

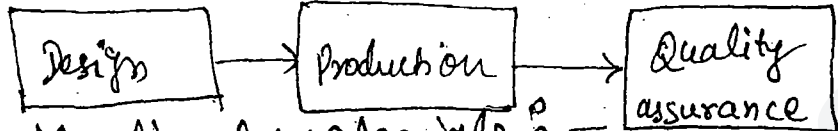
Syllabus:-

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

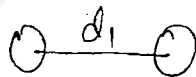
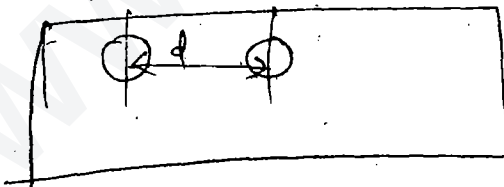
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Ref: book

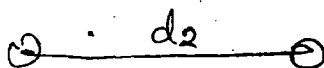
① Material science & metallurgy → Kodger & Kodger.

# Classification of materials

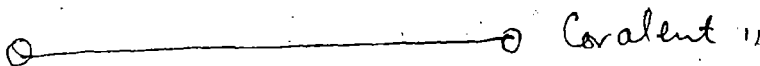
Metals	Polymer/ Plastics	Ceramics	Composite



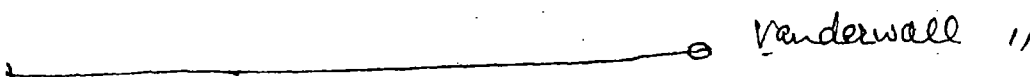
metallic bonding



ionic "

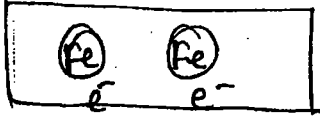


Covalent "



Vanderwall "

* Metals :-



1. metallic bonding $\Rightarrow$ d is less
 $\Rightarrow$ B.E is high
 (1) strength is high $\xrightarrow{\text{V.V.I}}$

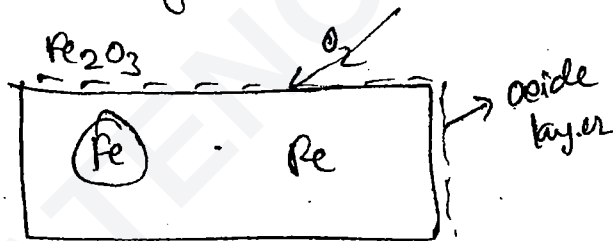
* (2) Ductility is good

(3) Electrically good conductors (free e^- s)

(4) Thermally good conductors

(5) density is high $\Rightarrow$ weight is more.

(6) Corrosive



(7) Servicing temp = $800 - 1000^\circ\text{C}$

(8) partially recyclable

(9) Environmentally friendly.

* Polymer/Plastics :-

C, H, O atoms only.

$\rightarrow$ Covalent-binding

(1) strength is less

(2) Ductility is high

(3) Electrically bad conductors
 (no free e^- s)

for mechanical properties

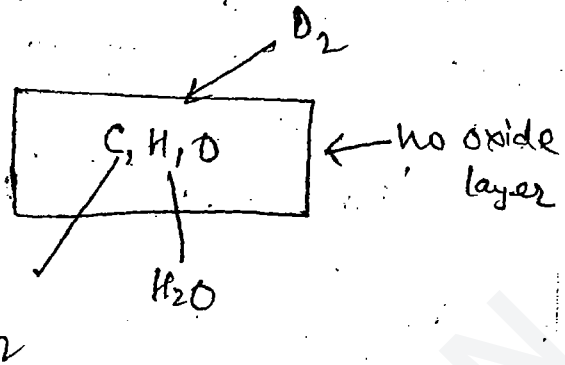
Strength & hardness $\propto$
 Toughness.

(4) thermally stable composites

(5) low density $\Rightarrow$ light weight

(6) anticorrosive

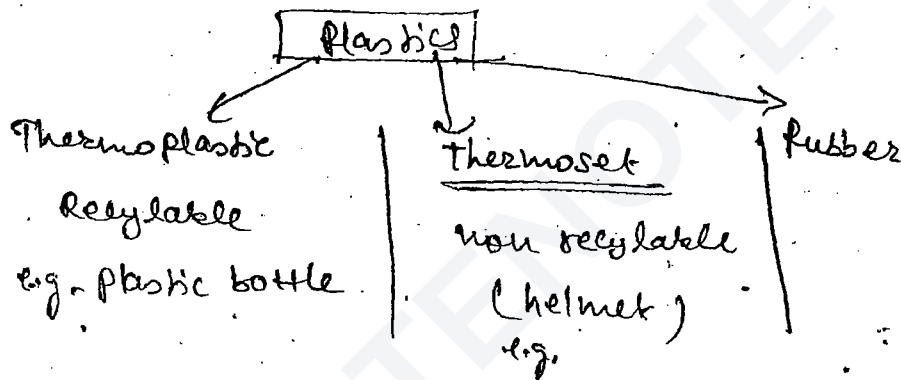
no oxide layer



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(7) Service temp = $300^\circ C$

(8) Recyclability



(9) Environmentally hazardous

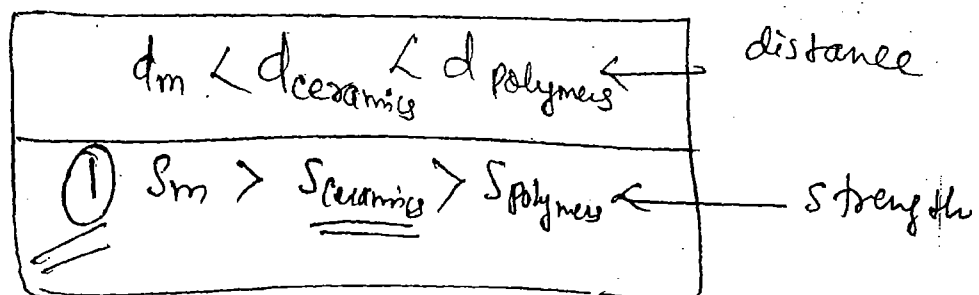
* Ceramics :-

$\rightarrow$ mixture of metal oxide powders.

Al_2O_3, SiO_2, ZrO_2

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

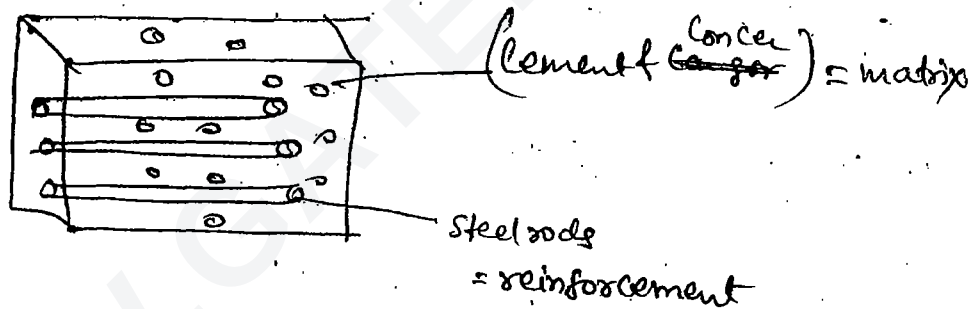
$\rightarrow$ ionic + covalent bondings



- ② → brittle in nature
- ③ → electrically bad conductors (no free e⁻s)
- ④ → thermally bad conductors
- ⑤ $P_{\text{metals}} > P_{\text{cer}} > P_{\text{polymers}}$
- ⑥ non-recyclable
- ⑦ servicing temp = 3000°C
- ⑧ Environmentally friendly.
- ⑨ Anti-corrosive.

* Composite material

→ Physical mixing of more than two metals.



$$M_1 + M_2 \Rightarrow C$$

Ex 1:

Steel + (Cement + Concr) $\Rightarrow$ R.C.S $\xrightarrow{\text{Reinforce}}$

$\downarrow$ High tensile strength $\downarrow$ high compressive strength $\Rightarrow$ Both high compressive & tensile strength

Ex 2:

Steel + Plastic
 $\Downarrow$
 High tensile strength

$\Downarrow$
 light weight

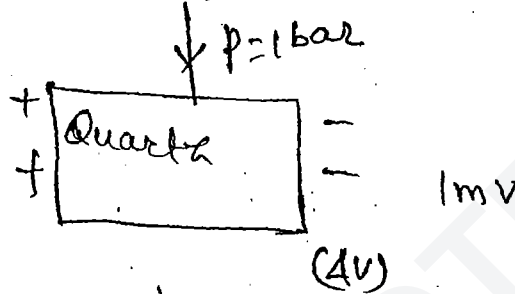
$\Rightarrow$ FRP

$\Rightarrow$ $\Downarrow$
 light weight & high strength.

(3)

* Smart material :- (Advance material)

Ex: Quartz (SiO_2)



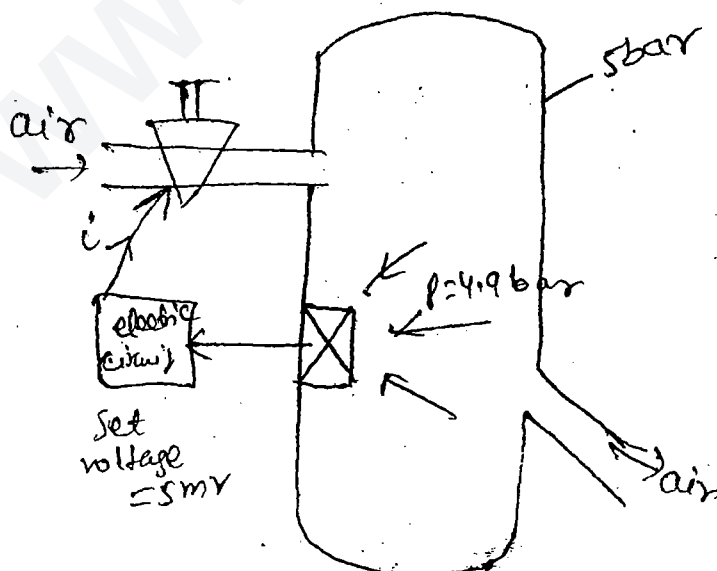
$$\Delta V \approx f(\text{pressure})$$

$\rightarrow$ If a material function based on its surrounding environments is known as a smart material.

for Ex: Quartz (SiO_2)

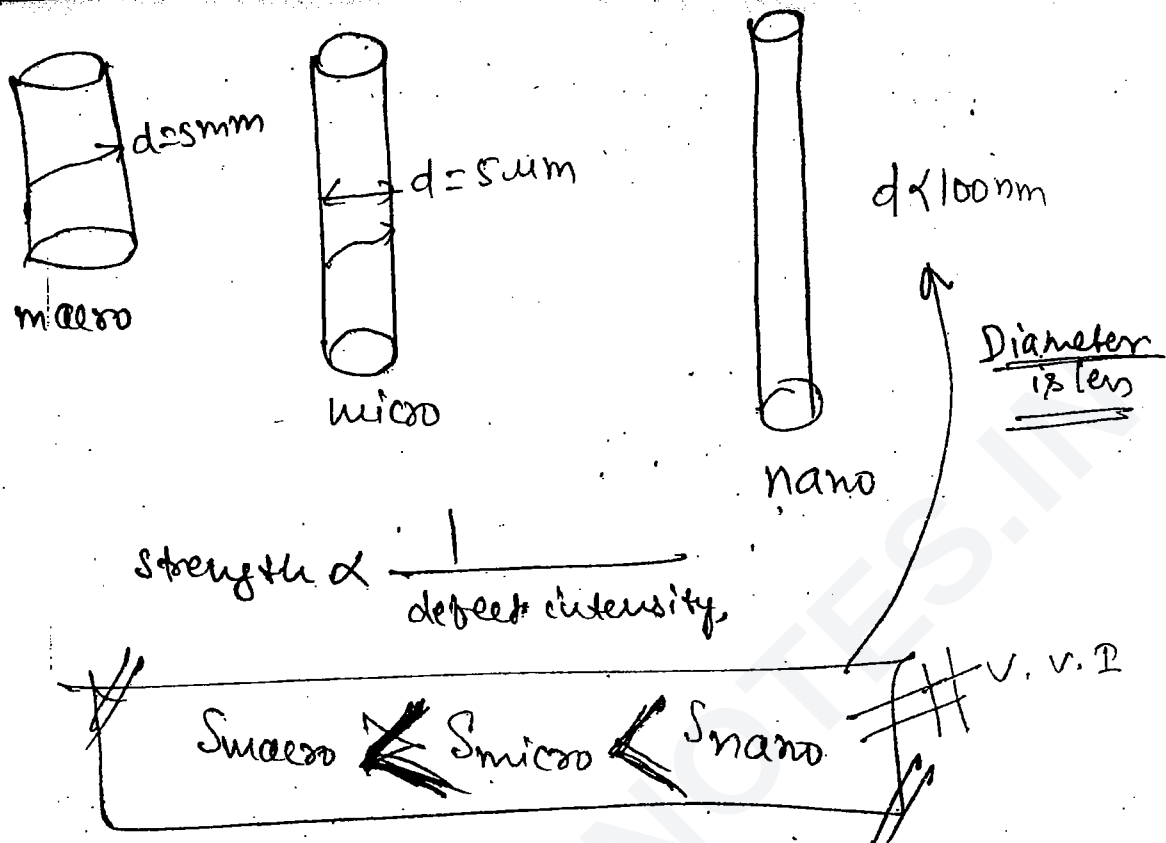
$\rightarrow$ The voltage generated ~~across~~ across the Quartz sensor is the function of pressure acting on the sensor.

$$\Delta V \approx f(\text{pressure})$$



bar	value
4.9	$\rightarrow$ open
0.1	$\rightarrow$ close

* nanomaterial *



→ 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 nanomaterials.

→ To produce nanomaterials, highly accurate production methods is required.

⇒ the defect size should be less.

⇒ strength is high.

Properties of material :-

(4)

① Physical

Color
density

② Mechanical

- 1) Strength
- 2) hardness
- 3) fracture toughness
- 4) ductility
- 5) stiffness
- 6) Brittleness
- 7) creep
- 8) fatigue
- 9) Resilience

③ Thermal

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

① Strength :-

→ ability of a material that can ~~resist~~ the mechanical load.

2) hardness

resistance offered by the material against mechanical deformation.

3) fracture toughness -

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

⑦ Creep:-

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

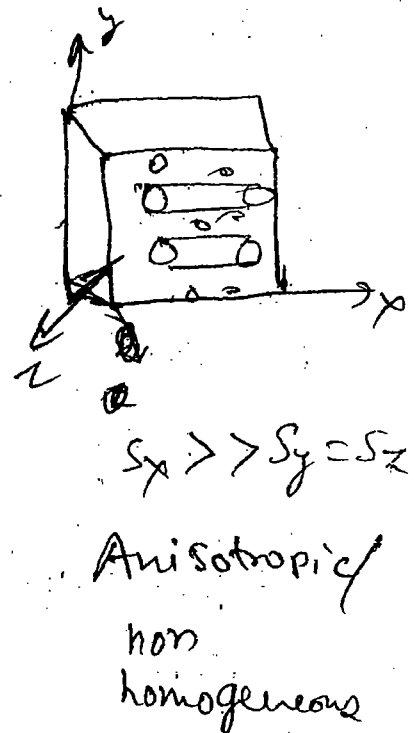
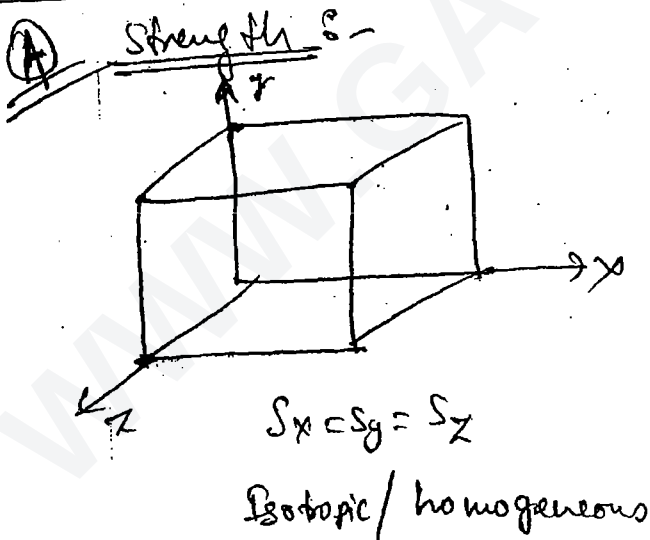
⑧ Fatigue:-

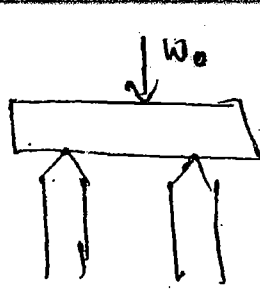
Time vs strain behaviour of a material under oscillating mechanical load.

⑨ Resilience:-

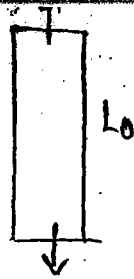
the ability of a material that can resist shock or impact loads without shape changes.

absorb energy against shock or impact load without shape changes.

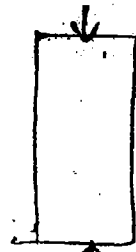




flexural/
bending



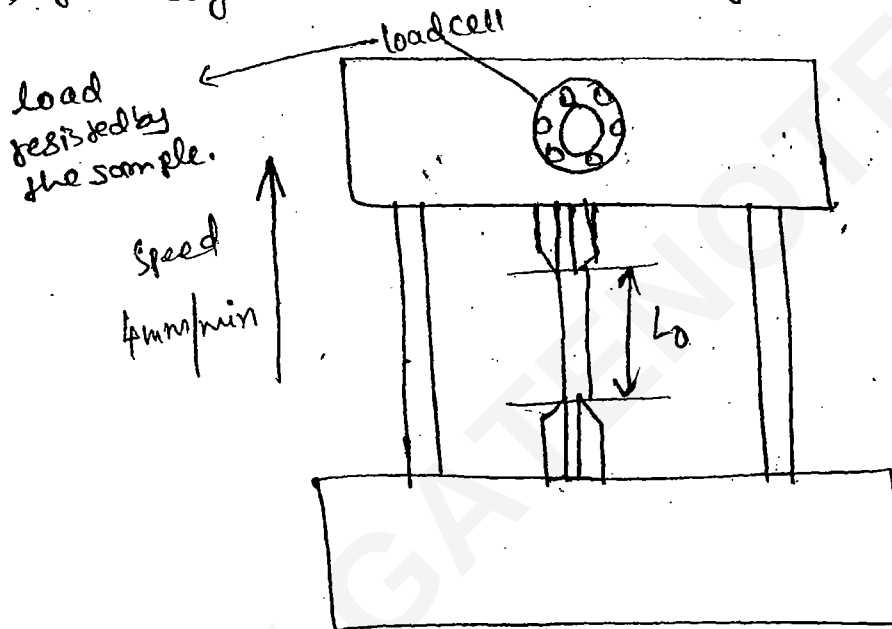
Tensile



Compressive

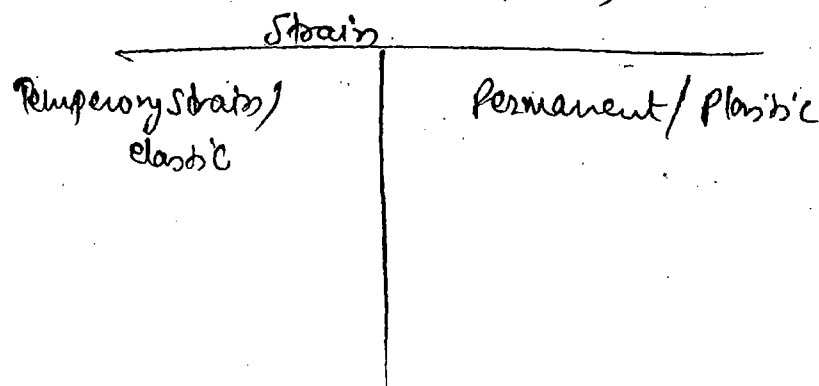
Tensile test

→ generally used universal testing machine

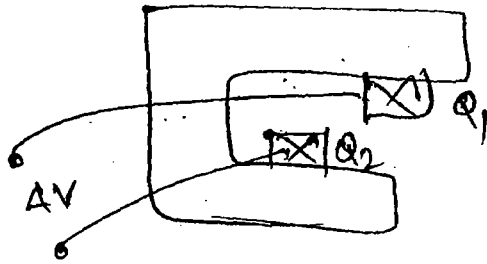


→ Shape Change = ΔL (mechanical deformation)

measured property of ΔL = strain
(ΔL , ΔB , ΔV)



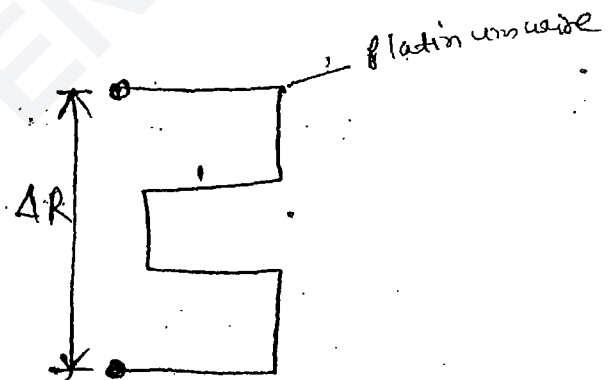
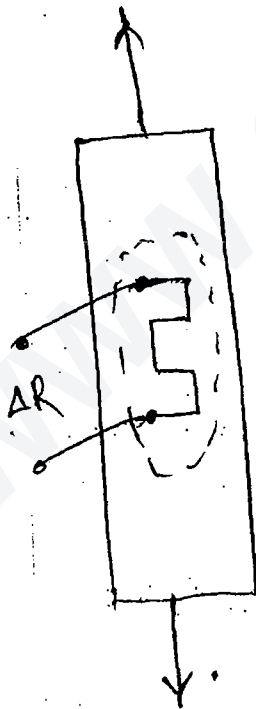
① extensometer (strain ~~meas~~ measuring device)



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

$$\Rightarrow \boxed{AV \propto \text{strain}}$$

② Strain gauge :-

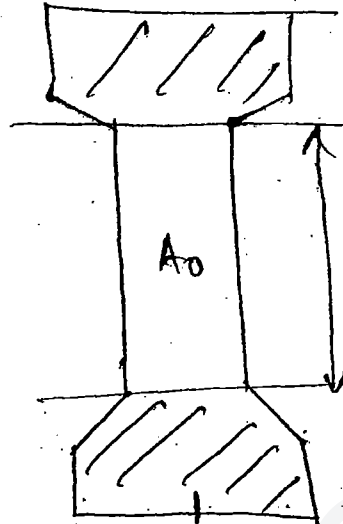


$$\boxed{\Delta R \propto \text{Strain}}$$

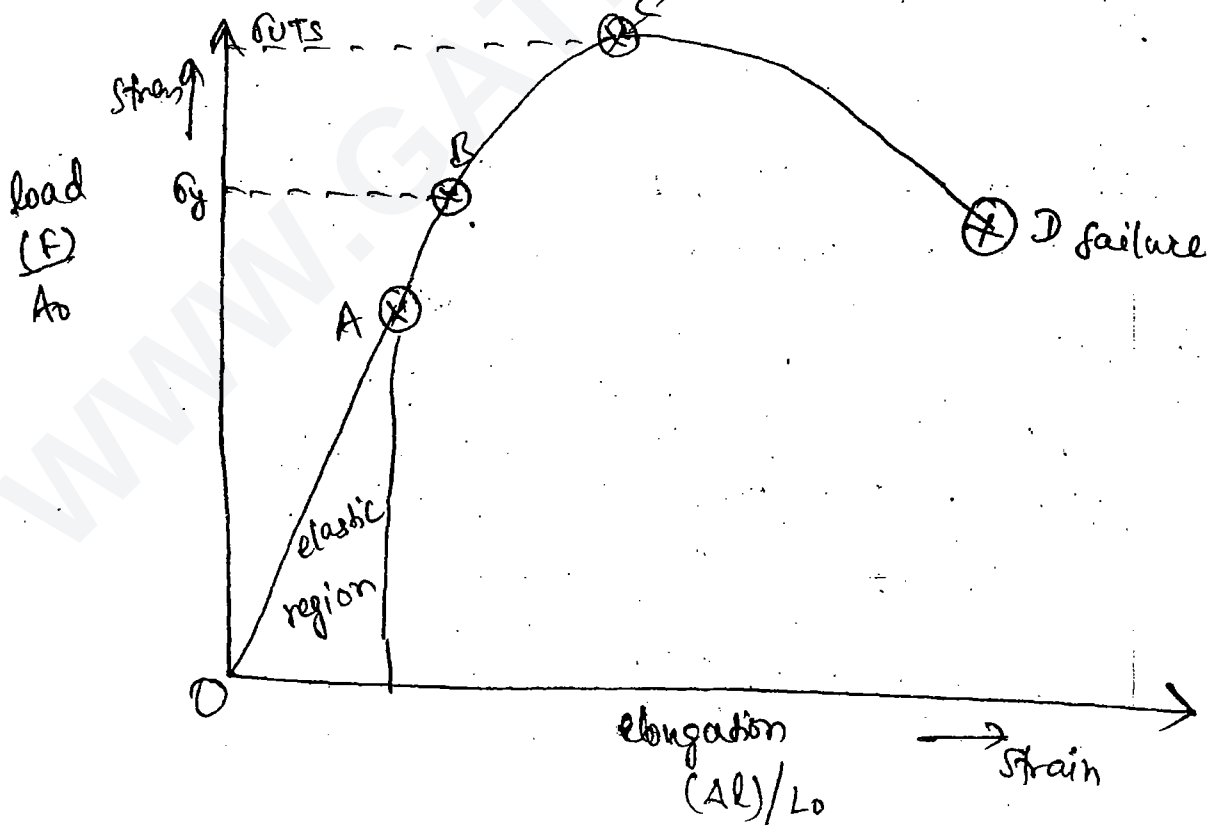
↑
resistance

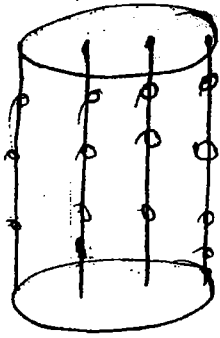
→ In strain gauge the change in electrical resistance (ΔR) is proportional to strain produced in the sample, therefore,

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



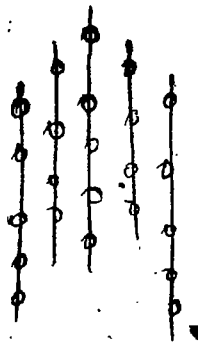
$$L_0 = 5.65 \sqrt{A_0}$$





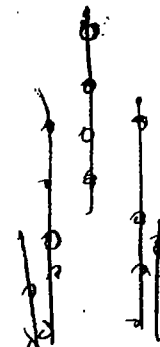
$P \ll B.E$

(OB)



$P > B.E$

(BC) slow



$P \gg B.E$

(C)

→ The sample is fixed between the grips of the UTM and the top ~~base~~ ^{grip} 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 is 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 7
called proportional region OA.

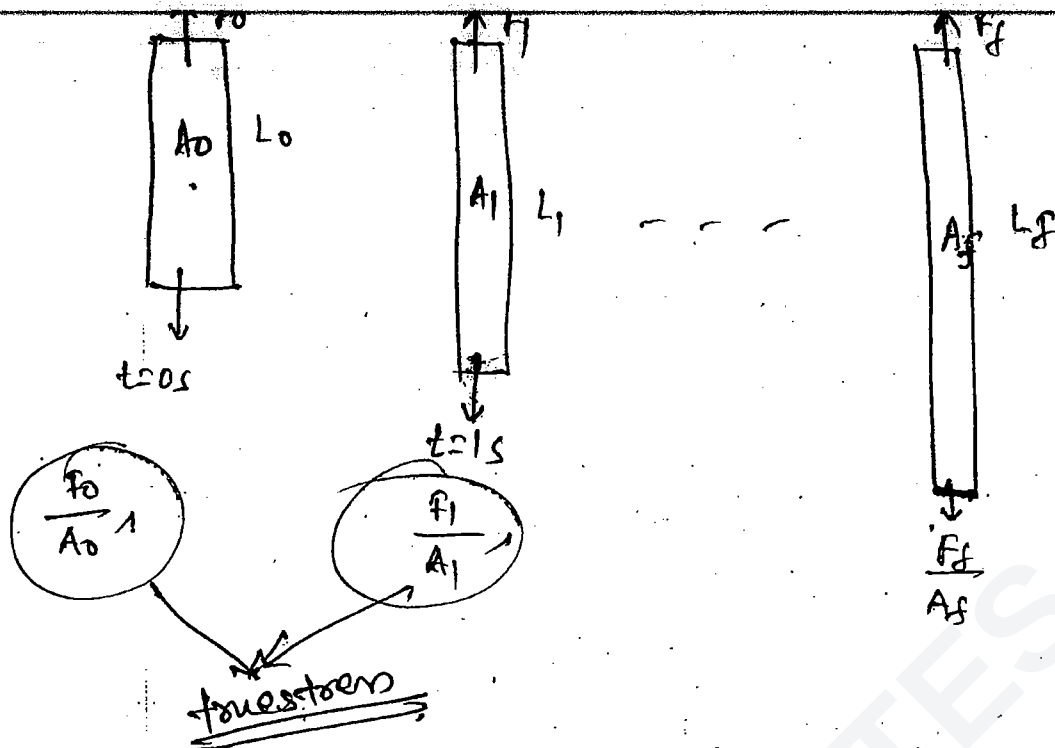
→ up to point B, stress is proportional to strain but by removal of the load, the sample will gain its original shape. i.e. called elastic region OB.

⇒ 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 $\Rightarrow$ 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 $A_1, A_2, A_3, \dots$ values.

