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Chapter No. 6 "MECHANICAL PROPERTIES OF METALS"

What are the mechanical properties of metals?

Metals are possessing the following properties.
(i) Hard
(ii) Strong → ability to with stand a certain force.
(iii) stiff → resistance to deformation.
(iv) Tough
(v) Brittle
(vi) Ductile.

What conditions are needed to be considered while studying the Mech properties of Metals:-

Following conditions are to be considered.

(i) Nature of load applied (stress i.e force/area)
(ii) Duration of load applied (const/fluctuating in t) → time
(iii) environmental conditions (temp, corrosion)

What is ASTM:-

Since mechanical properties are a great concern for 'producers', 'consumers', 'government agencies' and Research organizations.

An international professional body like ASTM (American society for testing and materials) defines and measures such properties.

more specific mechanical properties may ...
quired. i.e
(i) strongness (iv) brittleness
(ii) toughess (v) etc ...
(iii) ductility

...at are the basic methods to strengthen
metal.

...ain ...nement:-
... posed of grains which are tiny
...gions with a specific crystal structure
...ize refinement, the no. of grain
...es increases, hindering the movement
...slocation.
...his effectively strengthens the metal.
Methods like:-
(i) alloying
(ii) Heat treatment
(iii) mechanical deformation
} help to refine the grain size.

(ii) Solid Solution Strengthening:-

This method involves allowing foreign particles into the metal's crystal lattice. These alloying elements can disrupt the regular arrangement of atoms, creating strain fields that impede the regular movement of dislocation i.e strengthen's the metal.

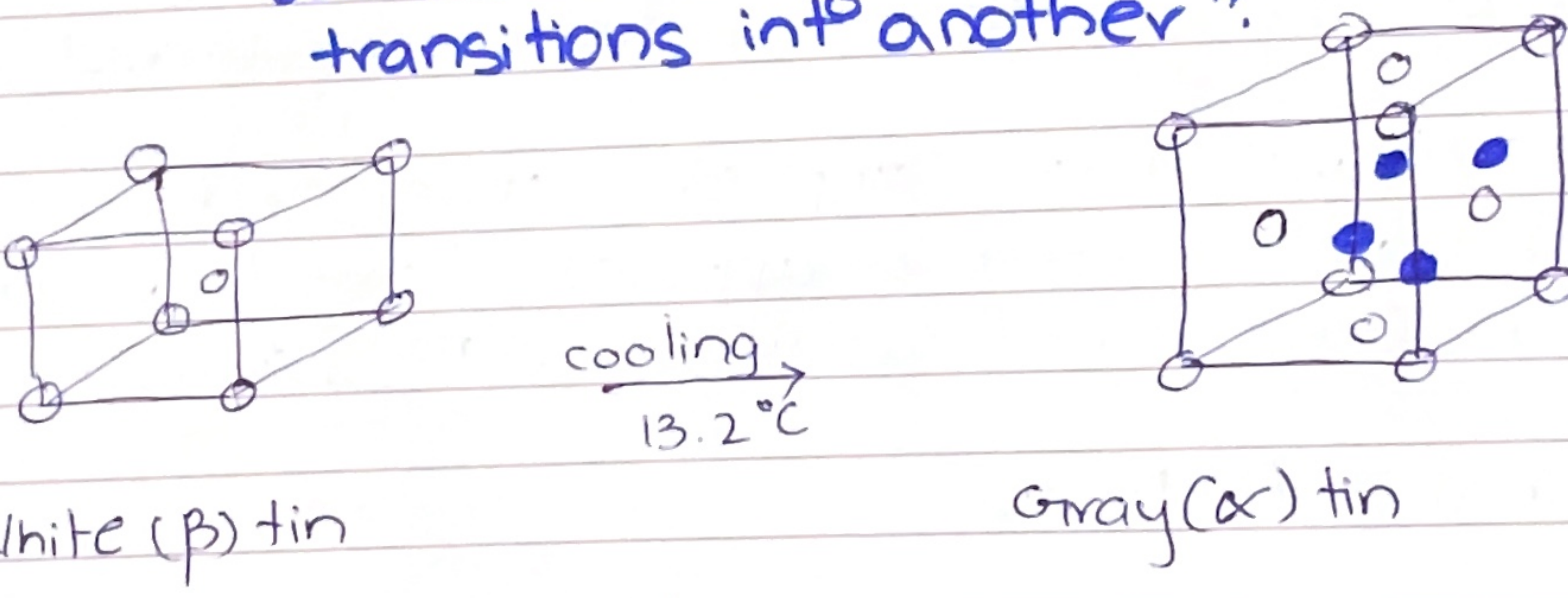
Common alloy metals are Cr, molybdenum

Q. Enlist some, metal and alloy processes.

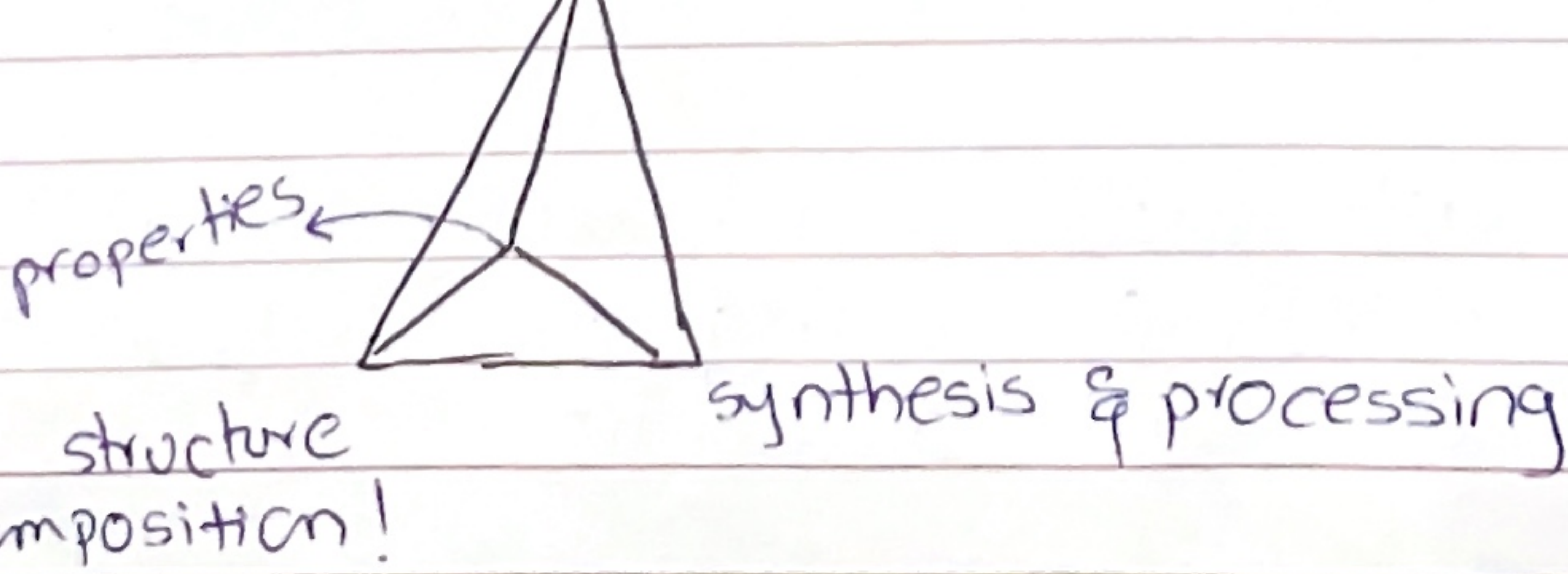
(i) Forging (cold working).
(ii) Bending copper wires.
(iii) Welding
(iv) maching (make a shape out of a workpiece)
(v) grinding
(vi) drilling
(vii) Non-uniform cooling
(viii) Non-uniform heating
(ix) phase change (e.g tin)
(x) Rolling
(xi) extrusion (material is forced through a die)
(xii) Forming operations.

