallic pieces in plastic part by this method.

<u>Ex</u>:- gascets, seals, washing machine outer envelops, automobile parts, refrigerator housing, helmets etc.

Ⓑ Transfer moulding -

→ ~~applicable to~~ thermosets only.

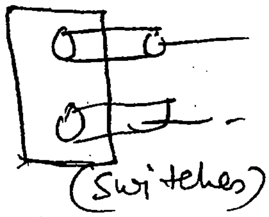


→ Thermoset liquid will be heated to 60 to 80°C so that the viscosity is reduced, the liquid is pressurised at outside the mold assembly and transferred into the space b/w the moulds, so that the liquid particles occupies the volume b/w the moulds with uniform compaction among the atoms.

↳ density of the component is uniform.

→ after filling the mould It will be subjected to heating process and termed as solid.

Ex:-



① uniform density of the component can be produced for simpler and complex shapes.

② ~~density~~ $\boxed{\rho_{plastic} \propto \underset{\substack{\downarrow \\ \cancel{load}\ pressure}}{P} \propto S_{plastic}}$ β_0

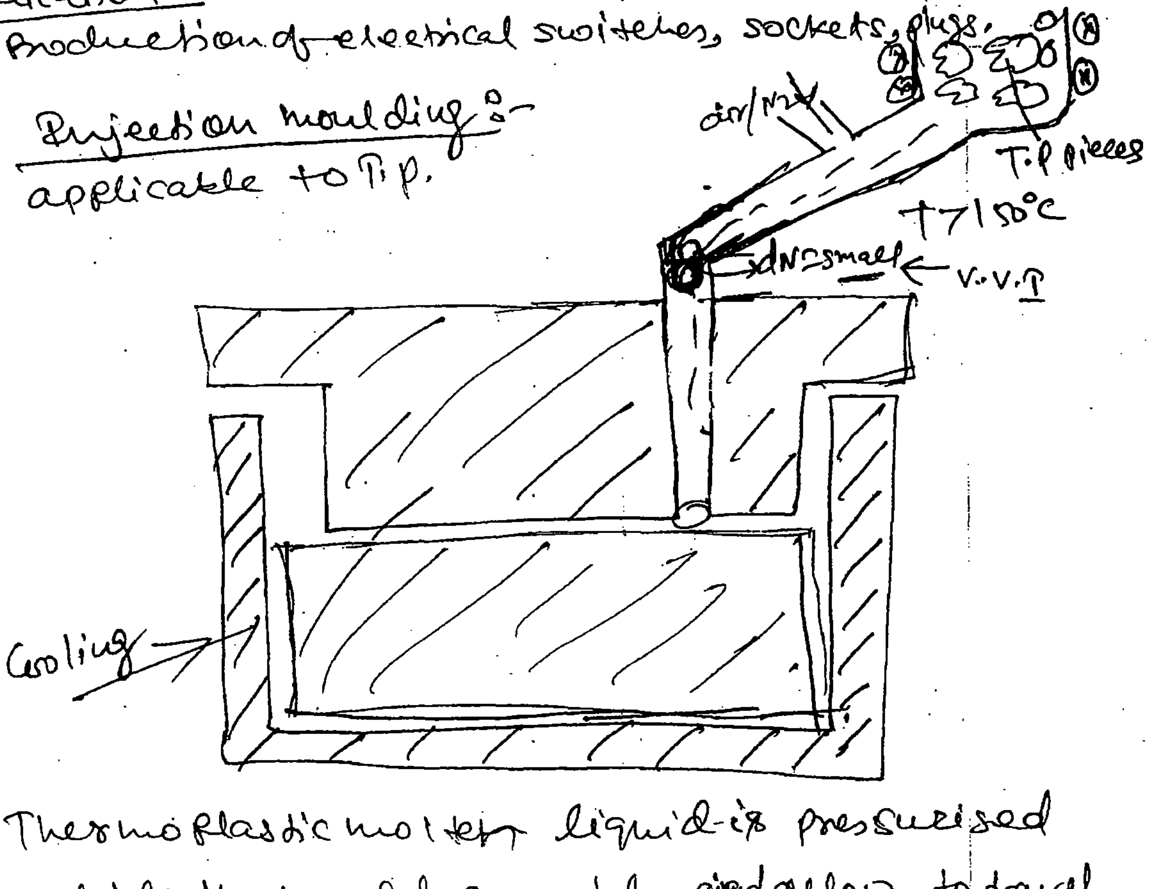
③ insertion of metal pieces is possible.

application

① Production of electrical switches, sockets, plugs.

Ⓒ Injection moulding :-

→ applicable to T.P.



→ Thermoplastic molten liquid is pressurised and outside the mould assembly ~~and~~ allow to travel through a nozzle of (dN) (injector); with high velocity and high pressure.

→ After filling the liquid in mould assembly, By cooling mould the liquid will termed as solid.

→ Any shape of the component can be produced.

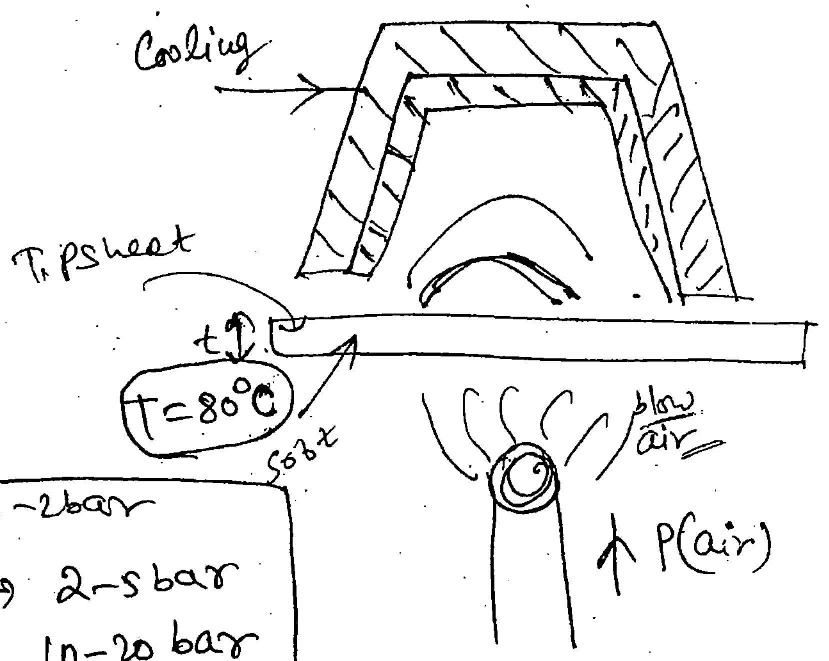
→ uniform density of plastics can be produced.

→ The component can be produced any no. of times till it achieves the required dimensional accuracy.