∴ $A_1 = A_0, A_2 = A_0, \dots$ is substituted,

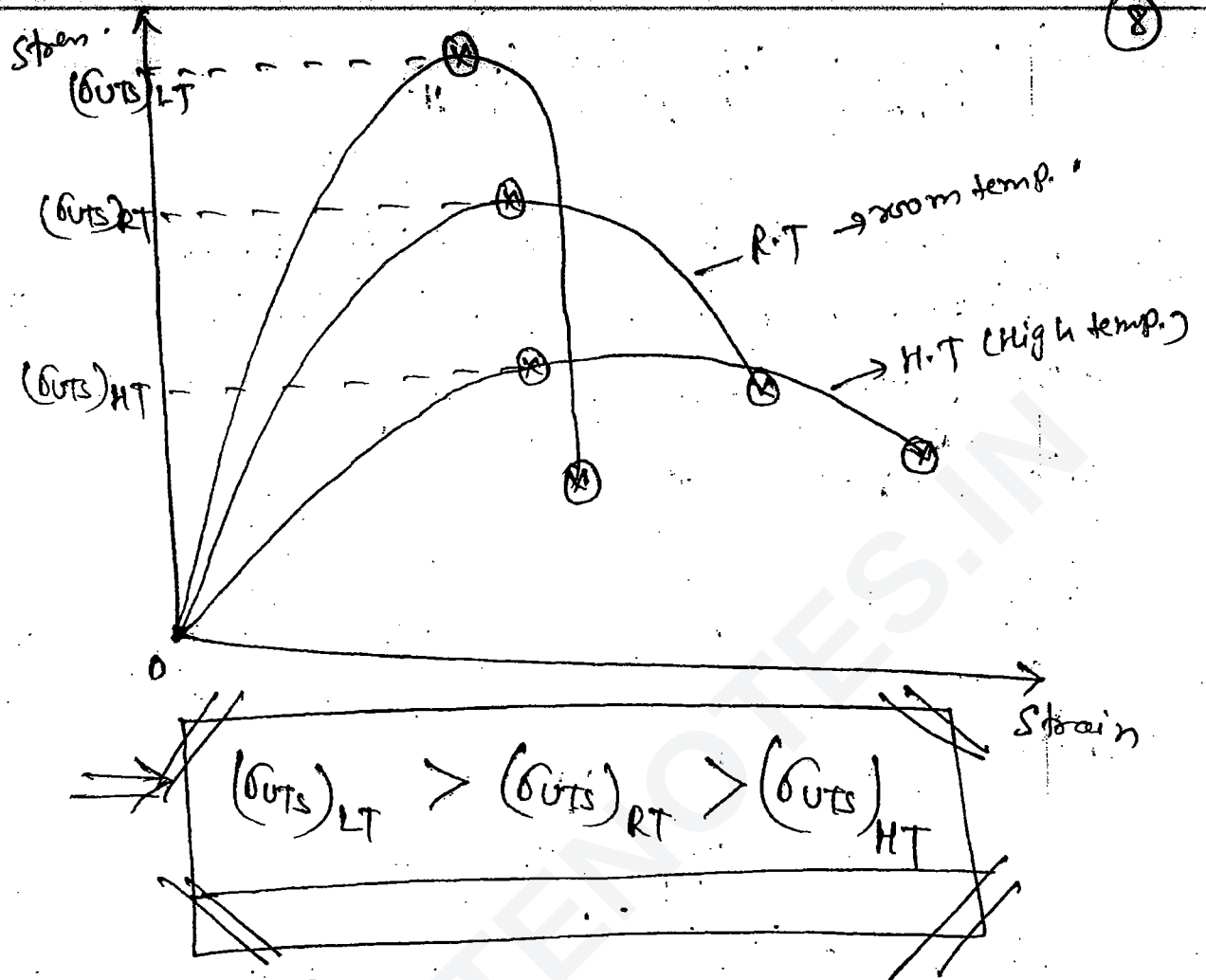
Hence, $\frac{F_0}{A_0}, \frac{F_1}{A_0}, \frac{F_2}{A_0} = \text{Engg. stress}$

⇒ Actually $A_1 < A_0, A_2 < A_1, A_3 < A_2, \dots$

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

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

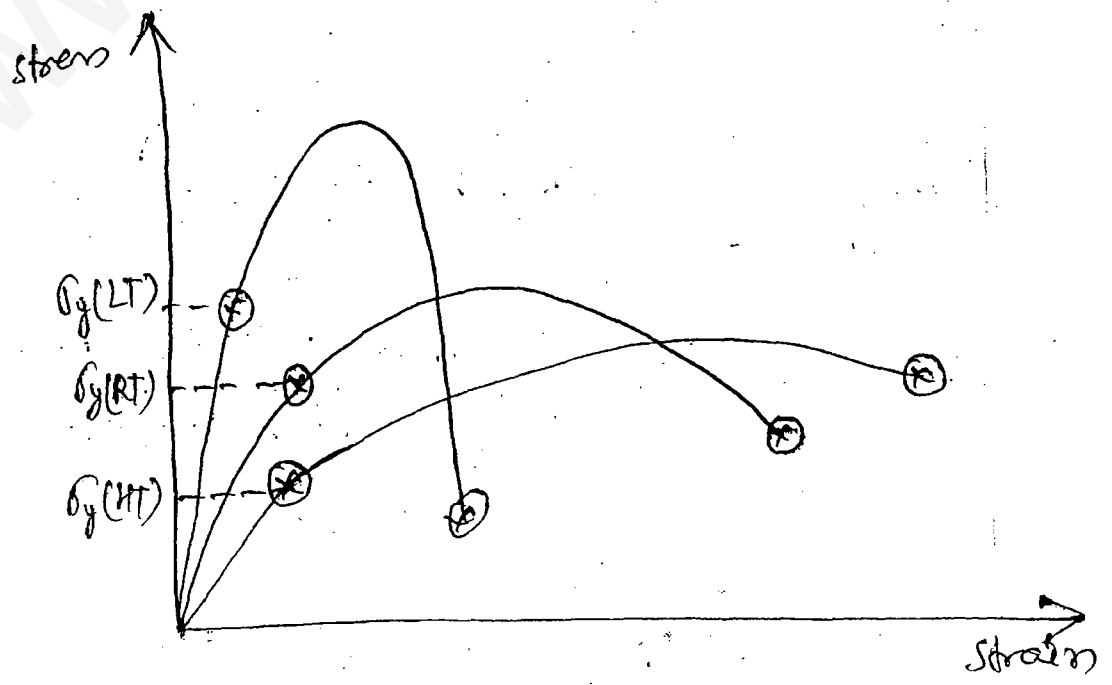
⇒ True stress vs true strain curve follow the path of (OABCD') whereas Engg-stress vs Engg-strain curve follow the path of (OABCD).



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

⇔ Binding energy decreases

⇔ Strength decreases.



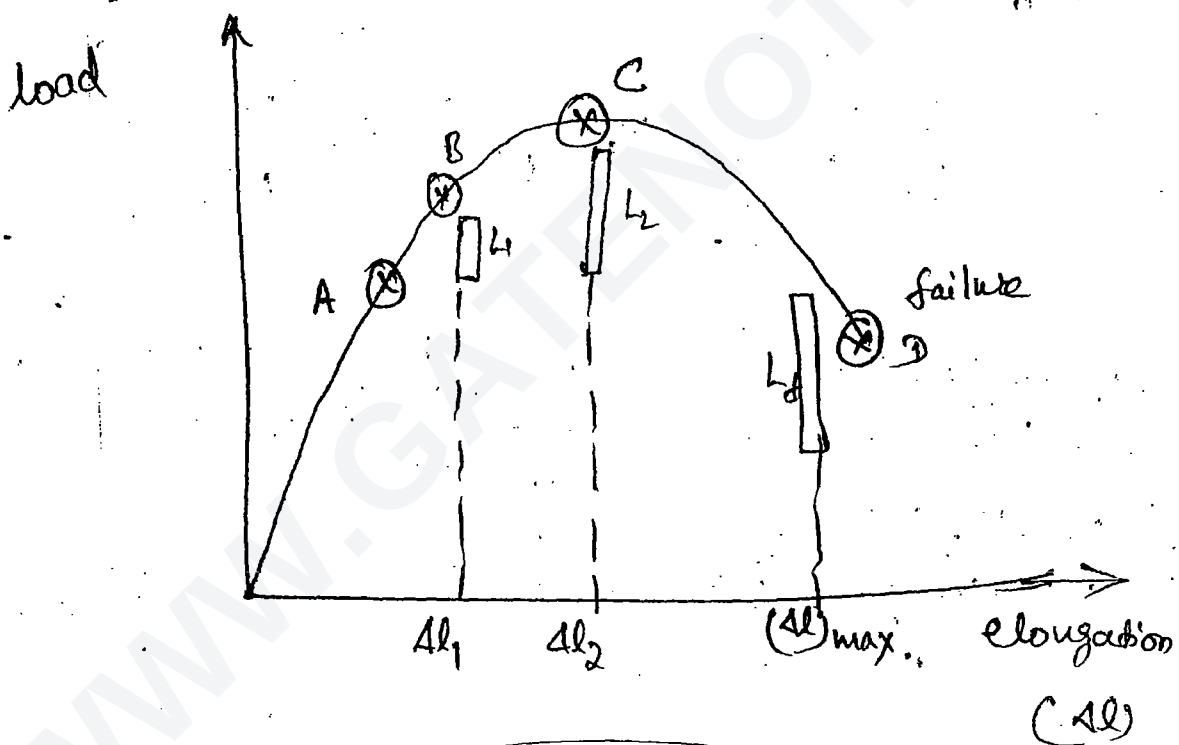
$$(\sigma_y)_{LT} > (\sigma_y)_{RT} > (\sigma_y)_{HT}$$

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

⇔ plastic deformation is easy.

⇔ yield stress decreases

⑧ Ductility measurement :-

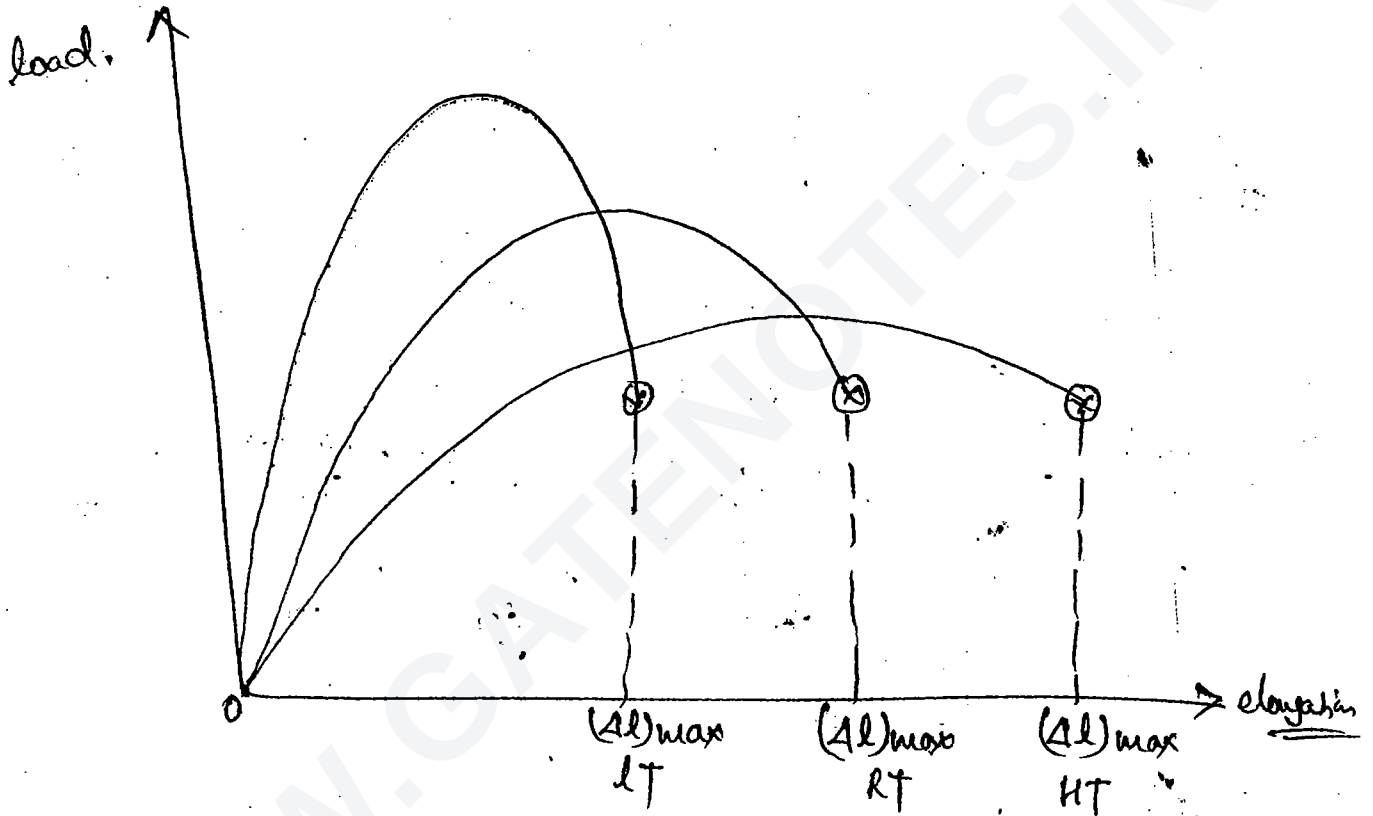


Ductility = % of elongation in length

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

Ductility = % $(\Delta l)_{\max}$ on the load vs elongation curve. (9)

- By calculating the percentage of elongation value in a sample at breaking point, ductility is measured.
- The max^u elongation will be observed on a load vs elongation curve at the breaking point i.e. $(\Delta l)_{\max}$.



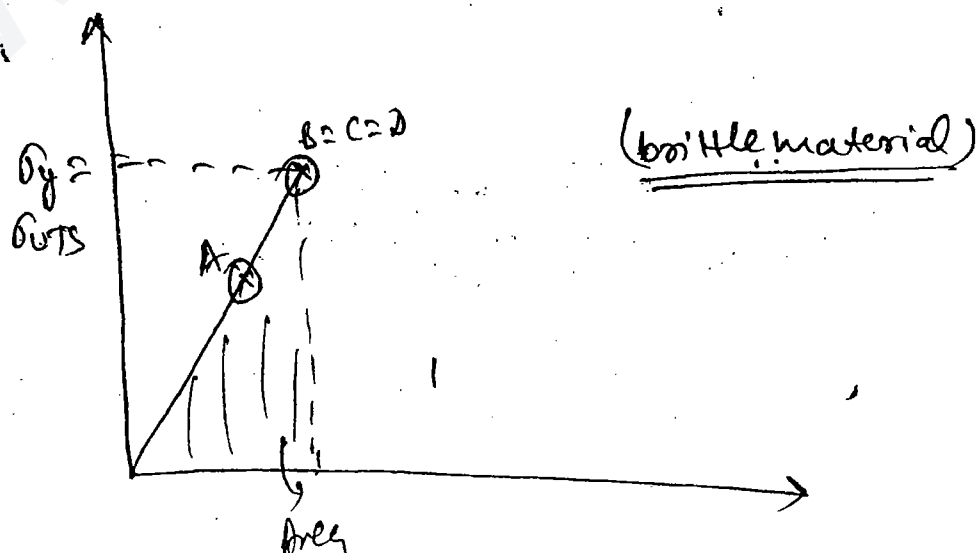
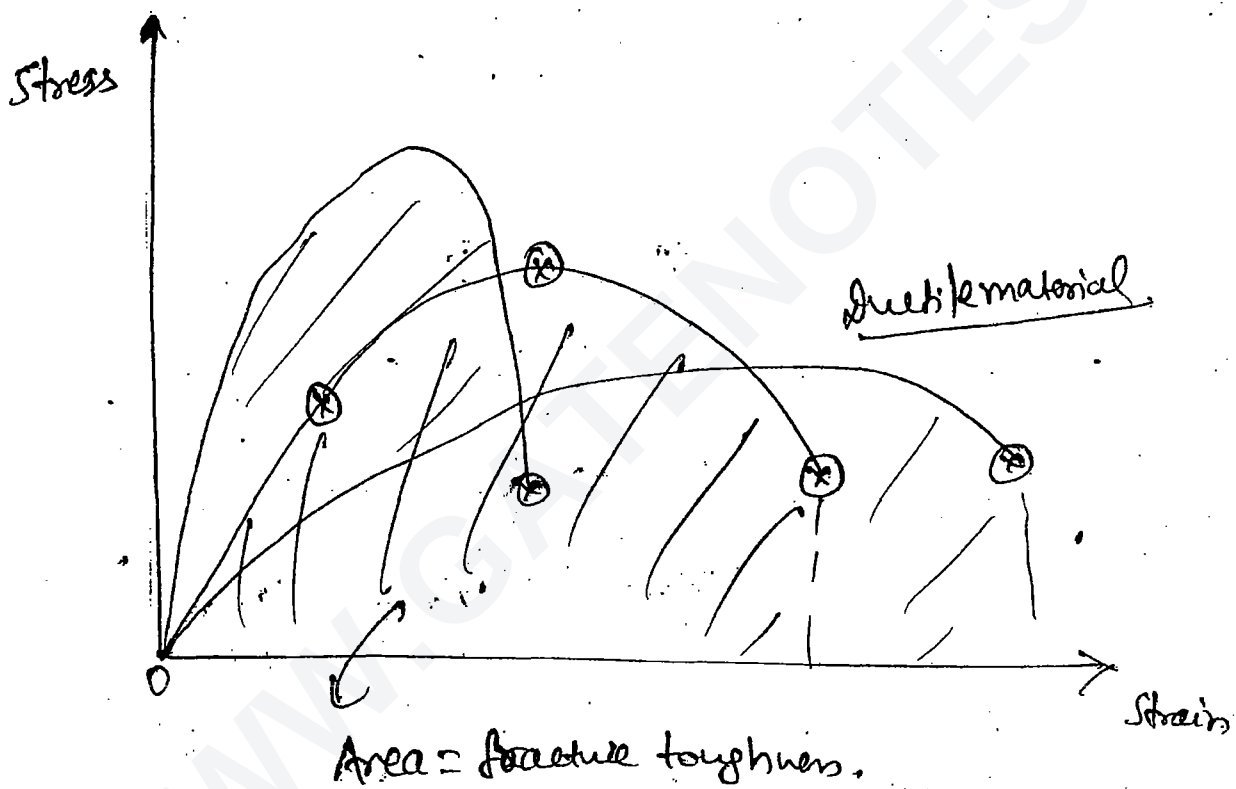
$$(\Delta l)_{\max LT} < (\Delta l)_{\max RT} < (\Delta l)_{\max HT}$$

Ductility

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

- ⇒ If a material is tested at high temperature
- undergo easy plastic deformation
- ⇒ undergo more strain
- ⇒ $(\Delta \epsilon)_{\text{max}}$ is more.
- ⇒ Ductility is high.

(c) fracture toughness measurements :-



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

$$A_{ductile} > A_{brittle}$$

⇒

$$F.T_{ductile} > F.T_{brittle}$$

fracture
toughness

⇒ A brittle material does not undergo plastic deformation.

→ A ductile material can absorb more energy against failure.

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

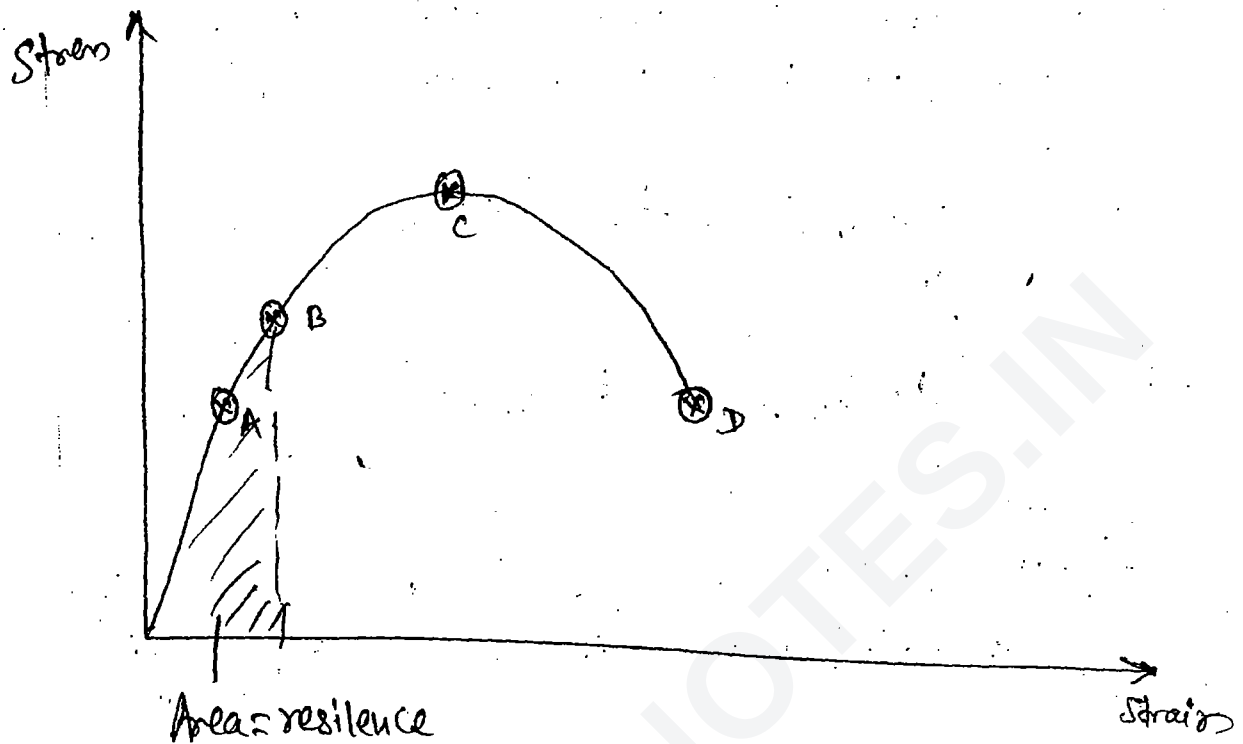
$$(F.T)_{L.T} < (F.T)_{R.T} < (F.T)_{H.T}$$

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

⇔ Area under the curve increases

⇔ Fracture toughness increases.

① Resilience measurement



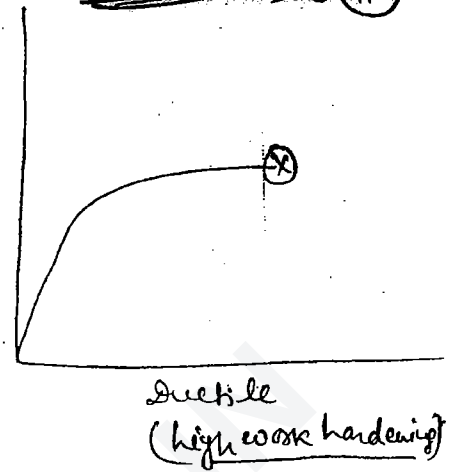
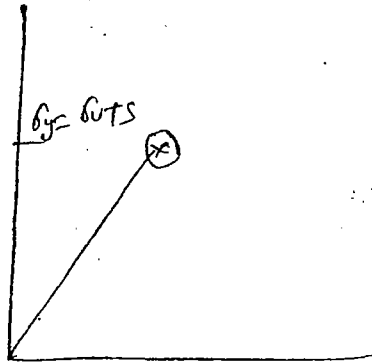
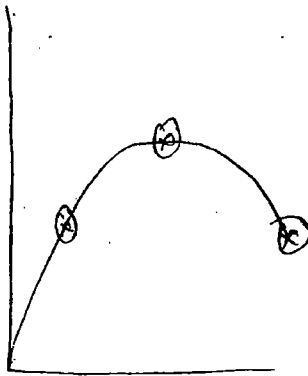
⇒ By calculating the area under the stress vs strain curve up to elastic point, resilience is determined.

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

⇒ If a material possess high resilience means it will absorb shock and impact loads most effectively without undergoing shape change of the component.

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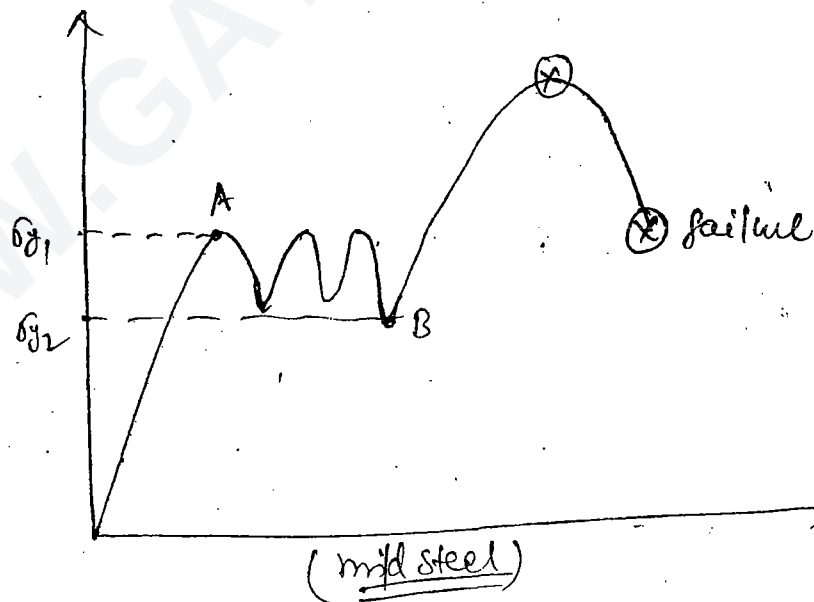
0 - 0.15% C $\Rightarrow$ mild steel

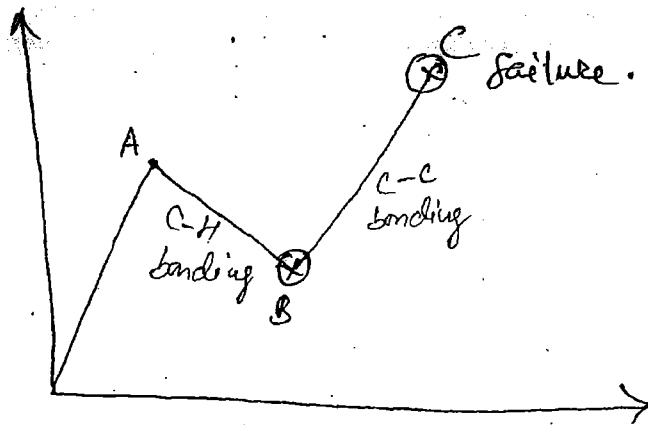
0 - 0.25% C $\Rightarrow$ L.C.S (low)

0.25 - 0.45% C $\Rightarrow$ M.C.S (medium)

0.45 - 2.11% C $\Rightarrow$ H.C.S (high)

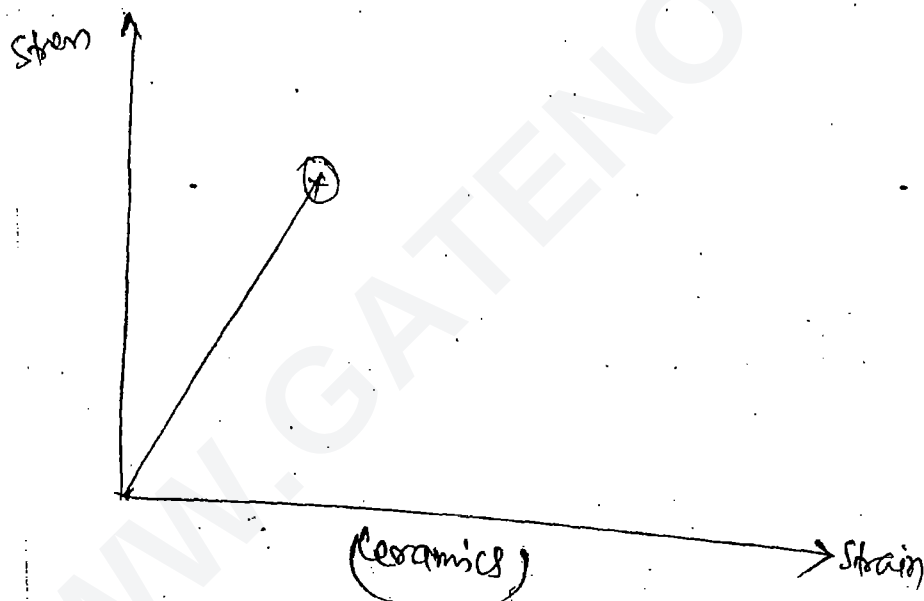
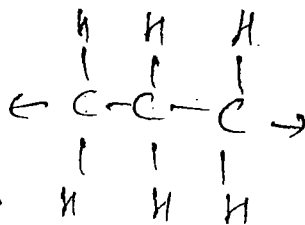
2.11 - 6.67% C = cast iron



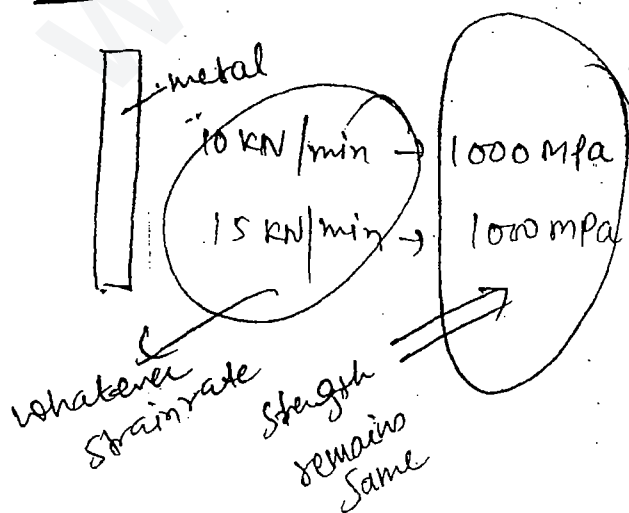


Plastic

C-H $\Rightarrow$ weak
C-C $\Rightarrow$ strong



NOTE:-



Plastic

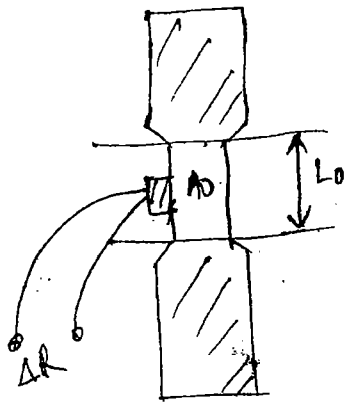
1 KN/min $\Rightarrow$ 100 mpa

5 " $\Rightarrow$ 80 mpa

15 KN/min $\Rightarrow$ 70 mpa

⇒ In case of metals the strength value is independent ⁽¹²⁾ 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 ~~strain rate~~ strength to the plastic material.

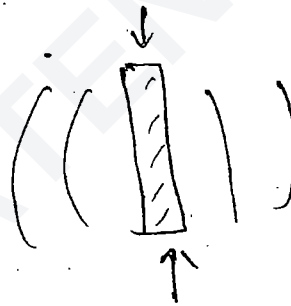
* Compression Test :-



$$L_0 < 2d_0$$

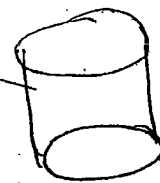
case-1, if $L_0 \gg d_0$

undergo buckling



case-2 if $L_0 \ll d_0$

strains are small



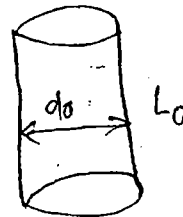
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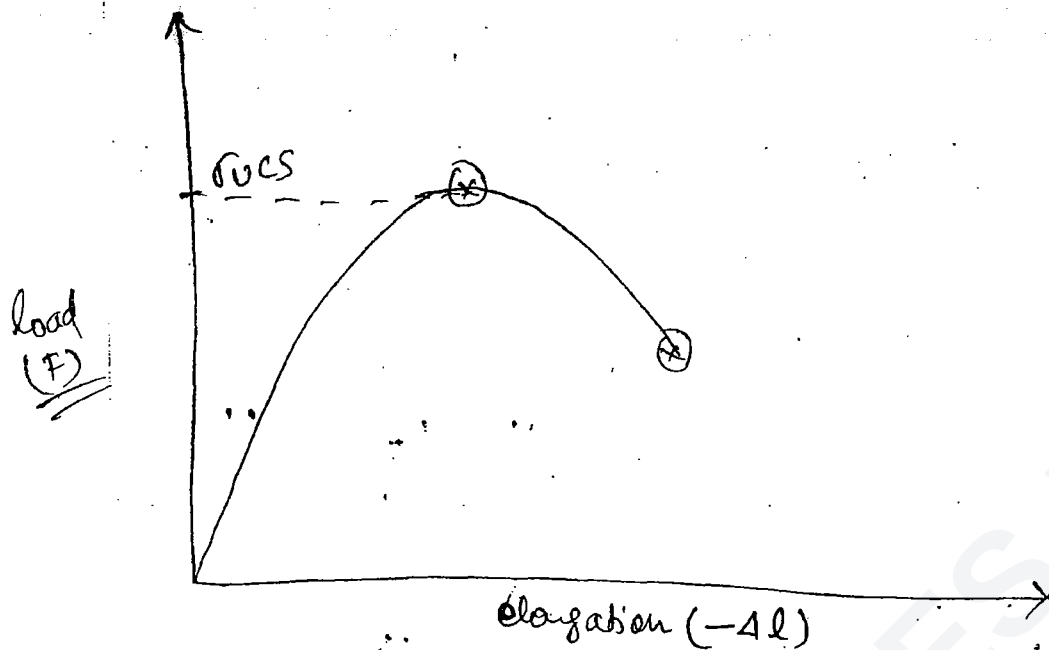
difficult to determine with the strain gauge also.

case-3 $L_0 < 2d_0$

then compressive load can be applied effectively at the same

time the strain produced can be measurable with the help of strain gauge.

