4/1/23

Testing of Materials → To identify mechanical properties of material

Tensile testing:

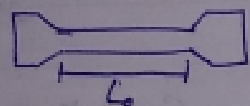
We get strength, toughness, resillance, etc... from tensile testing.

Advantages of tensile testing:

i) Standarisation.
ii) Wide range of properties from a single test.

→ Tensile test is conducted at room temperature.
→ Tensile test can also be done at high temp., but not commonly used.
→ Stress-Strain curve (S-S curve) is obtained from tensile test.

Dog bone shaped sample is used for tensile test.



This sample is symmetric about its long axis so that load is distributed uniformly over cross section. Load is applied uniaxially along specimen/ sample length & increases gradually until fracture occurs.

Elongation produced is measured at frequent intervals. The load and elongation data are plotted as curve called load-elongation curve.

To remove size effects on load, the load & elongation are obtained for unit cross-section area. Likewise elongation vary on length.

$$\underbrace{\sigma}_{\text{engg. stress}} = \frac{\overbrace{P}^{\text{load}}}{\underbrace{A_o}_{\text{cross section area}}}$$

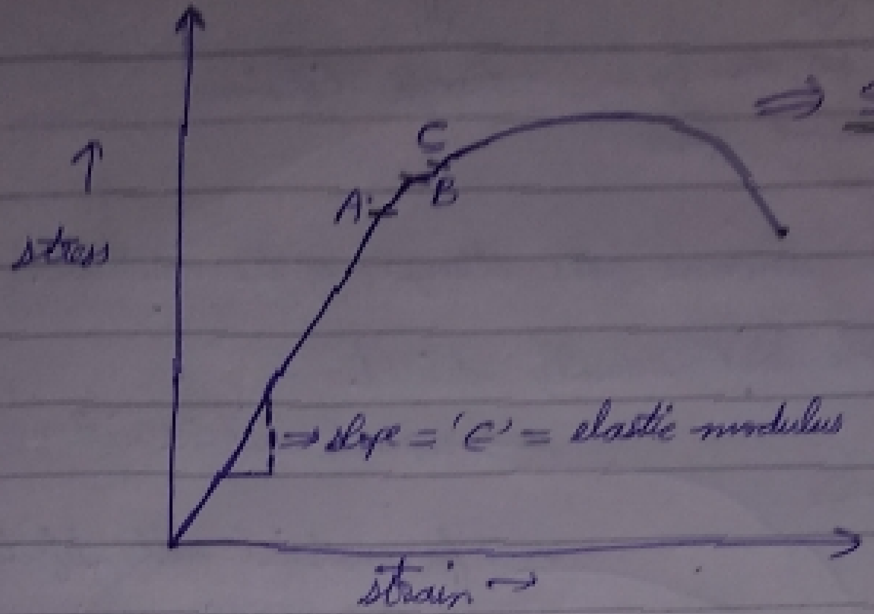
$$\underbrace{e}_{\text{engg. strain}} = \frac{\overbrace{\Delta L}^{\text{change in length}}}{\underbrace{L_o}_{\text{initial length}}} = \frac{L-L_o}{L_o}$$

This S-S curve is known as engineering, conventional or nominal stress-strain curve.

Shape of S-S curve depends on composition, plastic deformation or heat treatment, temp, state of stress & strain rate.

Page No.:
Date: / /

6/1/23



⇒ S-S curve

A → Proportionality limit (PL) ⇒ linear behaviour

B → Elastic limit (EL) ⇒ the point till which material deforms elastically. (non-linear behaviour)

Hook's law ⇒ $\boxed{\text{Stress} \propto \text{Strain}}$ → valid upto PL.

C → Yield point / yield stress (Y.S) ⇒ point at which appreciable plastic deformation starts.

0.2% elongation for yield stress according to US standards.
⇒ If elastic limit is 10 cm, then yield point will be at 10.002 cm.

$$\boxed{Y.S = \frac{P_{(0.2\%)}}{A_0}}$$ → acc. to U.S standards.