→ $\boxed{P \propto \rho_{plastic} \propto S_{plastic}}$

pressure

(D) Blow moulding :-



Ex air
1. water bottle → 1-2 bar
2. bucket figs → 2-5 bar
3. Sintex → 10-20 bar

→ A Thermoplastic film or sheet of thickness (t) is kept at the entrance of the mould in soft condition by heating the sheet to 80°C by blowing with high pressure air, the sheet will bend according to the internal shape of the mould, so that it achieve the required shape of the component.

→ By Cooling the mould, it will be termed as hard.

→ If the shape of the mould is complex, pressure distributes non uniformly,

↳ non uniform Compaction of the film takes place,

↳ non uniform thickness will form in the Component.

↳ dimensional accuracy will be less.

→ To produce high thickness plastic part, high blowing pressure are required.

Applications :-

plastic water bottels, bucket, jugs, liquid containe etc.

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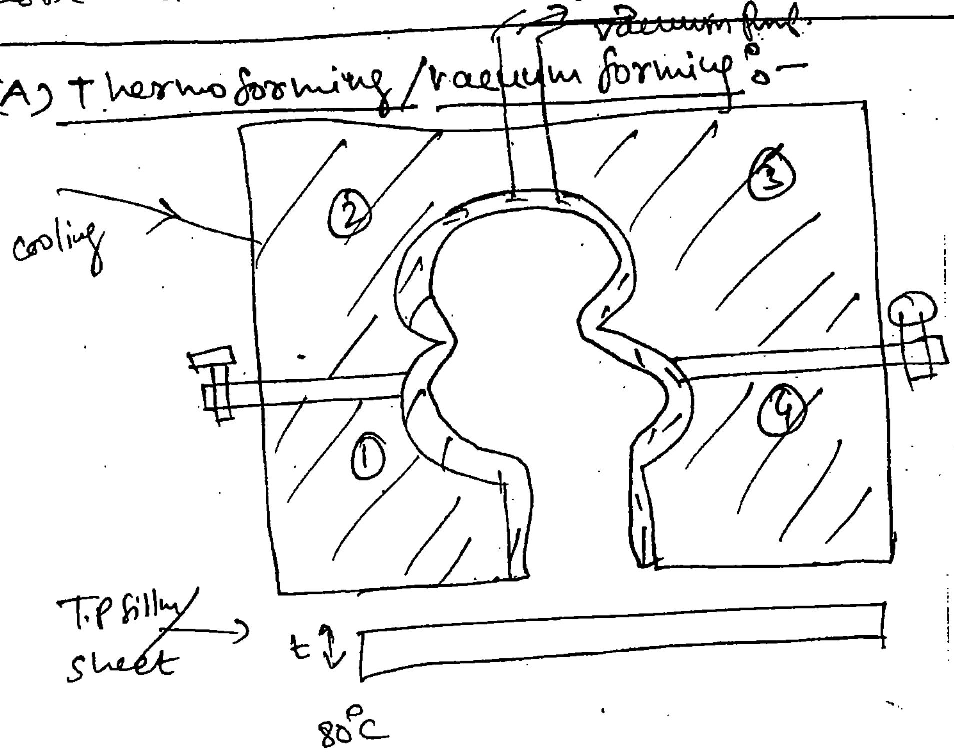
② (A) Thermoforming / vacuum forming :-



→ A thermoplastic ~~film~~ of sheet of thickness is kept at the entrance of the mould and subjected to vacuum suction phenomenon from the opposite end of the mould assembly. The film deposits slowly on the internal surface of the mould and achieved the required shape of Component. by Cooling the mould It will achieve the hardness.

→ Vacuum is a slow phenomenon and distributes uniformly though out the mould.

↳ composition is uniform.

↳ thickness of the component is uniform.

↳ dimensional accuracy is high.

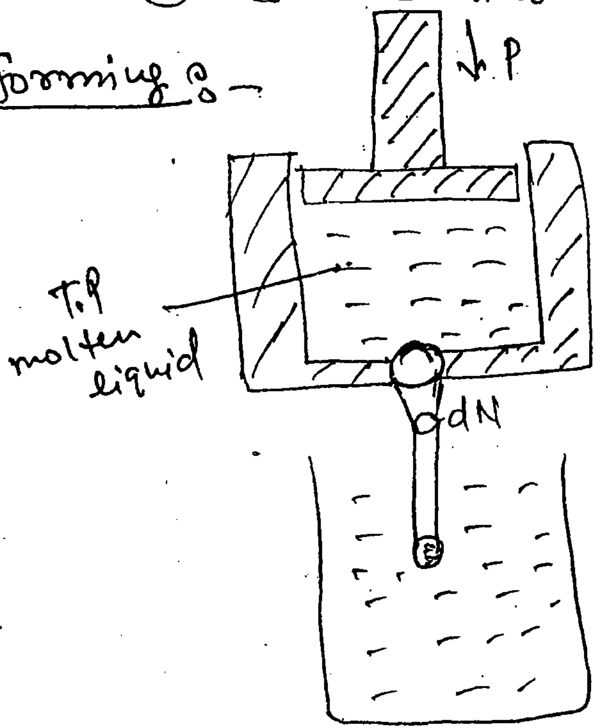
→ To produce large thickness plastic parts, high capacity vacuum pumps are required.

↳ difficult to produce & expensive.

applications :-

① cosmetic bottles ② medicine bottles.

(B) Extrusion forming :-



→ T.P molten liquid is pressurised in the mould assembly and allow to travel through a nozzle of dia. (dN). The molten liquid will extrude in the form of a rod shape of the dia. (dN) is subjected to cooling immediately in a quench medium. so that it forms as hard.

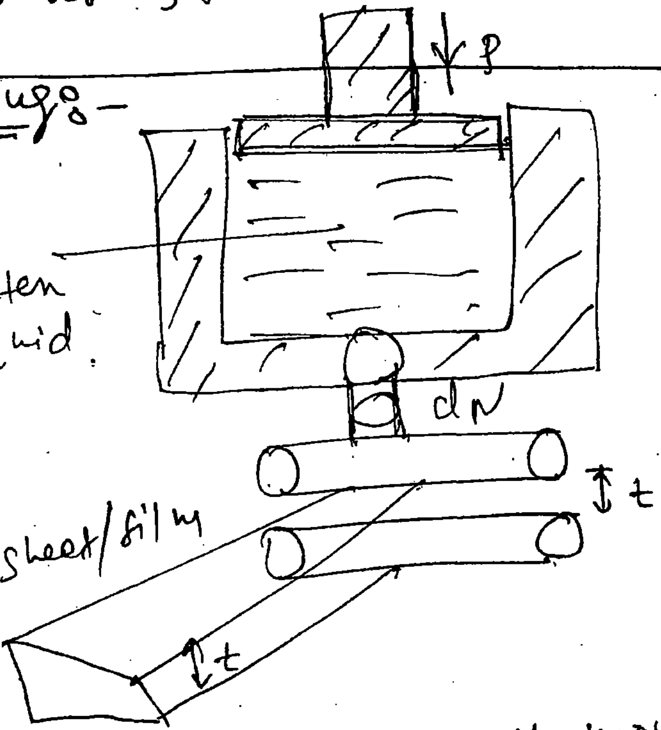
→ To produce plastic rods & wires, this method will be used.