Q. Describe the phase change process with an example.

"Phase change is a process in which one state of matter transitions into another".



Q. What are the societal demands for metals?



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Further more specific mechanical properties may also be required. i.e

(i) strongness
(ii) toughess
(iii) ductility
(iv) brittleness
(v) etc ...

Q. What are the basic methods to strengthen a metal.

(i) Grain Size refinement:-

Metals are composed of grains which are tiny crystalline regions with a specific crystal structure. By grain size refinement, the no. of grain boundaries increases, hindering the movement of dislocation.

This effectively strengthens the metal.

Methods like:-

(i) alloying
(ii) Heat treatment
(iii) mechanical deformation

} help to refine the grain size.

(ii) Solid Solution Strengthening:-

This method involves allowing foreign particles into the metal's crystal lattice. These alloying elements can disrupt the regular arrangement of atoms, creating strain fields that impede the regular movement of dislocation i.e strength's the metal.
en

Common alloy metals are Cr, molybdenum

if $\sigma > \sigma_y$ $F = \sigma_y A$
the failure occurs ← used to predict li
i.e strength.

(iii) Strain Hardening:-

It occurs when a metal is plastically deformed at temperatures below its recrystalization temp. This plastic deformation introduces & increase the dislocation density thus making the metal more resistant to any further deformation i.e increasing yield & tensile strength.

Q. Define stress and its types.

○ DEFINITION:-

"Internal force developemented in / developed in a material which tends to resist deformation when subjected to external forces".

$$\text{stress} = \frac{\text{Applied force}}{\text{c.s.a. of material}} = \frac{F}{A} = \frac{N}{m^2}$$

○ TYPES :-

Following are the various types of stresses.

(i) TENSIONAL STRESS:-

Type of stress that occurs by pulling a material along its axis. Tending to elongate.

(ii) COMPRESSIONAL STRESS:-

Type of stress that occurs by pushing or compressing the material together

& composition!

along its axis.

Shear Stress:- Type of stress that occurs when forces act parallel to the surface of a material in opposite directions.

TORSIONAL STRESS:- Type of stress that occurs when a material is subjected to a twisting about axis or a torsional load.

Q. Define "Engineering stress" and 'Engineering strain'

Engineering stress and engineering strain terminologies are commonly used in the field of materials science and engg to describe the behaviour of material (usually under standard condition) against the mechanical load.

Engg stress	Engg strain
	Fractional change in Dimension
$\sigma = \frac{F}{A_o}$	$\varepsilon = \frac{\Delta L}{L_o}$
F = applied force.	ΔL = change in length
A_o = original cross-sectional area.	L_o = original length.
Unit MPa = 10^6 N/m²	Dimensionless.
1 MPa = 1 psi (pounds per square inch)	expressed in %.

Q. Describe the phenomena of stress an strain when a load is applied.

On application of an axial load on a body suppose a cylinder; the body gets deformed (either elongates or reduces), the fractional change occurred in dimension of the body is called strain.

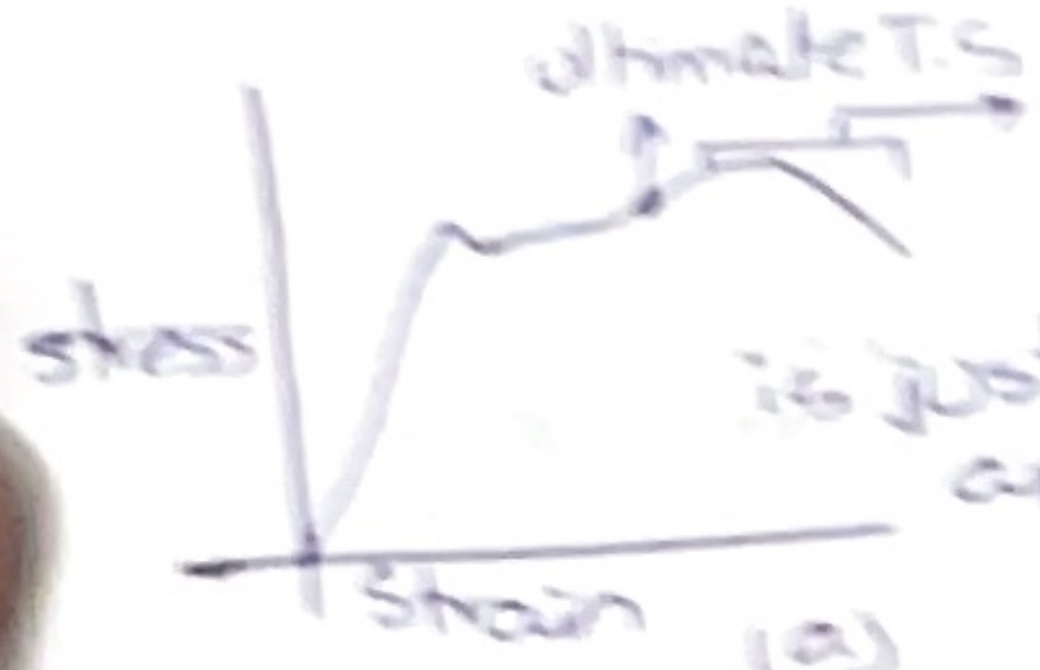
Now the body tries to regain its original size (due) to its plastic property. This tendency produces a restoring force within the body which is equal in magnitude to the applied load. This F_R is responsible for the stress in the body.

* Thus on increasing the applied load the strain increases following which the stress also increases. We can say strain is a cause and stress is an effect.

stress $\propto$ strain ✓

ENGG STRESS & STRAIN:-

The relation of stress and strain by this graph.



is just a approximation.

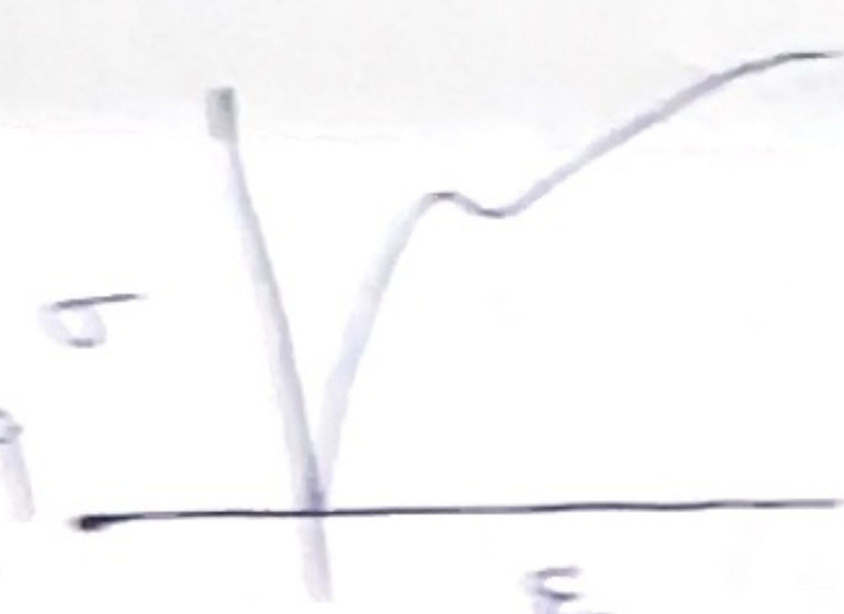
by $\sigma_e = \frac{F}{A_0}$ $\frac{\text{applied force / load}}{\text{original area}}$

ε_e $\varepsilon = \frac{\Delta L}{L_0}$ $\frac{\text{change in len}}{\text{og. len.}}$

Here stress & strain are called as engineering stress & engineering strain and thus (a) is the engineering stress-strain curve.