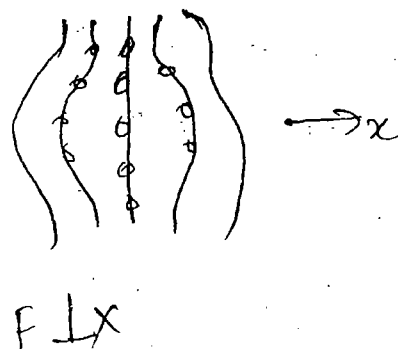
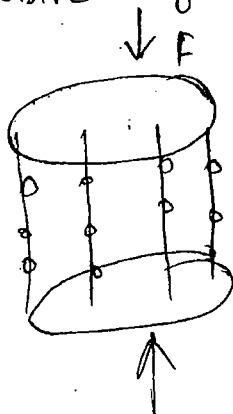


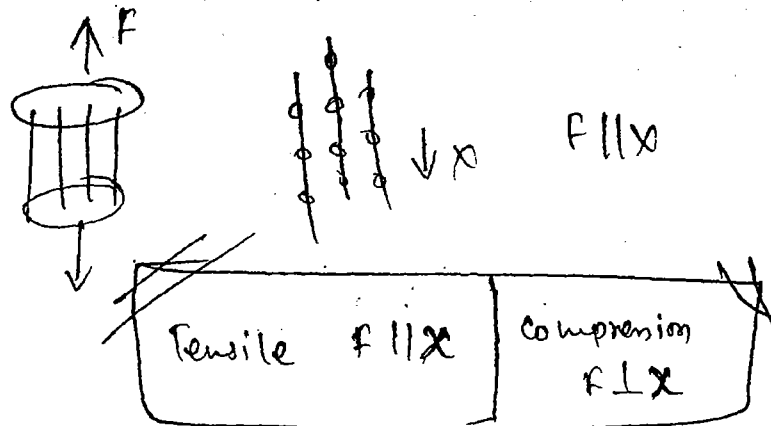


→ The sample is fixed between the grips of UTM and top plate is moved downwards with the certain speeds but the sample will resist the elongation in upward direction with a force F . Therefore, load vs elongation or stress strain curve can be obtained as shown in above fig.

→ 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 ($GUCS =$ Compressive strength of the material).





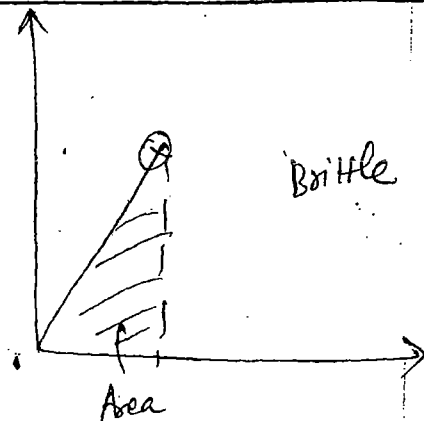
→ In case of Compression test, the displacement of atomic plane (x) is to the direction of F but in tensile condition it is parallel to F.

→ Powder made material poses high compressive strength but low tensile strength ex- Chock

→ Powder metallurgical component poses high compressive strength and whereas metal & alloys poses 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.



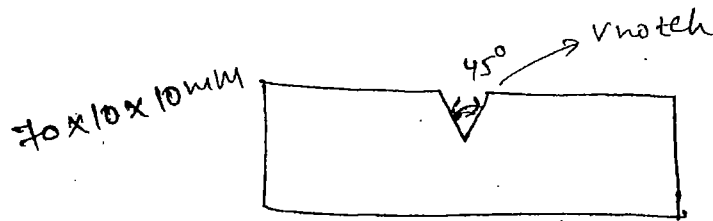
⇒ In case of brittle material

the area under the stress vs strain curve is less.

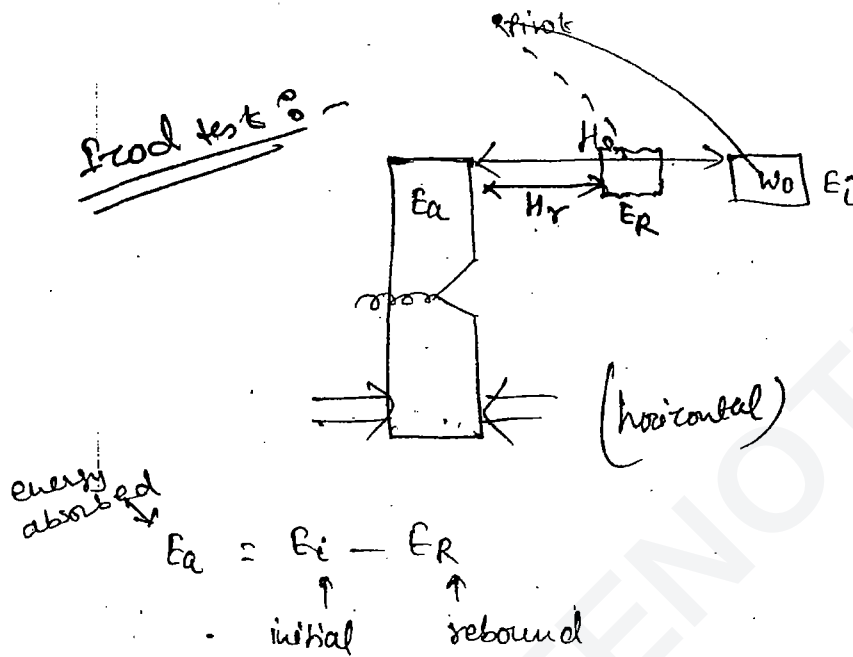
⇒ difficult to measure accurately without error

and therefore 2-~~rod~~ & Charpy test will be used.

Izod or Charpy test :-



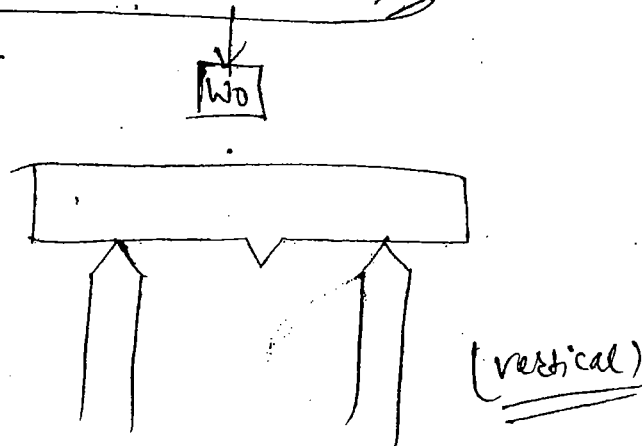
Izod test :-



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

$$f.T = E_a = H_0 W_0 - H_r W_r$$

Charpy test :-



- ⇒ The sample is fixed as a cantilever beam in the (14) 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_f) 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 Prod 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:-

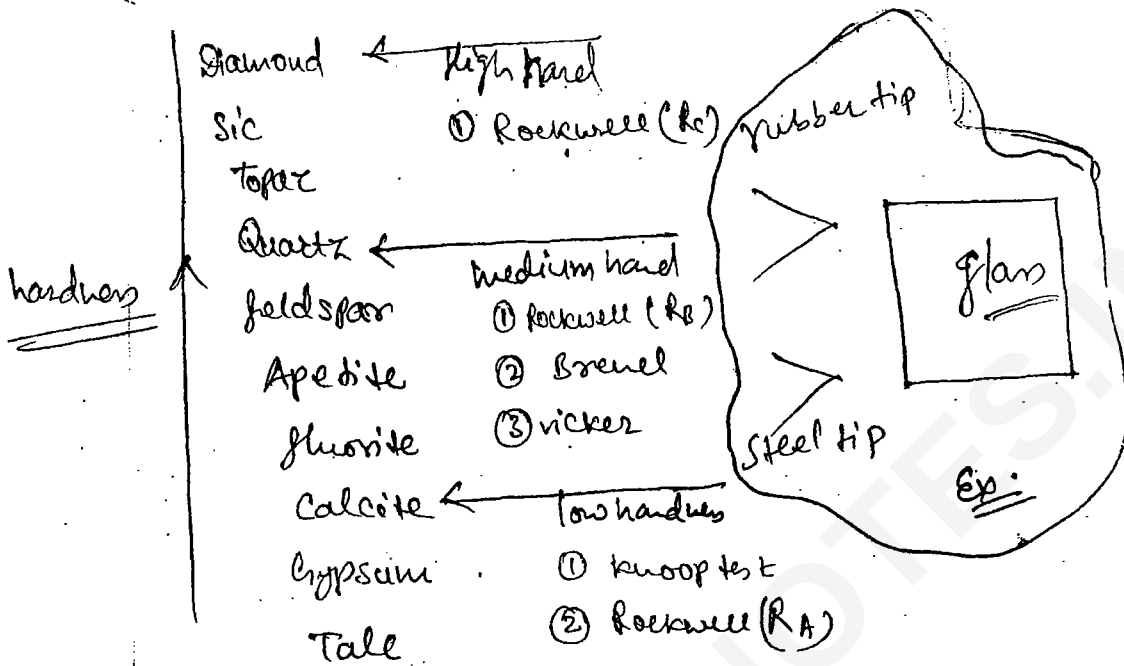
- ⇒ in case of ductile material the measured of S.T. this method is invalid because the sample undergo bending instead of failure.

Q) How to measure Hr.

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

* Hardness measurements :-

① Mho test / Scratch test :-

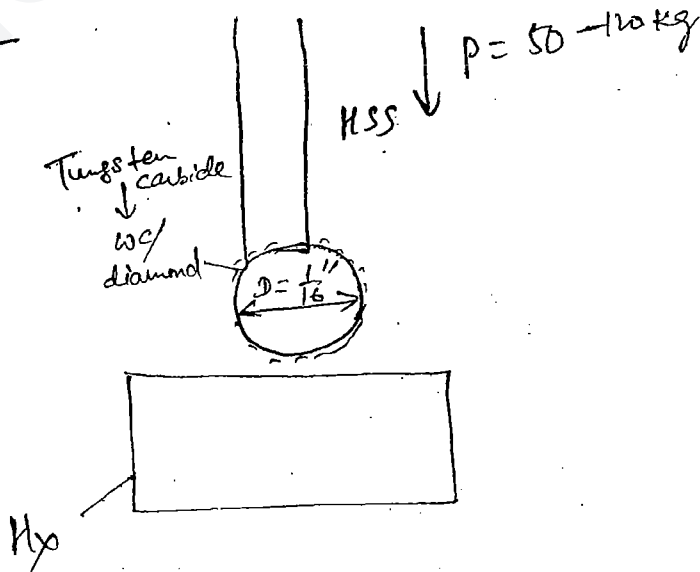


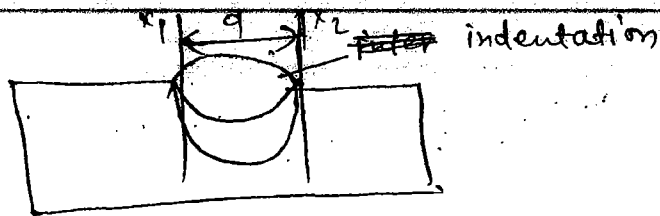
∴, $H_{tip} > H_{surface} \Rightarrow \text{Scratch forms}$

→ Mohs test is Qualitative method.

② Brenel test :-

Spherical
base
Indenter





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

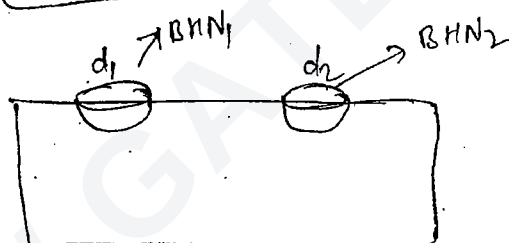
$$\Rightarrow \text{B.H.N} = \frac{2P}{\pi D \left[D - \sqrt{D^2 - d^2} \right]}$$

D = indenter dia.

P = load used to form indentation.

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

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



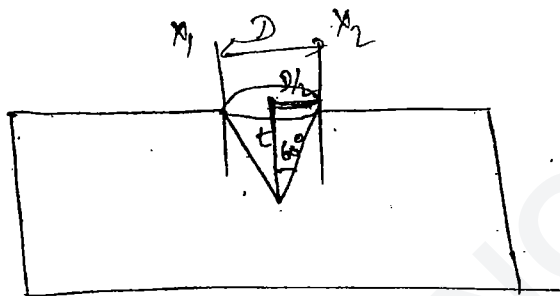
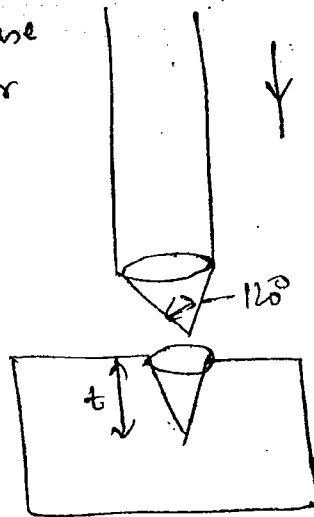
$$\left[\text{avg. BHN} = \frac{\text{BHN}_1 + \text{BHN}_2 + \dots + \text{BHN}_{10}}{10} \right]$$

② Koerkwell :-

Conical base indenter

$\downarrow P = 1-150 \text{ kg}$

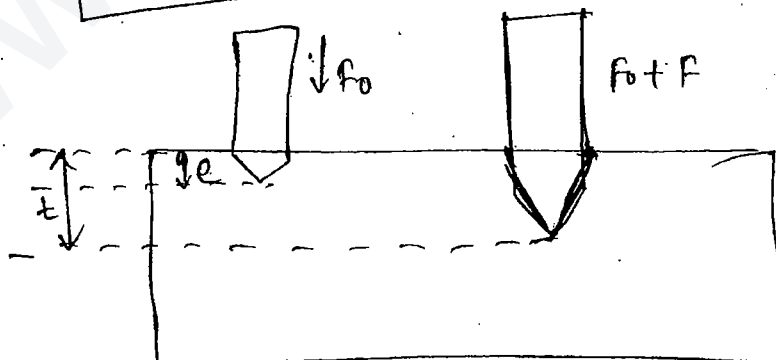
→ Hardness $\propto \frac{1}{t}$



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

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

→ $R.H.N = (e)^{-500t}$ → activation energy



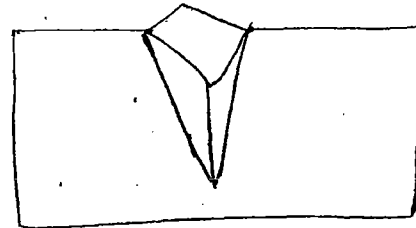
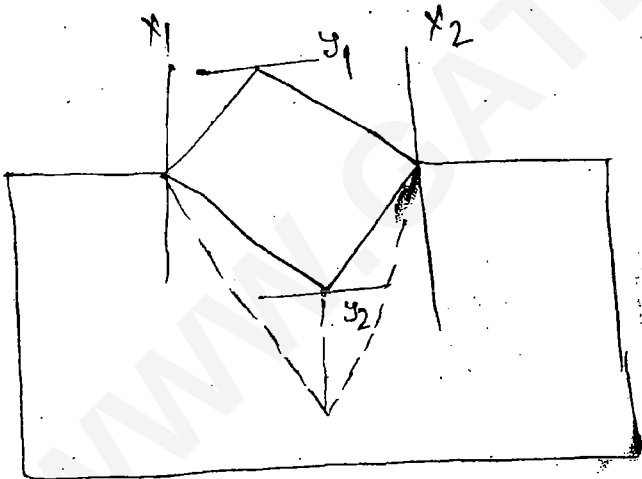
R_A	R_B	R_C
1-50 kg	50-100 kg	100-150 kg
100 hard	medium hard	high hard
Al, Au, Ag, Cu, Sb, etc.	Fe, Fe alloys, Mg, Al, Ni, etc.	MCS, HCS, C-2, Powder metal, ceramic, etc.
		SiC, WC, FeC etc. tools steel

③

Vicker test :-

Pyramid base indenter

$P = 50 - 120 \text{ kg}$



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

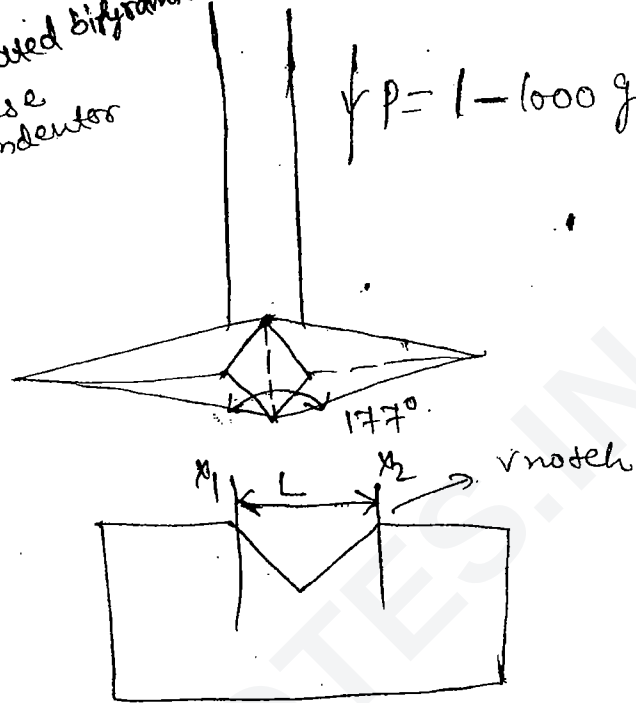
$$\rightarrow V.H.N = \frac{1.854 P}{(d_{avg})^2}$$

④ Knoop test -

or
microhardness
test

elongated bipyramidal
base
indenter

$$P = 1-1000 \text{ gm}$$



$$\Rightarrow K.H.N = \frac{14.22 P}{L^2}, \quad L = \text{notch length}$$

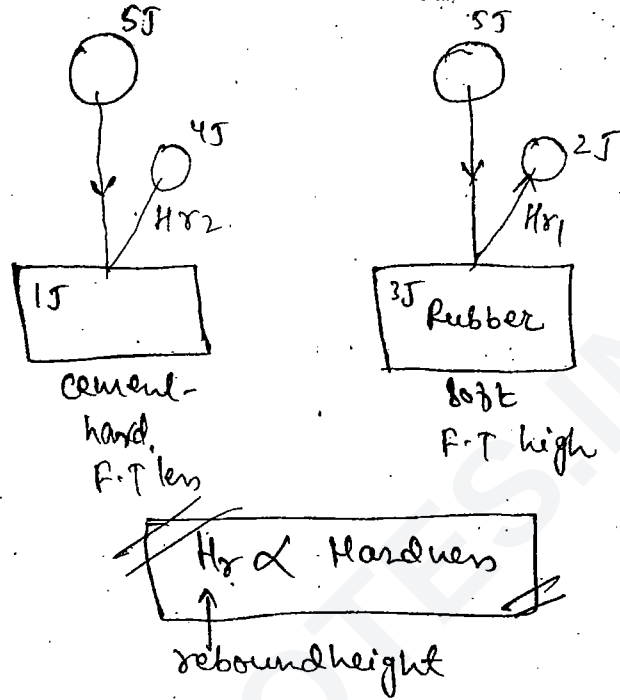
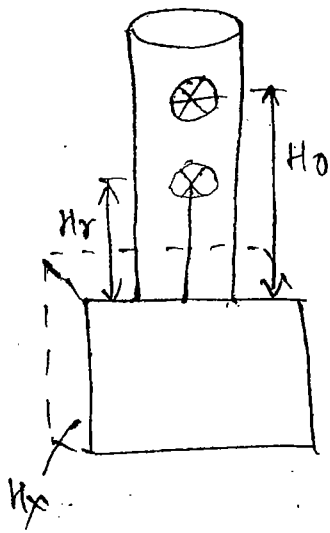
→ Knoop test is used for low hard materials and highly sensitive to indentation force -
silicon, germanium, gallium etc.

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

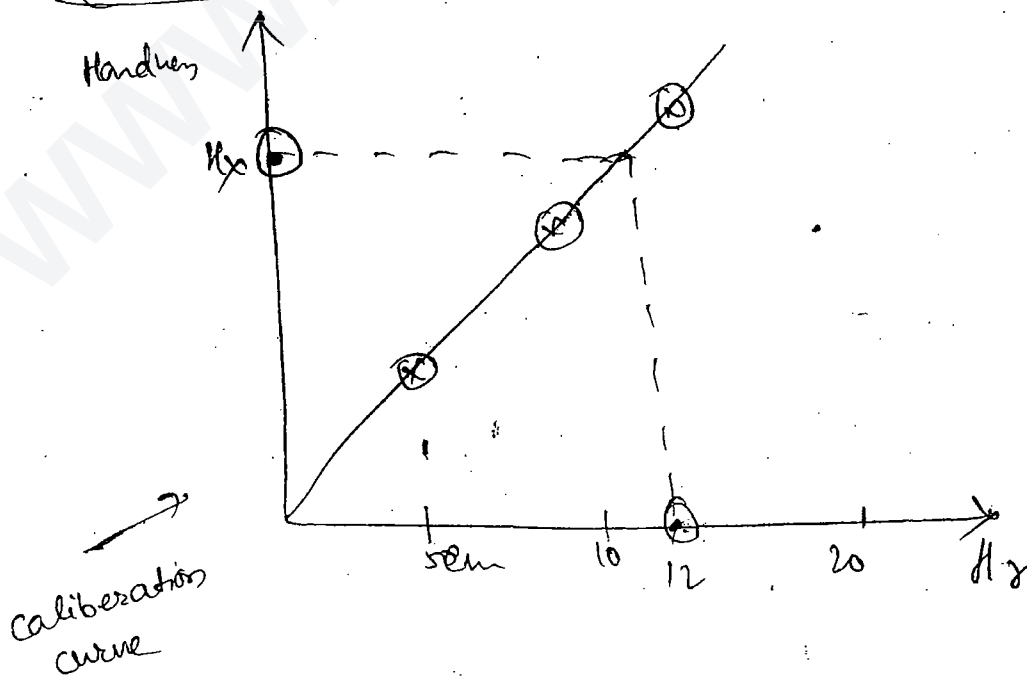
Shore method

Shore's scleroscope

(17)



Material	Hr value	Hardness
(Ace)	5cm	50
(Silver) Ag	10 cm	100
(Copper) Cu	20 cm	200
Rubber	12cm	Hx



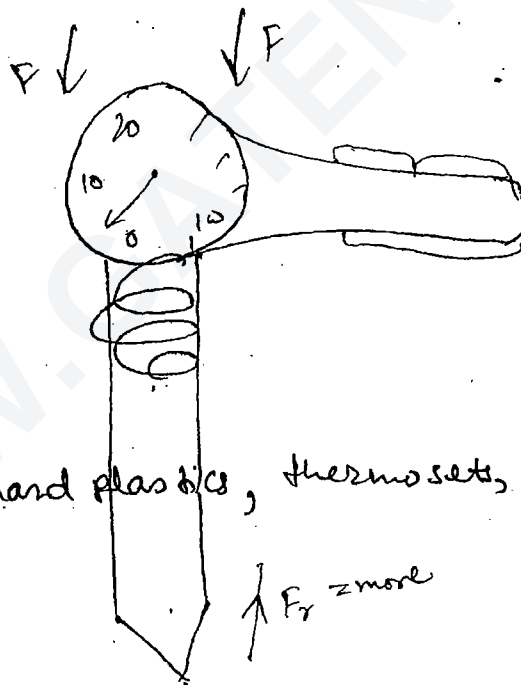
⇒ In Shore method for known materials for hardness, the H_R values are determined and a calibration curve is plotted as shown in figure.

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

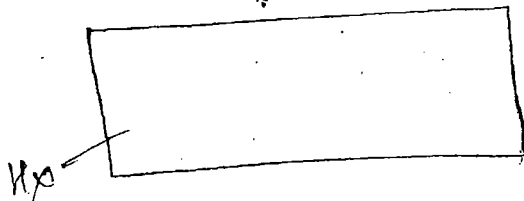
→ By taking the corresponding intercepts on the hardness axis to the H_R value, the hardness of the rubber material H_x will be determined.

⇒ This method applicable to soft plastic, thermo plastic materials & rubber.

* Barcol test -



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



$$F_R \propto -x$$

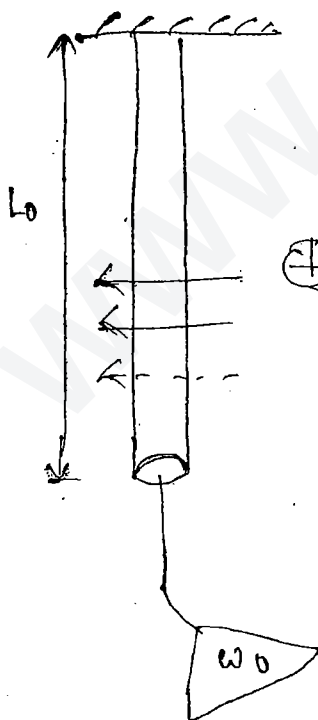
(18)

$$F_R = -Kx$$

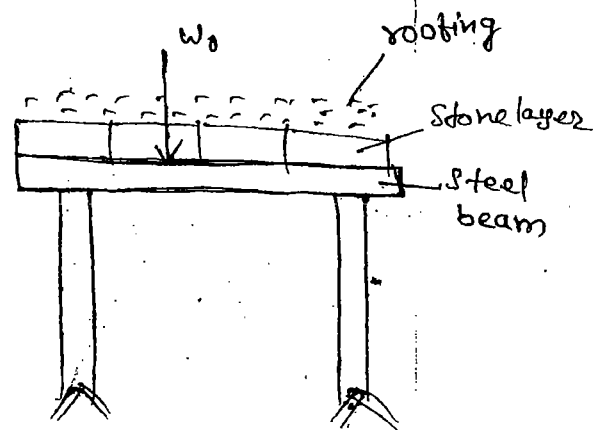
- If material is hard, penetration is difficult,
 $\Rightarrow$ reverse force generated (F_R) is more
 $\Rightarrow$ Spring will be compressed more
 $\Rightarrow$ needle shows higher value of hardness.

- If material is soft, penetration is easy,
 $\Rightarrow F_R$ is less
 $\Rightarrow$ Spring will be compressed less
 $\Rightarrow$ needle shows low value of hardness.

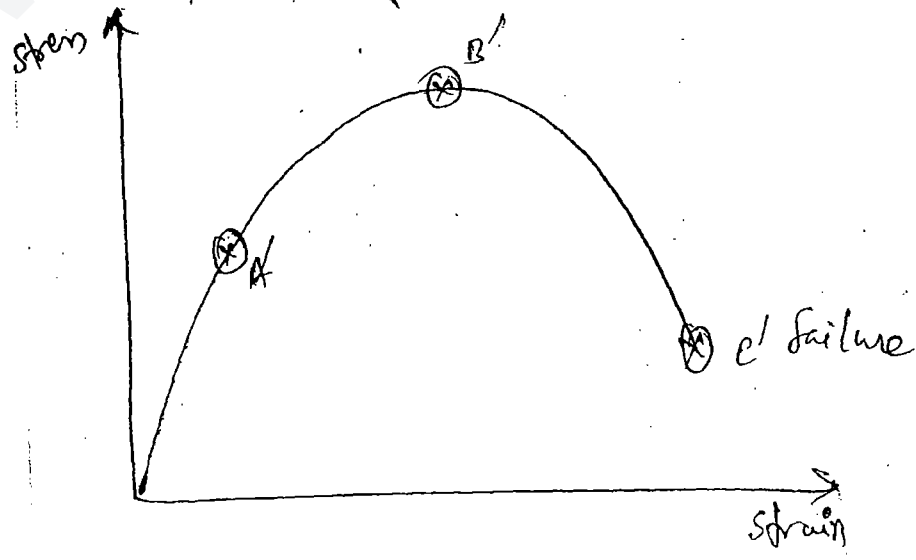
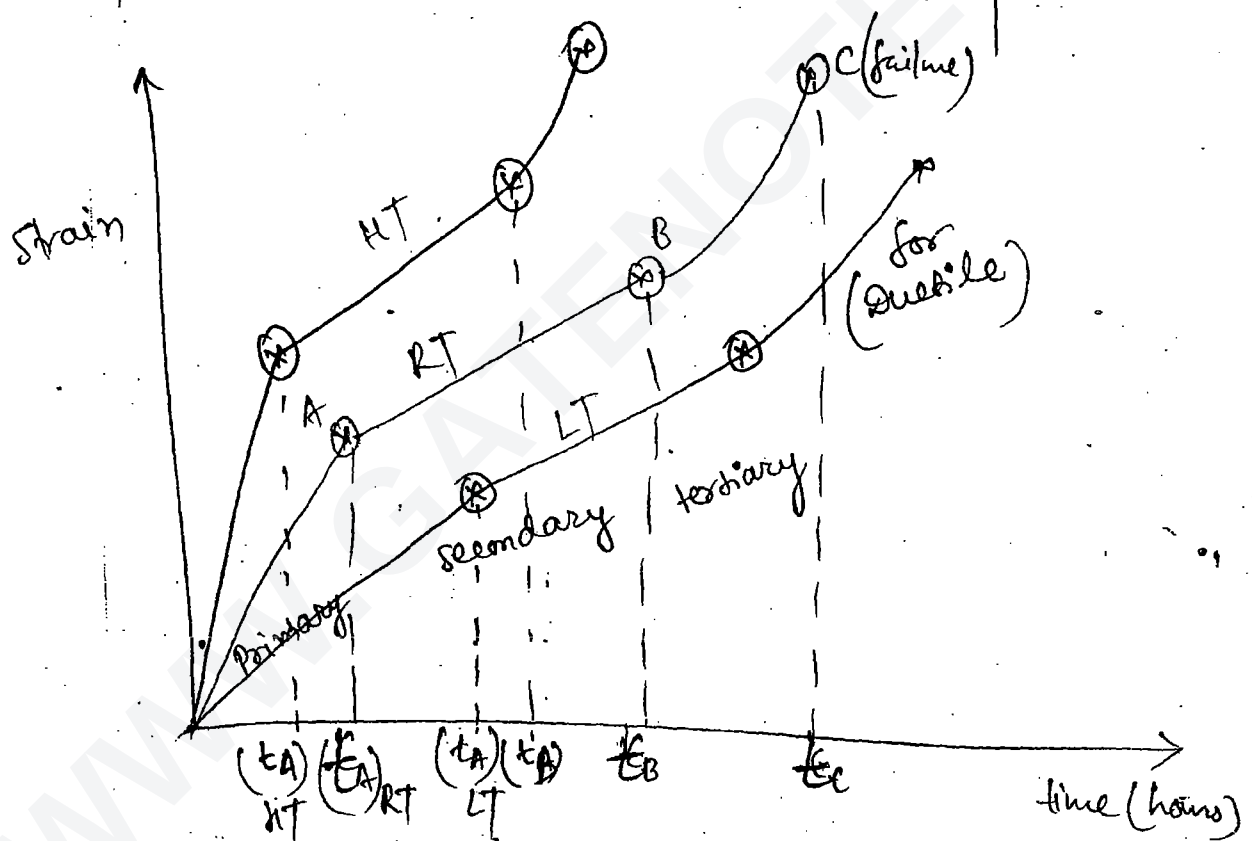
* Creep behaviour in ductile material :-

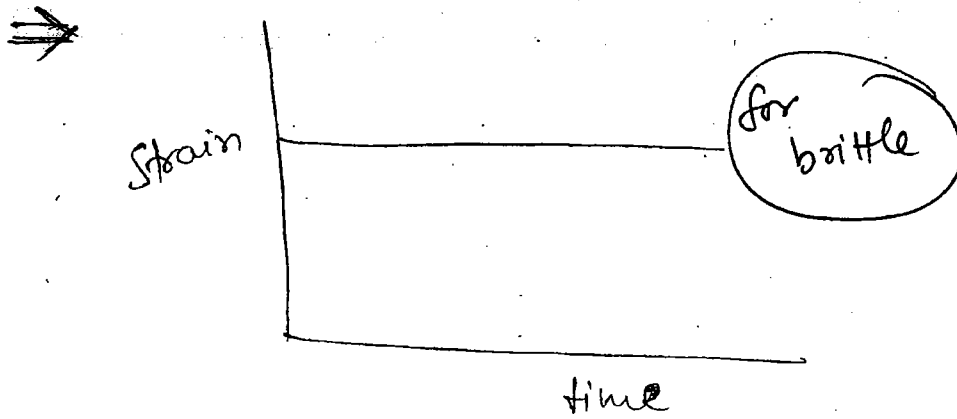


x_0 $t \approx 0$
 x_1 $t \approx 1 \text{ hr}$
 x_2 $t \approx 2 \text{ hr}$



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	$\Delta l_2 = x_2 - x_0$	$\frac{\Delta l_2}{l_0} = \epsilon_2$
...	...	...	...
$t = \eta$			ϵ_η





⇒ 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 gain its original shape.

⇒ represents elastic region (OA') 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 gain 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 severe 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 does not exist in brittle material because it does not undergo plastic deformation.