T.P molten liq + hardener → rod

' ' ' ' ' " + Plasticizer → wire

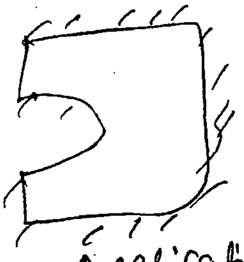
Ex- Nylon, wires, ropes, threads etc.

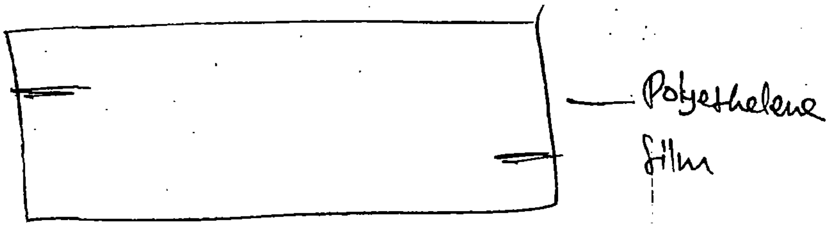
(c) Roll forming:-



→ T.P. molten liquid is pressurised in the mould and allowed to travel through the rollers assembly of specified ~~[illegible]~~ spacing. The liquid will extrude in the form of a sheet or film of thickness(t)

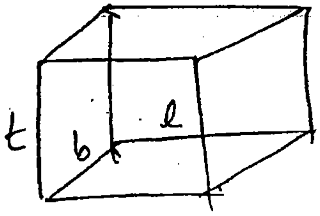
→ To produce Plastic sheets or film, this method is used.

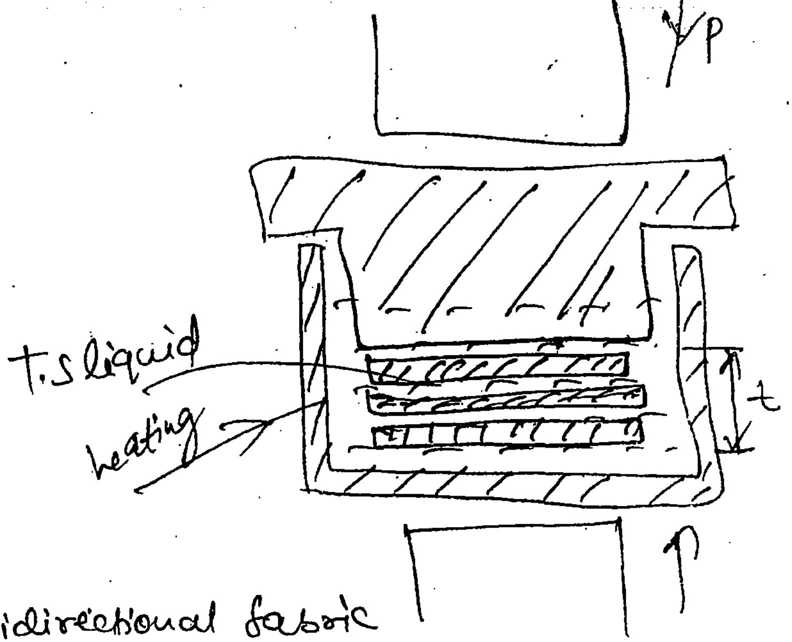


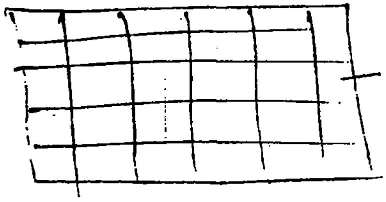


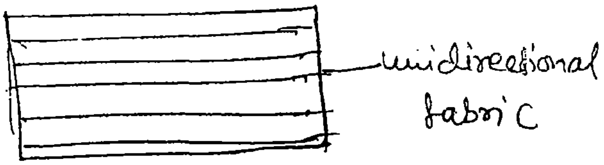
Applications:- Polyethelene film (carry bag)

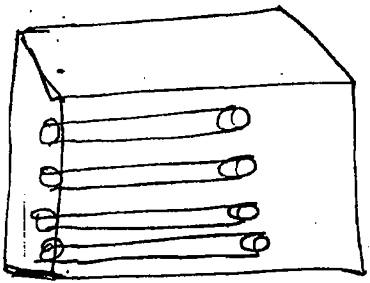
8)* Laminating :-







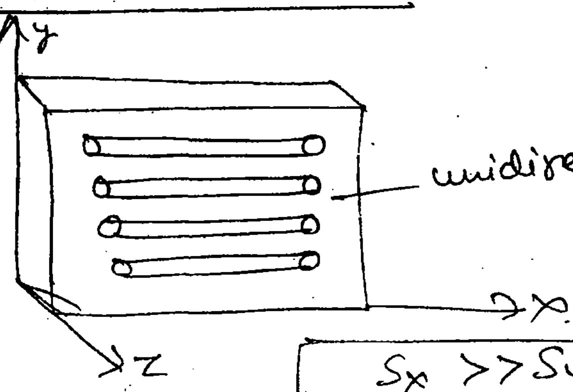




→ A thermoset liquid is kept in the mould of required shape of the component and high strength fibres will be kept in the liquid as layer structure, so that the thickness of the component 't' can be builded. By heating the mould assembly and subjecting to compression load, It will be termed as hard and achieve the required shape. as it is condition, The plastic possess low strength but after incorporation of high strength fibres, The strength of plastic will be increased tremendously; known as

fibre reinforced plastics (FRP).

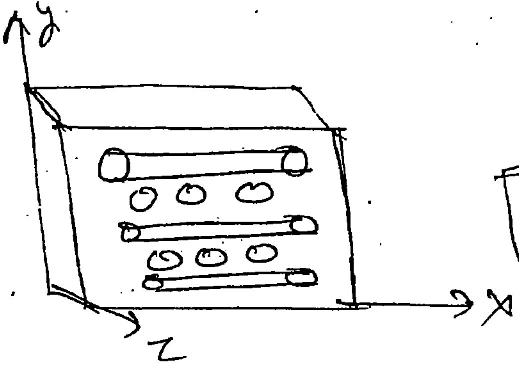
Case-1)



unidirectional FRP

$$\boxed{S_x >> S_y = S_z}$$

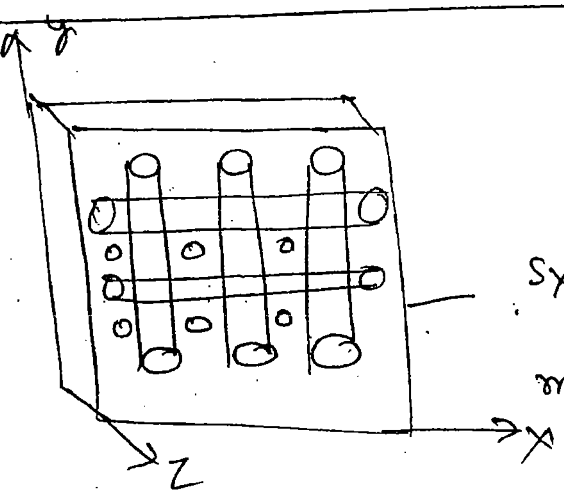
Case-2)



$$\boxed{S_x = S_y >>> S_z}$$

Bidirectional FRP

Case-3



$S_x = S_y = S_z$ = very high

multidirectional FRP

→ The strength of FRP can be changed by –

① varying the no. of layers

② varying the fibre orientations

→ ③ In FRP as for the design requirement, the strength & the thickness of the component can be controlled by arranging the fibres in the reqd. orientations,