"Necking is the rapid decrease in the engineering curve after max stress i.e ultimate tensile strength"

Q. Why do we use engg stress-strain & not the true stress-strain.



As we know the true stress-strain curve would increase after Y.S & necking (i.e not dropping after necking).

Reasons for not using true stress-strain

① it is difficult to measure the instanteous size of the cross-sectional area during a test

↓

(a requirement of true stress-strain)

② Most of the time our case study is just limited to the elastic region only.

where engg & true curves are similar.

True stress-strain curves are imp in

(i) manufacturing processes.

(ii) finite element analysis.

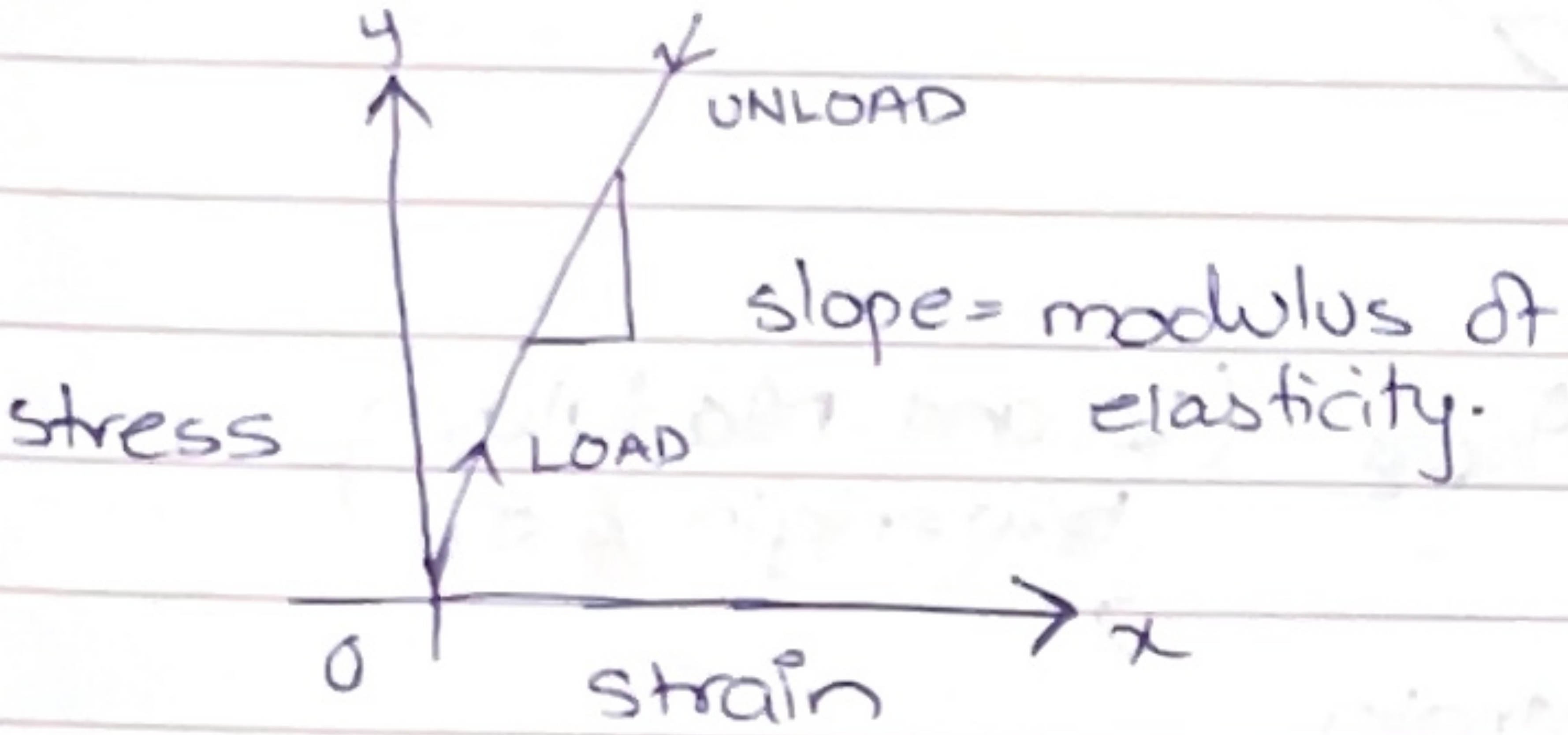
bonds are stretched!

Elastic DEFORMATION:-

$$\sigma = E\,\epsilon$$

(Const. of prop) → elastic / Young's Modulus → (GPa, psi units)

"The deformation in which the stress and strain are propotional is called as elastic deformation."



* when a load is applied it is called to stretch the bonds.

* Elastic means reversible. (the piece return's to orignal shape).

E ⇒ Measure of material's resistance to deformation or stifness.

Greater the modulus E, stiffer the material or lesser will be elastic strain resulting from the application of stress.

Graphical Analysis:- OR NON LINEAR $\sigma - \varepsilon$ graph:-

There are some material that donot have a linear stress-strain relationship (e.g:- gray cast iron, concrete and many polymers) In order to find modulus of elasticity in this case we take;

* E ranges b/w

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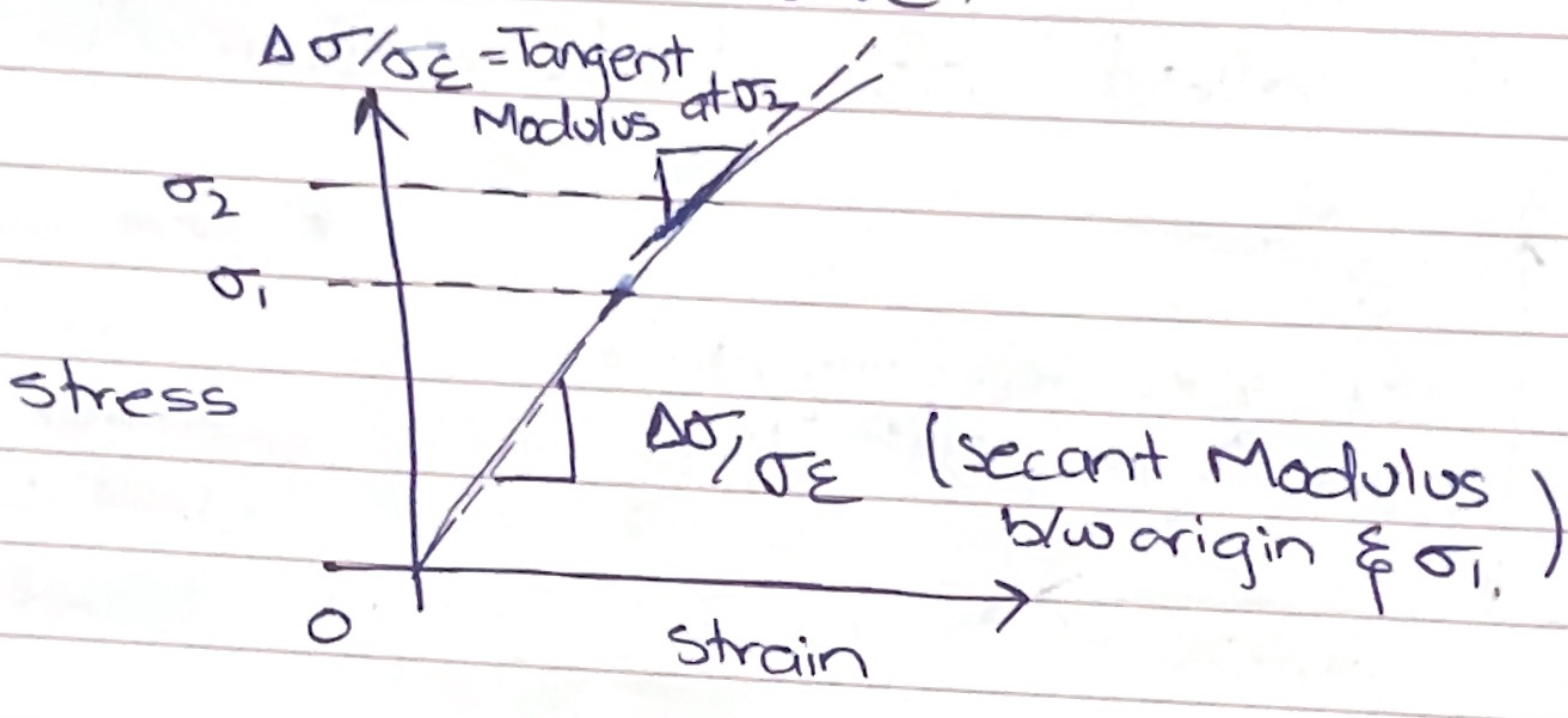
(i) **Tangent Modulus;** taken from the slope of stress - strain curve at a specified point/level.