⇒ Stress strain curve explains the ^{failure} behavior of material w.r.t load, and whereas creep curve explain the failure behavior 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 :-

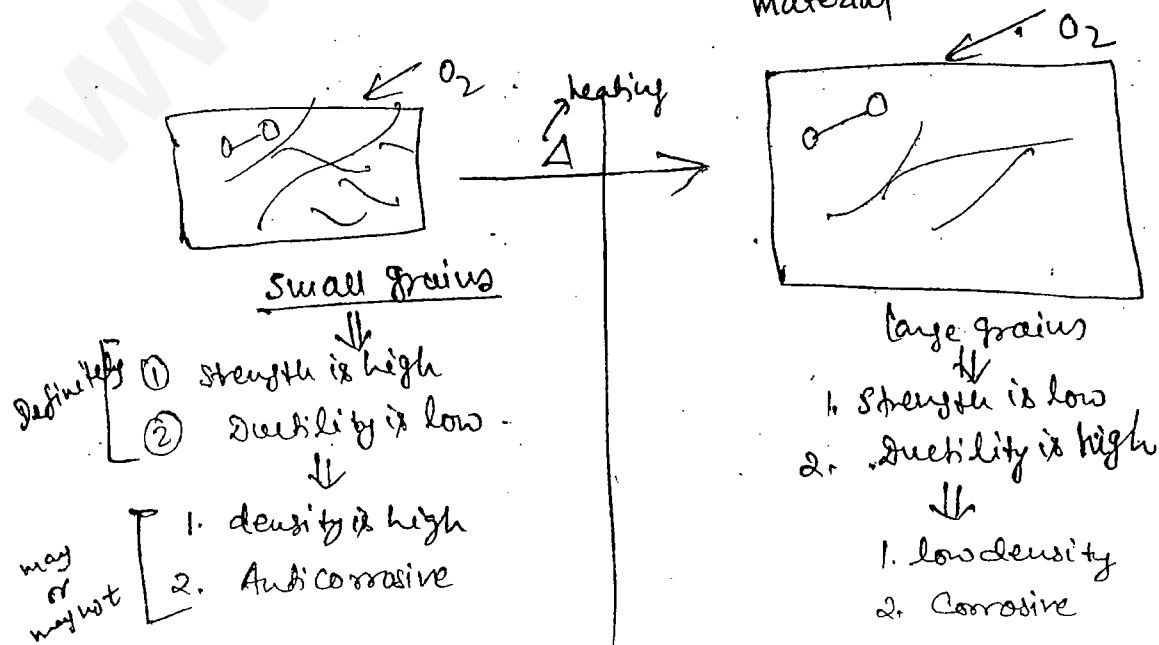
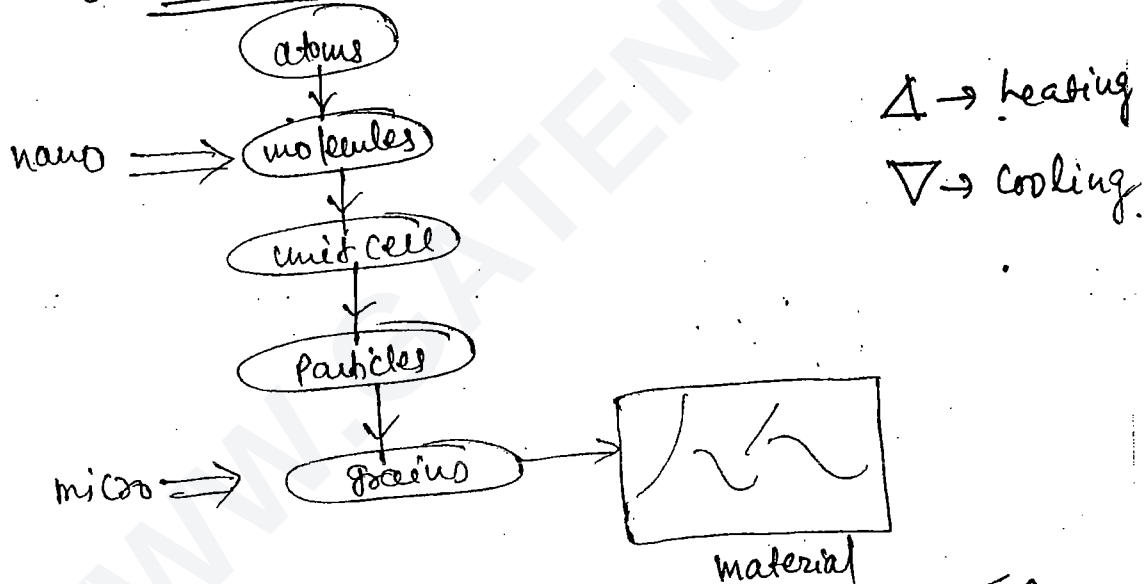
⇒ It is always preferable to operate a component at as low surrounding temp. as possible to improve the life of the component without shape change.

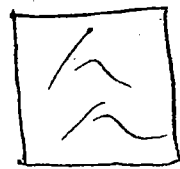
⇒ Therefore design of component at hightemp. environment is complex and difficult.

⇒ strength of a material depends on -

- ① Structure
- ② Defects
- ③ Composition

① Structure :-





Al
(Small grain)



Al
(large grain)

⇒ If a material possess with small grain is heated to high temperature followed by slow cooling process

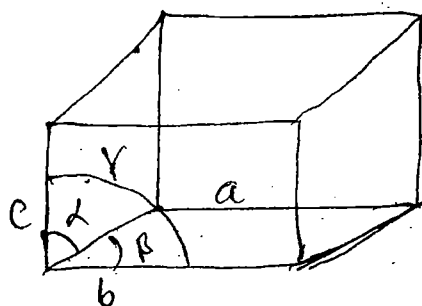
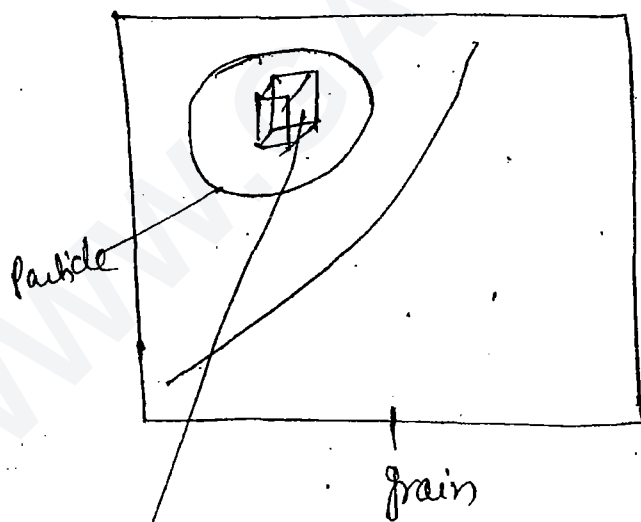
⇒ Small grains will combined and form larger grains

⇒ 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.

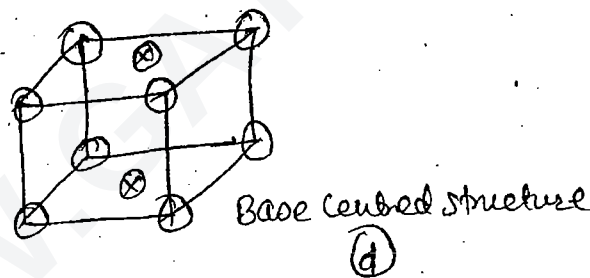
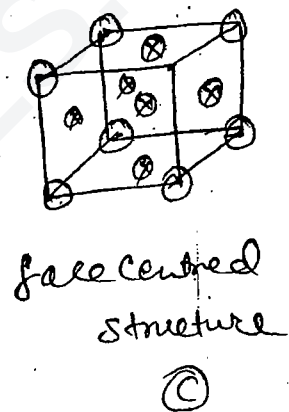
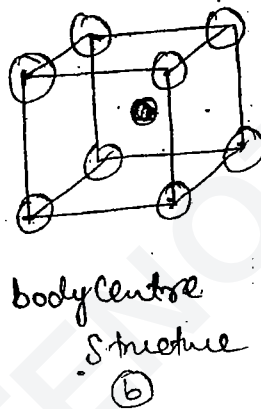
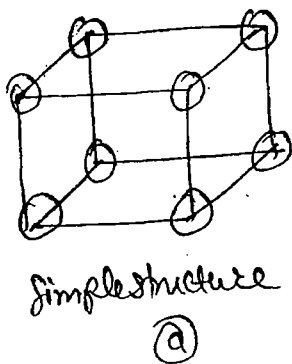


$a, b, c, \alpha, \beta, \gamma \rightarrow$ lattice

(21)

Structure of unit cell = structure of material

→ The min^u 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.



⇒ A unit cell contains $a, b, c, \alpha, \beta, \gamma$ ~~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.

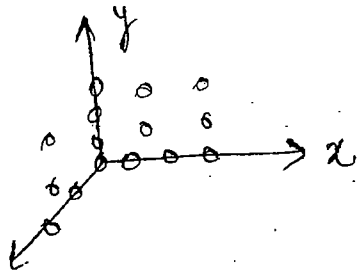
lattice parameters	Structure	Substructure	Material
① $a=b=c$ $\alpha=\beta=\gamma=90^\circ$	Cubic	$\rightarrow$ S.C $\rightarrow$ NaCl $\rightarrow$ b.c.c $\rightarrow$ α Fe, δ Fe $\rightarrow$ f.c.c $\rightarrow$ γ Fe $\leftarrow$ austenite (r-iron)	gate 2012
② $a=b \neq c$ $\alpha=\beta=\gamma=90^\circ$	Tetragonal	$\rightarrow$ S.T $\rightarrow$ B.C.T $\rightarrow$ f.c.c	Radium
③ $a \neq b \neq c$ $\alpha=\beta=\gamma=90^\circ$	Orthorhombic	$\rightarrow$ S.O $\rightarrow$ B.C.O $\rightarrow$ f.c.O $\rightarrow$ γ Mn $\rightarrow$ ba.C.O $\rightarrow$ U, Ga	
④ $a=b \neq c$ $\alpha=\beta=90^\circ, \gamma \neq 90^\circ$	Rhombohedral	$\rightarrow$ S.R	Bi (Bismuth)
⑤ $a=b \neq c$ $\alpha=\beta=90^\circ, \gamma=120^\circ$	Hexagonal	$\rightarrow$ S.H	cd, Zn.
⑥ $a \neq b \neq c$ $\alpha=\beta=90^\circ, \gamma \neq 90^\circ$	monoclinic	$\rightarrow$ S.M $\rightarrow$ γ Mn $\rightarrow$ ba.C.M $\rightarrow$ Plutonium Radioactive atom	
⑦ $a \neq b \neq c$ $\alpha \neq \beta \neq \gamma$	triclinic	$\rightarrow$ S.Tri	CuSO ₄

→ Structure & Substructure → Bragg's lattice

(22)

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

Crystalline



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

Types

① Single crystalline

- If entire volume of material contains a single grain is called as single crystalline.

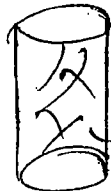
Ex- silicon, Ge, GaAs

↑
gallium arsenide



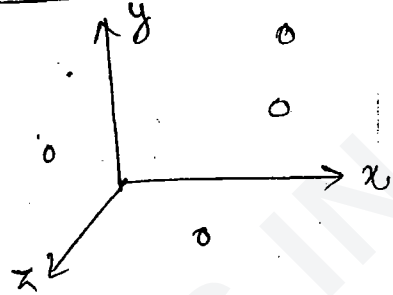
Single grain

② Polycrystalline



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

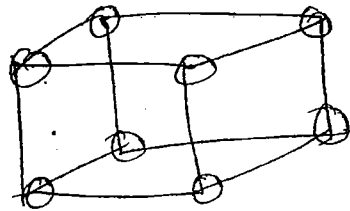
Amorphous



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

NOTE 8 =

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



Simple structure

⇒ Strength of unit cell is high

∴ no. of atoms in unit cell are more

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

(ii) Packing factor is high

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

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

⇒ 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 :-

23

$$a = b = c$$

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

no. of atoms = N

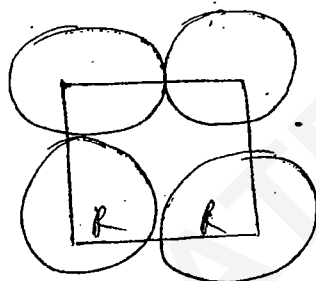
$$= \frac{N_c}{8} + \frac{N_f}{2} + \frac{N_b}{2} + \frac{N_{ba}}{2}$$

$\xrightarrow{\text{corner}} \quad \xrightarrow{\text{face}} \quad \xrightarrow{\text{body}} \quad \xrightarrow{\text{base}}$

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

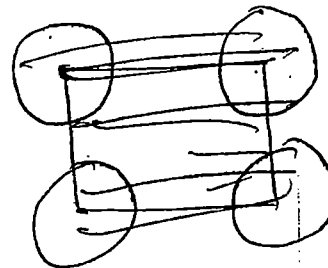
$$N = 1$$

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



$$a = 2R$$

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



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

$$P.f. = 0.52 = 52\%$$

ψ Packing factor for f.c.c :-

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

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

$$N = 4$$

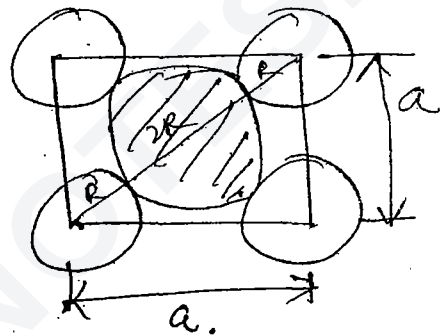
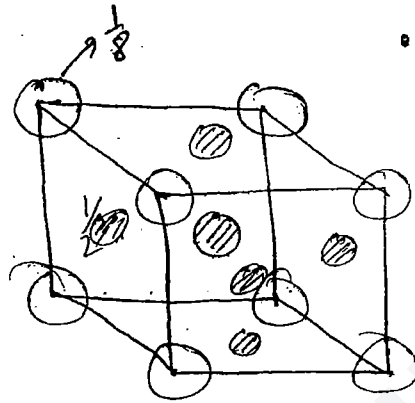
$$P.f = \frac{N \times \frac{4}{3} \pi R^3}{a \times a \times a}$$

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

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

$$8R^2 = a^2$$

$$\Rightarrow R = \frac{\sqrt{2}a}{4}$$



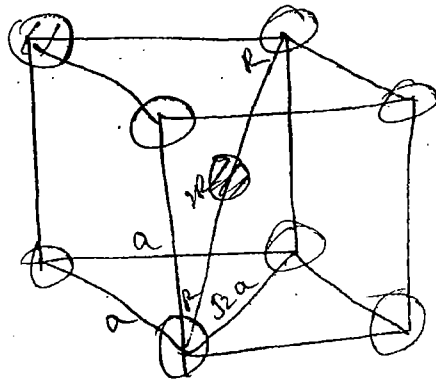
$$P.f = 0.74 = 74\%$$

ψ Packing factor for B.C.C

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

$$N = 2$$

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



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

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

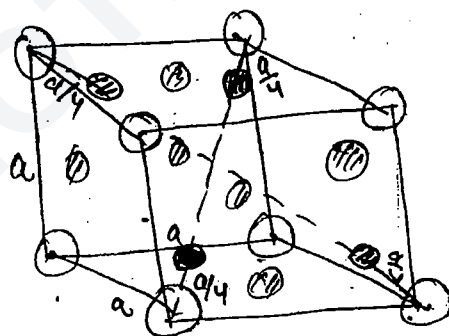
$$R = \frac{\sqrt{3}a}{4}$$

$$\text{hence, p.f.} = \frac{2 \times \frac{4}{3} \pi \left(\frac{\sqrt{3}a}{4}\right)^3}{a^3} = 0.68$$

$$\text{p.f.} = 68\%$$

4 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.



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

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

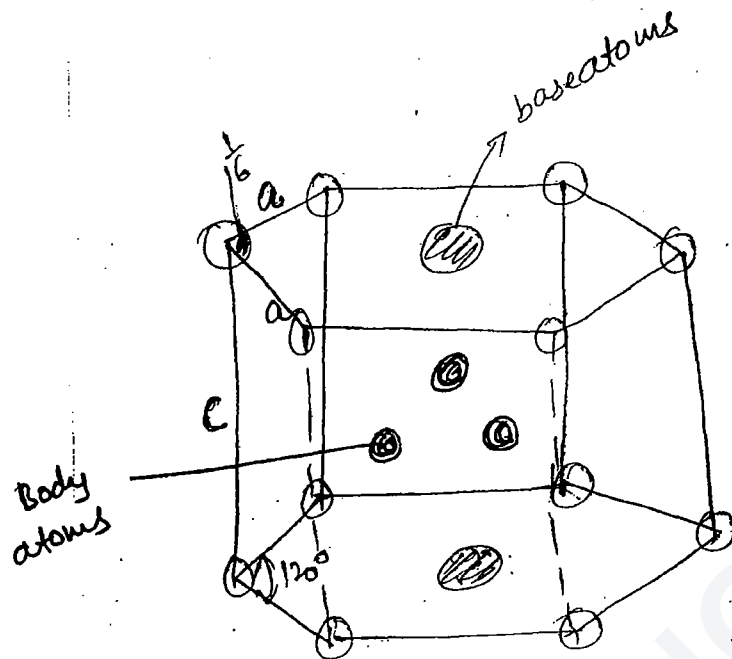
$$\begin{aligned} \text{p.f.} &= \frac{N \times \frac{4}{3} \pi R^3}{a^3} \\ &= \frac{8 \times \frac{4}{3} \pi \left(\frac{\sqrt{3}a}{8}\right)^3}{a^3} \end{aligned}$$

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

* Packing factor for hexagonal closed packed structure -

$$a = b \neq c$$

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



keep remember not 8

$$N = \frac{12}{8} + 0 + \frac{3}{1} + \frac{2}{2}$$

$$= 2 + 3 + 1$$

$N = 6$

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

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

$$S_{B.C.C} > S_{S.C}$$

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.

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

because B.C.C contains more no. of atoms in the unit cells

- ⇒ density is high
- ⇒ weight is more.

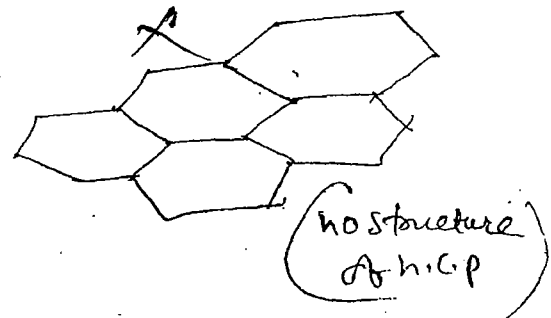
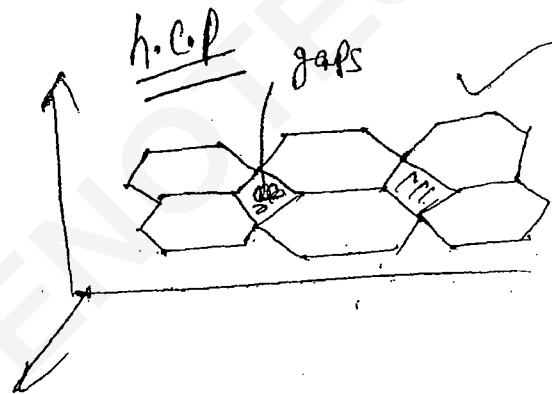
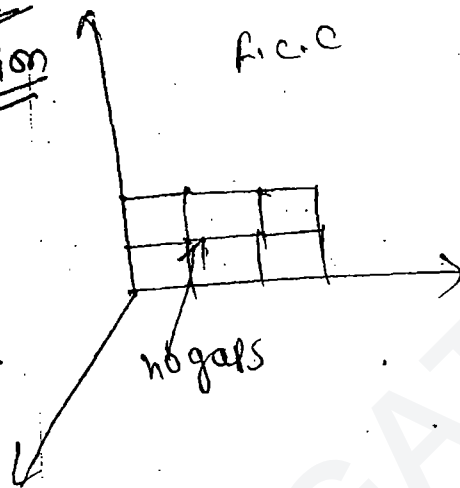
Case 2: If a material forms with s.c., b.c.c and f.c.c structures then

$$S_{f.c.c} > S_{b.c.c} > S_{s.c.}$$

$$P_{f.c.c} > P_{b.c.c} > P_{s.c.}$$

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

V.V.I
Exception



so,

$$S_{f.c.c} > S_{h.c.p}$$

$$P_{f.c.c} > P_{h.c.p}$$

⇒ During formation of h.c.p structures gaps will formed among the lattice atoms

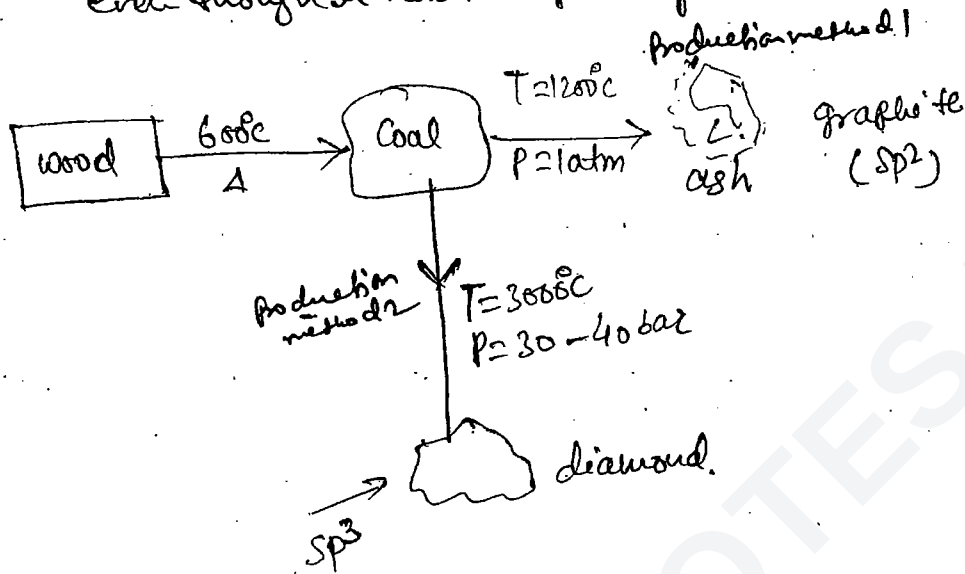
- binding energy decreases
- strength is less.

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

⇒ strength is high.

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



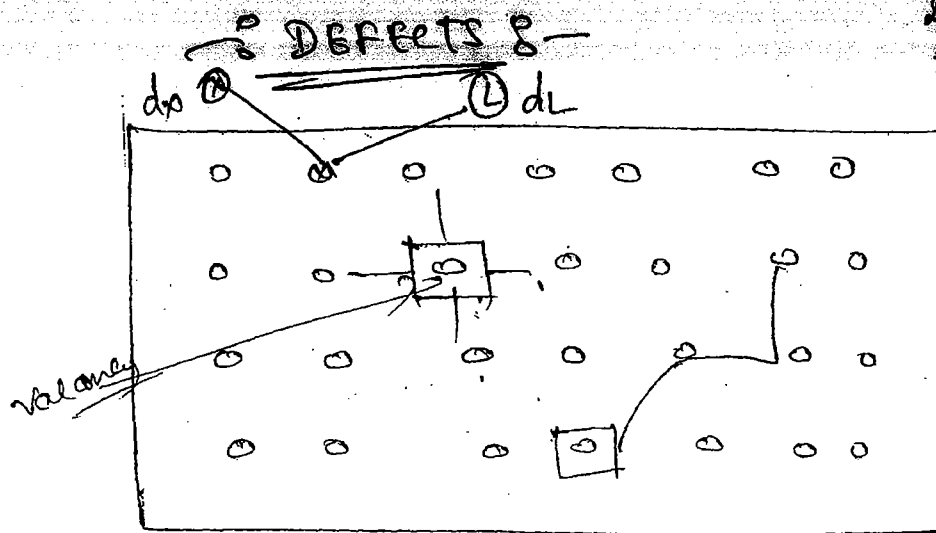
⇒ In diamond carbon atoms will form bondings with carbon atom itself with sp³ bonding, which possess highest binding energy among the atoms.

Therefore

⇒ It has high hardness & strength.

Note ^Q—

- ⇒ Production method changes the grain size of the material
- ⇒ grain size changes the atomic orientation
 - ⇒ change of atomic orientation gives change in structure
 - ⇒ change of structure changes the shape of materials. Strength



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

(A) POINT DEFECTS :-

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

i) vacancy :-

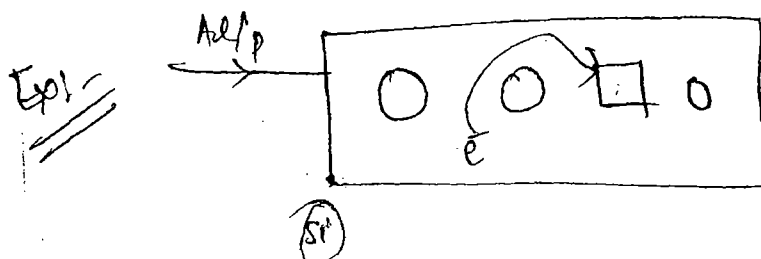
- missing of atom from the regular lattice site
- vacancies creates deficiency of bondings.
- ↳ strength of the material decreases.

ii) displacement of atoms -

→ movement of atom from one lattice site to another lattice site 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.



Ex. - In pure form (Si) is electrically bad conductor, (27)
but by addition of As/P it creates electron in the lattice.

(phosphorus)

These 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

① 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 change 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 :-

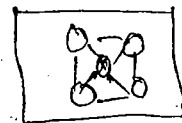
(i) $d_x = d_L$ $\sim$ dia. of lattice atom
 ↑
 dia. of foreign atom

(ii) Valency of X = valency of L

② 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. :-

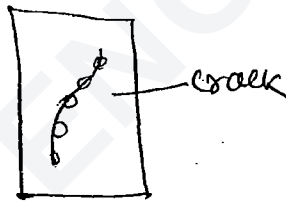
(i) $d_x < d_L$

(ii) valency of $x >$ valency of L

(B) LINE DEFECTS :- (Dislocation)

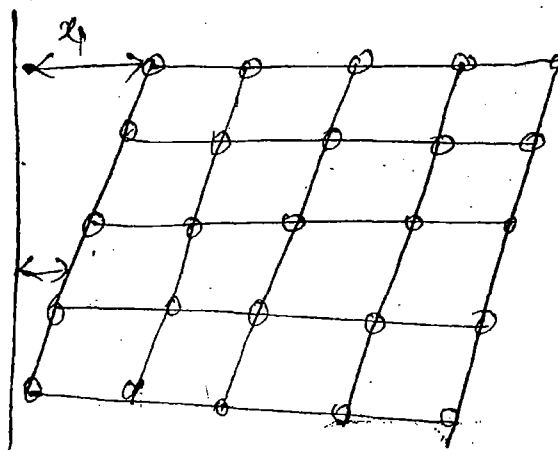
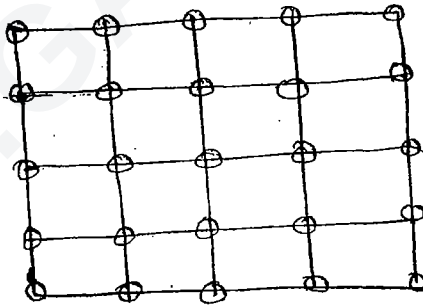
→ If the defect is confined to more than one no. of atoms, called as line defects.

Ex (i) crack :



(ii) slip phenomena :-

$F \rightarrow$



→ 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 slip phenomenon.

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

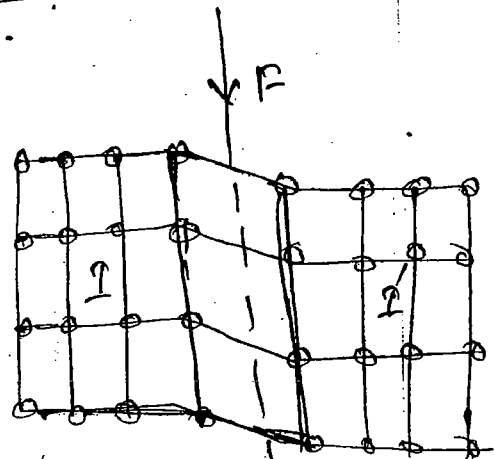
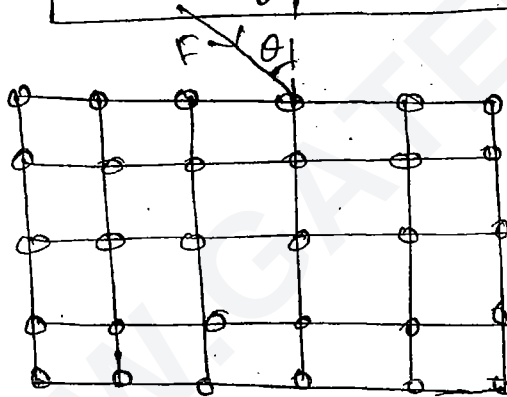
→ Slip phenomena causes plastic deformation in ductile materials.

↳ 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 :-

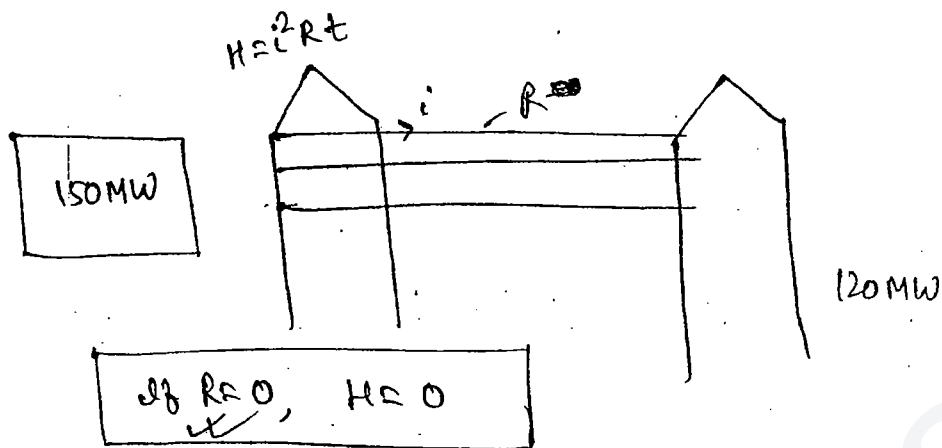


→ If an angled force is applied on the lattice, the atoms will displace along the line of force only. With respect to the plane of force, I and II are the mirror images (Sins).

Therefore,

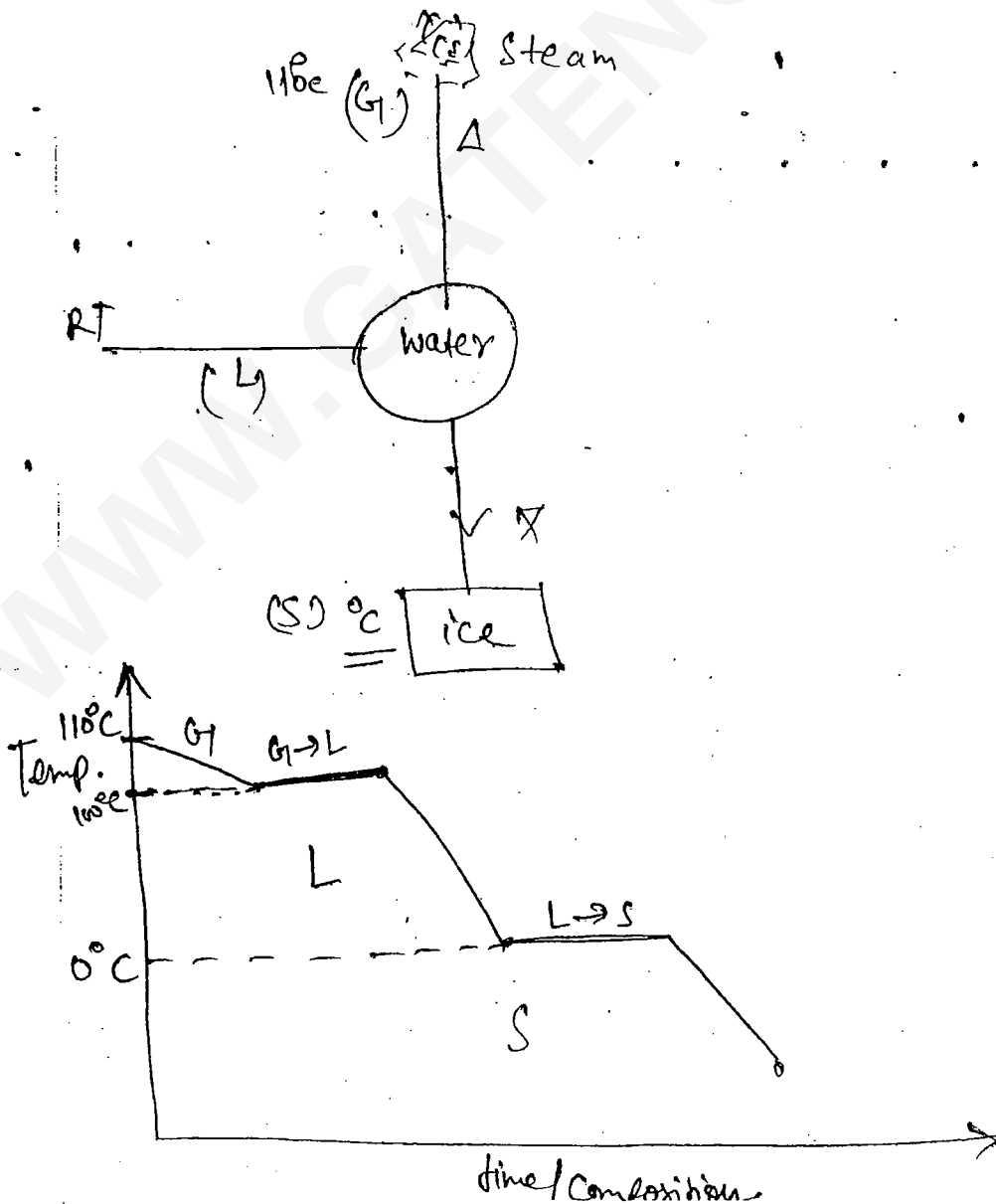
A lattice splits into two identical sublattices I & II' known as twinning phenomenon.