↳ Hence they are called as advanced materials.

→ In case of metals ~~all~~ strength remains same in all the directions.

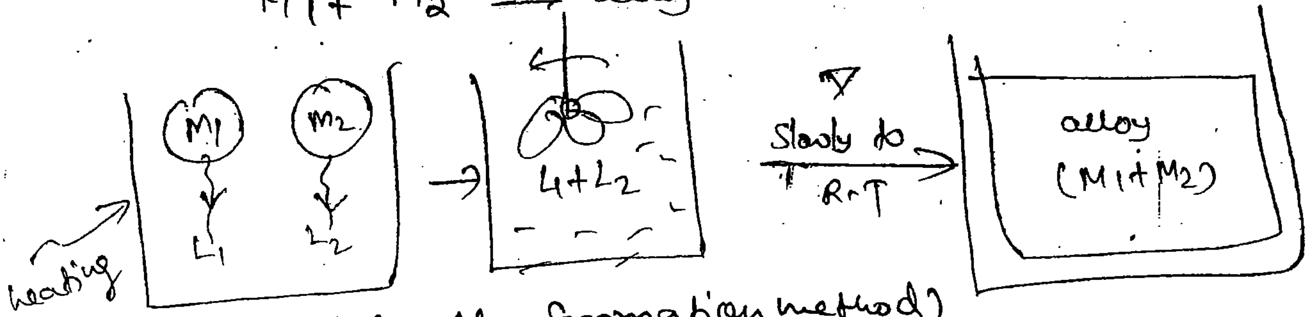
→ FRPs are anisotropic, because strength vary with respect to direction of the fibre.

→ FRPs are also called as composite materials with light weight and high strength characteristics.

Plastics	Purpose
① Polyethylene	→ good tensile strength e.g. carry bags, films, sheets, tubes etc.
② Polystyrene	→ sound proof plastic e.g. outer envelop of refrigerator
③ Poly vinyl chloride (PVC)	→ moisture resistance & electrical resistance e.g. pipes & tubes
④ Poly tetra fluoro ethane (PTFE) / Teflon	→ moisture resistance, scratch resistance, low friction coefficient. e.g. coating
⑤ Polycarbonate	→ high impact resistance goggles, helmet cover etc.
⑥ Nylon -	→ Ropes, clothes, thread
⑦ Acrylic	→ highly transparent plastic, moisture resistance e.g. paints, Antifungal

Powder metallurgy :-

$M_1 + M_2 \Rightarrow$ alloy



(general alloy formation method)

→ Production of components by using initial materials in the form of powders is known as powder metallurgy.

By mixing two metals with small difference in melting point and to form an alloy the following steps will be followed –

① Conversion of bulk metals into molten liquids

② obtaining homogeneous solution of ~~water mole~~ molten liquids.

③ obtaining an alloy by slow cooling process of molten mixture.

→ Powder metallurgy is applied in the following cases – (where general alloy formation method is invalid)

Case-I

Two metals with large diff. in melting point and to form an alloy.

Ex. $Fe + Cu \Rightarrow Z$

Fe 1598°C, Cu 1084

Case-II :- metal + (metal do not form molten liquid) e.g. tungsten (Powder)

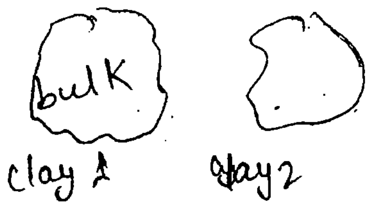
Fe + W.

Case-3 metal + compound

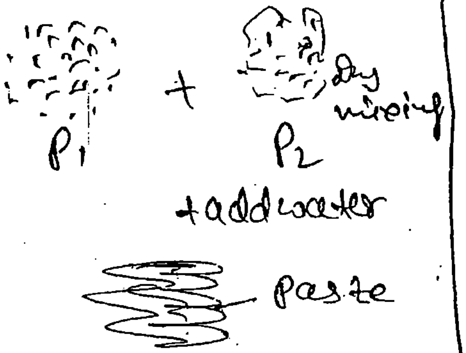
Ep- Fe + SiC

* Red brick production -

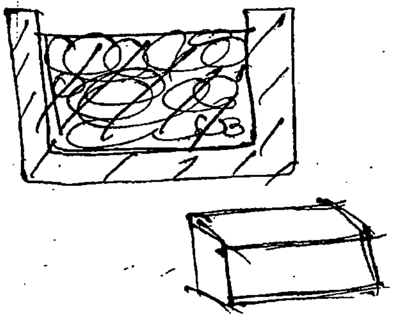
①



②



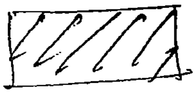
③



1. production of powders from material.

2. mixing of powders

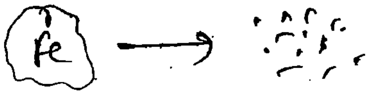
③ compaction

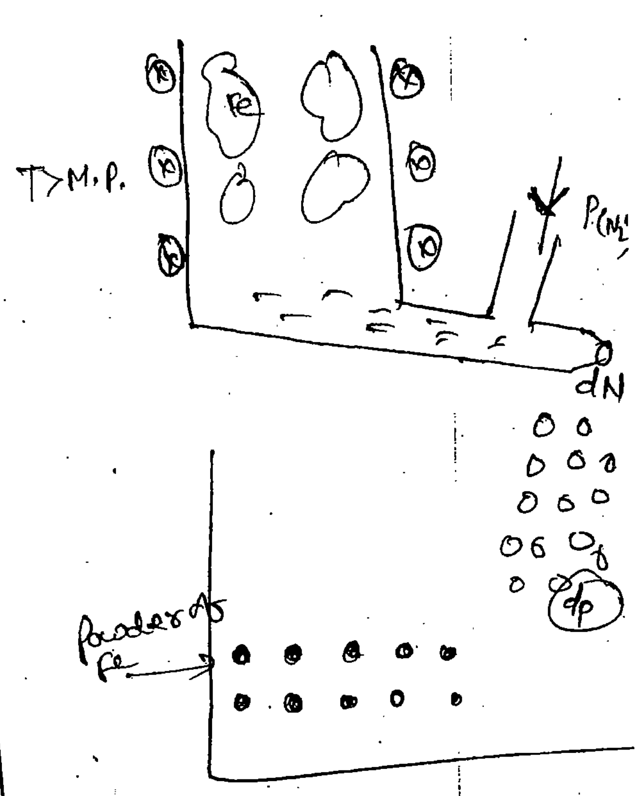


④ Sintering
(burning)

① Production of powders

Ⓐ automization :-





→ molten liquid of metal is allow to travel through a nozzle of dia. (dN) with high pressure & high vel.