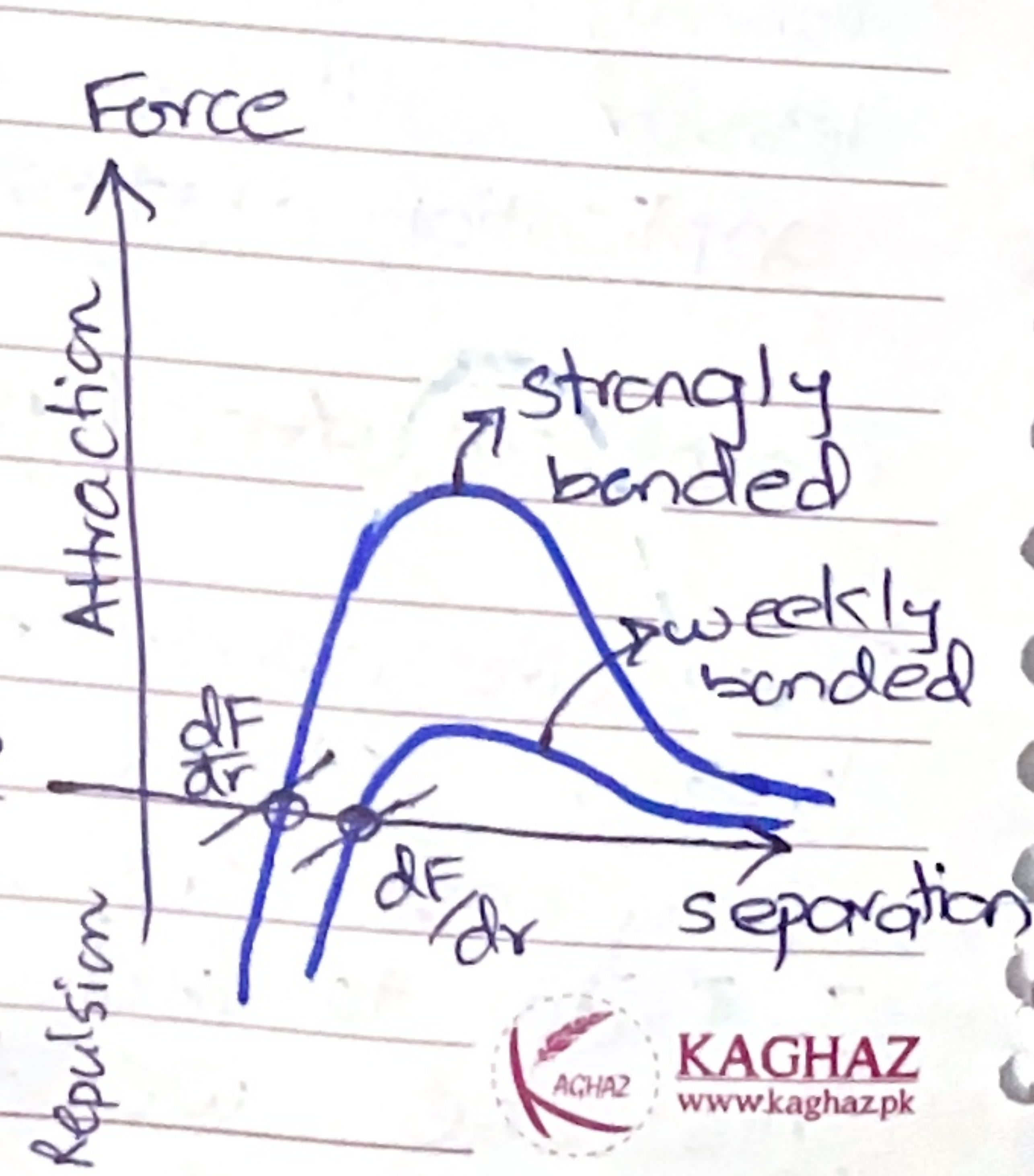
(ii) **Secant Modulus;** slope of the secant drawn from origin to some given point of the $\sigma - \varepsilon$ curve.



Q. Describe the relationship of E with inter atomic force separation curve.

$$E \propto \left(\frac{dF}{dr}\right)_{r_0}.$$

On the atomic scale, macroscopic elastic strain is manifested as small changes in the interatomic spacing and the stretching of inter-atomic bonds.
As a result, 'E' is the resistance to separation of adjacent atoms i.e interatomic bonding force.



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hat is why we say that the modulus is propotional to the slope of the interatomic F-separation at equilibrium

⇒ E For ceramic materials is same for metals.
⇒ Polymers have lower value of E

$$E \propto \frac{1}{T}$$

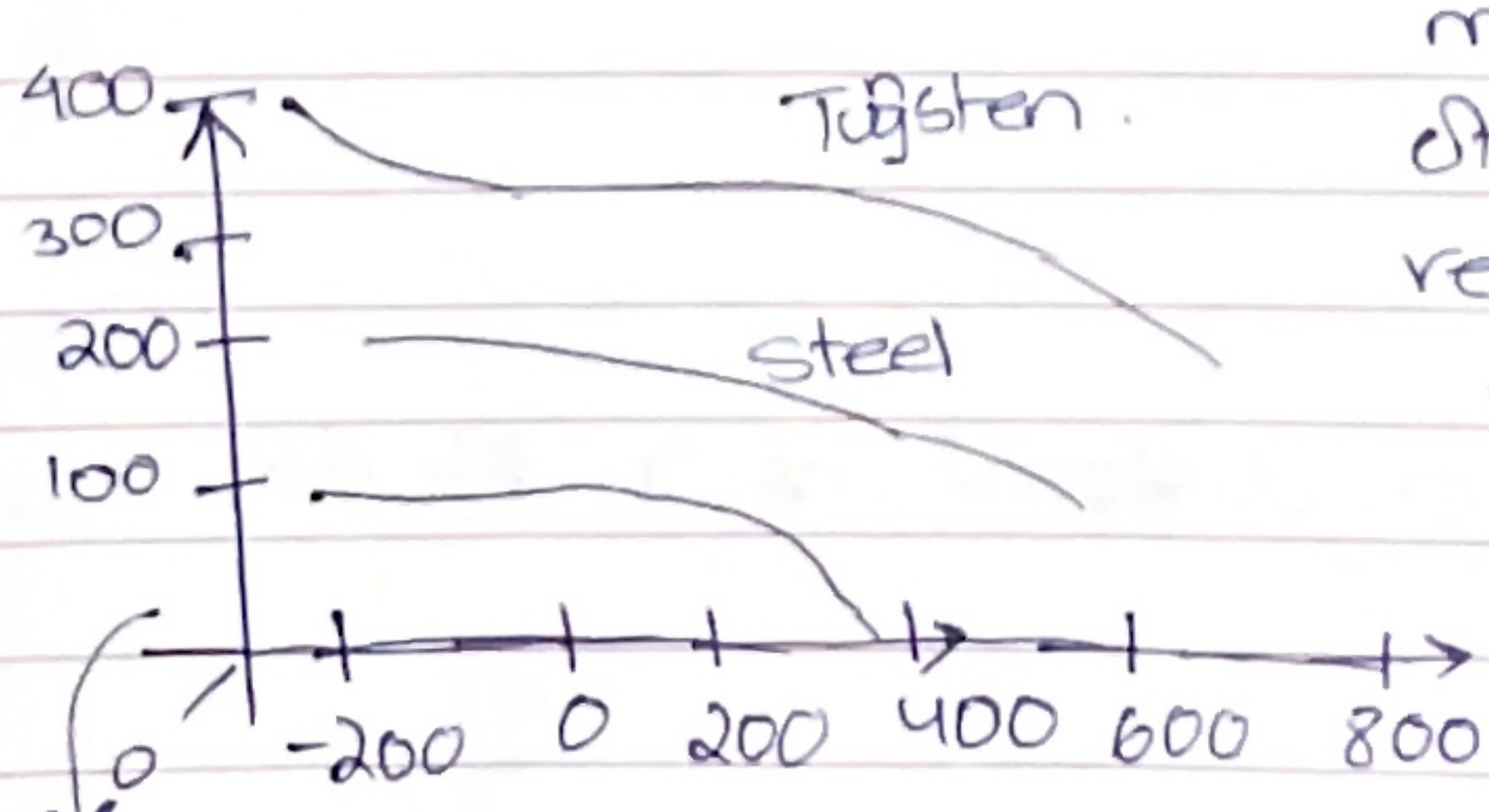
Q. Define shear stress & strain's relation.

