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Group 17
Lecture 21

Deformation of materials

Why we study deformation of materials:

We need to design material that will withstand applied load and in-service uses such as space exploration, space elevator, skyscraper, etc.

I. MEASURES OF MECHANICAL PROPERTIES OF MATERIALS

Engineering stress (σ): pressure due to applied load.

σ= force/ A_0 , where A_o is the cross-sectional area N/m^2 (Pa)

Stress is more directly adapted/connected/related to material properties than force

Strain(ε): Response of the material to stress

$\varepsilon = \Delta l/l_o$

Δl is change in length (new length – previous length)

l_o is the previous length

II. TYPES OF DEFORMATION

4 types:

1.Tension
2. Compression
3.Shear
4. Hydrostatic Compression

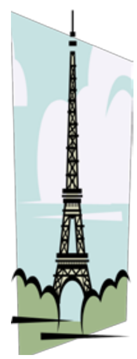
A. Tension/Compression

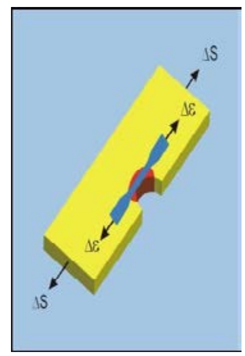
They are almost identical

In tension a material is "pulled"

$\sigma > 0$
$\varepsilon > 0$

(e.g.) cable in ski lift

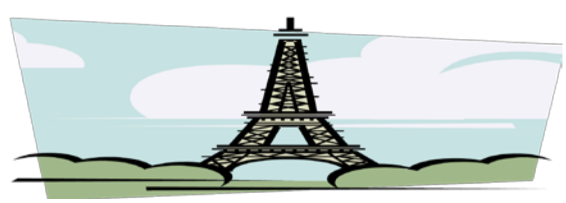




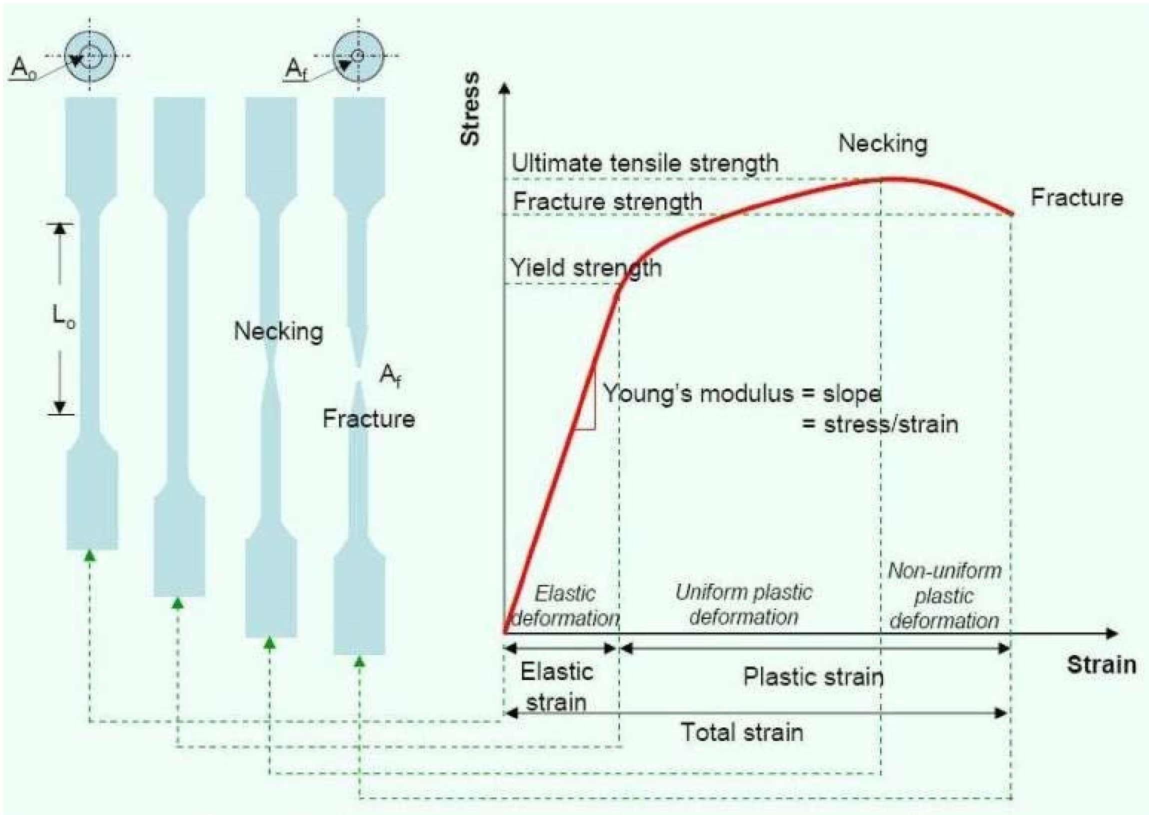
In compression a material is "pushed" (e.g.) Bridge

$\sigma < 0$
$\varepsilon < 0$

By convention, stress and strain are negative for compression



STRESS-STRAIN TENSILE TEST
Response of Metals under tension



Shape of Ductile Specimen at Various Stages of Testing

Elastic Deformation: Linear deformation when the material in under small load. Elastic means reversible. The stress is proportional to strain.

– Atomic bonds "stretch," but do not break.