→ The molten liquid will break into small liquid spherical droplets of dia. (dp), which will be cooled immediately & solidify.

↳ a powder of particle size (dp) is produced.

$$\boxed{\frac{1}{d_p} \propto \underset{\text{pressure}}{P_g}} \qquad \boxed{d_p \propto d_N}$$

→ Production rate is high.

→ all metal powders are produced by this method.

Ⓑ mechanical methods :-

→ for Brittle materials only.

→ machining/crushing/impacting/milling/grinding etc.

Ⓒ chemical methods :-

Reduction (removing oxygen)

$$Fe_2O_3 \xrightarrow{\overset{\otimes}{-O_2}} \overset{\text{Brittle iron}}{B_{Fe}} \xrightarrow[\text{method}]{\text{mechanical}} \overset{\text{Powder}}{P_{Fe}}$$

$$Al_2O_3 \xrightarrow{-O_2} B_{Al} \xrightarrow{M.M} P_{Al}$$

$$SiO_2 \xrightarrow{-O_2} B_{Si} \xrightarrow{M.M} P_{Si}$$

→ To produce powders from metal oxides, this method will be used.

→ By addition of suitable chemical, oxygen is removed from the compound (reduction) and termed as powders.

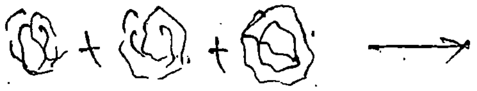
→ Production rate is less & the powders can be produced.

---

② Mixing of powders :-

$M_1 + M_2 + M_3 \longrightarrow$ Powder metallurgical component

mixing ratio



70% 20% 10%

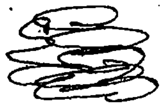
(Dry mixing)

↓

add solvent (acetone, alcohol, CCl_4) etc.

↓

wet mixing ⇒



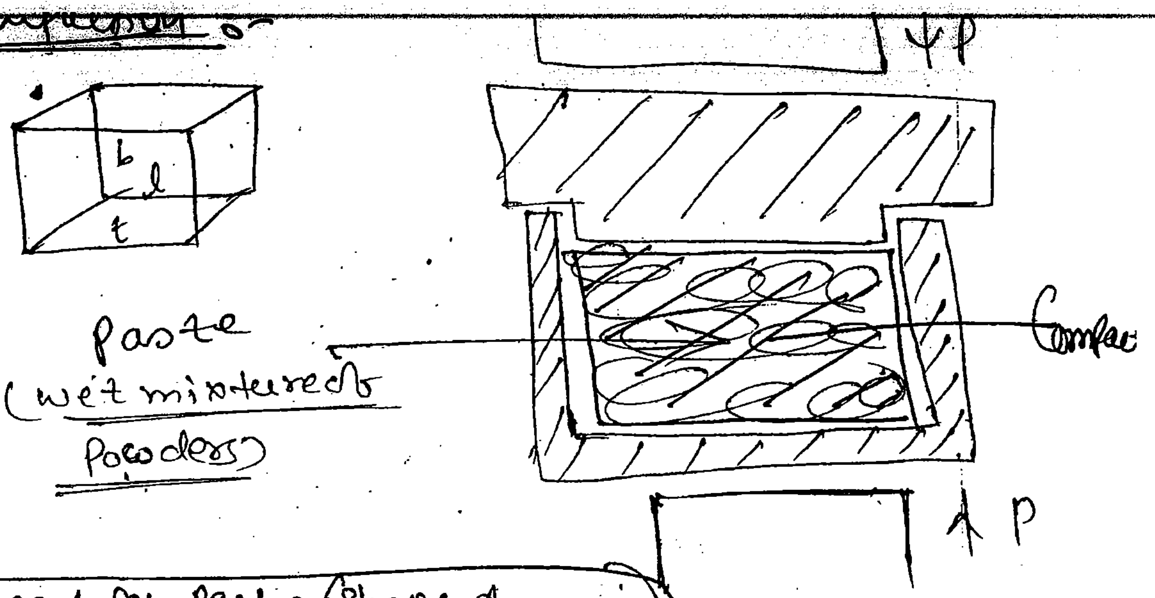
Paste (wet mixture of powders)

→ mixing is the most crucial stage in powder metallurgical process because, the mixing ratio of powders will be decided.

↳ Composition will be decided.

↳ final strength of powder metallurgical component will be decided.

(3) Compaction :-



→ shape of compact = (shape of final component)

→ The ~~weight~~ wet condition of the powder mixture (paste) ~~(wet)~~ is kept in the mould of required shape of the component & subjected to compaction under press.

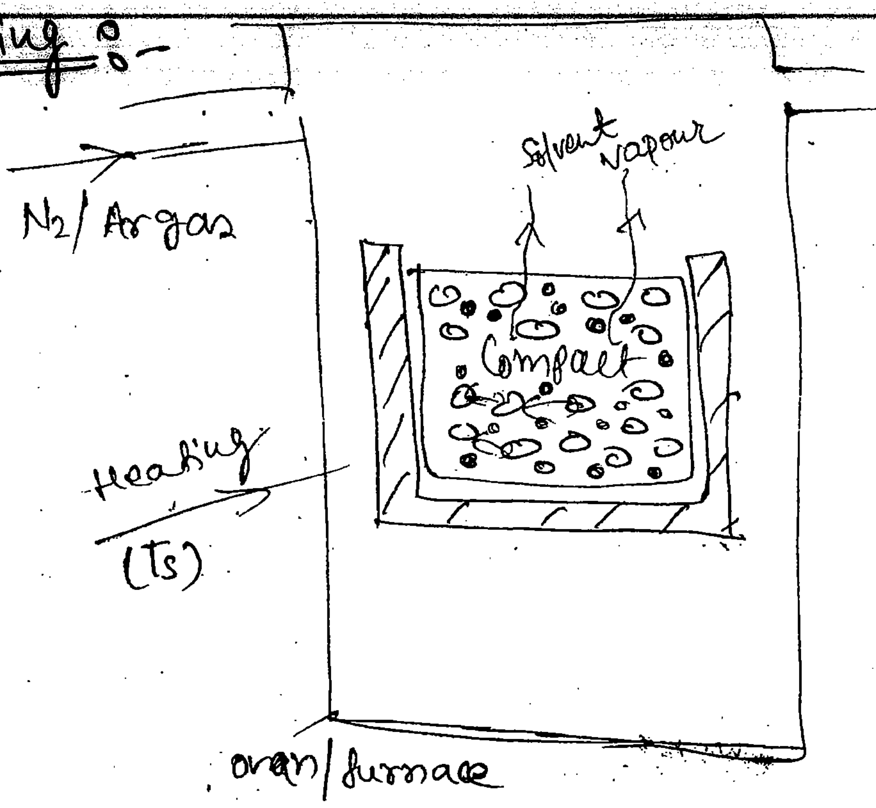
→ The powder particles come closer & achieves reqd. shape of the component is called compact.