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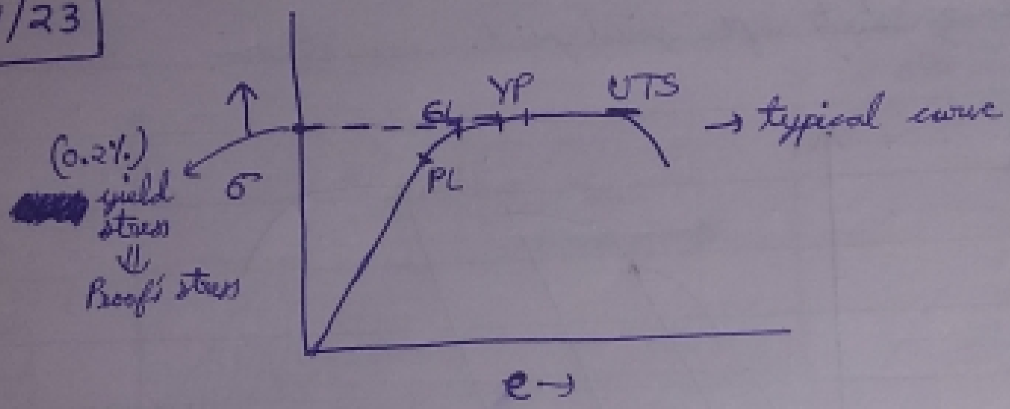


Modulus of elasticity $= \underbrace{E}_{\text{structure insensitive property}} = \frac{\sigma}{e}$ till PL.

→ Ability to resist elastic deformation, gives stiffness

$$\text{Stress} = \frac{\text{load}}{\text{Area}}$$

$$\boxed{Y.S = \frac{P(0.2\%)}{A_0}}$$

Ultimate Tensile Strength (UTS)
⇓
Ability to resist deformation before fracture
→ maximum stress that material can take

$$\boxed{UTS = \sigma_u = \frac{P_u}{A_0}}$$

P_u → maximum load
A_0 → initial area

Resilience → material absorbing energy when deformed elastically
Toughness → ability to absorb energy when deformed plastically
→ strain energy per unit volume

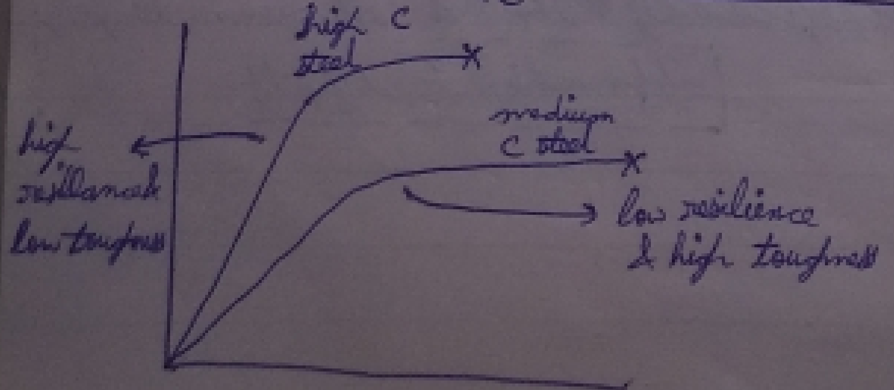
$$\boxed{\text{Modulus of resilience} = \frac{1}{2}\sigma e}$$ → area under elastic region

⇓

$$\frac{\sigma^2}{2E}$$ ← yield stress

$$\boxed{\text{Modulus of toughness} = \frac{2}{3}\sigma_{UTS}\, e_f}$$

e_f → strain at fracture point

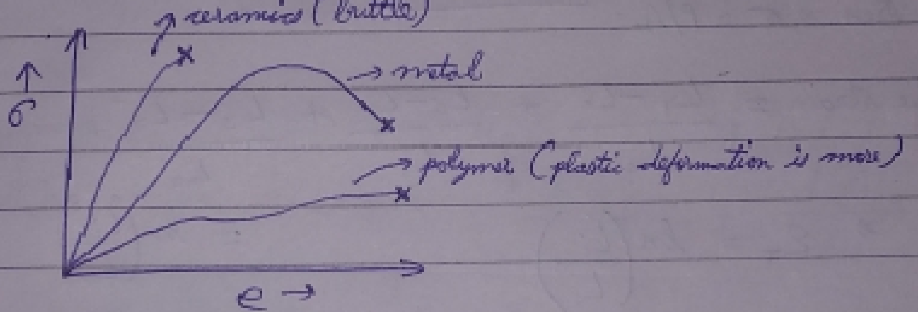


Ductility → Ability to flow plastically without getting fracture.

