UNIT-3

ENGINEERING MATERIALS

Vibha Masti

Feedback/corrections: vibha@pesu.pes.edu

Engineering Materials

Classification

1) Metals

↳ ferrous metals

- steels
- cast iron

steel: ductile
cast iron: brittle

↳ nonferrous metals

2) Non metals

↳ plastics
↳

- selection of materials
- impact strength, tensile strength, hardness

Metals

Ferrous Metals

- cheap

1) Steel (Fe & C)

low-C steel : 0.15 – 0.25%
medium-C steel 0.3 – 0.6% : high weldability
high-C steel : 0.65 – 1.5% : poor weldability
adding C strengthens it

more malleable, ductile

2) cast iron
2-4% carbon

(i) Grey cast iron : fractured surface looks greyish
- flakey structure (graphite flakes)
- weak, brittle
- good damping, resistance to wear
- good for compressive load; used as base for heavy machines

(ii) White cast iron : white (because of cementite)

Malleable cast iron: malleable after heat treatment.

Nodular cast iron : ductile after heat treatment
flakes ⟶ nodules

- Fe-C alloy > 2% C
- lower melting point
- can be casted easily

Non-Ferrous Metals

- Al, Cu, Pb, Ni, Zn, Au, Ag, Sn
- corrosion resistance, conductivity, heat conduction etc
- lower strength (Al): alloys to strengthen

Non-Metals

- polymers: temperature restriction

Plastics

- no corrosion

1) Thermosetting plastics

- cannot be remoulded
- cross-linking

- eg: bakelite, epoxies

2) Thermoplastic

- no cross-linking
- can be remoulded

- eg: PVC, polyethene

Ceramics

- metal oxides
- insulating materials

1. Glasses

Composites

continuous medium → matrix; strength (dispersion phase) → reinforcement

- matrix + reinforcement
- not homogeneous / single-phase
- set of new properties
- NAL: aircraft using composite instead of metals
- not detected by metal detectors
- wood: natural composite

1) Particulate Composite

- cement: stone + cement matrix (sand + water)

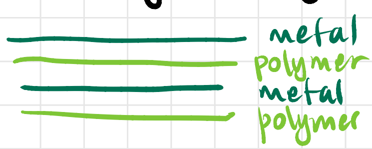
2) Fibre reinforced Composite

- RCC: reinforced cement concrete (steel rods + concrete)
- carbon fibre reinforced composite
- ceramic fibre reinforced

3) Laminar composite

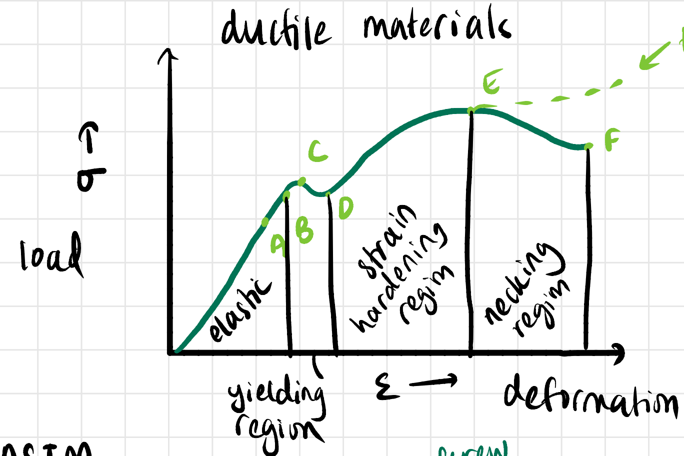
- layer by layer
- furniture

lighter weight



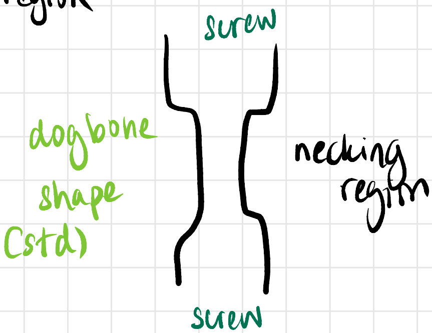
Stress & Strain

book Mechanics of Materials
Beer & Johnston



A: proportional limit
B: elastic limit
C: transition point / yielding point] upper yield point
D: min. load req for maintaining yielding] lower yield point