→ Superconductivity in materials
(Zero electrical resistance)



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

PHASE DIAGRAM



① Phase - Physical state of a material.

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

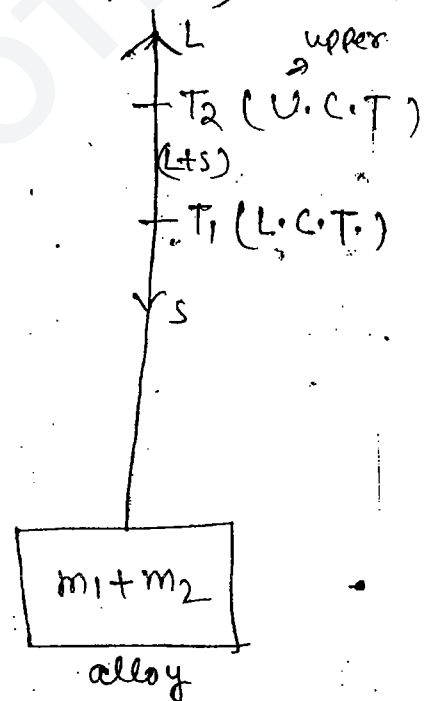
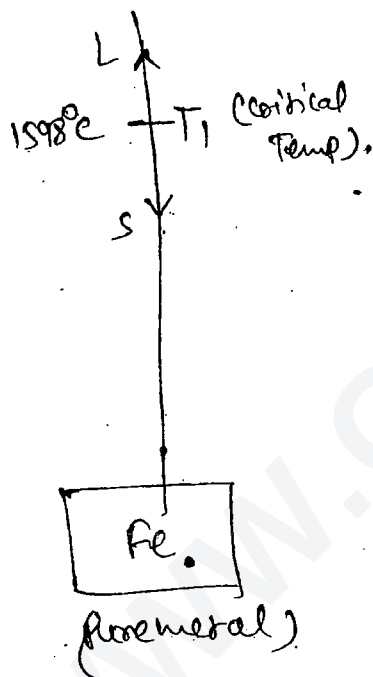
③ Phase diagram -

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 (noneq^b P.D)



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

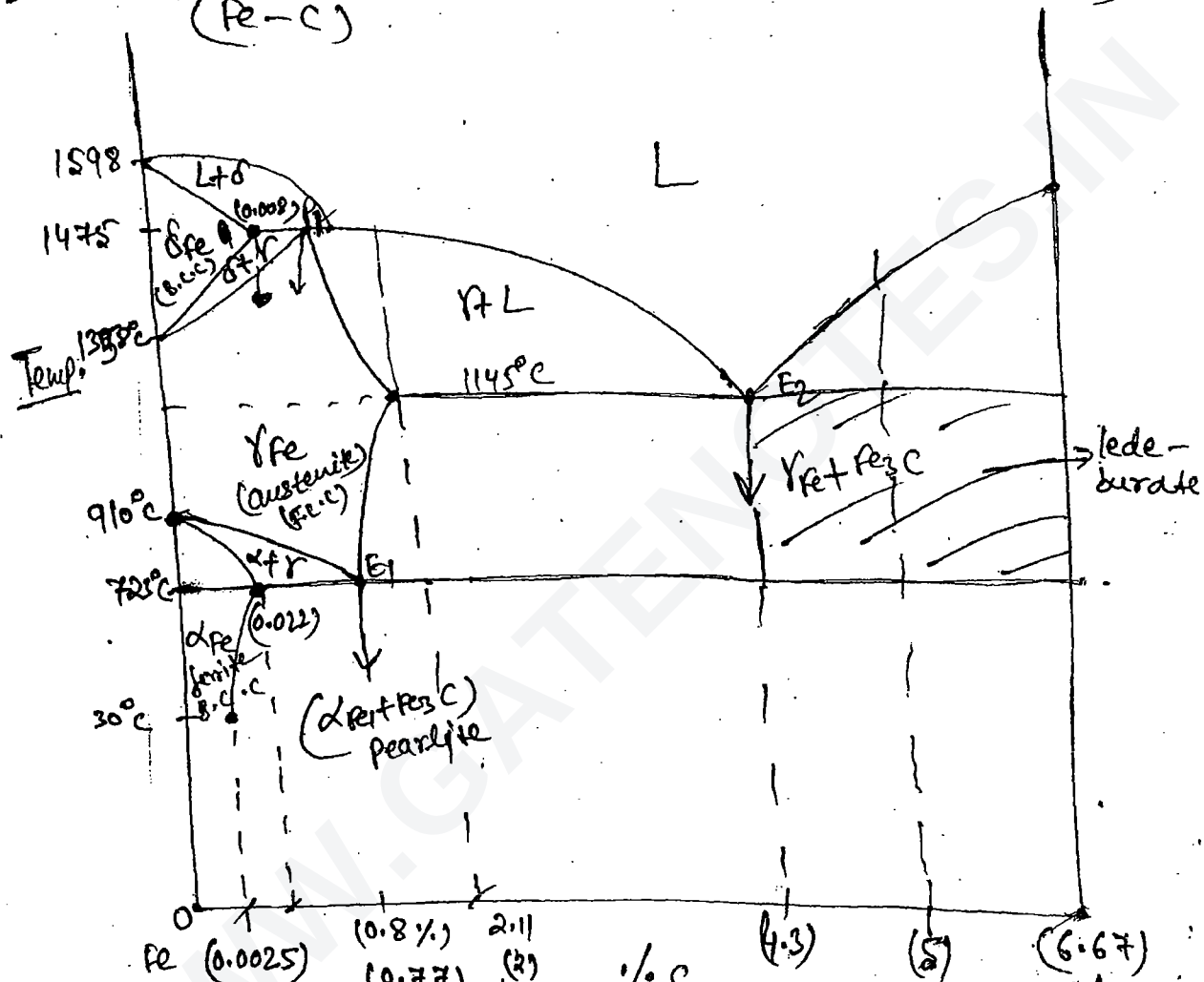
→ In case of an alloy the phase transition temp. is a range of temp. between T_1 and T_2 .

→ 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)

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

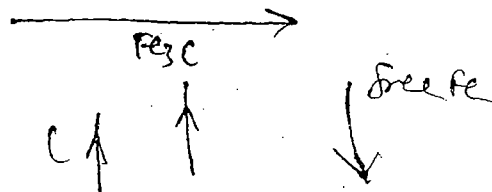
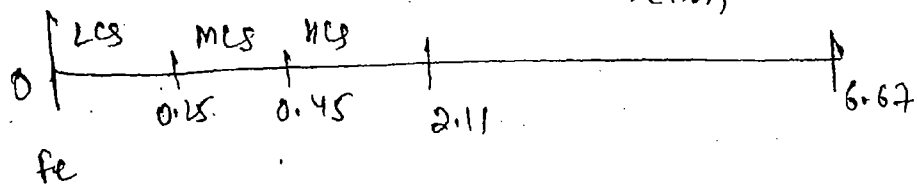
IRON-CARBON PHASE DIAGRAM (V.V.P) (Fe-C)



kl → weldability
H → hardness
ql → malleability

steel

cast iron



⇒ Carbon is added to iron to improve the strength of iron. (20)

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

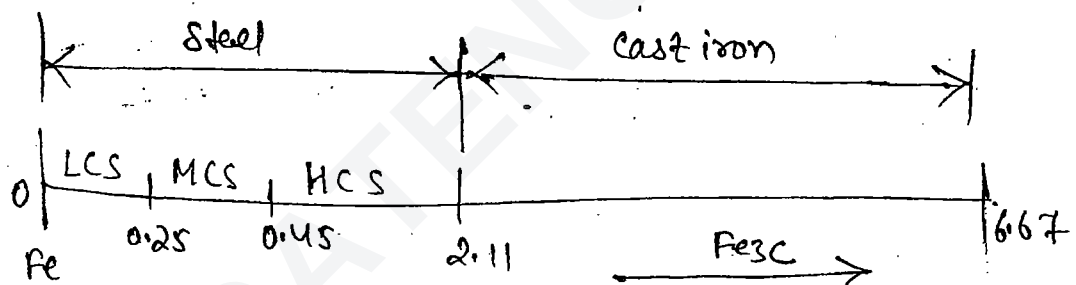
→ If carbon is added to iron, the max^{um} solubility of carbon in iron is 6.67%, known as critical concentration.

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

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

v.v.2
→ If any phase contains high carbon content, it possess high iron carbide volume.

⇒ It exhibits high hardness & brittleness.



$$H_{\text{Fe}} < H_{\text{Steel}} < H_{\text{C.I}}$$

Similarly,

$$H_{\text{Fe}} < H_{\text{LCS}} < H_{\text{MCS}} < H_{\text{HCS}} < H_{\text{C.I}}$$

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

$$M_{\text{Fe}} > M_{\text{LCS}} > M_{\text{MCS}} > M_{\text{HCS}} > M_{\text{C.I}}$$

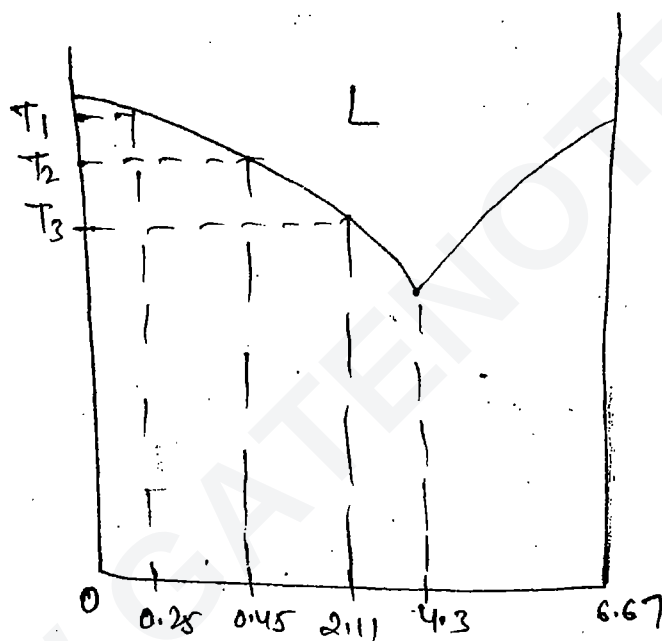
→ If any phase contains high carbon content (free iron is less) ⇒ difficult to weld,

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

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

$$\therefore C.R_{Fe} < C.R_{Lcs} < C.R_{Mcs} < C.R_{Hcs} < C.R_{C.I}$$

→ The melting form :-



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

therefore,

melting point → $M.P_{Fe} > M.P_{Lcs} > M.P_{Hcs}$

→ Low carbon steels are difficult to produce because

- ① melting temp. is high
- ② difficult to mixed minute carbon content at very high temp.

∴ L.C.S are expensive, but possess high strength (31) 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^u solubility of carbon is 0.008 % at 1475°C.

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

→ It exhibits similar properties to pure iron.

→ difficult to produce because production temp. is high.

→ δ -iron contains large grain $\Rightarrow$ ductile in nature.

→ Structure is B.C.C

ABOUT (γ -iron) :- (Austenite)

→ The max^u solubility of carbon is 2.11 % at 1145°C.

→ The min^u temp. at which γ -iron ~~exists~~ exists 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^u solubility of carbon is (0.022 %) at 723°C.

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

→ Structure is B.C.C.

→ α -iron will exhibit similar properties to 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 design load.

(ii) fails gradually

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

→ Strength of cast iron can be changed by!:-

① 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.

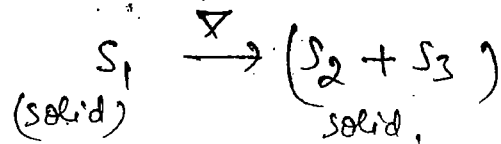
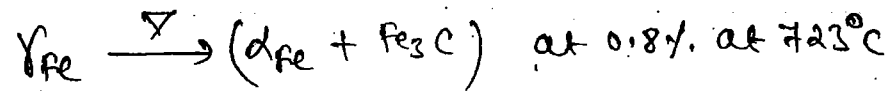
→ If the % of carbon is 2.11 to 5% then Melting point is min.

↳ called as easily castable range of carbon content.

↳ called as cast iron.

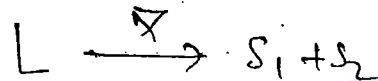
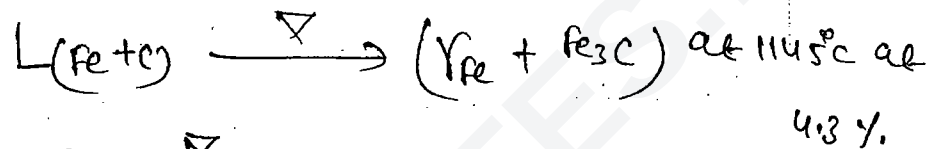
① At E_1 point (eutectoid point) :-

(32)



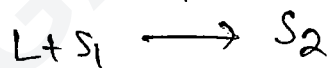
→ Eutectoid phase transformation.

② At E_2 point (eutectic point)

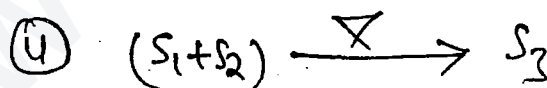


→ Eutectic phase transformation

③ at P_1 point (peritectic point)



(peritectic phase transformation)



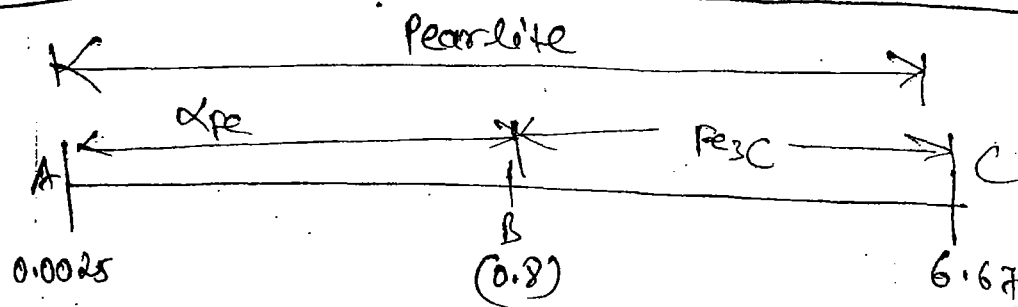
peritectoid phase transformation.

remember
solid → solid
liquid → solid

→ A mixed phase of $(\gamma_{Fe} + Fe_3C)$ existing b/w 4.3 – 6.67 % and $723 - 1145^\circ C$ is known as

Ledeburite phase.

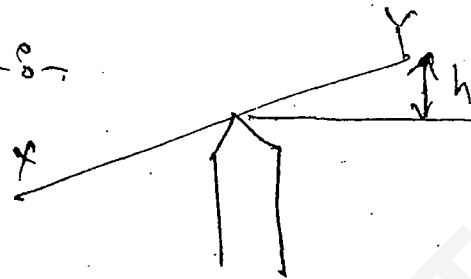
Q) Determine % α_{Fe} and % Fe_3C in pearlite phase at 0.8% C.



Rule: Lever rule:-

$$\%A \cdot X = \frac{\%A \cdot Y}{\%X \cdot Y}$$

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



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

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

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

$$\% Fe_3C = 12\%$$

* Types of steel :-

1/6/2012

Friday

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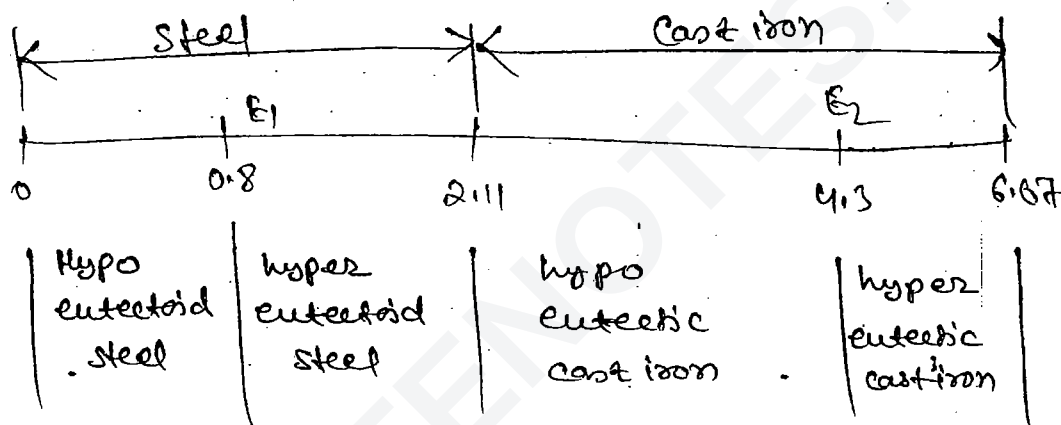
0 — 0.15% C $\rightarrow$ mild steel

0 — 0.25% C $\rightarrow$ LCS

0.25 — 0.45% C $\rightarrow$ MCS

0.45 — 2.11% C $\rightarrow$ HCS
(1.5%)

2.11 — 6.67% C $\rightarrow$ CI
(5%)



$\rightarrow$ any steel + Cr $\rightarrow$ stainless steel

any steel + alloying element $\rightarrow$ Alloyed steel

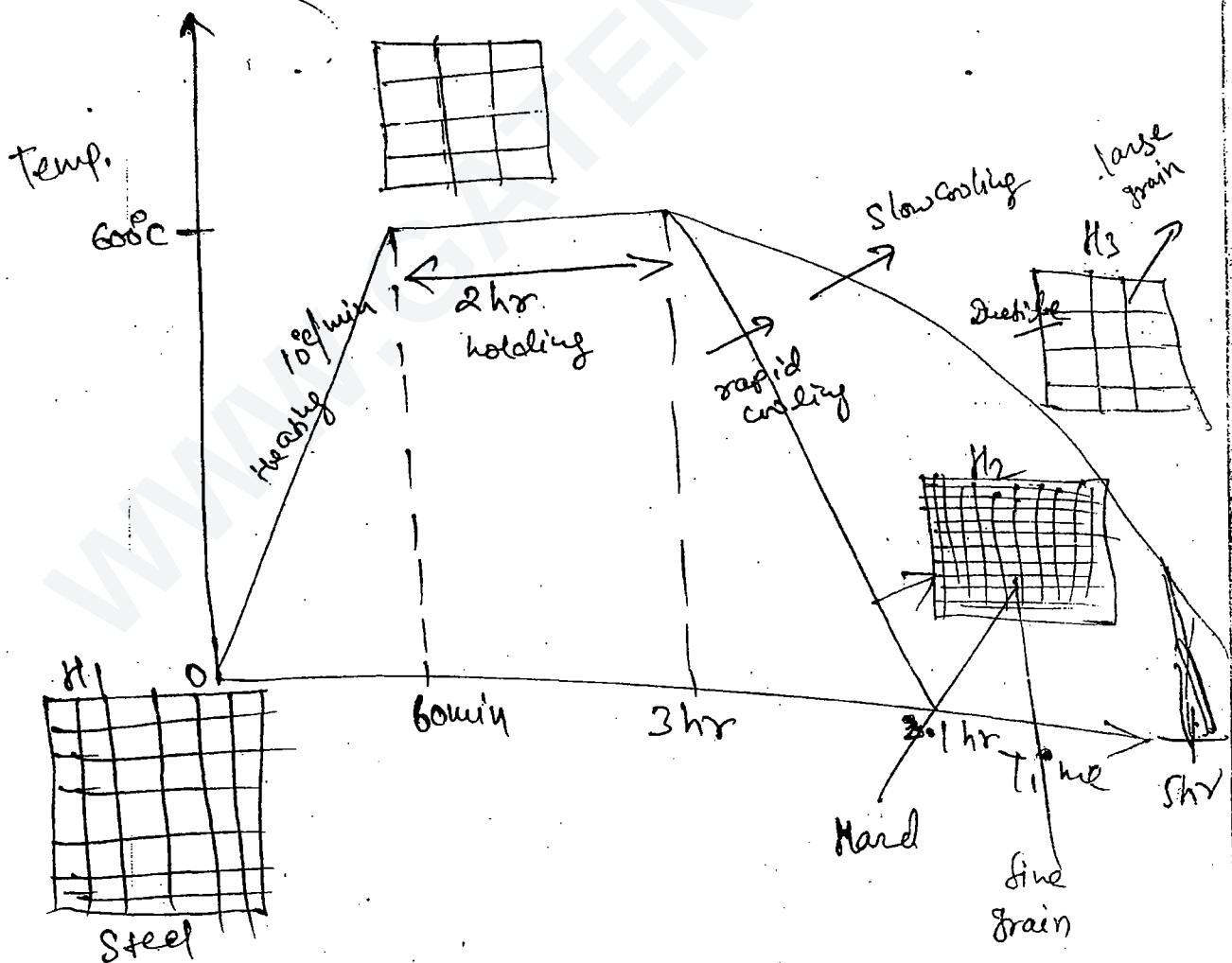
$\rightarrow$ V.V.2

Alloying element	Purpose
Cr	$\rightarrow$ improve corrosion resistance and <u>abgrassion</u> resistance. $\downarrow$ corrosion free
Si	$\rightarrow$ improve hardenability and formability
Mg	$\rightarrow$ Toughness & machinability
S	$\rightarrow$ machinability
Mn	$\rightarrow$ hardenability
tungsten $\rightarrow$ (W/V) vanadium	$\rightarrow$ improve high temp. hardness & strength
Al	$\rightarrow$ improve toughness

(Cobalt) Co	→ hardenability
→ Mo molybdenum	
→ Ni Nickel	improve toughness
(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 process so that the strength of steel can be changed, known as heat treatment process of steel.



→ Every heat treatment contains three steps →

(34)

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 increase.

* Types of heat treatment :-

① hardening

② annealing

③ normalising

④ Tempering

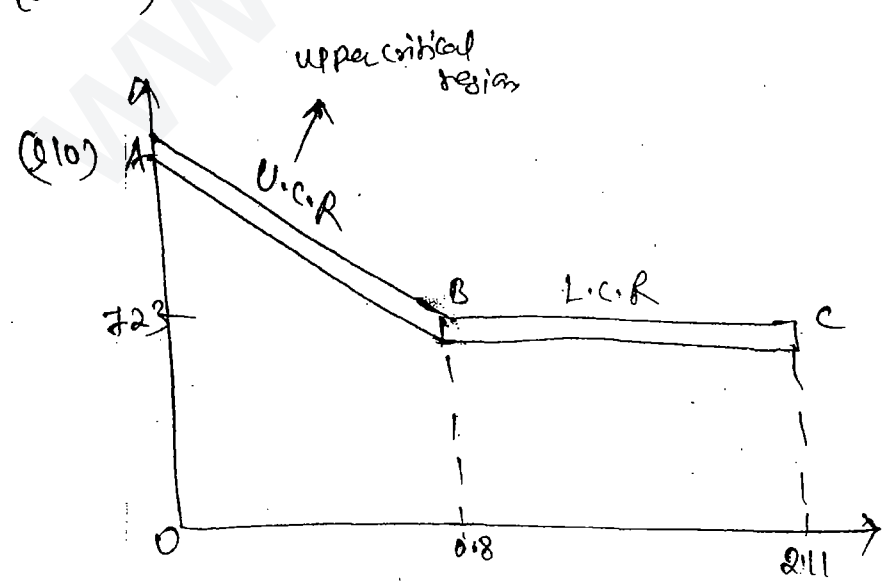
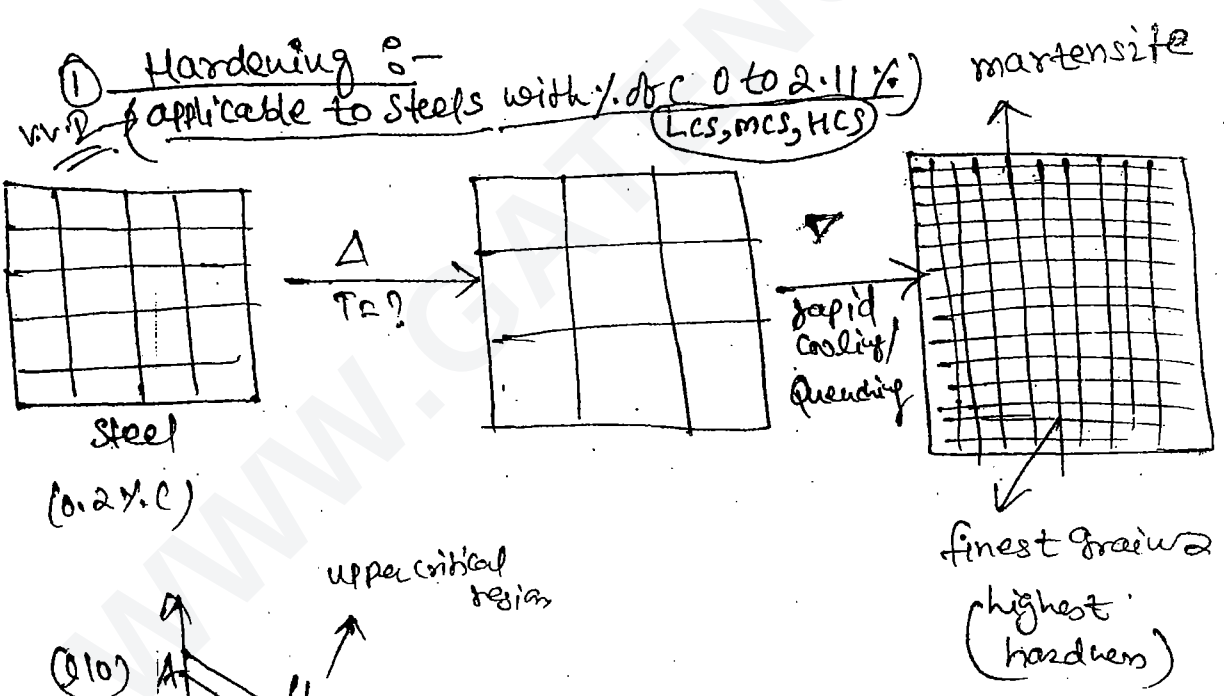
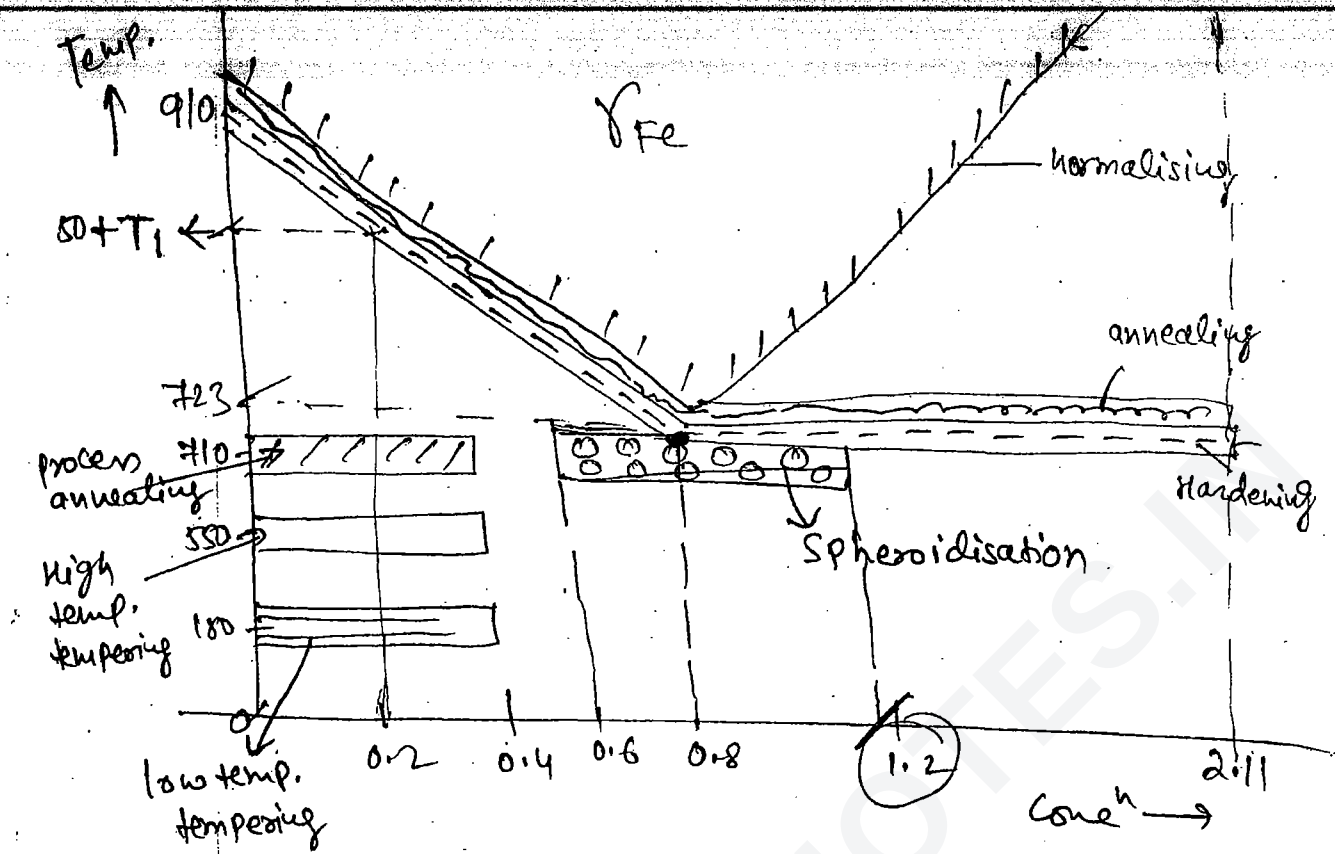
⑤ mar tempering

⑥ Quench tempering

⑦ case hardening

⑧ surface hardening.

shr

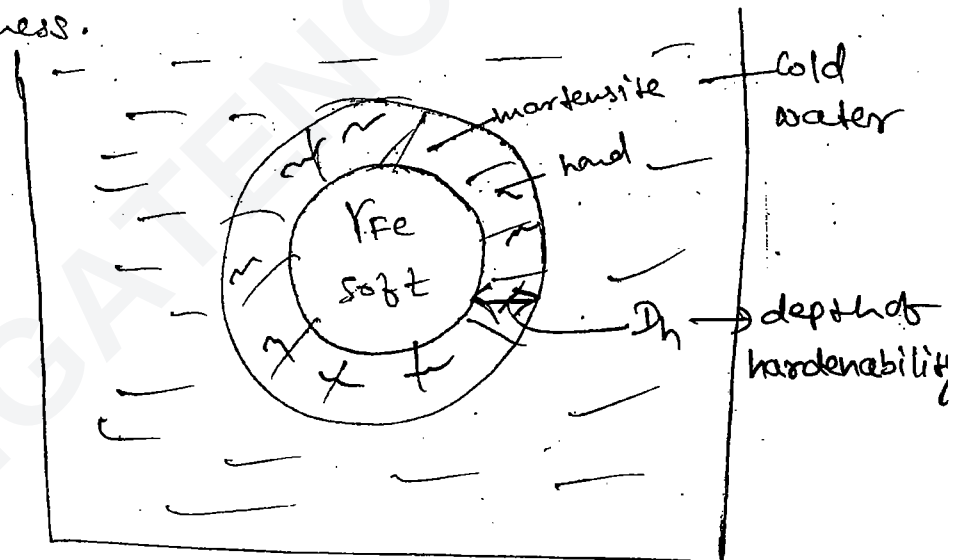


- T_c = 2
- (State next)
- (i) $0.8\% C = 0 - 0.8\% \Rightarrow 50^\circ C$ above U.C.T (AB)
- (ii) $0.8\% C = 0.8 - 2.11\% \Rightarrow 50^\circ C$ above L.C.T (BC)

⇒ 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 turns 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.

