Materials

Ferrous metals: carbon-, alloy-, stainless-, tool-and-die steels

Non-ferrous metals: aluminum, magnesium, copper, nickel, titanium, superalloys, refractory metals, beryllium, zirconium, low-melting alloys, gold, silver, platinum, …

Plastics: thermoplastics (acrylic, nylon, polyethylene, ABS,…)
thermosets (epoxies, Polymides, Phenolics, …)
elastomers (rubbers, silicones, polyurethanes, …)

Ceramics, Glasses, Graphite, Diamond, Cubic Boron Nitride

Composites: reinforced plastics, metal-, ceramic matrix composites

Nanomaterials, shape-memory alloys, superconductors, …

Properties of materials

Mechanical properties of materials

Strength, Toughness, Hardness, Ductility, Elasticity, Fatigue and Creep

Physical properties

Density, Specific heat, Melting and boiling point, Thermal expansion and conductivity, Electrical and magnetic properties

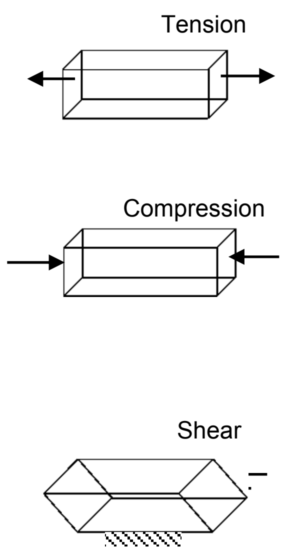
Chemical properties

Oxidation, Corrosion, Flammability, Toxicity, …

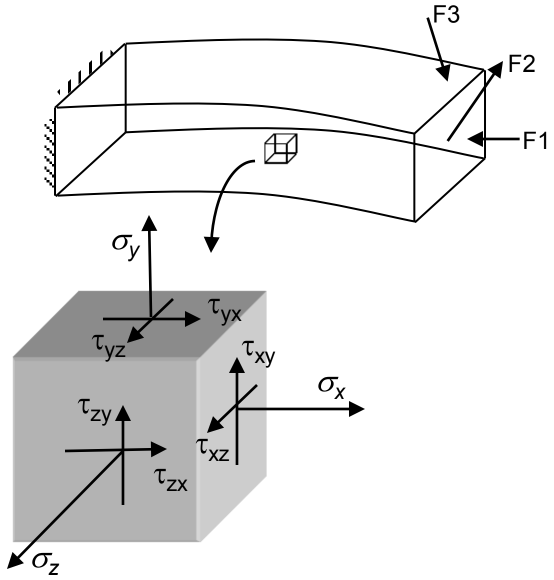
Mechanical properties: Stress analysis

stress = σ = Force/Area

Why do we need stress/strain (not just force, elongation) ?