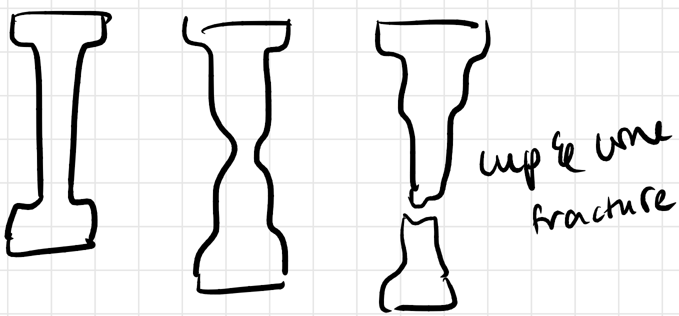
ASTM
↓
American Standard for Testing Materials



circular or flat cross-section

- Test on universal test machine / tensile test machine
  - universal test machine ← any stress
  - tensile test machine ← only tensile

- Standard specimen



Engineering stress

$$\sigma = \frac{F}{A_0} \leftarrow \text{original area}$$

length also initial.

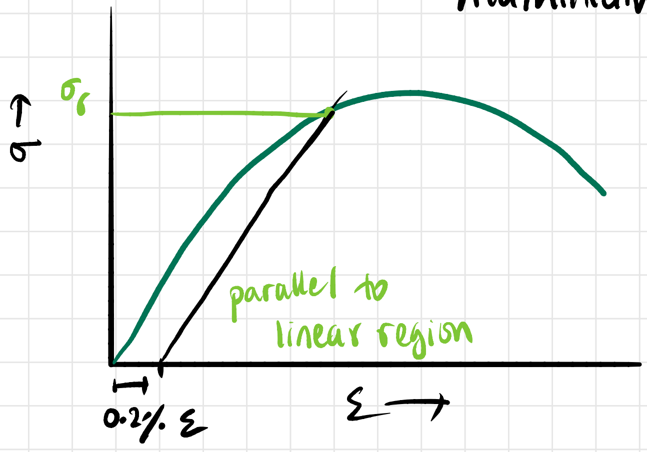
True Stress & strain

$$\sigma = \frac{\text{load}}{\text{instantaneous cross-sectional area}} = \frac{\text{load}}{A_{inst}}$$

$$\varepsilon = \frac{\Delta l}{l} \text{ (instantaneous)}$$

Engineering materials mainly used in elastic region

Aluminium



elastic
↓ yield point
plastic

Method: proof-stress method (0.2% offset materials) ← brittle & some ductile

Design Considerations

1) FOS - factor of safety

$$FOS = \frac{\text{ultimate stress}}{\text{allowable stress}} \quad (\text{always} > 1)$$

ultimate stress ← capacity

allowable stress ← designed to be allowed

Selection of appropriate FOS

(a) Variations that may occur in the properties of the member under consideration

(b) No. of loading cycles during its life

(c) Type of loading that has been applied to the component

(d) Type of failure that may occur

(e) Uncertainty due to method of analysis

(f) Deterioration may occur in the future because of poor maintenance or because of unpreventable natural causes.

(g) The importance of a given member to the integrity of the whole structure.

Standards Used to Design FoS

1. Steels

   American Institute of Steel Construction, specification for structural steel gradings

2. Concretes

   American concrete institute, building code req. for structural concrete

3. Timbre

   American Forest and Paper Association

4. Highway Bridge

   American Association of Highway

Q: 2 gauge marks are placed exactly 250mm apart on a 12mm diameter aluminium rod. Knowing that with an axial load of 6000N acting on the rod, the distance between the gauge marks is 250.18 mm. Determine the modulus of elasticity of aluminium used in the rod.