The imposion of compressive, shear or torsional stresses also evoke elastic behaviour. The stress-strain characteristics at low stress levels are virtually the same for both tensile and compressive situations

Shear stress & strain are propotional to each other.

⇒ $T = G\gamma$

'G' is the shear modulus, the slope of the linear elastic region of the shear stress-strain curve.



(°c temperature)

"Modulus of elasticity"

PLASTIC DEFORMATION :-

bonds stretch & plane shear during load

planes remained deformed sheared afterunload

permanent

"The point at which stress is no longer or to strain, causing permanent & non-recoverable change".

→ strength & hardness are measures of resistance

For metals usually after a strain of 0.005 causes plastic deformation. ↓ (in this ca

Q. what happen to the band in P. deformation.

The mechanism involves the breaking of bonds and reformation with new neighbouring atoms without the return to the original position.

Crystalline! — The plastic deformation for such materials is acquired by slip mechanism

Amorphous! — The plastic deformation for these materials is obtained by viscous flow mechanism.

Q. What is the role of dislocations in Plastic deformations?

eilding:- The stress level at which plastic deformation begins.

Propotional limit:- For metals at the experiencence of gradual elastic – plastic transition, the point of yielding may be determined, as the initial departure from linearity of stress-strain curve. i.e called as propotional limit. (P)

* P is difficult to be measured precisely.
Q. Define Y.S & method to measure in lineargraph.

Yeild strength:- As 'P' cannot be measured precisely, a convention is used by which a straight line parallel to the elastic portion of the stress-strain curve at some specified offset usually 0.02.

* The stress corresponding to the intersection of this line and stress-strain curve as it bends over to the plastic region is defined as the 'yeild strength' ? σ_y
(units MPa or Psi)

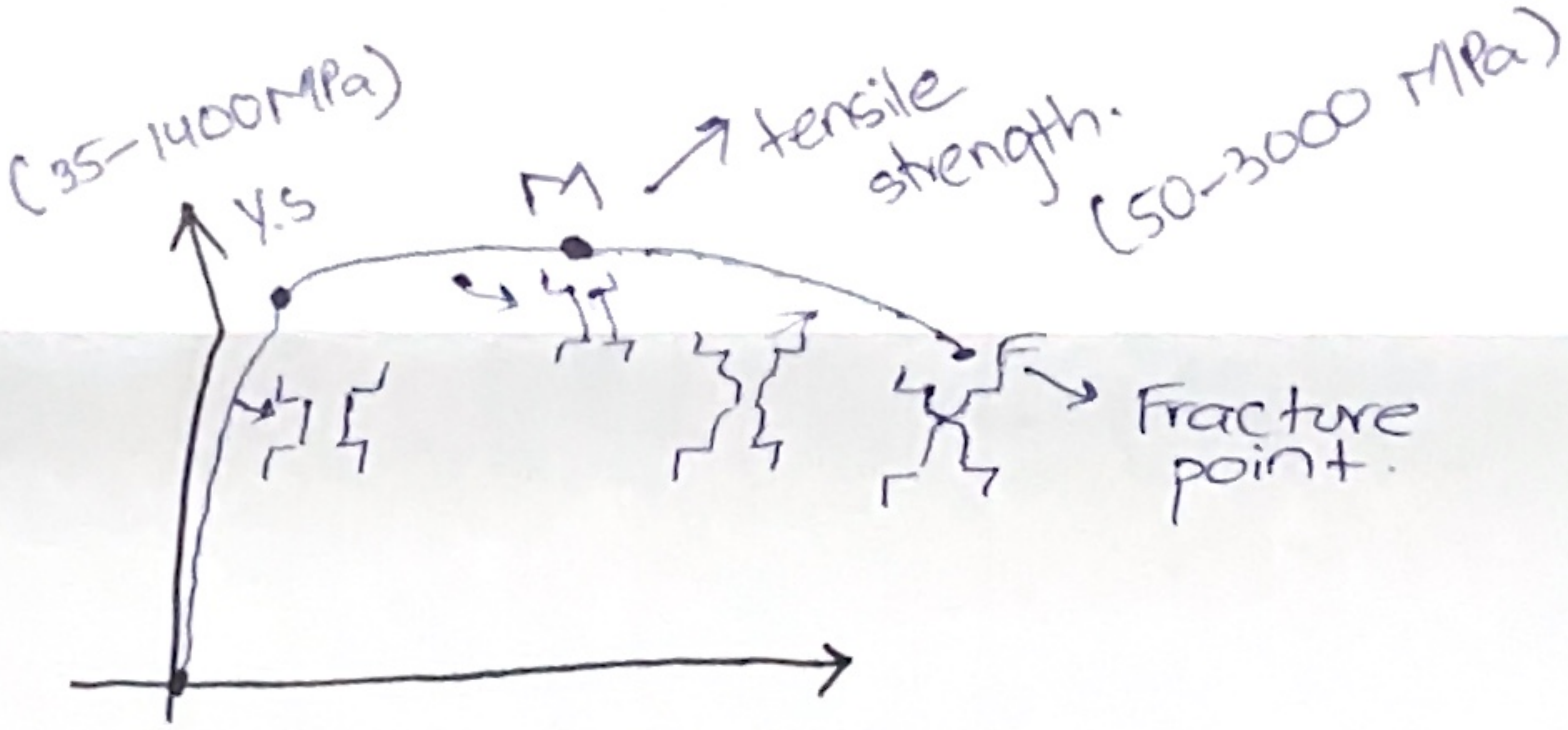
Resistance of materials to plastic deformation is due to yield strength.

$\sigma_y = ?$
(yield s
N =

Tensile strength:-

After yielding, the stress necessary to continued plastic deformation in metals increases to a maximum at point 'M' and then decreases eventually to the fracture point.

The tensile strength TS (MPa or psi) is the stress at the maximum on the engineering stress-strain curve that can be sustained before fracture



By $U_r = \frac{\sigma_y^2}{E}$

The resilient materials are those that have a high yield strength & a low modulus of elasticity.

Example:- alloys used in spring applications.

US unit:- inch-pound force per cubic inch.

Question: Describe stress strain tests and its types.

stress-strain tests are performed on materials in standard conditions to standardizied the results for people across the globe.

(i) Compression tests:-

The force applied is compressive and the speciemen contracts along the direction of stress.