⇒ $\boxed{\text{Ductility} = \%\ \text{elongation} = \frac{L_f - L_0}{L_0}} = \varepsilon_f = \%$ length elongation

Volume is constant ⇒ $A_0 L_0 = A_f L_f$ ⇒ $L_f = \frac{A_0 L_0}{A_f}$

$\boxed{\frac{A_0 - A_f}{A_0} = q} = \%$ area elongation



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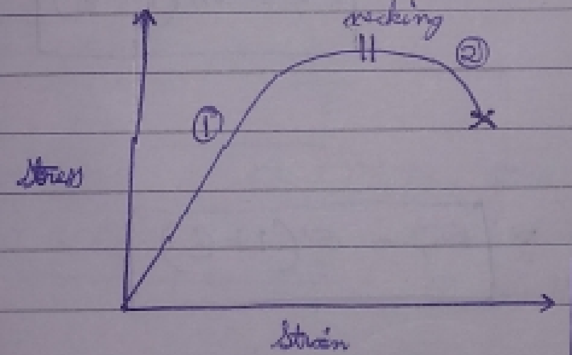
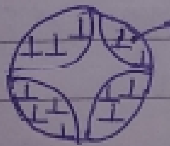


After necking 2 things occur i.e.,
i) strain hardening takes place, so more stress is required for elongation
ii) decrease in area of cross-section continuously.



movement of dislocations from source to destination ⇓ plastic deformation

& if dislocations are hindered by grain boundary so they are stuck at one point i.e, dislocation forest ⇒ strain hardening i.e., a strengthening mechanism starts.

In region ①, strain hardening dominates area of cross-section, so curve increases.

In region ②, area of cross-section dominates strain hardening, so curve decreases.

Relation b/w ε_f & q:

$$\varepsilon_f = \frac{L_f}{L_o} - 1 = \frac{A_o}{A_f} - 1 = \frac{A_o - A_f}{A_f}$$

$$q = 1 - \frac{A_f}{A_o} = \frac{A_o - A_f}{A_o}$$

$$\Rightarrow \varepsilon_f = \frac{A_o - A_f}{A_o} \times \frac{A_o}{A_f} = \frac{q}{1-q} \Rightarrow \boxed{\varepsilon_f = \frac{q}{1-q}}$$

True stress-strain curve $\Rightarrow$ we take instantaneous area & length

True stress $\Rightarrow$ $\sigma_T = P/A_i$ $\boxed{\sigma_T > \sigma}$ → because area continuously decreases

Engineering stress $\Rightarrow$ $\sigma = P/A_o$

True strain $= \frac{L_1 - L_o}{L_o} + \frac{L_2 - L_1}{L_1} + \frac{L_3 - L_2}{L_2} + \dots$

$$= \ln\left(\frac{L_i}{L_o}\right)$$

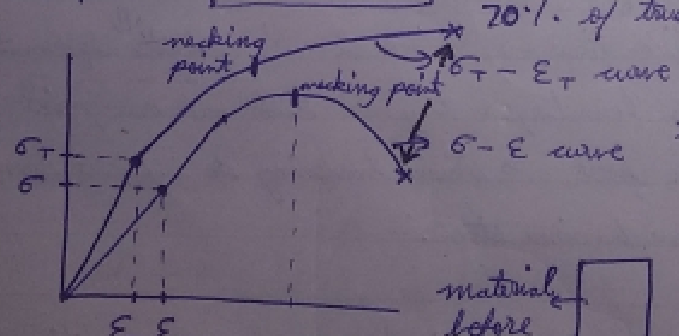
$$\Rightarrow \varepsilon_T = \ln\left(\frac{L_i}{L_o}\right)$$

Engineering strain $\Rightarrow$ $\varepsilon = \frac{L_i}{L_o} - 1$ $\Rightarrow$ $\boxed{\varepsilon_T = \ln(1+\varepsilon)}$

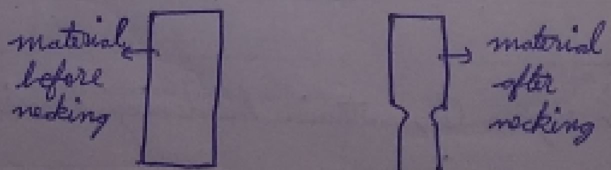
$$\sigma_T = \frac{P}{A_i} = \frac{P}{A_o} \times \frac{A_o}{A_i}$$

$$\varepsilon = \frac{L_i}{L_o} - 1 = \frac{A_o}{A_i} - 1 \Rightarrow \boxed{\sigma_T = \sigma(1+\varepsilon)}$$