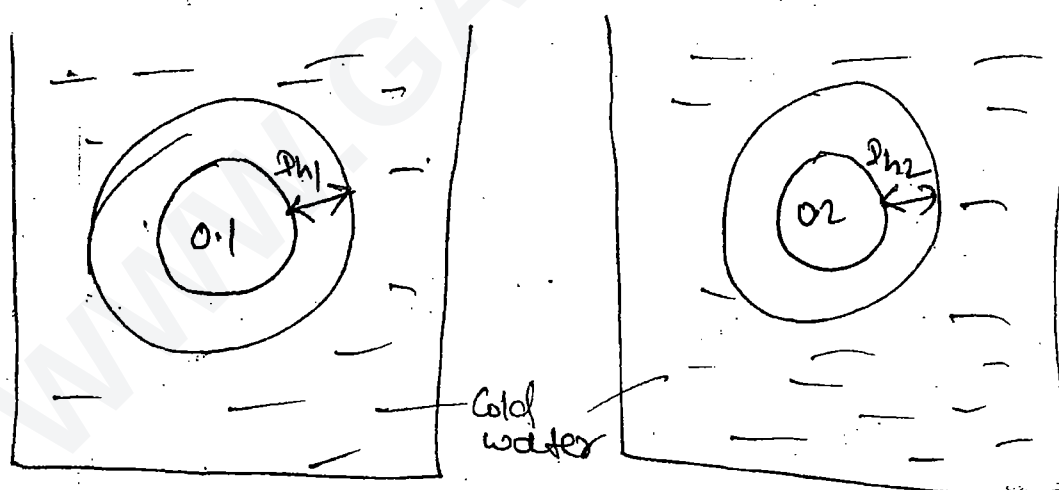
→ A hardened component process, extreme hardness on the outer surface, due to martensite phase,

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

↳ Due to sheer residual stresses, intensity of cracks will form on the surface.

Case-2.

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



→ $D_{h2} > D_{h1}$ because of carbon content

is high,

↳ iron carbide volume is high

↳ easily converts into martensite

↳ depth of hardenability is high

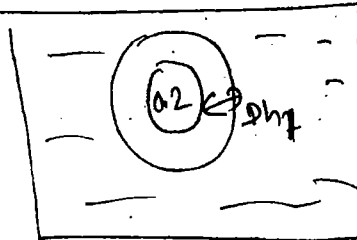
Note: →

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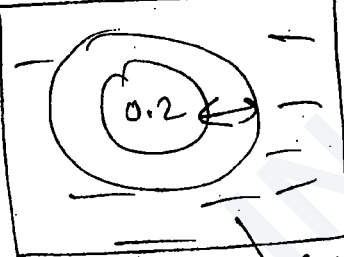
→ H.C.S are easily hardenable than L.C.S

V.V.P

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



hot water (65°C)



Cold water (15°C)

$$Dh_2 > Dh_1$$

because, as the quenching medium Temp. is low,

ΔT is more,

↳ heat transfer will be fast

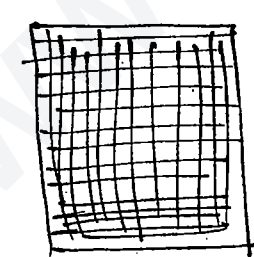
↳ more the vol. converts into martensite

↳ Dh is more.

② Full Annealing % =

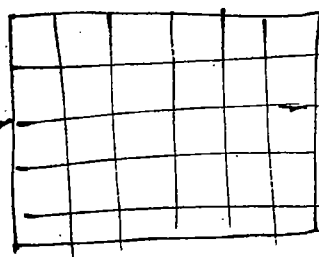
↳ applicable to steels with %C = 0 - 2.11% (L.C.S, M.C.S, H.C.S)

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



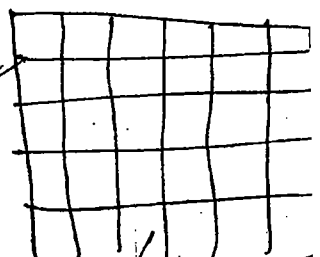
Hardened component (martensite)

Δ
 $T = ?$



(hardness decreases
ductility increases)

Slow cooling
furnace cooling



large grains
(Ductility ↑)

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

Ex 2

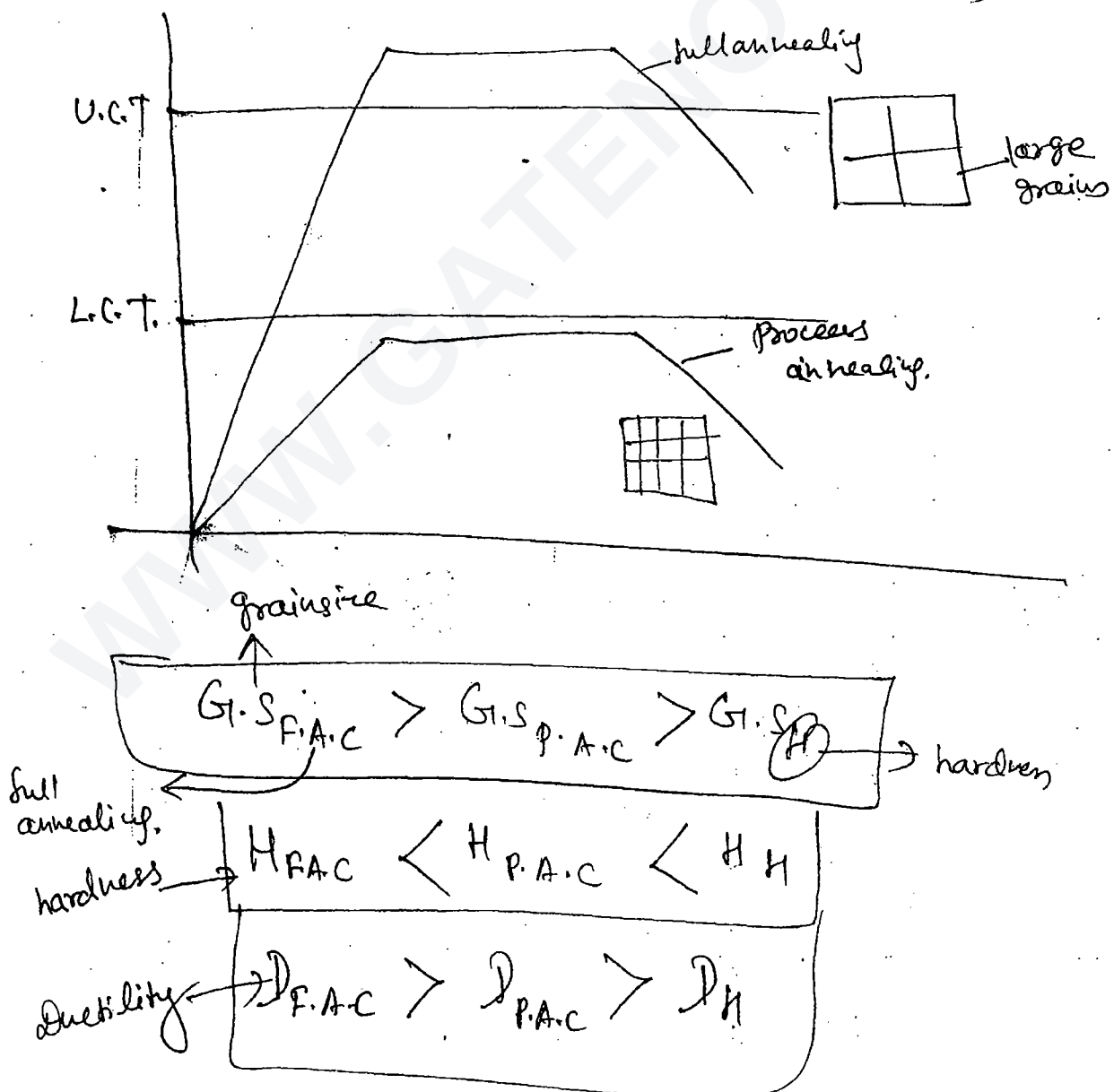
1) If $\%C = 0 - 0.8\%$ $\rightarrow$ $50^\circ C$ above U.C.T (AB)

2) If $\%C = 0.8 - 2.11\%$ $\rightarrow$ $50^\circ C$ above L.C.T (BC)

$\rightarrow$ In annealing due to slow cooling process the residual stresses will be relieved, but due to formation of large grains, the component will obtain ductility (hardness reduces).

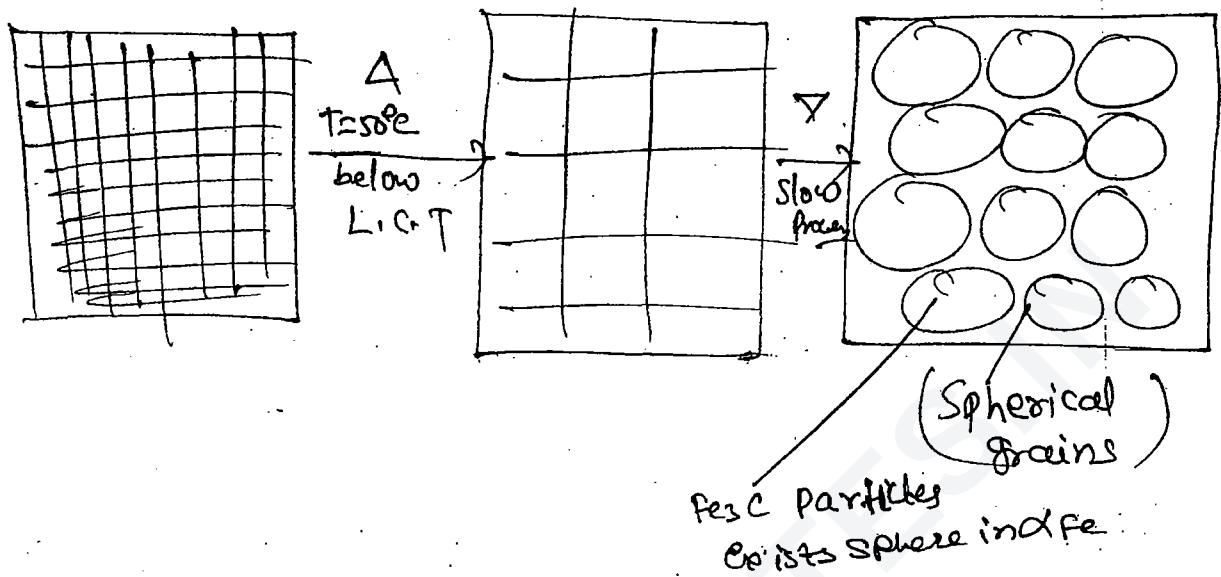
② Process annealing :-

$\rightarrow$ applicable to steel with $\%C = 0 - 0.4\%$
(LCS & MCS only)



- ③ Spheroidisation annealing :-

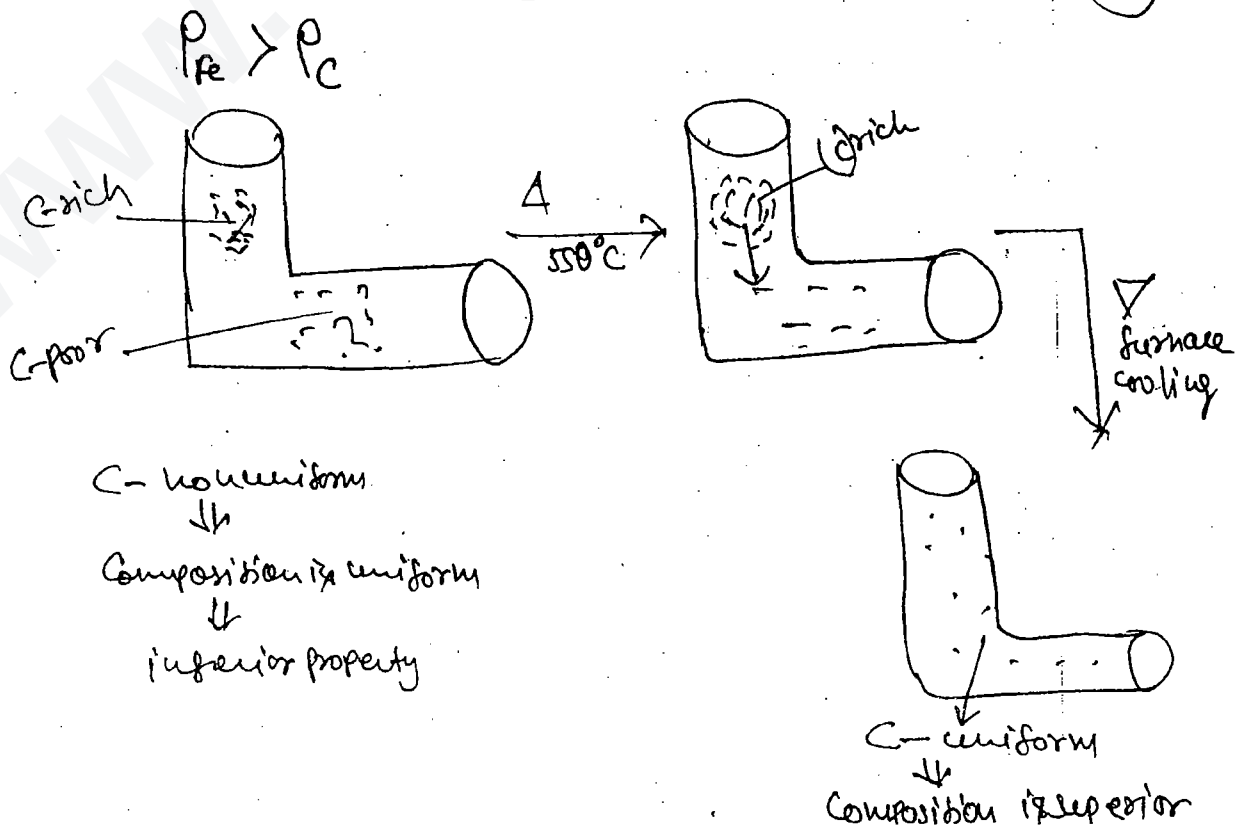
→ applicable to steels with $\%C = 0.6 - 1.2\%C$ (HCS only)



→ spherical grains offer uniform resistive force against the movement of the tool width with roll friction,
 ↳ machinability will be easy.

- ④ Diffusion annealing :-

→ applicable to steel $\Rightarrow$ [HCS + made by casting + in hardened state]



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

density $\rightarrow \rho_{Fe} > \rho_C$

↳ 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)

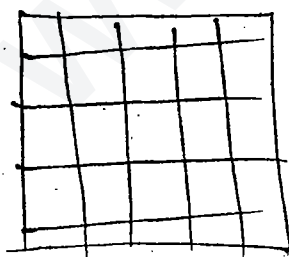
↳ Carbon distributes uniformly

to exhibit superior property.

③ Normalizing :-

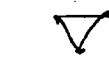
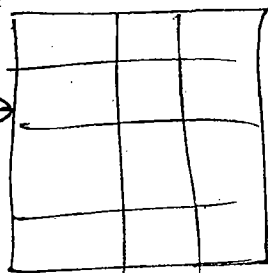
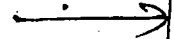
→ applicable to steels with $\%C = 0 - 2.11\%$ (LCS, MCS, HCS).

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

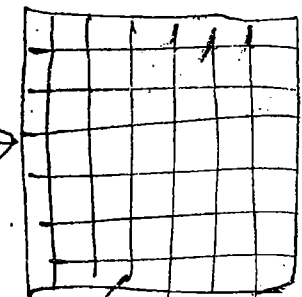


Steel

$T_{2?} 4$

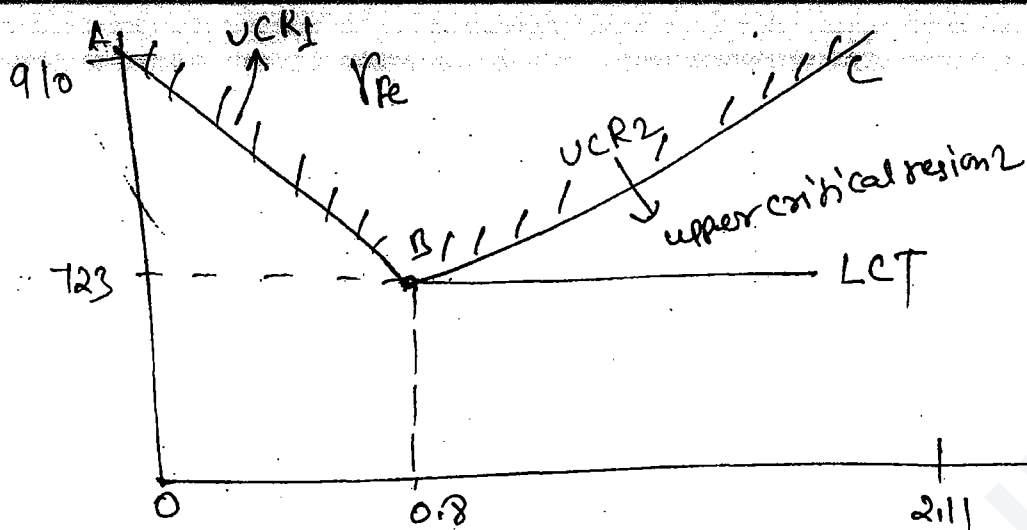


air cooling



pearlite

medium grains $(\alpha_{Fe} + \text{Fe}_3\text{C})$



→ T_c !

i) % of C = 0 - 0.8 $\Rightarrow$ 50°C above U.C.T (AB)

(ii) % of C = 0.8 - 2.11 $\Rightarrow$ 50°C above U.C.T (BC)

(iii) % of C = 0.8 $\Rightarrow$ 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.

<u>Hardening</u>	<u>Normalising</u>	<u>Annealing</u>
↳ rapid cooling	↳ air cooling	↳ furnace cooling
↳ small grains	↳ medium grains	↳ large grains
↳ martensite	↳ pearlite	↳ spheroid
↳ residual stress	↳ partially <u>dis</u>	↳ NO R.S.

$$G.S_H < G.S_N < G.S_A$$

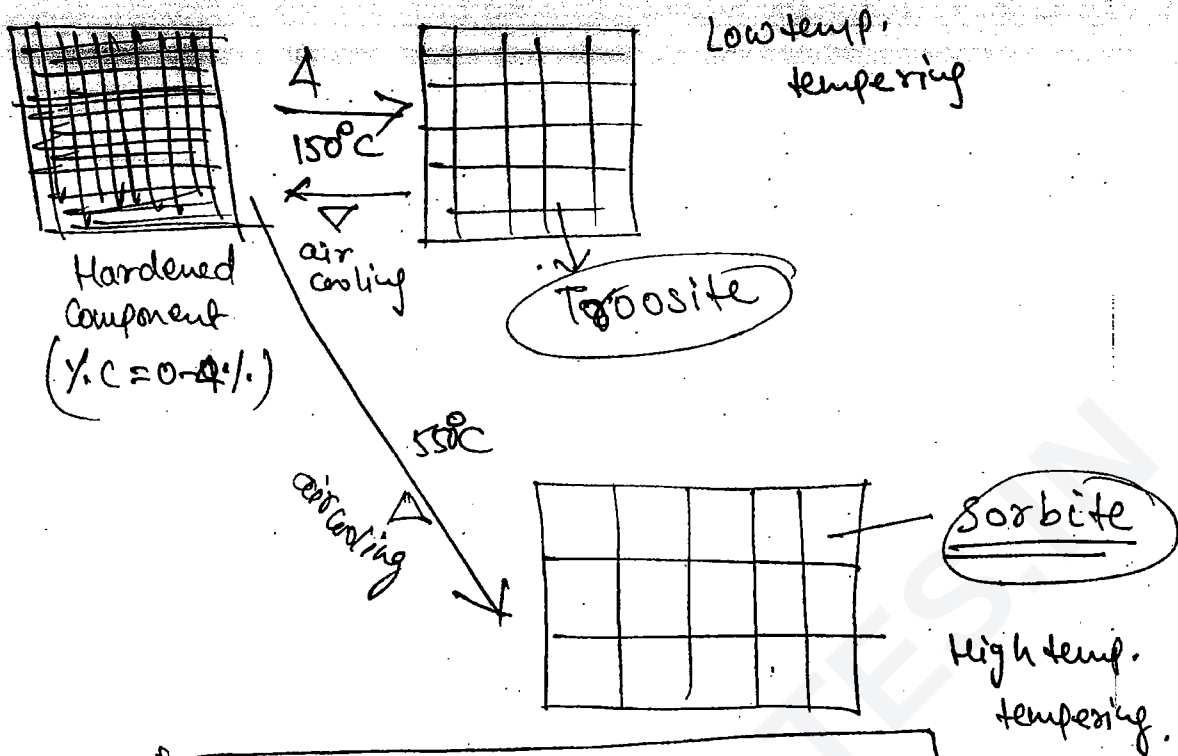
$$H_H > H_N > H_A$$

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



$G_{SH} < G_{SL.T.T} < G_{SH.T.T}$	
$H_H > H_{L.T.T} > H_{H.T.T}$	High temp. tempering.
$H_{Marsite} > H_{Troosite} > H_{Sorbite}$	

* (5) case hardening :-

- low carbon steels are difficult to harden by hardening process, because they possess low carbon content
 - ↳ low carbide volume is less
 - ↳ difficult to produce martensite.

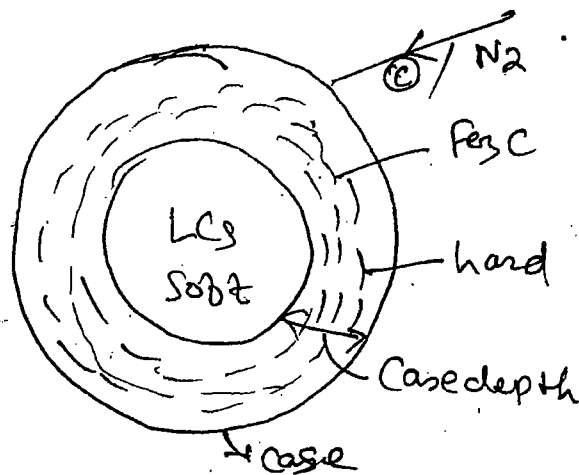
→ even though to achieve hardness, the hardening should be done, at a quenching medium of very low temp. but at that temp. the residual stresses will be greater than the strength of the material.

$$\sigma_{R.S} > \sigma_{UTS}$$

↑
Residual stress

↳ Components will break into pieces.

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



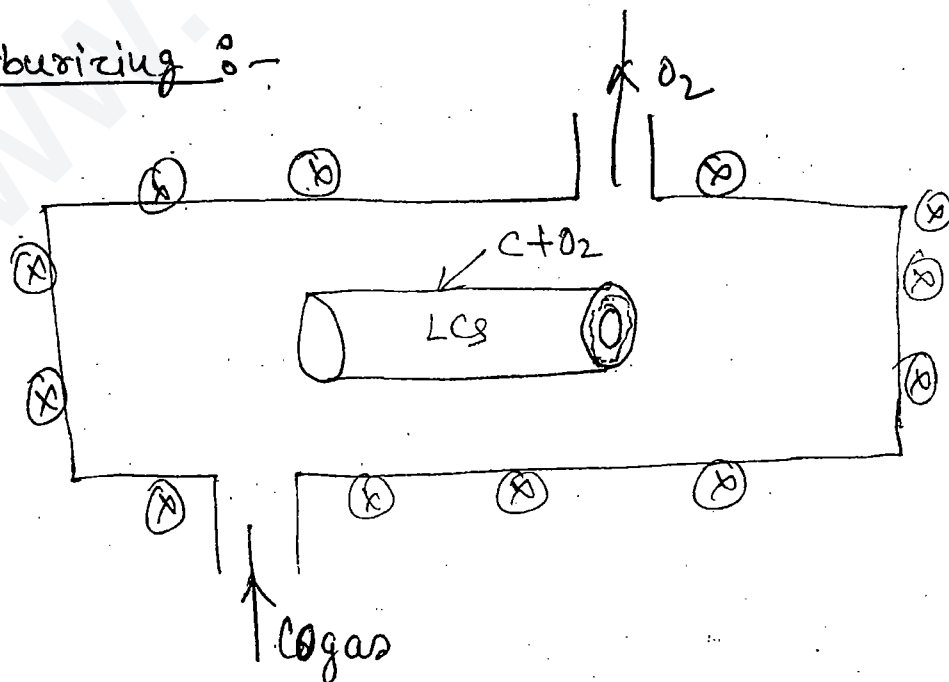
→ By incorporating C/N₂ atoms on to the outer envelop (Case of the components) iron carbide or iron nitride phases will be formed. and hence it will be termed as hard.

→ 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 :-

→



$T = 850-900^\circ\text{C}$

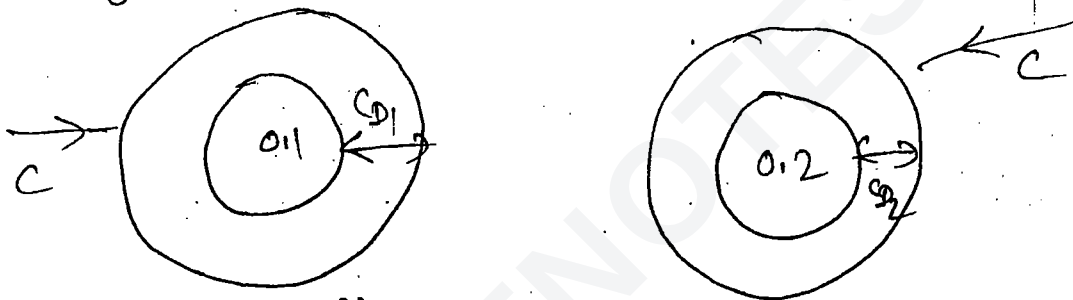
medium = CO gas, $\text{CO} \rightarrow \text{C} + \text{O}_2$

→ case depth = 0.5 mm/hr

→ 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



Case depth → $CD_1 > CD_2$ because if the component contains low carbon component it is easy to add external carbon atoms.

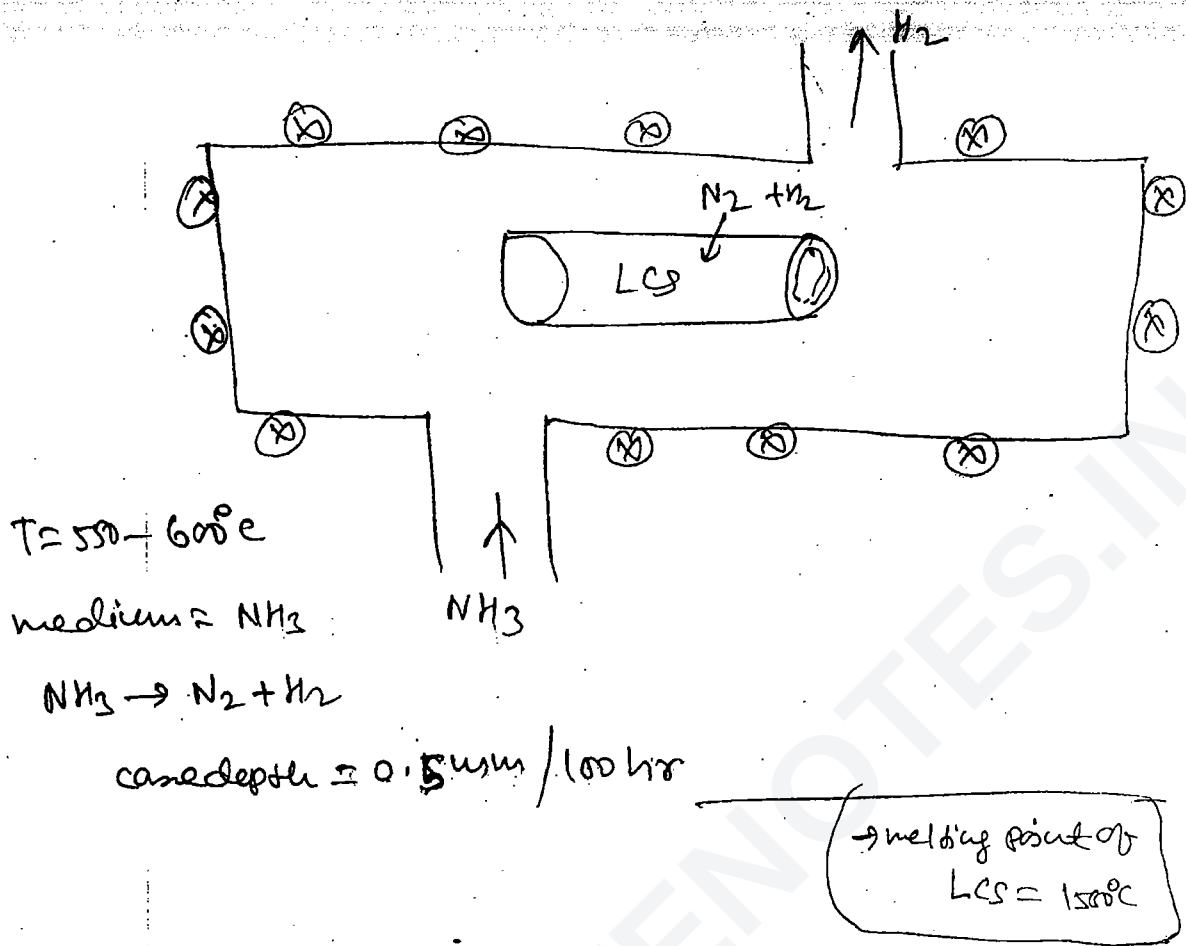
↳ high case depth

NOTE :-

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

② Nitriding :-

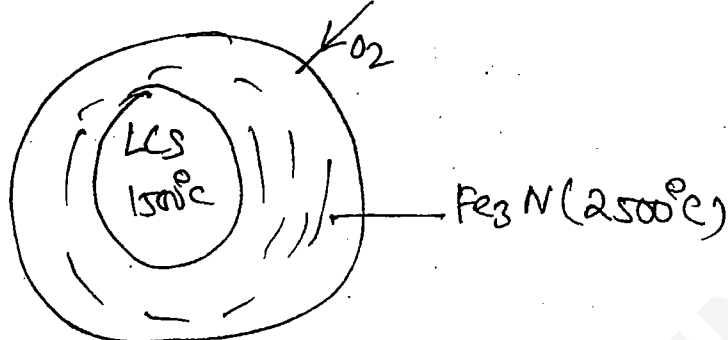
→ By incorporating N₂ atoms on to the outer envelop of the component, it will be termed as a hard by forming ~~Fe₃N~~ (Fe₃N)



- 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.
 - ↳ erosion of material is less
 - ↳ wear resistance is high.