$\delta L = 0.18\text{ mm}$ $\quad L = 250\text{mm}$

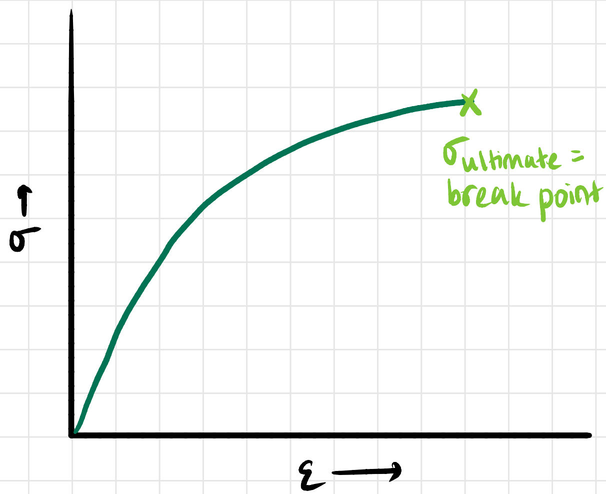
$d = 12\text{mm}$

$P = 6000\text{ N}$

$$E = \frac{4PL}{\pi d^2 \delta L} = \frac{(4)(6000)}{\pi(12\times10^{-3})^2} \times \frac{250}{0.18}$$

$E = 73.68\text{ GPa}$

Brittle Materials



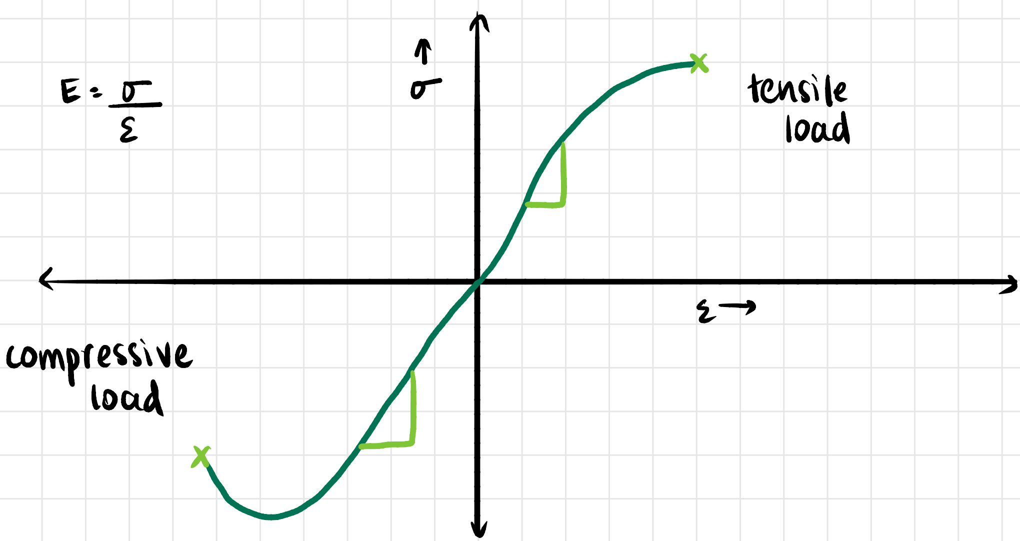
no yielding

- No necking (reduction in cross-section area)
- Reaches ultimate stress and then breaks