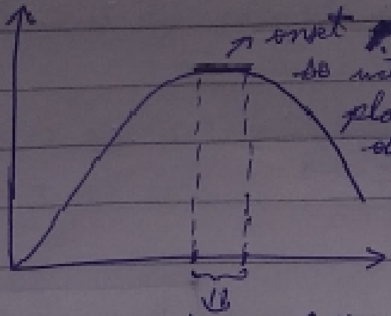
$\boxed{\varepsilon_T < \varepsilon}$ → for 100% engineering strain, we need nearly 70% of true strain



$\Rightarrow$ these points will be valid till necking point only



After necking, triaxial state of stresses occur i.e., non-uniform stress develop. So fracture point shift to right.



onset of necking generally for range of values. so without change in stress, strain increases, so plastic instability or instability in tension is observed

$dP = 0$ (At the point of necking)

$$\Rightarrow dP = 0 \Rightarrow d(\sigma_T A) = 0 \Rightarrow A\,d(\sigma_T) + \sigma_T\,dA = 0$$

$$\Rightarrow \frac{d(\sigma_T)}{\sigma_T} = -\frac{dA}{A}$$

WKT, $A_i L_i = A_o L_o \Rightarrow d(A_i L_i) = d(A_o L_o)$

$$\Rightarrow L_i\,d(A_i) + A_i\,d(L_i) = 0 \Rightarrow \frac{d(L_i)}{L_i} = -\frac{d(A_i)}{A_i}$$

$$\Rightarrow \frac{dL}{L} = -\frac{dA}{A} = \varepsilon_T$$

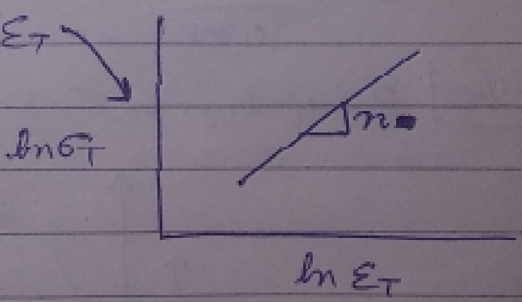
$$\Rightarrow \frac{d(\sigma_T)}{\sigma_T} = \frac{dL}{L} = \varepsilon_T \Rightarrow \boxed{\frac{d(\sigma_T)}{\sigma_T} = d\varepsilon_T}$$

$$\Rightarrow \boxed{\frac{d(\sigma_T)}{d(\varepsilon_T)} = \sigma_T}$$

$\Rightarrow$ true stress at necking point is equal to slope of the true stress – true strain curve at the necking point.

24/1/23 Power law $\longrightarrow$ $\boxed{\sigma_T = k\,\varepsilon_T^{\,n}}$

$$\Rightarrow \ln \sigma_T = \ln k + n \ln \varepsilon_T$$



$n \rightarrow$ strain hardening exponent

$k \rightarrow$ strength coefficient

$k =$ true stress at $\varepsilon_T = 1$

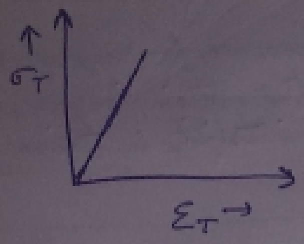
i.e., $\sigma_T = k(1)^n \Rightarrow \sigma_T = k$.

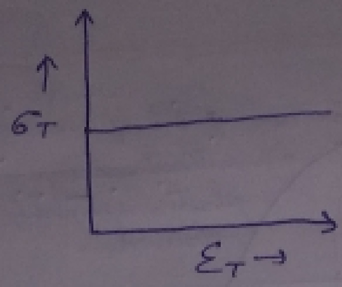
$n \uparrow \Rightarrow$ ability to strain harden $\uparrow$ (slope is more)

$\boxed{0 \le n \le 1}$

$n = 0 \Rightarrow$ perfectly plastic

$n = 1 \Rightarrow$ perfectly elastic





$$\frac{d(\ln \sigma_T)}{d(\ln \varepsilon_T)} = n \Rightarrow \frac{\frac{d(\sigma_T)}{\sigma_T}}{\frac{d(\varepsilon_T)}{\varepsilon_T}} = n \Rightarrow \boxed{\frac{d\sigma_T}{d\varepsilon_T} = n\left(\frac{\sigma_T}{\varepsilon_T}\right)}$$

At necking point, $\dfrac{d\sigma_T}{d\varepsilon_T} = \sigma_T \Rightarrow \sigma_T = n\left(\dfrac{\sigma_T}{\varepsilon_T}\right)$

$\Rightarrow \boxed{n = \varepsilon_T} \rightarrow$ another condition at necking point

Q) If true stress – true strain curve is given by $\sigma = 1400\,\varepsilon^{0.33}$ where σ is in MPa. What is ultimate tensile strength in MPa.