Plastic deformation: It refers to the nonlinear deformation when the material is under large loading. <u>Plastic changes are permanent</u>.

– Some bonds will break
– Superposition of elastic change and plastic change

Ultimate tensile strength(UTS): The maximum stress a material can withstand before experience non-uniform deformation (necking).

Yielding strength(σ_y): Maximum stress before the onset of plastic deformation (Bounds of Elasticity)

-Method for determining Yielding Strength:

1. Start at 0.002 strain
2. Draw a line || to linear region
3. Point of intersection with the curve is the Yielding Strength

-High UTS means more resistance to failure.

-High Yielding strength means resistant to permanent deformation.
-It is important to note that for brittle materials (ceramic, glass, etc), UTS is not a material property since each time we do the test, it gives a different value since those materials are not homogenous.

Stress-strain tensile test in ceramics is a measure of the largest flaw in the material.
– a large flaw will have a lower UTS
– a small flaw will have a higher UTS

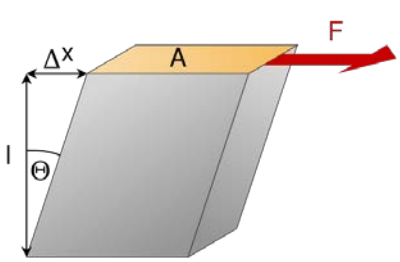
Elastic modulus (Young's modulus):
Material's resistance to elastic deformation.

Hooke's law: σ=Es, where σ is stress, E the elastic modulus and s is strain.

For metals typically: E = 45-400 GPs
For rubber: E = 0.01-0.1GPs

B. SHEAR

-When the deformation is due to forces parallel to the faces of the solids.

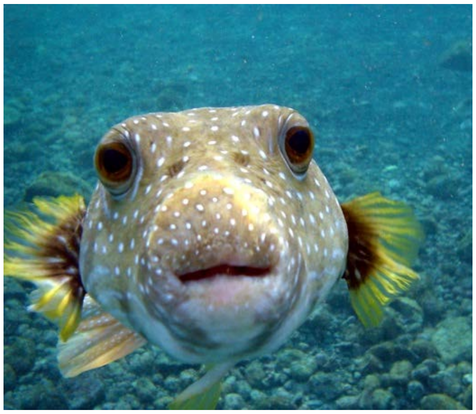


τ=F/ A_o , where τ is the shear stress.

Shear strain: γ=tan θ

Shear Modulus
– Like Young's Modulus, but for shear
– τ = G γ where G is the Shear Modulus

C. HYDROSTATIC COMPRESSION



- compression is applied equally on each face.
-

σ_h=F/A_o , where σ_h is the hydrostatic compression stress

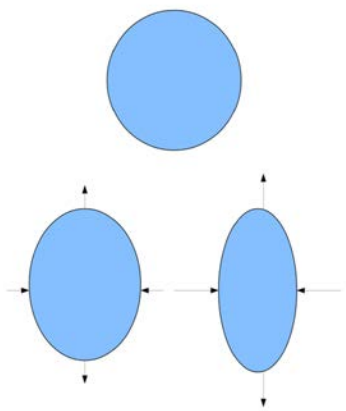
Remember that compression has negative stress and strain by convention

(E.G). A fish in water

Bulk Modulus
– Like Young's Modulus, but for Hydrostatic compression
– Since deformations are 3 dimensional they involved volume and not just length
– P = -K (ΔV/Vo) where K is the bulk modulus

IV. POISSON RATIO (υ)

When a material is deformed in one direction, it tends to also deform in the other directions. The poisson ratio describes the relationship between a deformation in one dimension and the resulting deformations in the other two dimensions in isotropic materials (anisotropic are different due to non-uniformity).



$\varepsilon_z = \Delta l/l_o$

$\varepsilon_y = \varepsilon_x = \Delta d/d_o$

$\upsilon = -\varepsilon_x / \varepsilon_z = -\varepsilon_y / \varepsilon_z$

"l" is vertical deformation.
"d" is horizontal deformation

Typical values for the Poisson ration:

Polymers ~ 0.40
Metals ~ 0.33
Ceramics ~ 0.25

→ A high poisson ration means that the material will deform more in all directions if subjected to stress in one direction.

The moduli used for different stresses can be expressed in terms of the Poisson ratio.

$$G = \frac{E}{2(1+\nu)} \qquad K = \frac{E}{3(1-2\nu)}$$

The Poisson ratio can range between -1 and 0.5.

– In a material with a negative Poisson ratio, the material's girth would increase when stretched.

– Rubber has a Poisson ratio of close to 0.5

V. TRUE STRESS AND ENGINEERING STRESS

Issues with engineering stress:

– Change in cross sectional area are always compared to initial area. This causes problems when there are large deformations in area.

– After necking, the cross-sectional area decreases → stress decreases only because the initial cross-sectional area is used to measure stress.

True Strain:

– True strain is the sum of all instantaneous strains

$$d\epsilon = \frac{dl}{l}$$

$$\epsilon_T = \int d\epsilon = \int_{l_0}^{l_f} \frac{dl}{l} = \ln \frac{l_f}{l_0}$$

True Stress:

– Uses instantaneous cross-sectional area as reference for stress rather than the initial cross-sectional area.

$$\sigma_T = \frac{F}{A_i}$$

– True stress is related to engineering stress by:

$$\sigma_T = \sigma(1+\varepsilon)$$

True stress and true strain are essentially equal to engineering stress and engineering strain for elastic deformations and differ for plastic deformations.