Equations like $\sigma = \frac{F}{A}$. $\varepsilon = \frac{\Delta L}{L_0}$ are used to compute compressive stress and strain.

(i) Not a very common test,
(ii) Used for material's where plastic deformation/strain is desired. (i.e for br
(iii) Here stress is taken to be negative, strain is already negative.

(ii) Shear Stress Test:-

For tests using purely shear force, shear stress is given by τ

$$\tau = \frac{F}{A_0} \text{ (applied force)}$$

that are distance h apart.

parallel to upper & lower faces.

Shear strain γ is defined as the tangent of the strain angle φ

$$\gamma = a/h = \tan\varphi.$$

(iii) Torisional test:-

Special form of shear in which the material is twisted in a manner about its axis (longitudinal).

⇒ Usually performed on cylinder and solid shafts or tubes.

⇒ here shear stress τ is a function of applied torque T whereas strain γ is related to angle of twist ϕ.

GEOMETRICAL CONSIDERATIONS OF STRESS STATES!

$$\sigma' \Rightarrow \sigma \cos^2\phi \Rightarrow \sigma\left(\frac{1+\cos 2\phi}{2}\right) \text{ ; normal stress } (\perp)$$

$$\tau' \Rightarrow \sigma \sin\phi \cos\phi = \sigma\left(\frac{\sin 2\phi}{2}\right) \text{ ; shear stress } (\parallel)$$

—— ①

Derivation of ①

Shear force = $F\cos(90-\phi) = F\sin\phi$.

Shear Area = $A / A\cos\phi$.

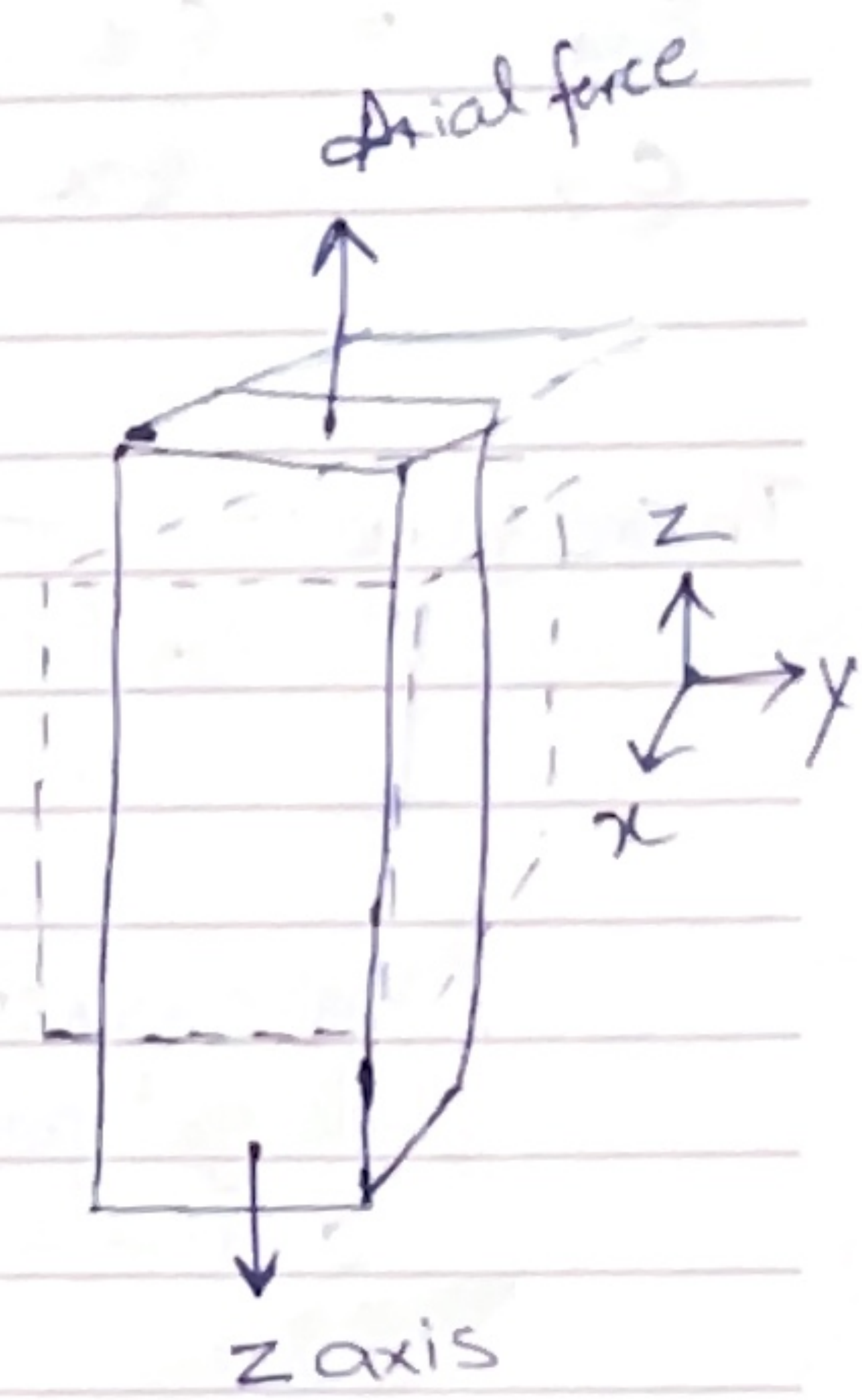
∴ shear stress = $F\sin\phi / A/\cos\phi \Rightarrow \sigma \sin\phi \times \cos\phi$

POISSON RATIO:-

Tells us about how a material will deform in different types of loading.

* The direction along which the load is applied is called as the longitudinal axis. The direction's perpendicular to it are called as lateral directions.

When a load is applied to a material in one direction it will also deform in the lateral directions.



let Lx, Ly, Lz be the original dimensions of the cuboid

then; $\frac{\Delta Lx}{2}$, $\frac{\Delta Ly}{2}$ & $\frac{\Delta Lz}{2}$ are the changes in these dimension when the load is applied.

* now strain on all three directions) is;

(measure of deformation)

$$\varepsilon x = \frac{\Delta Lx}{Lx}, \quad \varepsilon y = -\frac{\Delta Ly}{Ly}$$

$$\varepsilon z = -\frac{\Delta Lz}{Lz}$$

" Poisson ratio will tell us how much ... will contract in lateral direction if we p... it in the longitudinal /Axial. direction...

it is find that the longitudinal load applied makes resultant strains in the lateral direction to be equal.

$$\varepsilon_y = \varepsilon_z \quad \text{—— (1)}$$

also propotional to the strain in the longitudinal direction

$$\left.\begin{array}{l} \varepsilon_y \propto \varepsilon_x \\ \varepsilon_z \propto \varepsilon_x \end{array}\right\} \text{—— (2)}$$

$\therefore$ by (1) & (2)

$$\frac{\varepsilon_y}{\varepsilon_x} = \frac{\varepsilon_z}{\varepsilon_x} \Rightarrow \text{material constant.}$$

$$v = -\frac{\varepsilon_x}{\varepsilon_z} = -\frac{\varepsilon_y}{\varepsilon_z}$$

Therefore :- dimension less

$$\left[v = (-)\frac{\varepsilon\ \text{lateral}}{\varepsilon\ \text{longitudinal/Axial}} \right]$$

by convention; to get positive answer.

$\varepsilon_{\text{longitudinal}} = +ve$
$\varepsilon_{\text{lateral}} = -ve$

also :-

$$E = 2G(1+v)$$

elastic Modulus | shear Modulus | poisson ration.

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ange of 'v' usually $(-1.0 \rightarrow 0.5)$
'v' occurs in elastic regions & for isotrophic materials.