Sol. $K = 1400$, $n = 0.33$, UTS is obtained at necking point $\Rightarrow n = \varepsilon_T \Rightarrow \varepsilon_T = 0.33$

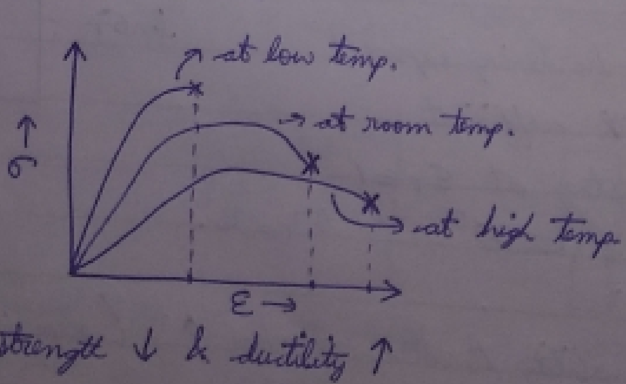
$\Rightarrow \sigma_T = 1400\,(0.33)^{0.33} \Rightarrow \sigma_T = 971\,\text{MPa}$

$\varepsilon_T = \ln(1+\varepsilon) \Rightarrow \varepsilon = e^{0.33} - 1 \Rightarrow \varepsilon = 0.39$

$\sigma_T = \sigma\,(1+\varepsilon) \Rightarrow 971 = \sigma\,(1+0.39)$

$\Rightarrow \sigma = \dfrac{971}{1.39} \Rightarrow \underline{\sigma = 698\text{ MPa}}$.

$\boxed{25/1/23}$ Effect of temp. on S–S curve:



At high temp., strength ↓ & ductility ↑

At lower temp., strength ↑ & ductility ↓

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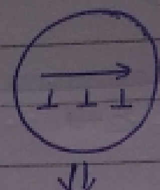
The dislocations slip on a slip plane.



FCC → 12 slip systems

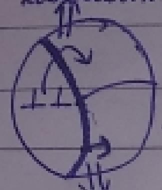
HCP → 3 slip systems

slip system → i) slip plane
ii) slip direction

At higher temp., no. of slip systems increases i.e., slip ability ↑ so deformation ↑ thus increasing ductility.

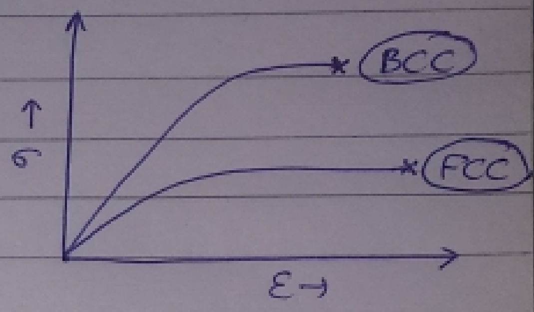
If slip systems ↑, then mobility of dislocation ↑.

dislocation climbs because it obtains energy because temp. is increased



→ At higher temperature

grain boundary slides

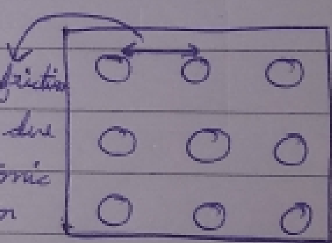


Sliping ability is more for slip planes which are closely packed.

FCC is closely packed, so sliping ability is more in FCC than BCC.

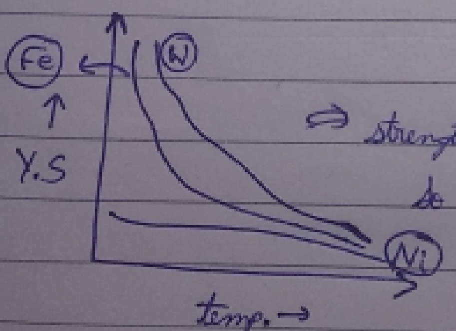
FCC is more ductile because it has more slip systems

lattice friction stresses due to atomic friction



For more lattice friction stresses, strength will be more.

BCC has more lattice friction stresses, so more strength for BCC i.e., Strength of BCC > strength of FCC.



⇒ strength loss is more in BCC than FCC.

So FCC is not temp. sensitive because strength loss is not significant in FCC.

Effect of strain rate

$$\boxed{\text{Strain rate} = \frac{\varepsilon}{t} = \dot{\varepsilon}}$$

For more strain rate, more deformation in less time.