⇒ thickness, ~~and~~ density and the strength of powder metallurgical component can be controlled by varying ~~the length~~ compact load P.

$$\boxed{P \propto \frac{1}{t} \propto \rho_{pmc} \propto S_{pmc}}$$

→ If the component shape is complex, the load distribution is non uniform.
↳ non uniform density will form in the component

(4) Sintering :-



V. V. P

powder made material have high compressive strength but low ka tensile strength.

→ obtaining strength in the compact by heating process is known as sintering.

→ After heating chemical bonds will formed among the powder particle and hence strength increases tremendously,

→ sintering is performed either in inert atmosphere or under vacuum To avoid oxidation of the compact.

→ During sintering time, the solvent added in the mixing stage will evaporate and comes out from the compact.

↳ heat produces, porasity.

∴ Powder metallurgical component possess min^m porasity, which is unavoidable.

* selection of sintering temp :-

① $M_1 + M_2 + M_3 \longrightarrow$ P.M.C

400°c 600°c 1200°c

write melting point of alloying elements

② select lowest M.P among alloying element.

L.M.P = 400°c

③ $\boxed{T_s = 0.8\,(LMP)} = 0.8 \times 400 = 320°c$

→ The compact should be heated below its (LMP) among the alloying elements, known as sintering temp. (Ts).

* Presintering :-

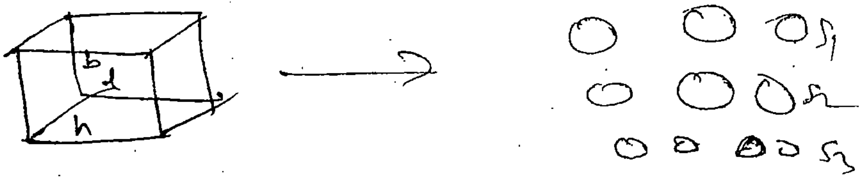
→ To minimize the porasity in the powder metallurgical components during compaction stage, the mould is heated to 60°c and subjected to compaction (hot pressing), so that solvent is ~~reduce~~ removed partially during compaction stage.

∴ In the final sintering process, the solvent vapours can be reduced,

↳ ~~porosity~~ porasity can be minimized.

Characteristics of powders :-

① powder possess more surface area than bulk state of the material.



$A_{S_{Bulk}} = 2(lb+bh+lh)$ $\qquad$ $A_{S_p} = A_{S_1} + A_{S_2} + A_{S_3} + \dots$

$$\boxed{A_{S_p} > A_{S_b}}$$

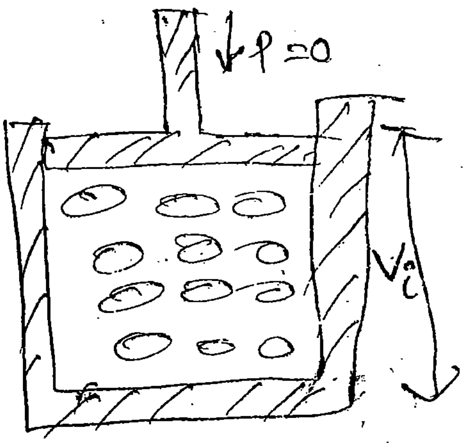
② ↳ no. of atoms exposed on the surface will be more.

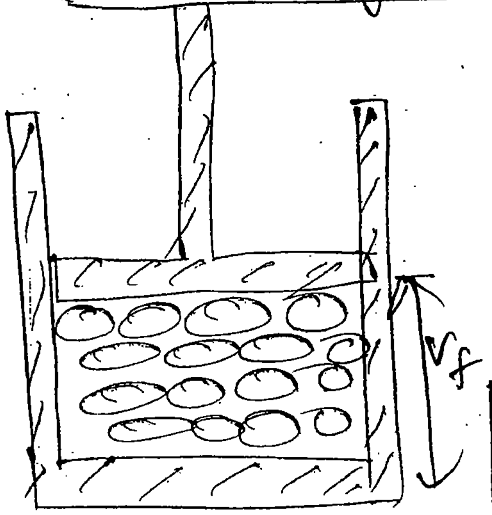
↳ tendency to form more no. of bondings.

↳ strength will be high.

∴ Powder metallurgical components exhibits more hardness & brittleness even though it has little porosity.

② Compressibility ratio (CR)





$$CR = \frac{V_i}{V_f} = 1-3$$

(Coarse powder)

$= 3-10 \rightarrow$ fine powder

Note:- It is always suggested to use different sizes of powders in fine size to produce a powder metallurgical component. So, that the component can be filled effectively without leaving gap.

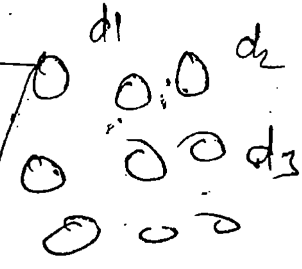
↳ density can be increased.

↳ Strength of the component increases.

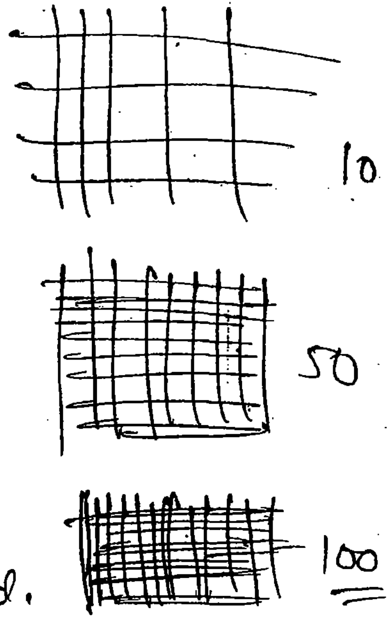
③ particle size / powder size :-

$$\boxed{d_{avg} = \frac{d_1 + d_2 + \dots + d_n}{n}}$$

↑ powder size or particle size



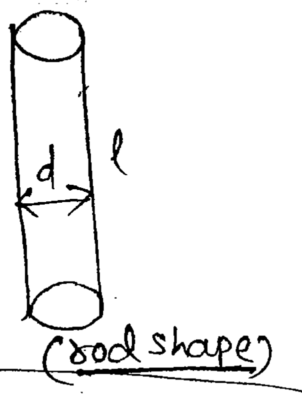
$$\boxed{\text{particle size} = \left(\frac{1}{\text{mesh no.}}\right)''}$$