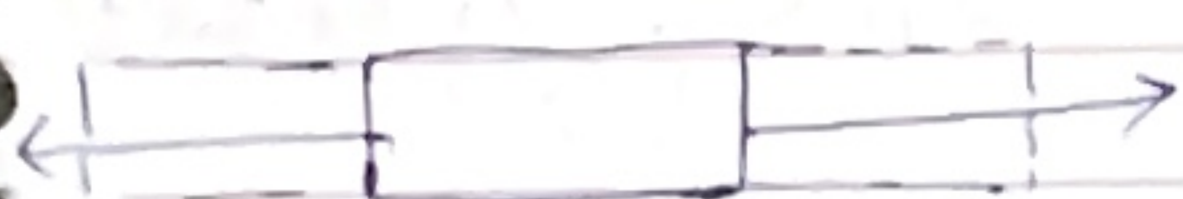
Cases of Poisson Ration :-

① $0 < v \leq 1/2$

materials with such poisson ratio will contract laterally when pulled longitudinally.

② $v = 0$

materials will such value are not contracting laterally when pulled longitudinally.



e.g cork.

③ $-1 < v < 0$

the material will increase laterally when pulled longitudinally and vice versa.
(exotic materials).
e.g specially engineered foams.

ANELASTICITY:-

Usually for elastic materials it is thought that when the stress / load is removed from a body the strain will recover / return to 0. This phenomena seems time-independant.

However for some materials when load / stress is removed the strain may not go back to zero directly or (take some time); the phenomena is time-dependant now and named 'anelasticity' or 'viscoelasticity'.

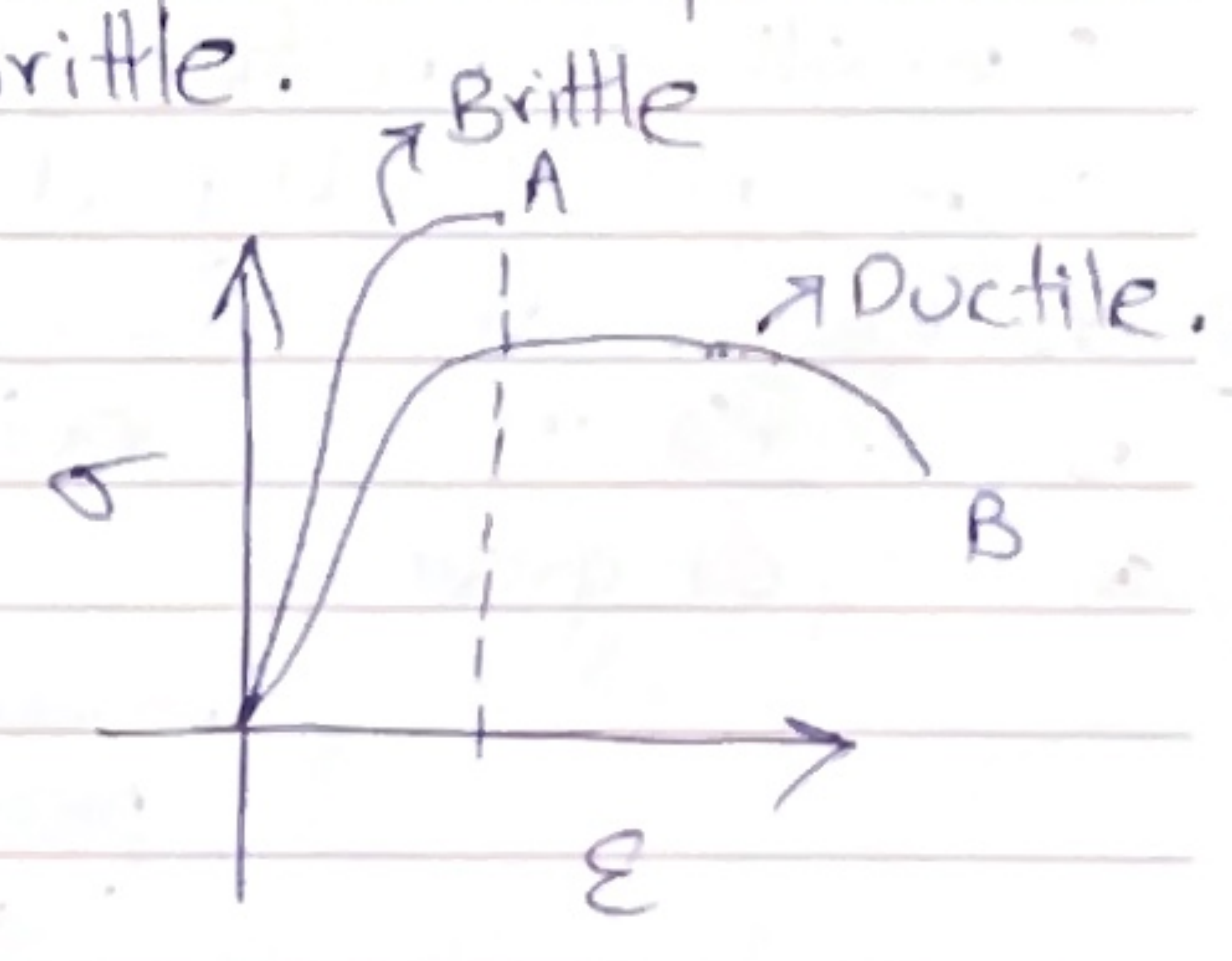
Example:-

Anelasiticity is insignificant in metal
" " significant in polymers.

DUCTILITY:-

"The measure of deformation of a material at fracture point".

A metal with very little or no plastic deformation at fracture is known as brittle.



Ductility is quantitatively expressed as %

① elongation %

$$\%EL = \left(\frac{l_f - l_i}{l_i}\right) \times 100$$

(final, initial)

② % Reduction in Area;

$$\%RA = \left(\frac{A_o - A_f}{A_o}\right) \times 100.$$

Q. Why is the knowledge of ductility important to us?

① it tells us about the degree at which the structure will deform plastically after fracture

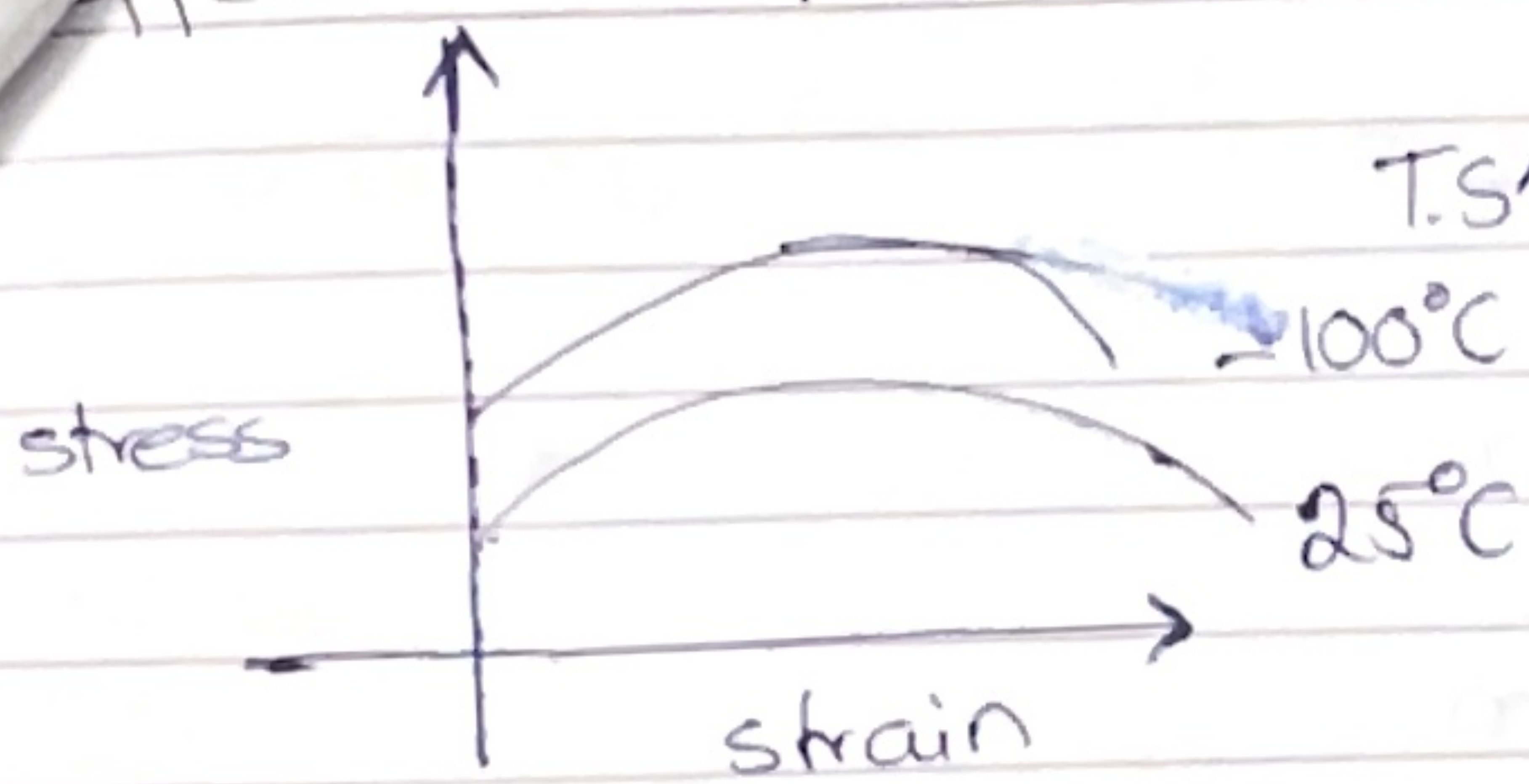
② it tells us about the degree of allowable deformation at fabrication process.