Concrete σ–ε curve

- concrete: sand + cement + stone composite
- ceramic material

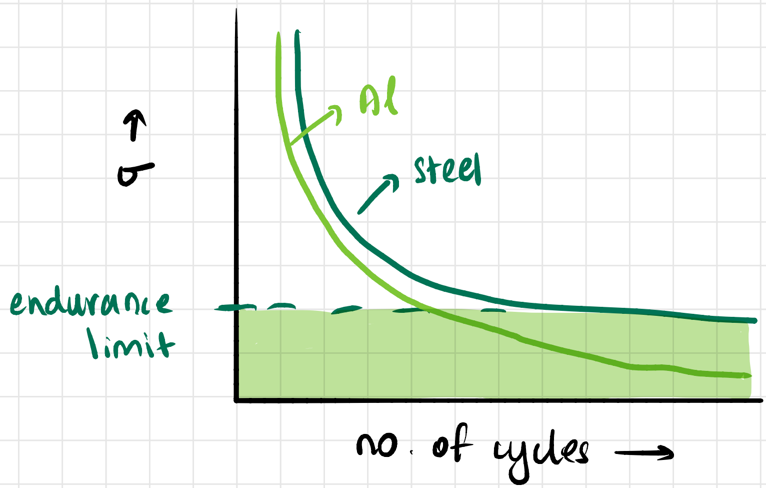
$E = \frac{\sigma}{\varepsilon}$



- Compressive load: welds gaps in brittle materials and takes more load than tensile
- Tensile: breaks
- In brittle materials, on tension side, first linear elastic range is observed and then rupture.
- In compression, linear elastic region is significantly larger and rupture does not occur as stress reaches its max. value.
- Instead, stress decreases in magnitude and strain keeps increasing until fracture
- E is same in T and C.

Fatigue Loading or Repeated Loading

S-n curve



- When loading is within elastic limit, material returns to its initial condition after the load is removed.
- We can say loading can be repeated many times provided the stress remains within elastic limit.
- When loadings are repeated $1000 - 10^6$ times, rupture or failure occure at a stress much lower than the static breaking strength.
- This phenomenon is known as fatigue.
- Fatigue failure is a brittle failure for ductile materials

S-n curve

Graph drawn between maximum stress and no. of cycles required to cause failure

Endurance limit

Stress for which failure does not occur even for an indefinitely large no. of cycles.

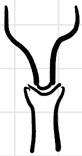
For non-ferrous metals like Al and Cu, stress at failure continues to decrease as the number of loading cycles is decreased.

For such metals, we can define endurance limit as stress corresponding to failure after a specified no. of loading cycles, such as ~500 million cycles

Types of Fracture

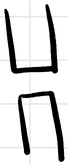
1) Ductile fracture

- necking, cup & cone
- normal loading conditions (low rate) for ductile



2) Brittle fracture

- flat broken surface



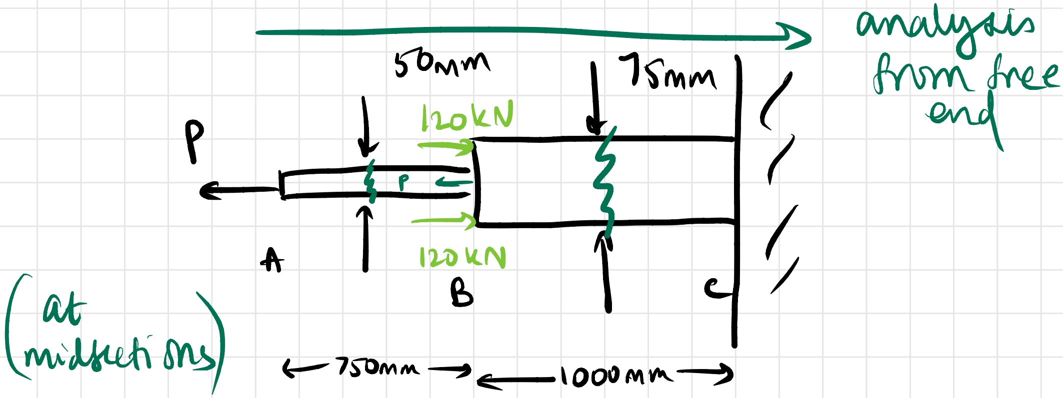
Numericals

Sign convention: +ve : T , -ve : C

$$\sigma = \frac{F}{A}, \quad \varepsilon = \frac{\delta l}{l} \quad \Rightarrow \quad E = \frac{\sigma}{\varepsilon}$$

(Composite bars)

Q: 2 solid cylindrical rods AB and BC are welded together at B and loaded as shown. Determine the magnitude of force P for which tensile stress in rod AB is twice the mag. of comp. stress in BC.