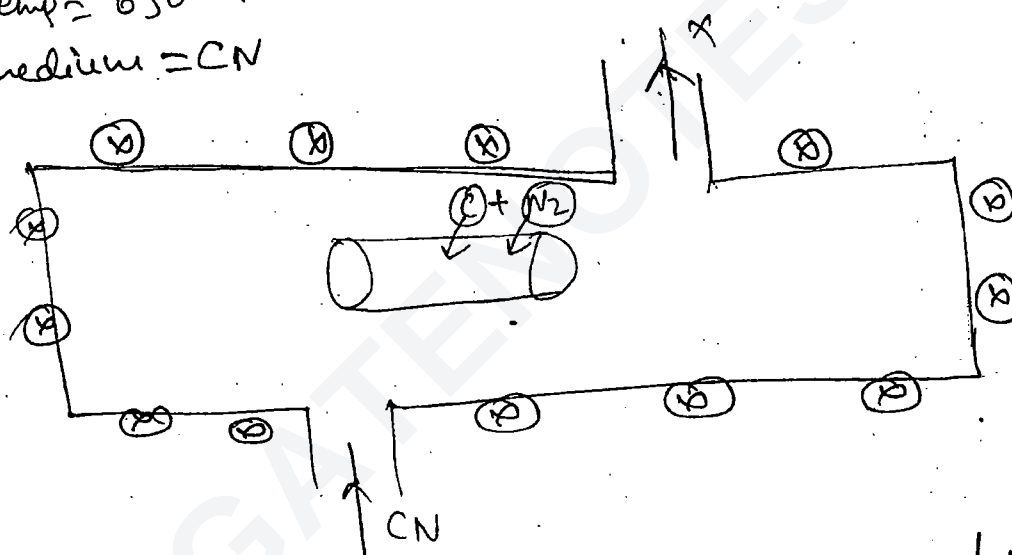
- Nitride steel possess good surface finish,
 ↳ friction will be less
 ↳ abrasion resistance is high.

(91)



③ Cyaniding

Temp = 650-700°C
 medium = CN



case depth = 0.5 mm / 10 hrs

<u>Hardening</u>	<u>Mar tempering</u>	<u>Austempering</u>
quench bath temp = 160°C Ffe M (martensite)	quench bath temp = (150°C) in oil Room temp in air M martensite	quenching at bath temp = 723°C (oil) constant (RT) in air large grains (bainite)

→ 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.

Mar tempering :-

- applicable to steels with % of C $\leq 0 - 0.4\%$
- Partial residual stress
- less intensity cracks
- Interrupted quenching
- whole vol. converts into martensite

Aus tempering :-

- Steel with % of C $\geq 0.8\%$
- no stress.
- no intensity of cracks.
- Isothermal quenching
- Converts into bainite phase.

Note :-

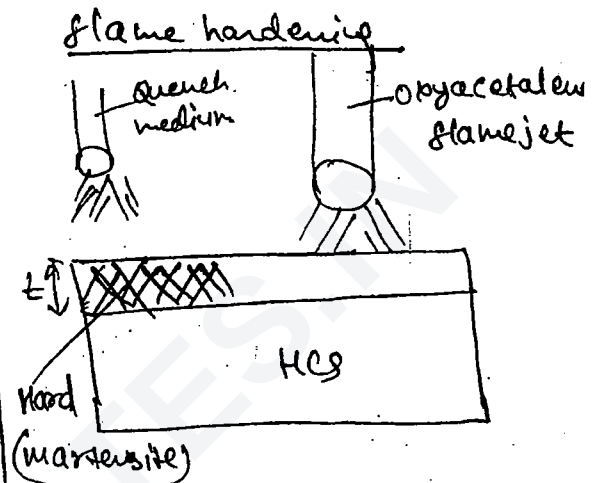
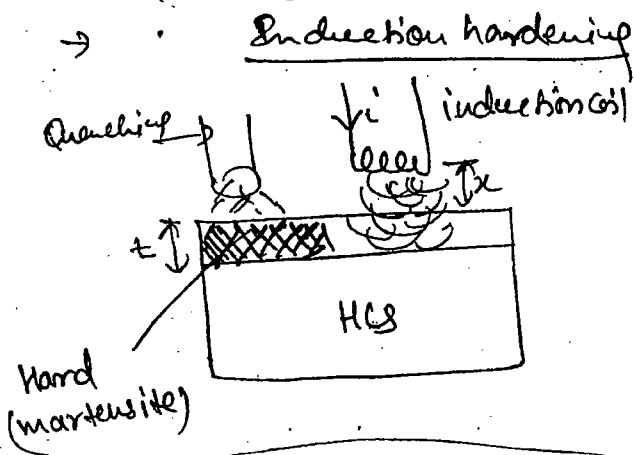
In aus tempering, the % of C is $\geq 0.8\%$ and subjected to quenching at a quenching medium of temp = 723°C then bainite will be formed. During quenching of the quenching medium temp is

more than 100°C. Then the metal will form austenite bainite.

→ Hence Quench bath temp should be maintained constant.

* Surface hardening :-

→ applicable to HCS only.



→ By using induction coil or

oxyacetylene 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, ex - Steel plates & sheets.

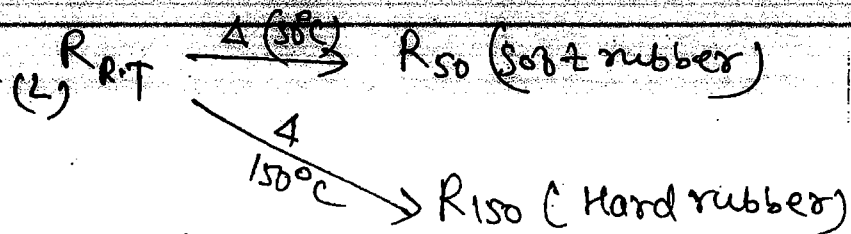
Plastics :-

C, H, O atoms only

- ① non corrosive
- ② light weight
- ③ low strength
- ④ service temp = 300°C

Thermoplastics (T.P.)	Thermosets	Rubber/elastomers
① polymer term as soft & <u>by heating</u> ② At room temp available in the form of <u>solid</u>. ③ $T.P. \xrightleftharpoons[\text{(S) (R.T.)}]{\text{(L) (H.T.)}}$ ④ Recyclable ⑤ service temp = <u>150°C (max)</u> ⑥ By heating $\Rightarrow$ losses strength by cooling $\Rightarrow$ gains strength ⑦ shaping $\Rightarrow$ during cooling ⑧ environmentally hazardous ⑨ <u>Ex</u> - Polyethylene, polystyrene, teflon, PVC (Polyvinyl chloride)	① polymer term as hard by heating ② At room temp. $\Rightarrow$ liquids ③ $T.S. \xrightleftharpoons[\text{(L) (R.T.)}]{\text{(S) (H.T.)}}$ ④ non recyclable e.g. - Helmet ⑤ service temp = <u>300°C</u> ⑥ By heating $\Rightarrow$ gains strength By cooling $\Rightarrow$ no change ⑦ shaping $\Rightarrow$ during heating ⑧ environmentally hazardous than thermoplastics ⑨ <u>Ex</u> - epoxy resin, phenolic resin, vinyl ester (liquid)	① polymer term as hard by heating but the hardness achieved is a function of temp. to which it is heated. Hardness $\propto T$ ② at room temp. $\Rightarrow$ liquids ③ $R \xrightleftharpoons[\text{(L) (R.T.)}]{\text{(S) (H.T.)}}$ ④ non recyclable ⑤ service temp = <u>300°C</u> ⑥ By heating $\Rightarrow$ gains strength by cooling $\Rightarrow$ no change ⑦ shaping $\Rightarrow$ during heating <u>Ex</u>

Note :-



(43)

Hardness $\propto f(\text{Temp.})$

$\rightarrow H \propto \text{Temp.}$

Ex^o:- ① butyl rubber $\Rightarrow$ soft rubber $\Rightarrow$ car tubes

② Nitrile rubber $\Rightarrow$ high temp. sustainable
Ex - gas cable

③ Styrene butadiene rubber (SBR)

$\rightarrow T.P/T.S/R + \text{additive} = \text{plastic}$

* Additives :-

$\rightarrow$ compound used to improve mechanical or thermal or any property of polymer.

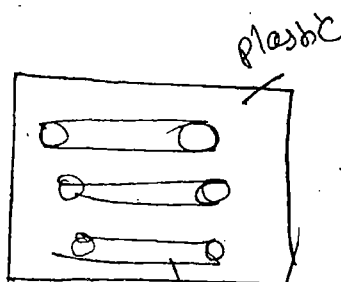
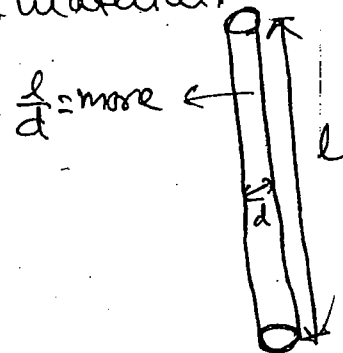
① Asbestos -
gives moldability and heat resistance.

② Mica -
improve thermal conductivity & electrical resistance.

③ filler
improve mechanical strength of material.

Steel :

Steel fibre
Carbon "
Glass "
Graphite "
Aramid/Kevlar "



filler (reinforcement)

f. R. P
fibre reinforcement
plastic

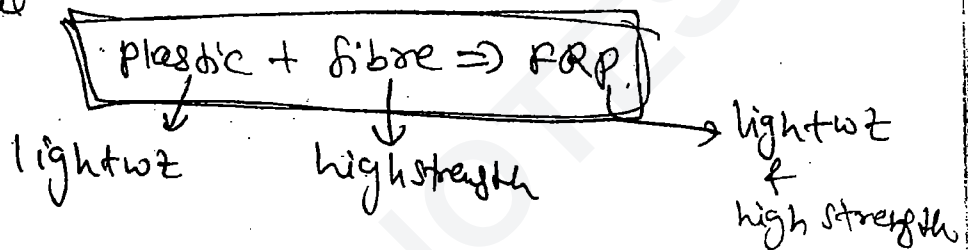
$$M_1 + M_2 \Rightarrow C \Rightarrow \text{composite}$$

→ as it is condition, polymer possess low strength but by incorporating 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.

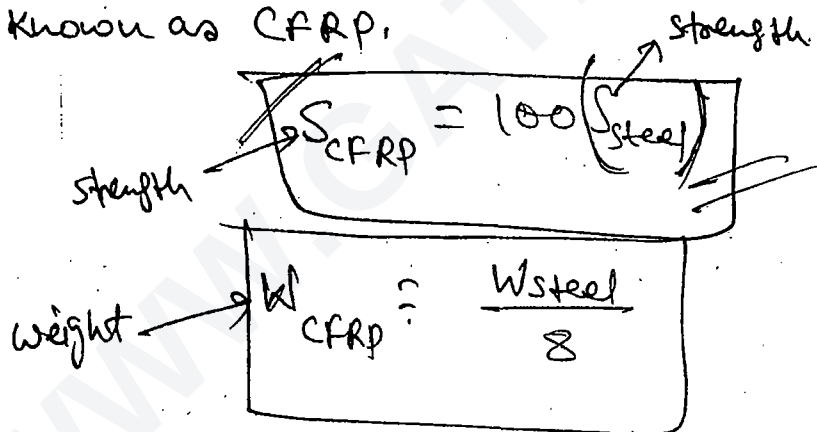
Ex^o - $M_1 + M_2 \Rightarrow \text{FRP}$

material



* CFRP -

→ If carbon fibre is embedded in a plastic part, known as CFRP.



CFRP properties

- 1) lightweight
- 2) high strength
- 3) service temp = 300°C

applications of CFRP :-

(14)

- aerospace structure
- aircraft components
- rocket motor casting etc.

* Glass fibre R.P. :- (GFRP)

- If glass fibre is embedded in the plastic part, called as GFRP.

- highly anti-corrosive
- light weight,
- SGFRP < SCFRP

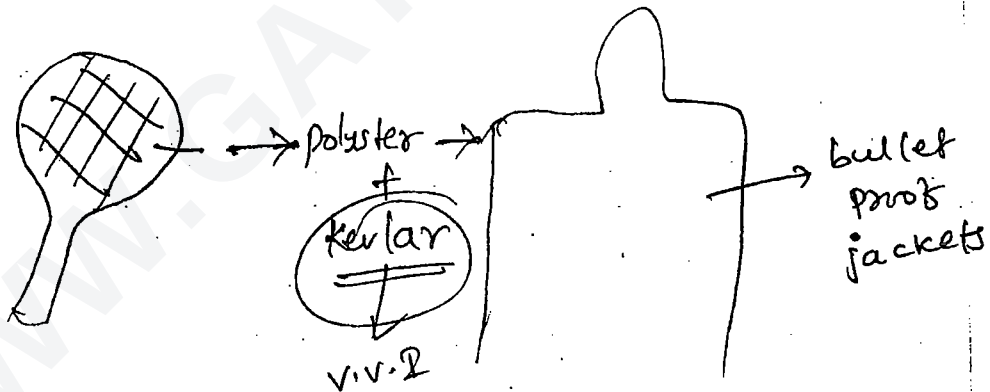
applications

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

* Graphite FRP :-

- If graphite fibre is embedded in a ~~glass~~ plastic part, is called GFRP.

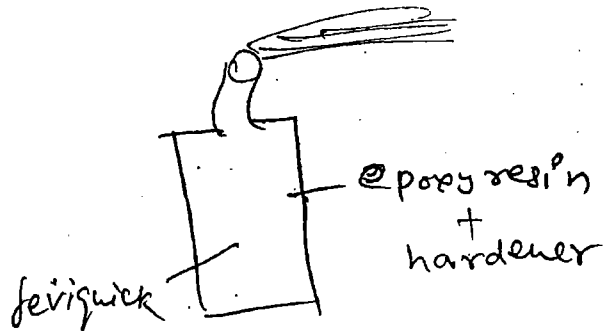
- high temp. sustainable
- strength high < CFRP
- light weight



* 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

- ① Compression moulding (TS & TP)
- ② Transfer " (TS)
- ③ Injection " (TP)
- ④ Blow " (TP)

② Forming

- ① Thermoforming (TP)
- ② Roll forming (TP)
- ③ Extrusion " (TP)

③ laminating (TP & TS)

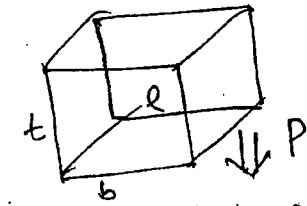
TP → Thermoplastic

TS → Thermosets

① Compression moulding 2-

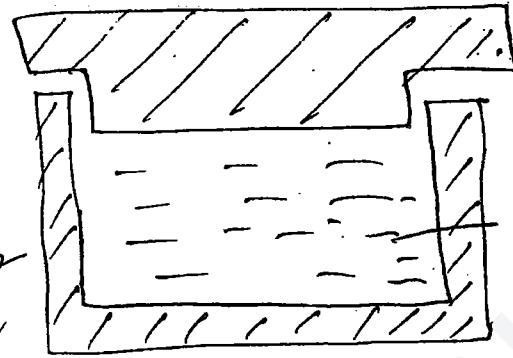
→ T.P & T.S

Case-2 Thermosets



liq → gel → solid

heating

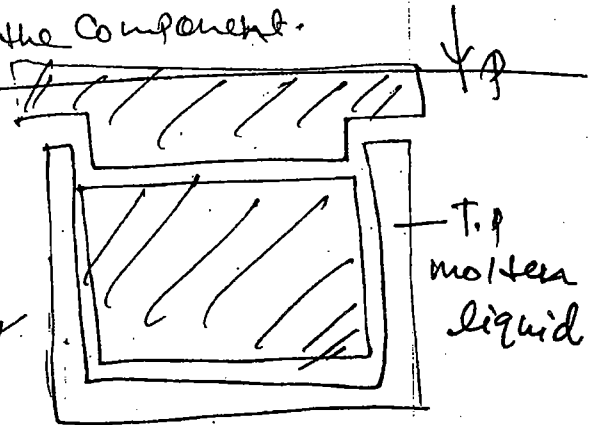


→ A thermoset liquid is kept in the mould of required ~~case~~ shape of the component and subjected to heating under press. during heating process. the liquid will undergo the following changes.

→ 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-2 T.P

cooling



→ 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.

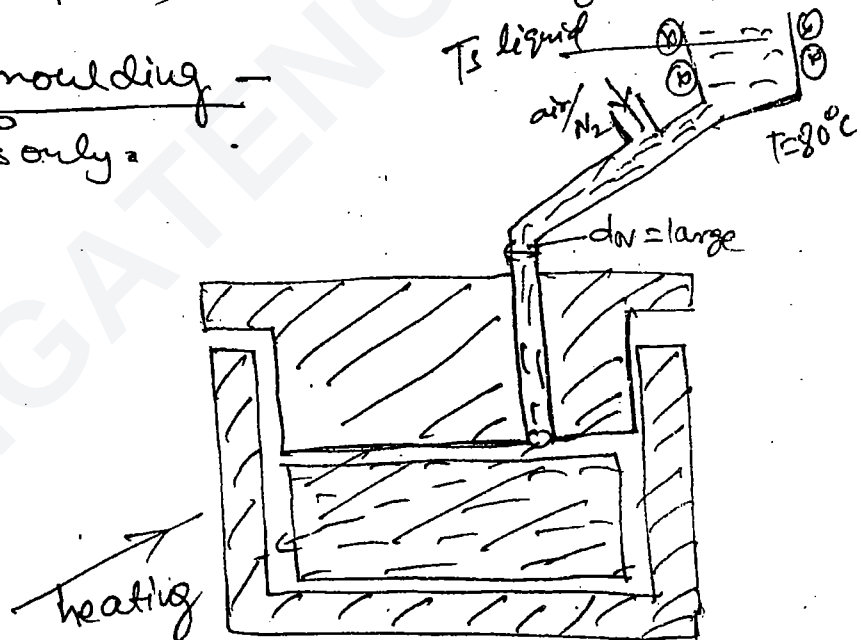
- ① thickness, density and the strength of the plastic can be controlled by varying the compression load p .

$$\rho \propto \frac{1}{t} \propto P_{\text{plastic}} \propto S_{\text{plastic}}$$

- 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.

Ex - gaskets, seals, washing machine outer envelope, automobile parts, refrigerator housing, helmets etc.

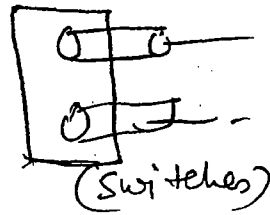
- ④ Transfer moulding -
applicable to
→ Thermosets only.



- 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.

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Exp.

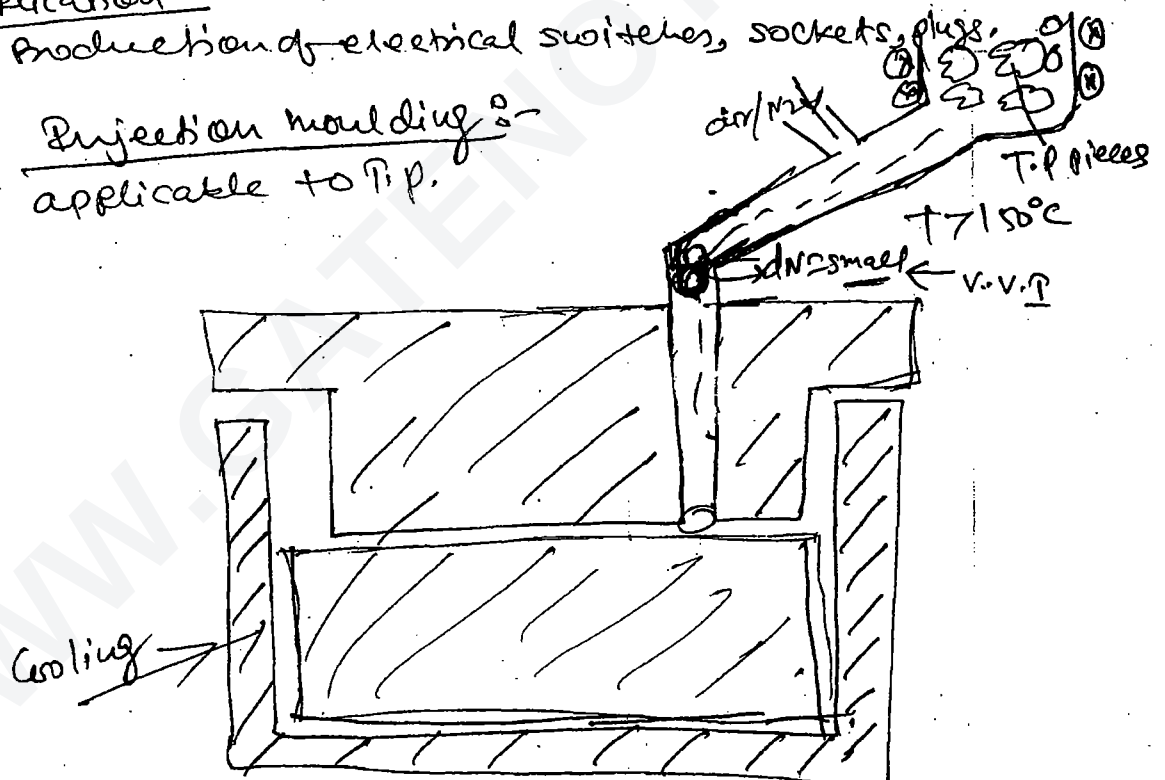


- ②

$\rho \propto P \propto S_{\text{plastic}}$
 $\downarrow$
~~but~~ pressure

- application

- ① Production of electrical switches, sockets, plugs.
- ② 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.

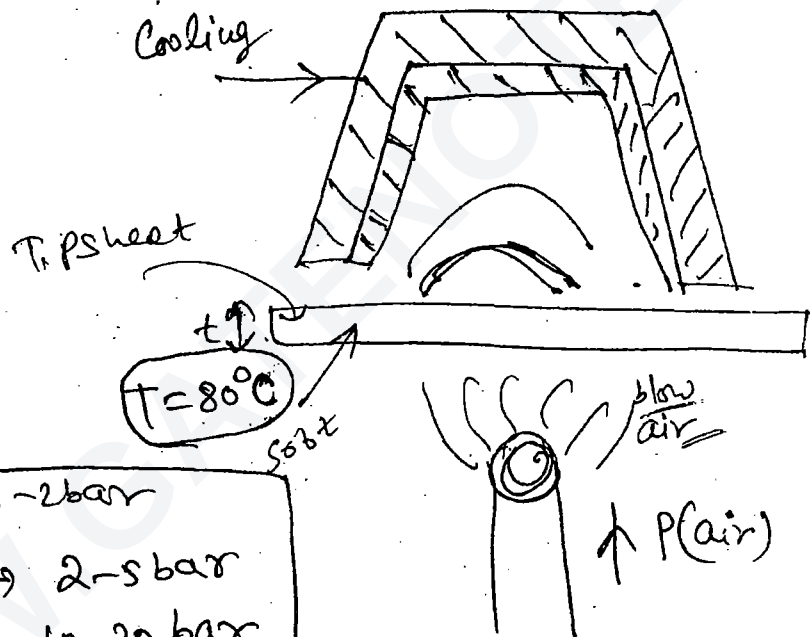
→ After filling the liquid in mould assembly, ^{By cooling} the liquid will turned as solid.

- Any Shape of the Component can be produced.
- uniform density of plastic can be produced.
- The Component can be produced any no. of times till it achieves the required dimensional accuracy.

$$P \propto \rho_{\text{plastic}} \propto S_{\text{plastic}}$$

Pressure

④ Blow moulding :-



- Ex:
1. water bottle → 1-2 bar
 2. bucket lids → 2-5 bar
 3. Sinter → 10-20 bar

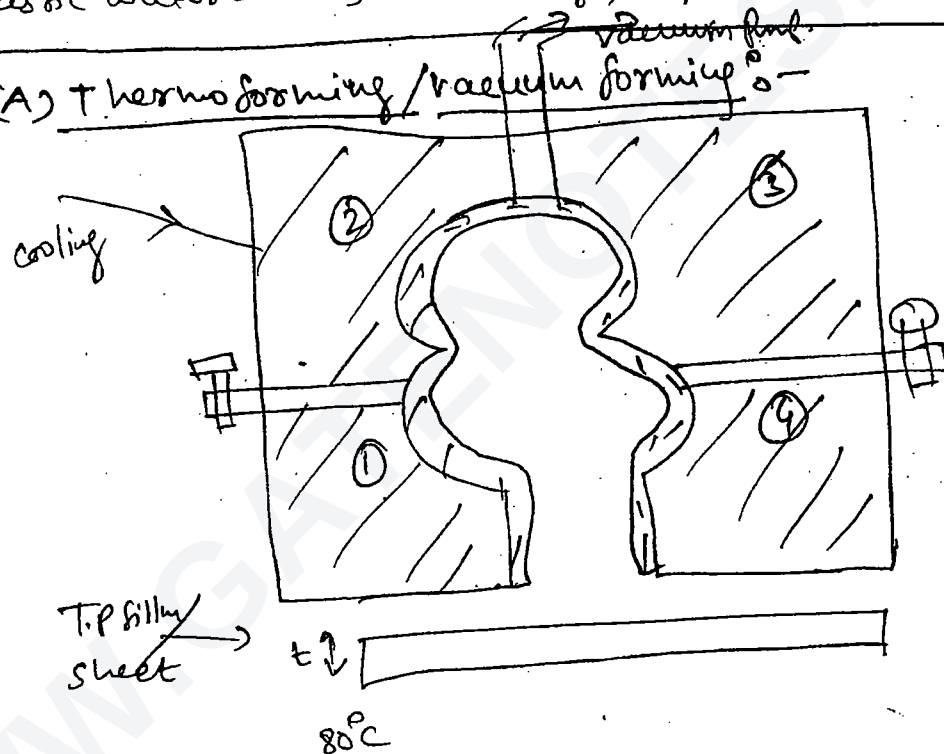
- Thermoplastic film or sheet of thickness (t) is kept at the entrance of the mould in soft condition by heating the sheet to 80°C by blowing with high pressure air, the sheet will bend according to the internal shape of the mould, so that it achieves the required shape of the component.

- By cooling the mould, it will be termed as hard. (17)
- 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 bottles, bucket, jugs, liquid containers etc.

(2) (A) Thermoforming / vacuum forming:-



- A thermoplastic film or sheet of thickness t 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 through out the mould.

→ Compression is uniform.

↳ thickness of the component is uniform.

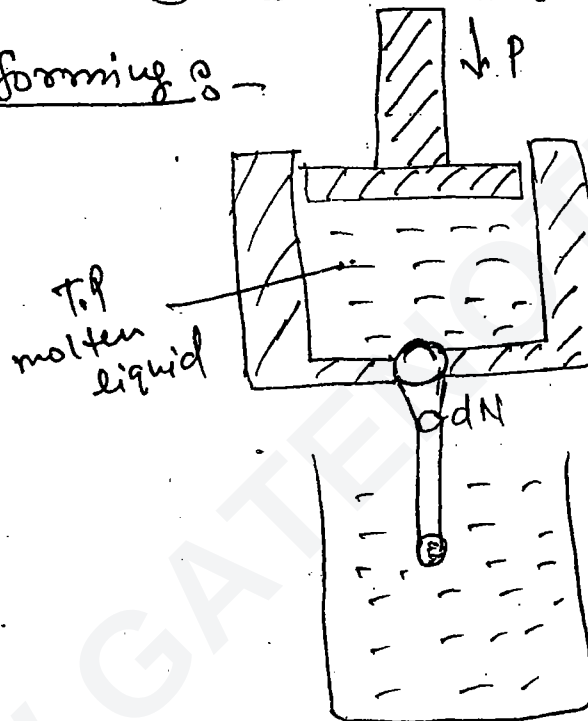
↳ dimensional accuracy is high.

→ To produce large thickness plastic parts, high capacity vacuum pumps are required.
↳ difficult to produce & expensive.

applications :-

① cosmetic bottles ② medicine bottles.

③ Extrusion forming :-

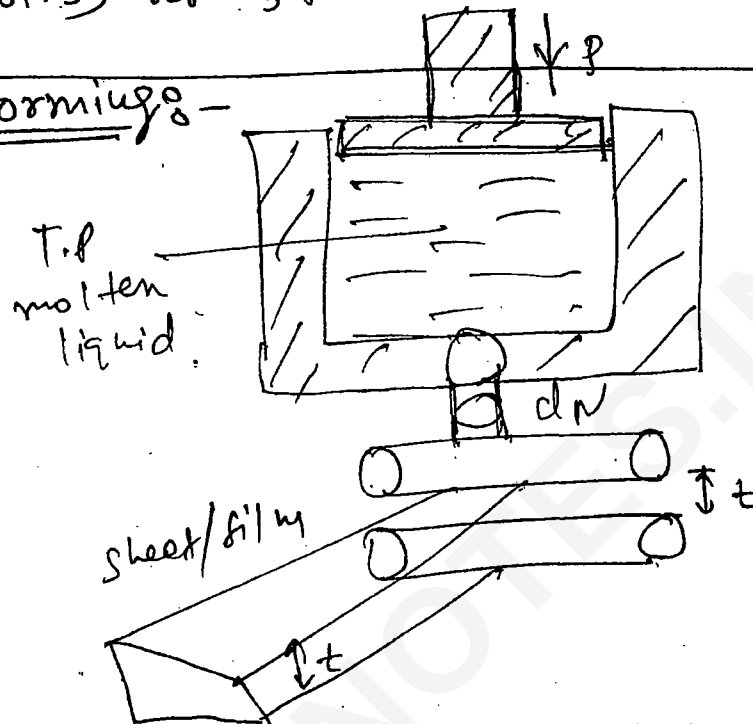


→ T.P molten liquid is pressurised in the mould assembly and allows to travel through a nozzle of dia. (d_N). The molten liquid will extrude in the form of a rod shape of the dia. (d_N) it is subjected to cooling immediately in a quench medium. so that it turns as hard.

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

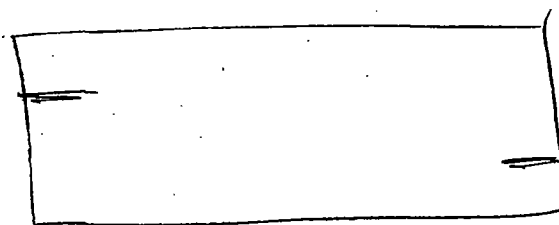
T.P. molten liq. + hardener $\rightarrow$ rod
 " " " + Plasticiser $\rightarrow$ wire
 Ex - Nylon, wires, ropes, threads etc.

(C) Roll forming -



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

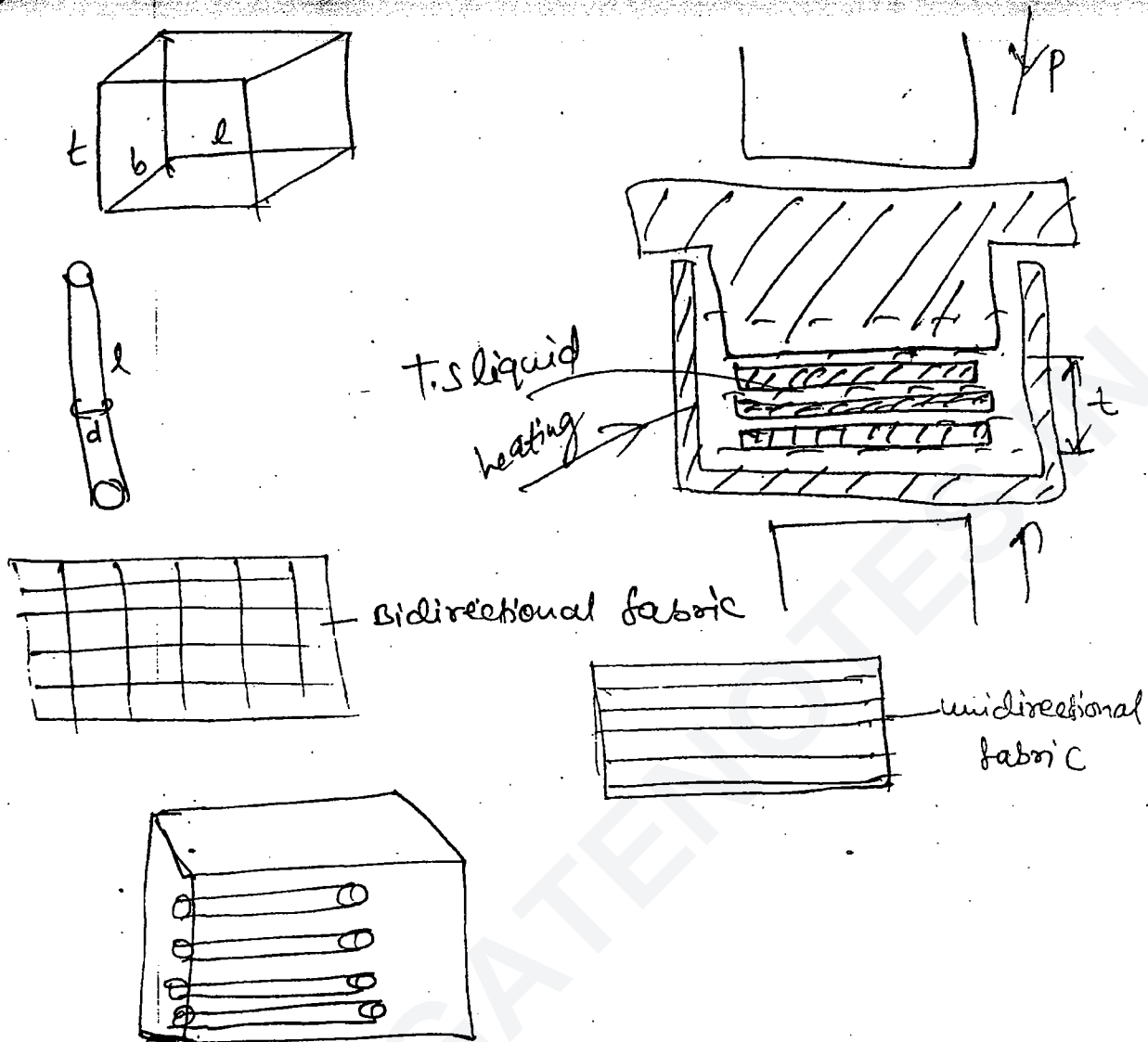
$\rightarrow$ To produce plastic sheets or film, this method is used.