Question.
Why does ductility increases with the increase in temp?

As the temp↑ the K.E↑ of the atoms &
① molecules also increase which makes dislocations easier in the crystal lattice.
② The elevated temp also reduces the yield strength of materials allowing them to deform plastically at lower stress levevels
③ At elevated temp the grain boundaries becomes more mobile and thus allowing easy sliding of grains.

→ all of these factors enchance plastic deformation and increase ductility.

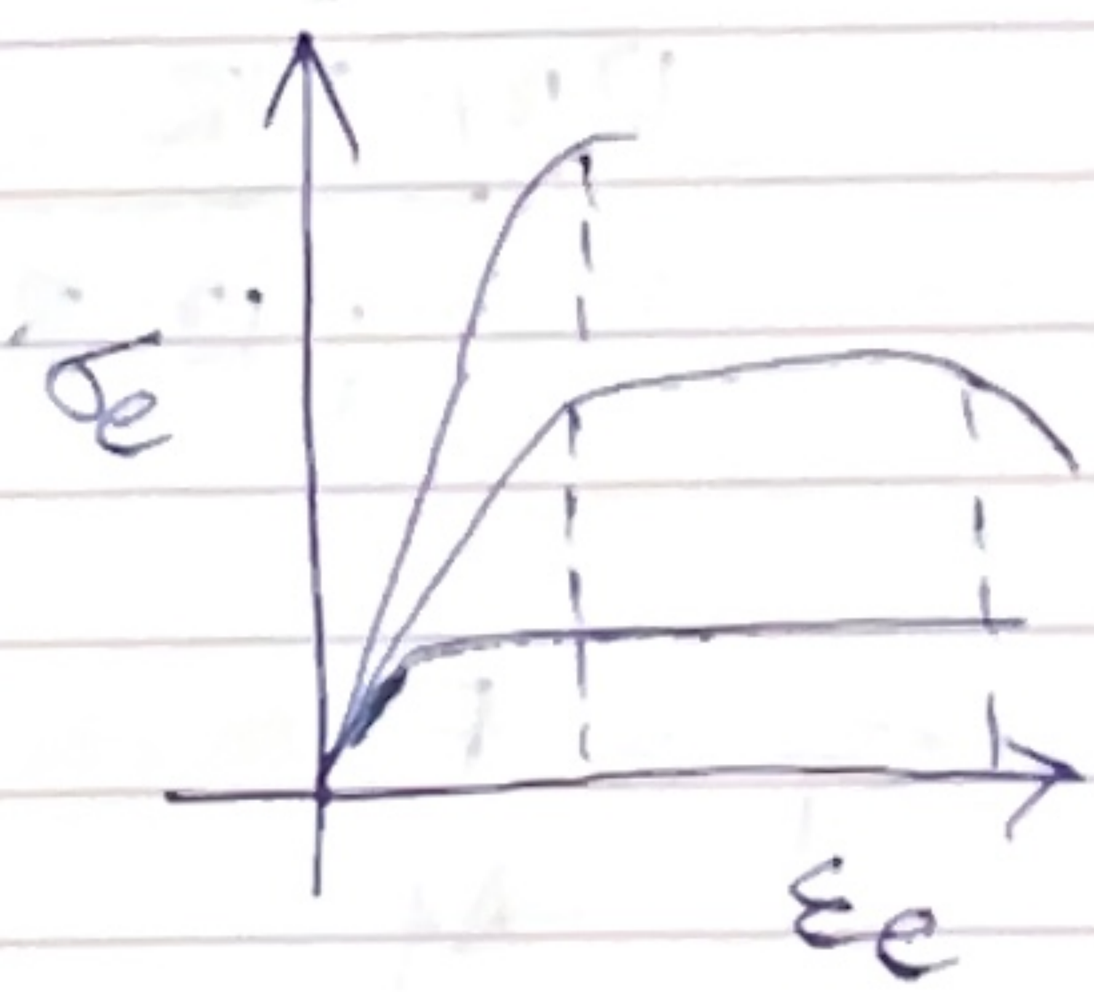
Affect of temp on stress – strain behaviour.



T.S↑ / Y.S↑ with temp↓
Ductility↑ with temp↑
E const with temp↑↓

Thermal expansion & softneing also occurs at high temp.

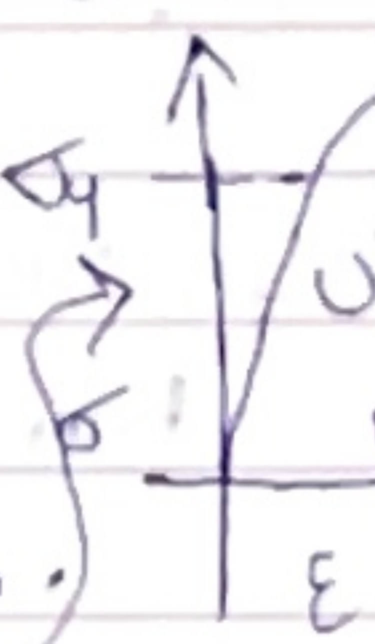
Toughness:- (J/m³)
Capacity of a material to absorb energy per unit volume before fracture.



$$\text{Toughess} = \sigma \times \varepsilon = \frac{F}{A} \times \frac{\Delta L}{L} = \frac{\text{Energy}}{\text{Volume}} \Rightarrow J/m^3.$$

Greater the area under the curve > greater will be the toughness & viceversa.

⇒ strength increases along Y-axis.
⇒ ductility increases along X-axis.



$U_r = \int_0^{\varepsilon_y} \sigma \, d\varepsilon$

$\boxed{U_r = \frac{1}{2}\sigma_y \varepsilon_y}$

strain & stress at yeilding

RESILIENCE:-
The ability of a material to absorb energy during elastic deformation and the energy is recovered upon unloading.

SI unit ⇒ J/m³ also $\boxed{U_r = \frac{1}{2}\sigma_y^2/E}$

"Modulus of Resilience 'U' is important ↓ "strain energy per unit volume required to stress a material from an ~~up~~ unloaded state to the point of yeilding."