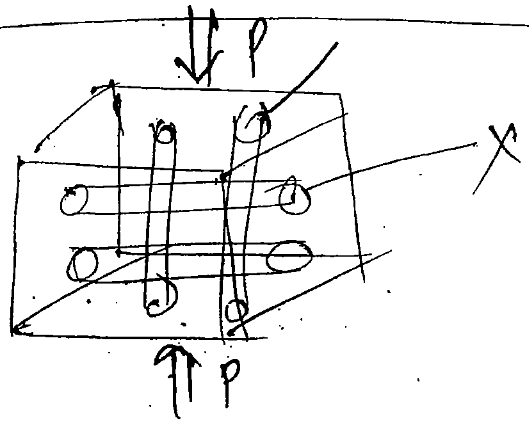


→ By doing filtering process of a powder, on different sizes of meshes, ~~the powder size~~ mesh no. is determined and Hence particle size or powder size is determined.

* production limitation of P.M.C ⟹

$\frac{l}{d} \leq 2.5$

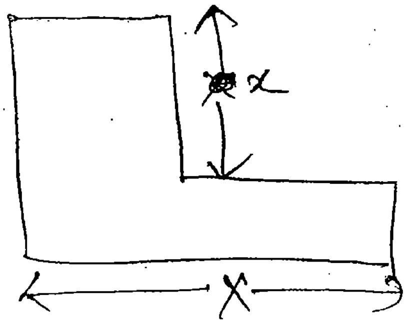


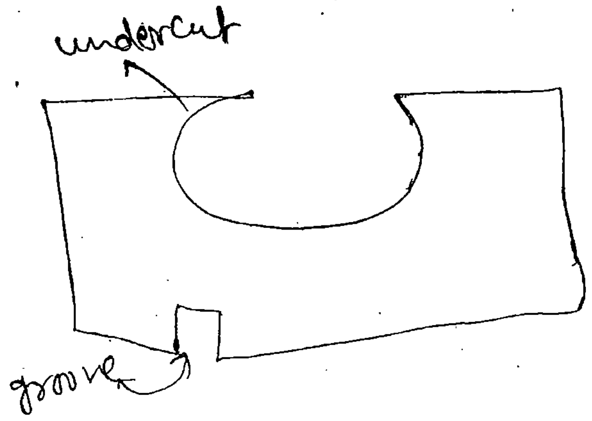


→ insertion of cross holes in the direction of P is possible, but ⊥r to P is not possible.

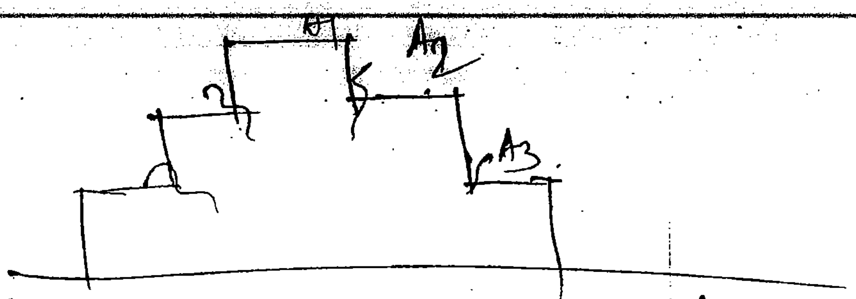
Steep shape,

$\boxed{x \leq 0.25X}$





→ difficult to · Insert undercut & groove.



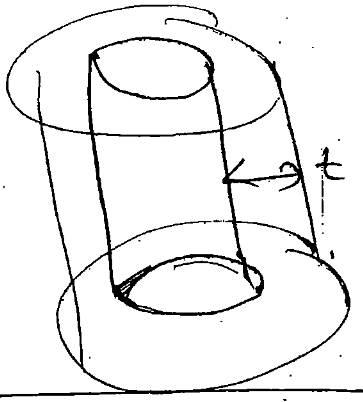
→ difficult to produce complex, or multisteeped Structure.

Cylindrical shape

$\boxed{t \geq 1\text{mm}}$

for other shape,

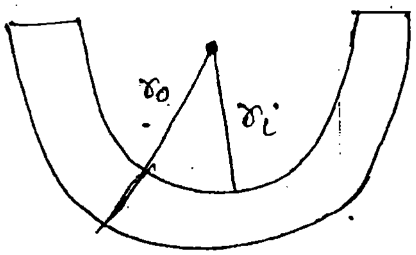
$t \geq 1.5\text{mm}$



Curved shapes

$r_i \geq 2.5\text{mm}$

$r_o \geq 3\text{mm}$



→ even though to produce the above shapes, after production of the component, mechanical operations, should be performed to shape change the component, which is very difficult because powder metallurgical components possess extreme hardness.

∴ Superhard cutting tool bits are required to shape the component

↳ The job will become difficult.

Hence during production of PMC, shape of compact = shape of final component will be maintained.

so, that with min^m mechanical operations, shaping of the component can be done.

* Advantages & disadvantages :-

① any combination of materials can be mixed and the components can be produced.

② thickness, density and the strength of the component can be controlled by varying the compaction load (P).

③ difficult to produce large size and complex shapes of component, with uniform density.

④ easy to produce small sizes of the components, any shape.

⑤ By using powders of magnesium, Zn, Al, Ti, $\overset{\text{antimony}}{Sb}$ etc. difficult to produce the components because these powders will undergo explosion during compaction.

⑥ In super hard cutting tool ~~width~~ bits, the tips will be coated by iron - carbide, wc/sic using powder metallurgical process.