$$A_{AB} = \frac{\pi \times 50^2}{4} = 625\pi = 1963.5$$

$$A_{BC} = \frac{\pi \times 75^2}{4} = \frac{5625}{4}\pi = 1406.25\pi = 4417.9$$

$$\sigma_{AB} = \frac{P}{A_{AB}} = \frac{P}{625\pi}$$

$$\sigma_{BC} = \frac{240-P}{A_{BC}} = \frac{(240-P)4}{5625\pi}$$

$$\sigma_{AB} = 2\sigma_{BC}$$

$$\frac{P}{625\pi} = \frac{2 \times 4(240-P)}{5625\pi}$$

$$5625P = (1920-8P)625$$
$$9P = 1920 - 8P$$
$$17P = 1920$$

$$P = 112.94 \text{ kN}$$

Q: 80m long wire of 5mm diameter is made of steel with $E = 200$ GPa and ultimate tensile stress of 400 MPa. If a factor of safety 3.2 is desired, determine
(a) largest allowable tension (P)
(b) corresponding elongation of the wire (δ)

$$A = \frac{\pi d^2}{4} = \frac{25}{4}\pi \text{ mm}^2 = 19.635 \times 10^{-6} \text{ m}^2$$

$$\epsilon = \frac{\delta}{L} = \frac{\delta}{80}$$

$$E = \frac{\sigma}{\varepsilon} = \frac{PL}{A\delta}$$

$$\delta = \frac{PL}{AE}$$

factor of safety

$$FOS = \frac{\text{ultimate stress}}{\text{allowable stress}} = \frac{\sigma_u}{\sigma_{all}}$$

$$\sigma_u = \frac{P_u}{A}$$

$$3.2 = \frac{400 \times 10^6}{\sigma_{all}}$$

$$\sigma_{all} = 125 \text{ GPa}$$

$$P_{all} = \sigma_{all} \times A$$

$$P_{all} = 2454.37$$

$$P_u = \sigma_u A$$

$$= 7853.98$$

$$\delta_{all} = 50 \text{ mm} \qquad \delta_u = 160 \text{ mm}$$

Q: A control rod made of yellow brass must not stretch more than 3mm when the tension in the wire is 4kN. Knowing that E = 105 GPa and the max. allowable normal stress is 180 MPa determine,

(a) smallest diameter
(b) corresponding max L.

$P = 4\,kN$

$\sigma_{all} = 180\ MPa$

$\delta = 3mm$

$E = 105\ GPa$

$$\sigma_{all} = \frac{P_{all}}{A}$$

$A = 2.22 \times 10^{-5}\ m^2$

$d^2 = \frac{4A}{\pi} = 2.83 \times 10^{-5}\ m$

$d = 5.32 \times 10^{-3}\ m$

$= 5.32\ mm$

$$E = \frac{\sigma_{all}}{\varepsilon_{all}}$$

$\varepsilon_{all} = 1.714 \times 10^{-3}$

$$\frac{\delta}{L} = \varepsilon_{all} \Rightarrow L = \frac{\delta}{\varepsilon_{all}} = \frac{3mm}{1.1714 \times 10^{-3}}$$

$L = 1.75\,m$

Q: An 18 m long steel wire of 5mm diameter is to be used in the manufacture of a pre-stressed concrete beam. It is observed that the wire stretches 45mm when a tensile force P is being applied. Knowing that E = 200 GPa, determine the magnitude of the force P and the corresponding stress in the wire.

$L = 18\text{ m}$ $\quad$ $P = ?$

$d = 5\text{ mm}$ $\quad$ $E = 200\text{ GPa}$

$\delta = 45\text{ mm}$ $\quad$ $\sigma = ?$

$$\sigma = E\varepsilon = 200 \times 10^9 \times \frac{45 \times 10^{-3}}{18}$$

$$\sigma = 5 \times 10^8\text{ Pa} = 500\text{ MPa}$$

$$\sigma = \frac{P}{A} = \frac{4P}{\pi d^2}$$

$$P = \frac{\pi d^2 \sigma}{4} = 9.82\text{ kN}$$

Q: A polystyrene rod of L = 300mm and d = 12mm is subjected to a 3kN tensile load. Knowing that E = 3.1 GPa, determine