Polyethylene film

Applications - Polyethylene film (carry bag)

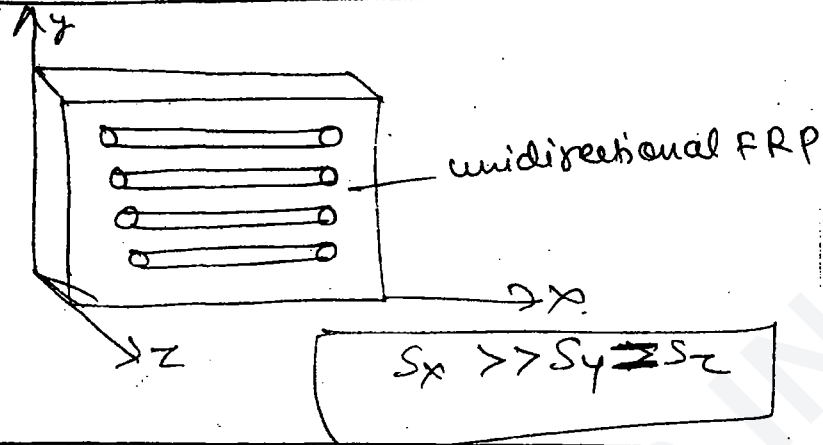
8/8 Manufacturing 8-



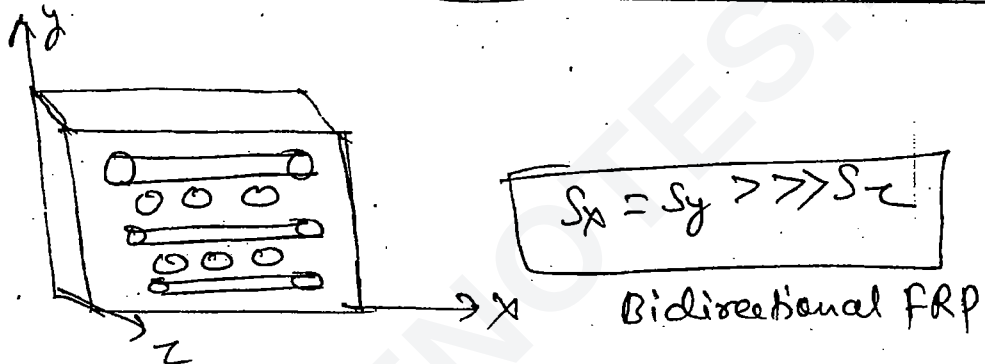
→ A thermoset liquid is kept in the mould of required shape of the component and high strength fibres will be kept in the liquid as layer structure, so that the thickness of the component (t) can be builded. By heating the mould assembly and subjecting to compression load, it will be termed as hard and 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 (19)
fibre reinforced plastics (FRP).

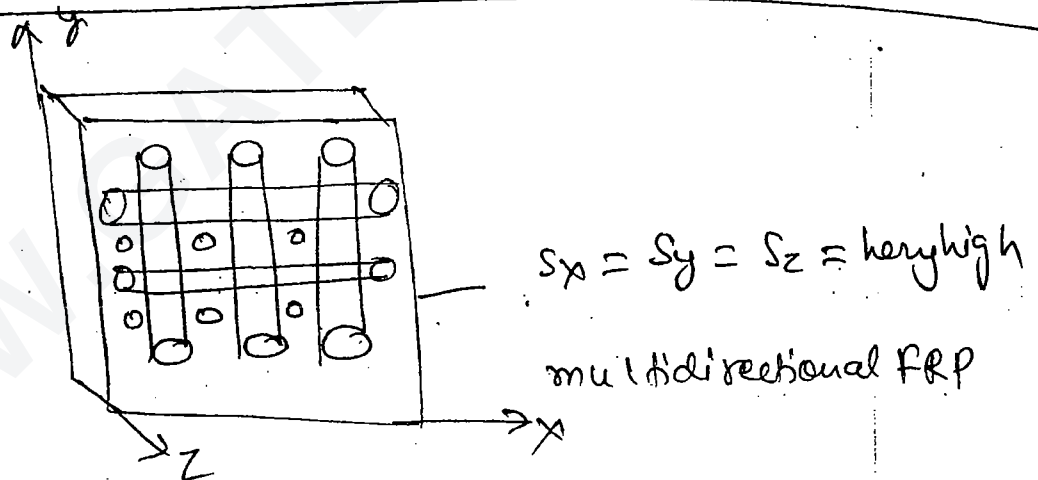
Case-1)



Case-2)



Case-3



→ The strength of FRP can be changed by -

- (1) varying the no. of layers
- (2) varying the fibre orientations

→ In FRP as for the design requirements, 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.

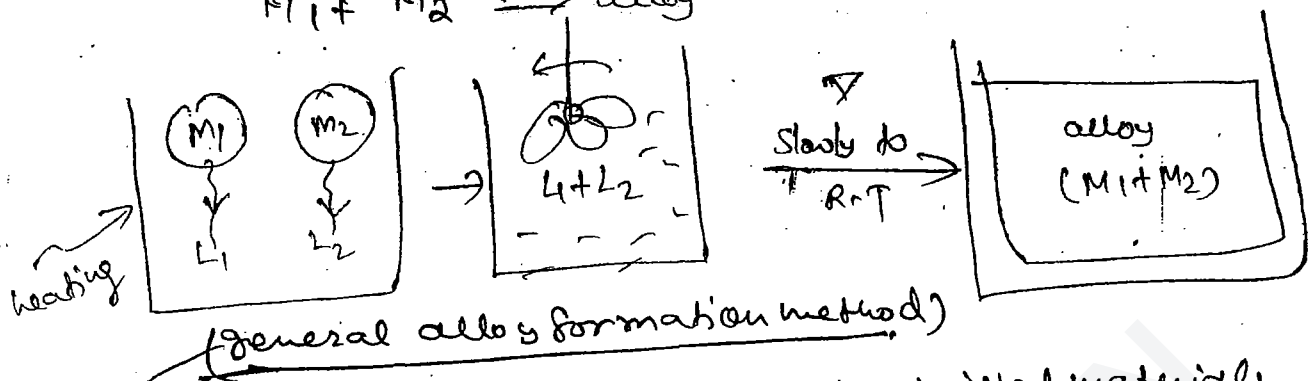
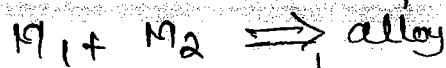
→ In case of metals ~~all~~ strength remains same in all the directions.

→ 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 Polyvinyl chloride (PVC)	→ moisture resistance & electrical resistance e.g. pipes & tubes
④ Polytetrafluoroethane (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, Antibungal

* Powder Metallurgy *



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

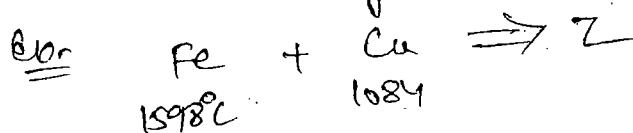
By mixing two metals with small difference in melting point and to form an alloy the following steps will be followed -

- ① Conversion of bulk metals into molten liquids
- ② obtaining homogeneous solution of ~~water~~ molten liquids.
- ③ obtaining an alloy by slow cooling process of molten mixture.

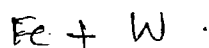
→ Powder metallurgy is applied in the following cases -
(where general alloy formation method is invalid)

Case-1

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



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

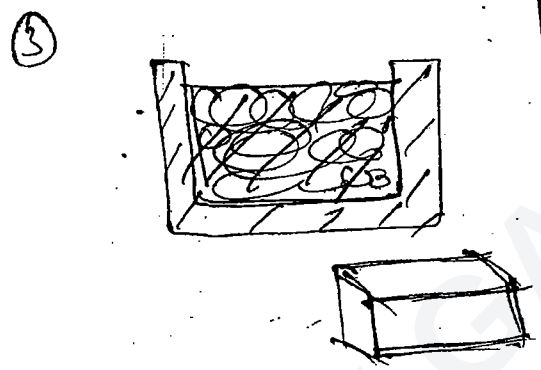
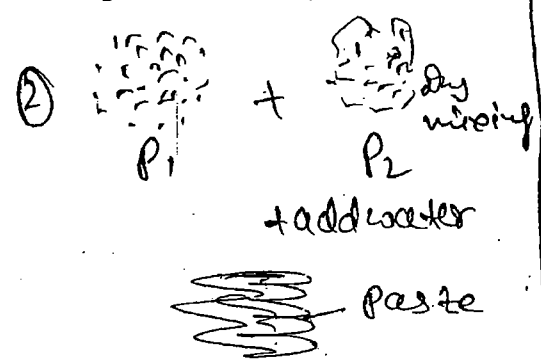
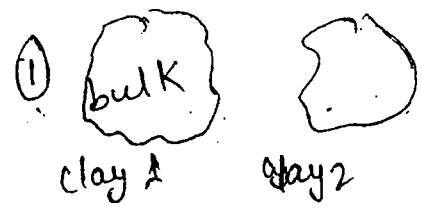


Ques-3

metal + compound

ex- Fe + SiC

* Red brick production -



1. production of powders from material.

2. mixing of powders

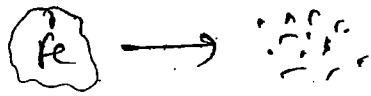
③. compaction



④ Sintering
(burning)

① Production of powders

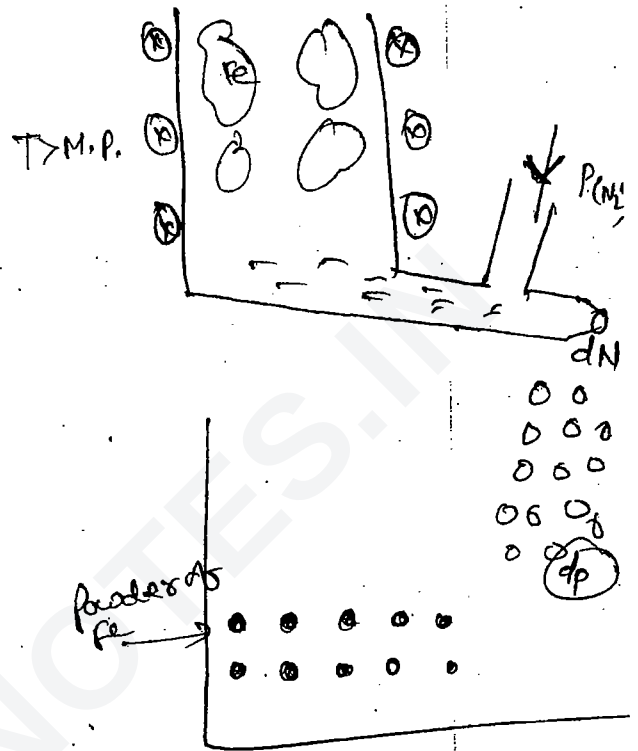
① atomization :-



- molten liquid of metal is allowed 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 particulate (dp) is produced.

$$\frac{1}{dp} \propto P_g$$

↓
pressure



$$dp \propto dN$$

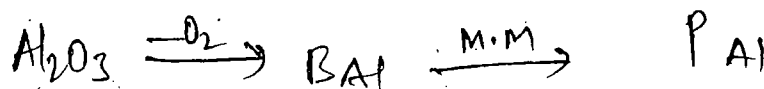
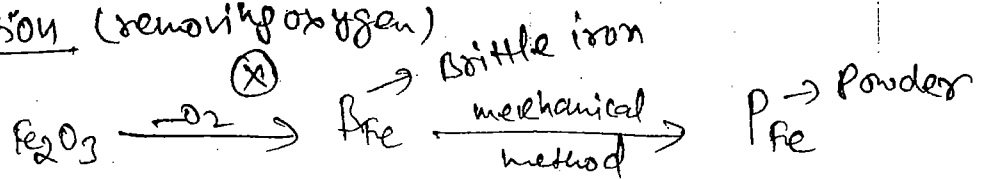
- Production rate is high.
- all metal powders are produced by this method.

② mechanical methods :-

- for brittle materials only.
- machining/crushing/impacting/milling/grinding etc.

③ chemical methods :-

Reduction (removing oxygen)



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

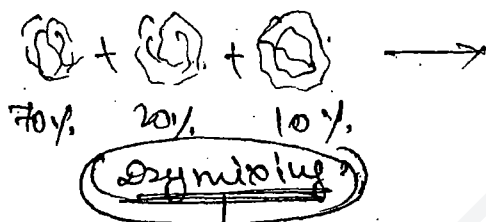
→ By addition of suitable chemical, oxygen is removed from the compound (reduction) and termed as powders.

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

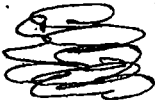
② Mixing of powders :-

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

mixing ratio



↓
add solvent. (acetone, alcohol, etc.)

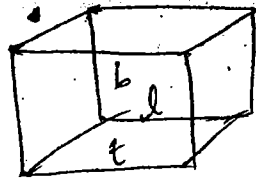
↓
Wet mixing $\Rightarrow$  Ppte (wet mixture of powders)

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

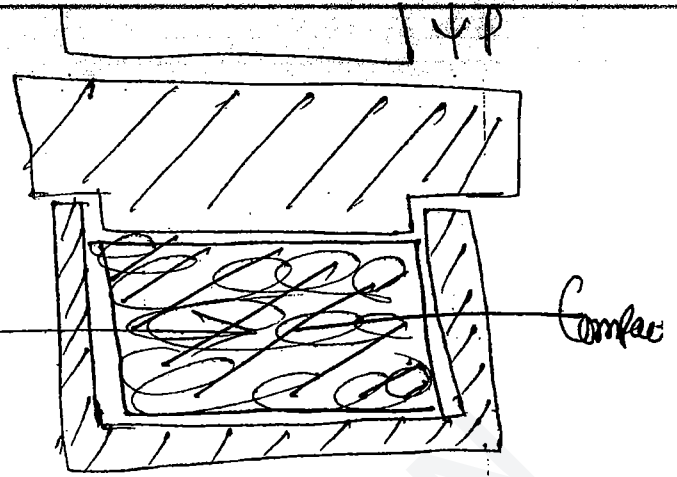
↳ Composition will be decided.

↳ final strength of powder metallurgical component will be decided.

5) Compaction



Paste
(wet mixture of
Powders)



→ Shape of Compact = Shape of Final Component

→ The ~~wet~~ ^{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.

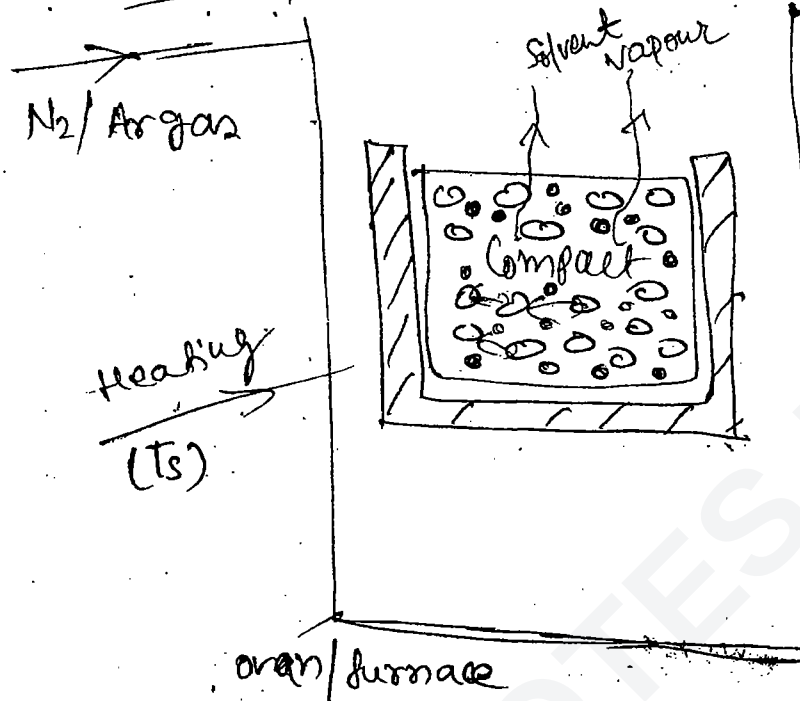
⇒ Thickness, ~~and~~ density and the strength of powder metallurgical component can be controlled by varying ~~the length~~ compact load P .

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

→ as 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 tensile strength.

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

→ After heating chemical bonds will form among the powder particles and hence strength increases tremendously.

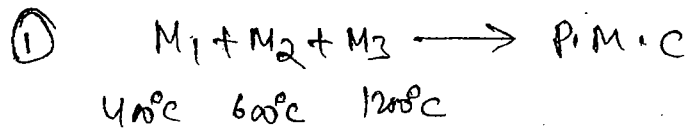
→ sintering is performed either in inert atmosphere or under vacuum to avoid oxidation of the compact.

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

↳ heat produces, porosity.

∴ Powder metallurgical component possess with porosity, which is unavoidable.

* Selection of sintering temp. :-



Write melting point of alloying elements

② Select lowest M.P among alloying element.
L.M.P = $400^\circ C$

$$\textcircled{3} \quad \boxed{T_s = 0.8 (LMP)} = 0.8 \times 400 = \underline{\underline{320^\circ C}}$$

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

(T_s) :-

* Pre-sintering :-

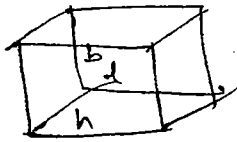
→ To minimize the porosity in the powder metallurgical components during compaction stage, the mould is heated to $60^\circ C$ and subjected to compaction - (hot pressing), so that solvent is ~~reduced~~ removed partially during compaction stage.

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

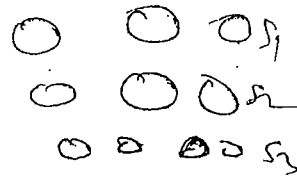
↳ ~~porosity~~ porosity can be minimized.

Characteristics of powders :-

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



$$A_{S_{bulk}} = 2(lb + bh + lh)$$



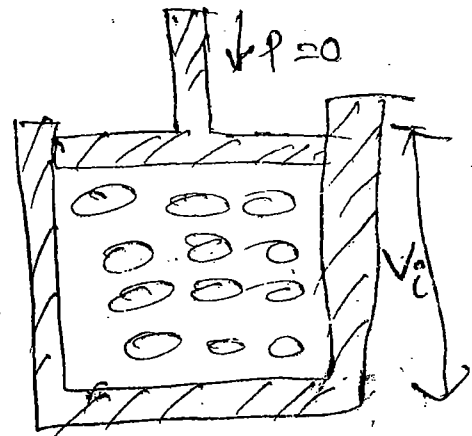
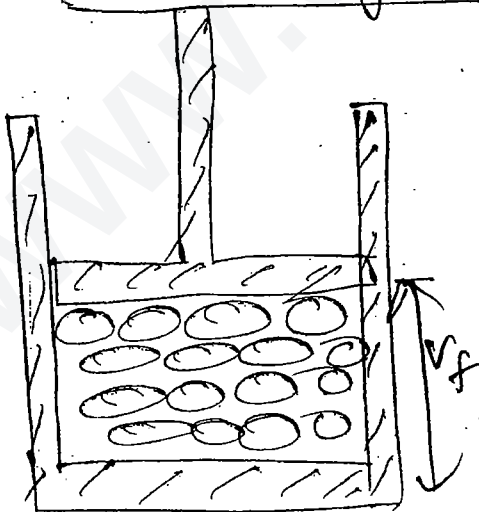
$$A_{Sp} = A_1 + A_2 + A_3 + \dots$$

$$A_{Sp} > A_{Sb}$$

- 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 exhibit more hardness & brittleness even though it has little porosity.

- ② Compressibility ratio (CR)



$$CR = \frac{V_i}{V_f} = 1 - 3 \quad (\text{Coarse powder})$$

$$= 3 - 10 \rightarrow \text{fine powder}$$

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.

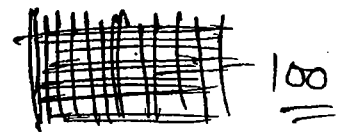
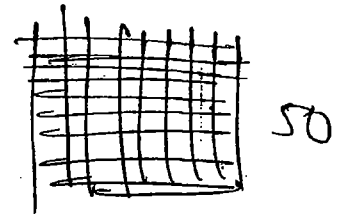
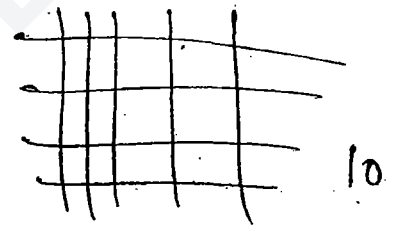
↳ strength of the component increases.

③ particle size / powder size :-

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

↑
powder size / particle size

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

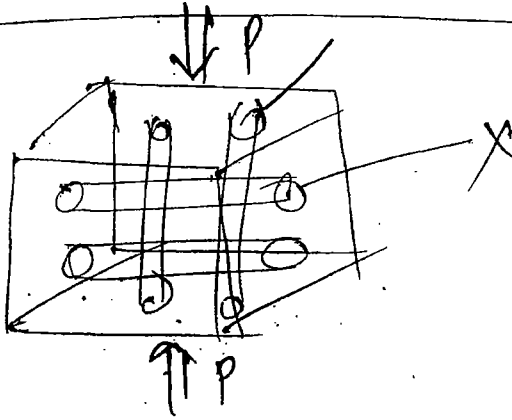
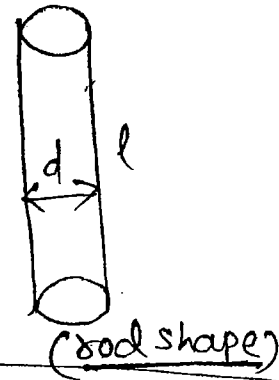


→ By doing filtering process of a powder, on different sizes of meshes, ~~the powder size~~ mesh no. is determined and hence

particle size or powder size is determined.

* production limitations of P.M.C $\Rightarrow$

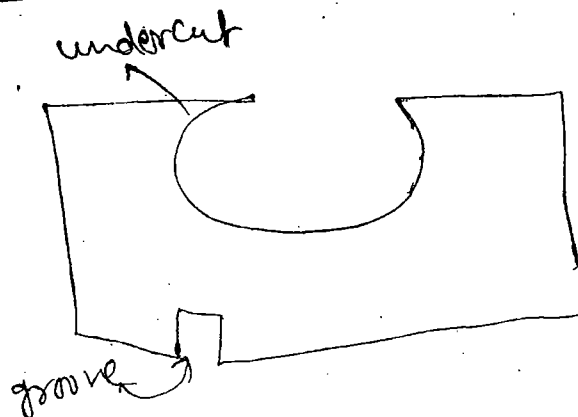
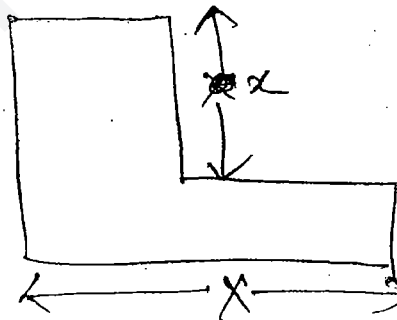
$$\frac{l}{d} \leq 2.5$$



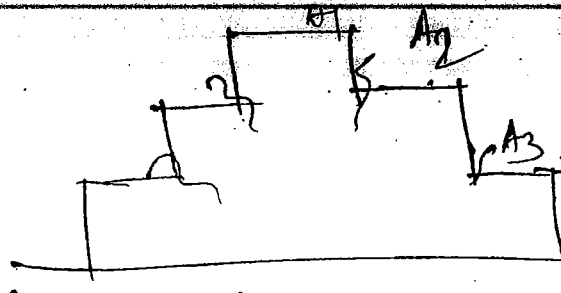
$\rightarrow$ insertion of cross holes in the direction of P is possible, but $\perp$ to P is not possible.

Step shape,

$$x \leq 0.25X$$



$\rightarrow$ difficult to insert undercut & groove.



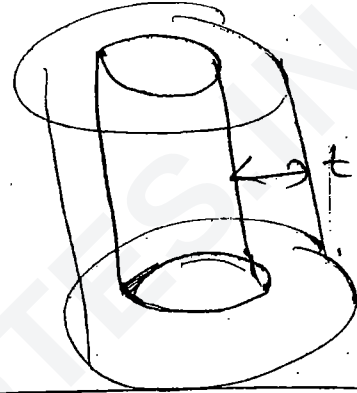
→ difficult to produce complex, or multisteped structure.

Cylindrical shape

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

for other shape,

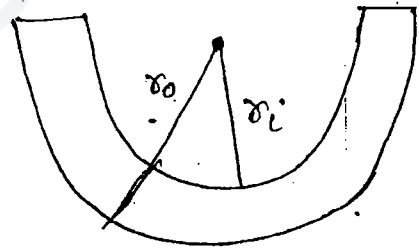
$$t \geq 1.5 \text{ mm}$$



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 100% 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/pressure (P).
- (3) difficult to produce large size and complex ~~the~~ 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, ^{antimony} Sb etc. difficult to produce the components because these powders will undergo explosion during compaction.
- (6) In superhard cutting tool ~~with~~ ^{bits}, the tips will be coated by WC - carbide, WC/SiC using powder metallurgical process.
- (7) In production of ceramic material, $[P_{Al_2O_3} + P_{ZrO_2} + P_{SiO_2} = \text{Ceramics}]$ which can sustain up to 2500°C will be produced.

* Types of steel

0 — 0.15% C $\Rightarrow$ mild steel

0 — 0.25% C $\Rightarrow$ LCS

0.25 — 0.45% (C) $\Rightarrow$ MCS

0.45 — 2.11% (C) $\Rightarrow$ HCS
(1.5%)

2.11 — $\frac{6.67}{(5\%)}\%$ (C) $\Rightarrow$ C.I

$\rightarrow$ any steel + Cr $\Rightarrow$ stainless steel
(LCS/MCS/HCS) (1-26%)

$\rightarrow$ any steel + alloying element $\Rightarrow$ alloyed steel

V.V.I. $\left\{ \begin{array}{l} \text{LCS} + \text{Cr} \Rightarrow \text{stainless steel} \\ \quad (10-20\%) \\ \text{HCS} + \text{Cr} \Rightarrow \text{stainless steel} \\ \quad (1-5\%) \end{array} \right\}$

<u>LCS</u>	<u>MCS</u>	<u>HCS</u>
$\rightarrow$ %C = 0 — 0.25%	$\rightarrow$ 0.25 — 0.45% C	$\rightarrow$ 0.45 — 1.5% C
① low hard / 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 ^(medium) moderately weldable	④ difficult to weld.
⑤ Corrosive Corrosion resistance is low.	⑤ Corrosion resistance is high than LCS.	⑤ Corrosion resistance is high

<u>LCS</u>	<u>MCS</u>	<u>HCS</u>
6) expensive 7) possess high fracture toughness 8) M.P. is high ($1500-1400^{\circ}\text{C}$)	6) low cost 7) less than LCS (fracture toughness) 8) MP ($1400-1300^{\circ}\text{C}$)	6) low cost 7) possess low fracture toughness 8) MP ($1300-1200^{\circ}\text{C}$)
<u>Applications</u> In production of Tubes, pipes, tanks, sheets, car body, plate etc.	<u>Applications</u> reinforcing bars in cement structures, tool gears, shafts shafts, aircraft component, automobile parts, axles, spring wires, connecting rods, etc.	<u>application</u> → machine tools, hammers, knives, dies, punches, milling cutters, sizers, etc.

① ferroitic stainless steel

→ 12-25% Cr, 0.1-0.35% C

→ behaves like (MCS) • stronger than LCS, magnetic in nature, in annealed 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) :-

0.09% 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,

$$\alpha = 0.000023 \text{ mm/}^\circ\text{C}$$

~~Applications~~
→ 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% S

2.11 — 6.67 % C $\Rightarrow$ C.I
(5%)

① gray cast iron :-

(2.5 - 4 % C), 1.8 % Si, 0.5 % Mn $\rightarrow$ hardenability

$\rightarrow$ ~~is~~ soft in nature.

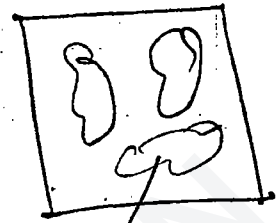
$\rightarrow$ dark porous structure.

applications -

Pipes, agricultural implements,

Cylinder block of I.C. engines,

brake drum, machine tool beds.



Fe₃C particles
exist as flake
type shape
grains.

② White Cast Iron -

2.9 - 5 % C, 1.15 % Si, 0 - 0.6 % Mn

$\rightarrow$ appearance as white in colour, hardened & brittle in nature.

$\rightarrow$ high wear resistance & abrasion resistance.

$\rightarrow$ applications -

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

③ ~~not~~ malleable C.I :-

2.5 % C, 1 % Si, 0.5 % Mn

$\rightarrow$ possess good tensile strength

$\rightarrow$ ductility, malleability

$\rightarrow$ shock & impact resistance.

Ex - Track wheels, automobile parts, side road equipment, cams, pipe fittings etc.

④ Nodular C.I :-

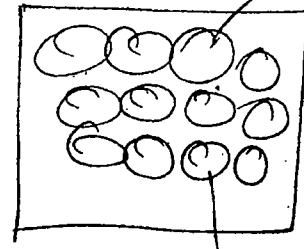
3-3.5% C

2-2.5% Si, 0.4% Mn, 0.1% Mg ✓

Particle
Resist

→ easy machinability due to spherical grains.

→ ductility is similar to malleable cast iron.



as
sphere

spherical grains.

→ Corrosion resistance is similar to gray cast iron.

→ Tensile strength greater than gray cast iron.

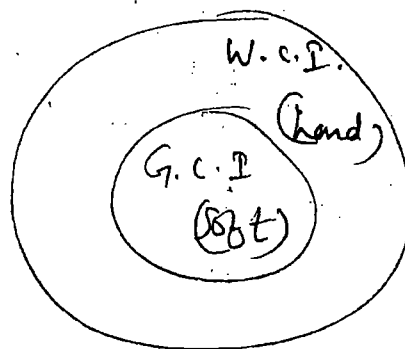
applications

hydraulic cylinders, valve, 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.

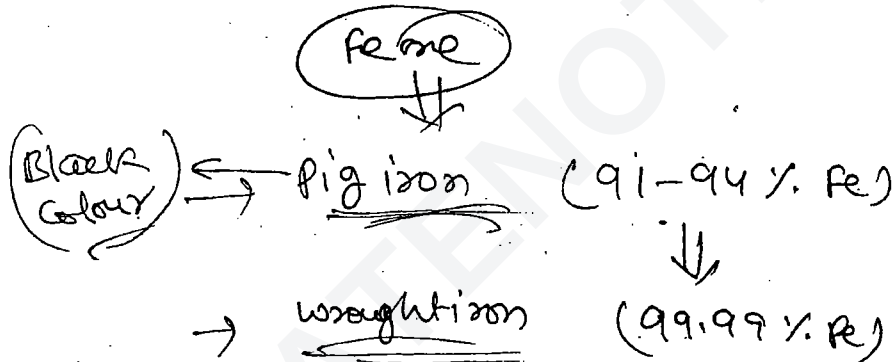
applications → drawing dies, rollers ~~for cement~~ for sheet mills, sand glass nozzles, brake shoes etc.

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 possesses very high carbon content.
- ② improvement in properties in steel by adding alloying element is tremendous because it possesses low carbon content.



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