⑦ In production of ceramic material,

$$\left[P_{Al_2O_3} + P_{ZrO_2} + P_{SiO_2} = \text{Ceramics}\right]$$

which can sustain up to 2500°C will be produced

* Types of steels :

0 — 0.15% C ⇒ mildsteel

0 — 0.25% C ⇒ LCS

0.25 — 0.45% (C) ⇒ MCS

0.45 — 2.11 % (C) ⇒ HCS
(1.5)

2.11 — 6.67% (C) ⇒ C.I
(5%)

→ anysteel (LCS/MCS/HCS) + Cr (1–26%) ⇒ Stainless steel

→ anysteel + alloying element ⇒ alloyed steel

V.V.I

LCS + Cr (10–20)% ⇒ Stainless steel

HCS + Cr (1–5%) ⇒ Stainless steel

LCS	MCS	HCS
→ %C = 0–0.25%	→ 0.25 – 0.45 % C	→ 0.45 — 1.5 %C
① lowhard/ highly ductile	① medium hard/medium ductile	① high hard/ low ductile
② easily machinable	② difficult than LCS, machinable	② difficult to machined without addition of sulphur.
③ difficult to harden or difficult to heat treat	③ easily hardenable or easy heat treatable	③ easy hardenable
④ easily weldable	④ moderately (medium) weldable	④ difficult to weld.
⑤ Corrosive Corrosion resistance is low.	⑤ Corrosion resistance is high than LCS.	⑤ Corrosion resistance is high

LCS	MCS	HCS
6) expensive	6) low cost	6) low cost
7) Possess high fracture toughness	7) less than LCS (fracture toughness)	7) posses low fracture toughness
8) M.P is high (1500–1400°C)	8) MP (1400–1300°C)	8) MP (1300–1200°C)
Applications	Applications	application
In production of Tubes, pipes, tanks, sheets, carbody, plate etc.	reinforcing bars in cement structures, tool gears, ~~shapes~~ shafts, aircraft component, automobile parts, axles, Spring wires, Connecting rods, etc.	→ machine tools, hammers, knifes, dies, Punches, milling cutters, sizles, etc.

① ferritic Stainless steel

→ 12–25% Cr, 0.1–0.35% C

→ behaves like (MCS). stronger than LCS, magnetic in nature, in anealled condition they Possess good Tensile strength.

applications -

1) all decorative application with good smoothness & surface finish

2) high temp. & high pressure application.

② **Austenitic S.S :-**

0 – 0.15% C, 6 – 23% Ni, 16 – 26% Cr

LCS good toughness

- → possess all property of LCS with good toughness.
- → possess highest corrosion resistance among all the series.
- → highly shock resistance.
- → In industrial pipe lines, chemical processing equipment, domestic utensils.

③ **Martensitic S.S :-**

(0.1 — 1.5% C), 6 – 18% Cr, 0 – 2% Ni

- → possess property of H.C.S.
- → easily hardenable.
- → high corrosion resistance with little ductility.
- → All machined part, automobile part.

④ **low thermal expansion steel (Invar steel) :-**

0.59% C, 12% Ni, 5% Mn, 3 – 4% Cr

HCS

- → possess HCS property.
- → good hardenability & toughness.
- → surface finish is good. ; high corrosion resistance.
- → Thermal expansion coefficient,

$$\boxed{\alpha = 0.000023 \ mm/°C}$$

→ Cylinder, head bolts, valve seating, cylinder liners of aero engine

⑤ **Maraging steel** –

17–19 % Ni, 0.1 % C, 8–12 % Co, 3–5 % Mo, 0.2 – 0.6 % Ti

0.01 % Al

- Possess good fracture toughness & fatigue resistance.
- high wear resistance.
- high temp. hardness & strength.
- low corrosion resistance, but after nitriding heat process high corrosion resistance.

Applications

→ aircraft components

→ aero engines

→ outer envelop of rocket motor casing

→ crank shafts

→ gears

→ bicycle frame etc.

⑥ **HSS** :-

0.6 to 0.8 % C, 3–4 % Cr, 17–18 % W,

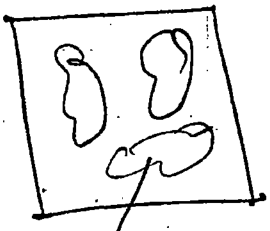
0.9–1.3 % V, 0.1 – 0.4 mn,

0.2 – 0.4 % Si

2.11 — 6.67 % C ⇒ C.I
(5 %)

① gray cast iron :-

(2.5 – 4 % C), 1.8 % Si, 0.5 % Mn → hardenability



Fe3C particles exists as flake type shape grains.

→ Soft in nature.

→ Dark porous structure.

applications -

Pipes, agricultural implements, cylinder block of I.C engines, brake drum, machine tool beds.

② white cast iron -

2.9 – 5 % C, 1.15 % Si, 0 – 0.6 % Mn

→ appearance as white in colour, hard & brittle in nature.

→ high wear resistance & abrasion resistance.

→ applications -

ball bearing surfaces, rollers ~~for~~ pressure, ring of wheels, railways brake blocks, liners for cement mixtures, wall meals.

③ malleable C.I :-

2.5 % C, 1 % Si, 0.5 % Mn

→ posses good tensile strength

→ ductility, malleability

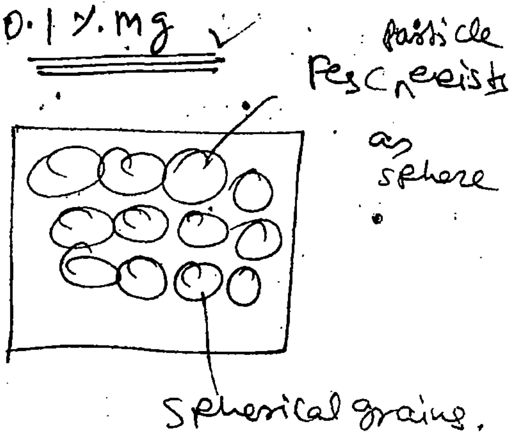
→ shock & impact resistance.

Ex - Track wheels, automobile parts, rile road equipments, cams, Pipe fittings etc.

④ Nodular C.I :-

3—3.5% C

2- 2.5% S, 0.4% mn, 0.1% mg ✓



→ easy machinability due to spherical grains.

→ ductility is similar to molleable cast iron.

→ Corrosion resistance is similar to gray cast iron.

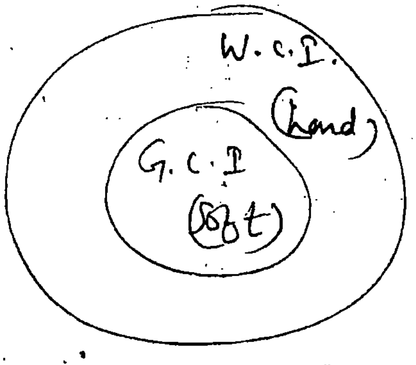
→ Tensile stregth greater than gray cast iron.

applications

hydraulic cylinders, wall, cylinder heads for compressor, & diesel engines, connecting rods high pressure pipe etc.

⑤ Chilled C.I :-

2.8—3.6% C, 0.5—0.8% Si, 0.4—0.6% mn



→ A G.C.I with ~~outer~~ envelop of W.C.I phase is known as chilled C.I.

→ outer surface is hard and inner surface is soft.

applications → drawing dies, rollers ~~[illegible]~~ for sheet mills, sand glass nozzles, brake shoes etc //

Alloyed C.I:-

Any C.I + alloying element → alloyed C.I

Note! →

① Improvement in properties in cast iron by adding alloying elements is marginal because it posses very high carbon content

② improvement in properties in steel by adding alloying element is tremendous because it posses low carbon content.

Fe ore

⇓

Black Colour ⇄ Pig iron (91–94 % Fe)

⇓

→ wrought iron (99.99 % Fe)