(a) elongation of rod

(b) normal stress in the rod

$P = 3\text{ kN}$ $\quad$ $L = 0.3\text{ m}$ $\quad$ $d = 12\text{ mm}$ $\quad$ $E = 3.1\text{ GPa}$

$$E = \frac{\sigma}{\varepsilon} = \frac{PL}{A\delta} \Rightarrow \delta = \frac{PL \times 4}{E \pi d^2}$$

$$\delta = 2.57\text{ mm}$$

$$\sigma = \frac{P}{A} = 26.53\text{ MPa}$$

Q: A nylon thread is subjected to 8.5 N tension force. Knowing that $E = 3.3$ GPa and that the length of the thread increases by 1.1%, determine
(a) diameter
(b) stress

$P = 8.5$ N
$E = 3.3$ GPa
$\frac{\delta}{L} = 1.1$

$$E = \frac{PL}{A\delta} \Rightarrow A = \frac{PL}{E\delta} = 2.342 \times 10^{-7}$$

$$\frac{\pi d^2}{4} = 2.34 \times 10^{-9}$$

$$d = 5.46 \times 10^{-5} \text{ m}$$
$$= 54.6 \, \mu m$$

Q: A 60m long steel wire is subjected to 6kN tensile loads. $E = 200$ GPa and length of rod increases by 48 mm, determine (a) smallest diameter that may be selected for the wire and (b) corresponding normal stress.

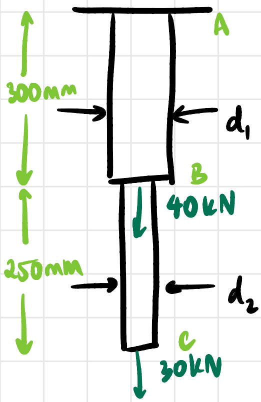
$L = 60$m $P = 6$kN (T) $E = 200$ GPa $\delta L = 48$ mm $d = ?$ $\sigma = ?$

$$E = \frac{PL}{A\delta L} \Rightarrow A = \frac{PL}{E\delta L} = 3.75 \times 10^{-5} \text{ m}$$

(a) $\frac{\pi d^2}{4} = A \Rightarrow d = \sqrt{\frac{4A}{\pi}} = 6.91$ mm

(b) $\sigma = \frac{P}{A} = \frac{6000}{3.75 \times 10^{-5}} = 160$ MPa

Q: Two solid cylindrical rods AB and BC are welded together at B. Knowing that max average normal stress is 175 MPa in rod AB and 150 MPa in rod BC, determine smallest allowable values of d_1 and d_2.



Rod BC

$$\sigma_{BC} = \frac{30 \times 10^3 \times 4}{\pi d_2^2}$$

$$150 \times 10^6 = \frac{3 \times 10^4 \times 4}{\pi d_2^2}$$

$$d_2^2 = \frac{3 \times 10^4 \times 4}{\pi \times 150 \times 10^6} \Rightarrow d_2 = 15.95 \text{ mm}$$

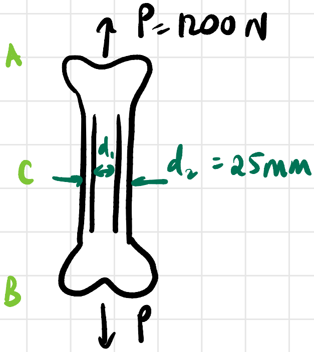
Rod AB

$$\sigma_{AB} = \frac{70 \times 10^3 \times 4}{\pi \times d_1^2} = 175 \times 10^6$$

$$d_1^2 = \frac{7 \times 10^4 \times 4}{\pi \times 175 \times 10^6}$$

$$d_1 = 22.57 \text{ mm}$$

Q: $\sigma_{avg} = 3.80\,MPa$, $P = 1200N$, $d_2 = 25mm$, $d_1 = ?$ (at c)



$$\sigma = \frac{4P}{\pi(d_2^2 - d_1^2)}$$

$$3.8 \times 10^6 = \frac{4 \times 1200}{\quad}$$

Statically Indeterminant Problems

When available static equilibrium equations are not sufficient to find reaction force or internal forces acting are called as statically indeterminant problems.