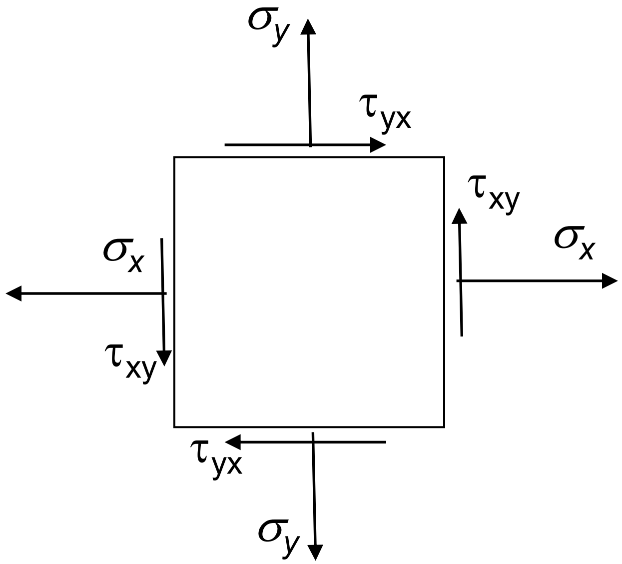


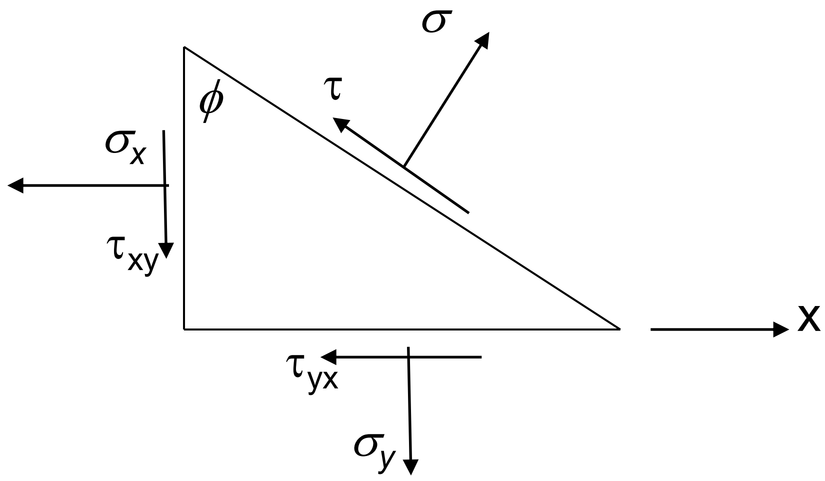
Tensile, compressive and shear stresses



Stresses in an infinitesimal element of a beam

Stress Analysis: Principal directions in 2D case





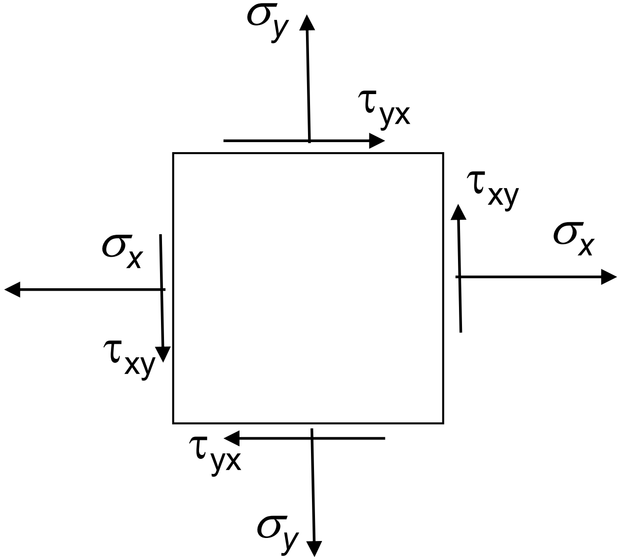
$$\sigma = \frac{\sigma_x + \sigma_y}{2} + \frac{\sigma_x - \sigma_y}{2}\cos 2\phi + \tau_{xy}\sin 2\phi$$

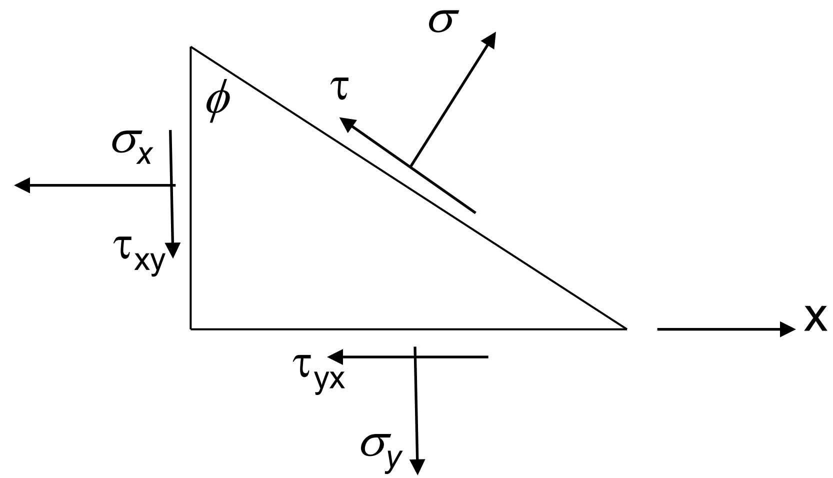
$$\frac{d\sigma}{d\phi} = 0 \quad => \quad \tan 2\phi = \frac{2\tau_{xy}}{\sigma_x - \sigma_y}$$

- principal directions are orthogonal to each other

- 0 shear stress along PDs

Stress Analysis: Principal shear stress in 2D case

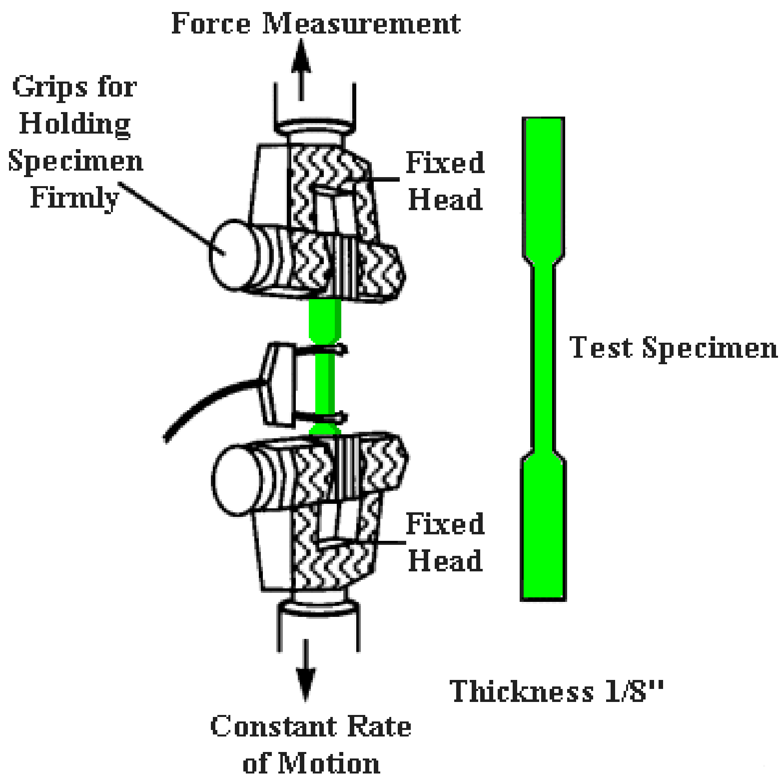




$$\tau = \frac{\sigma_y - \sigma_x}{2}\sin 2\phi + \tau_{xy}\cos 2\phi$$

$$\frac{d\tau}{d\phi} = 0 \quad => \quad \tan 2\phi = \frac{\sigma_x - \sigma_y}{2\tau_{xy}}$$

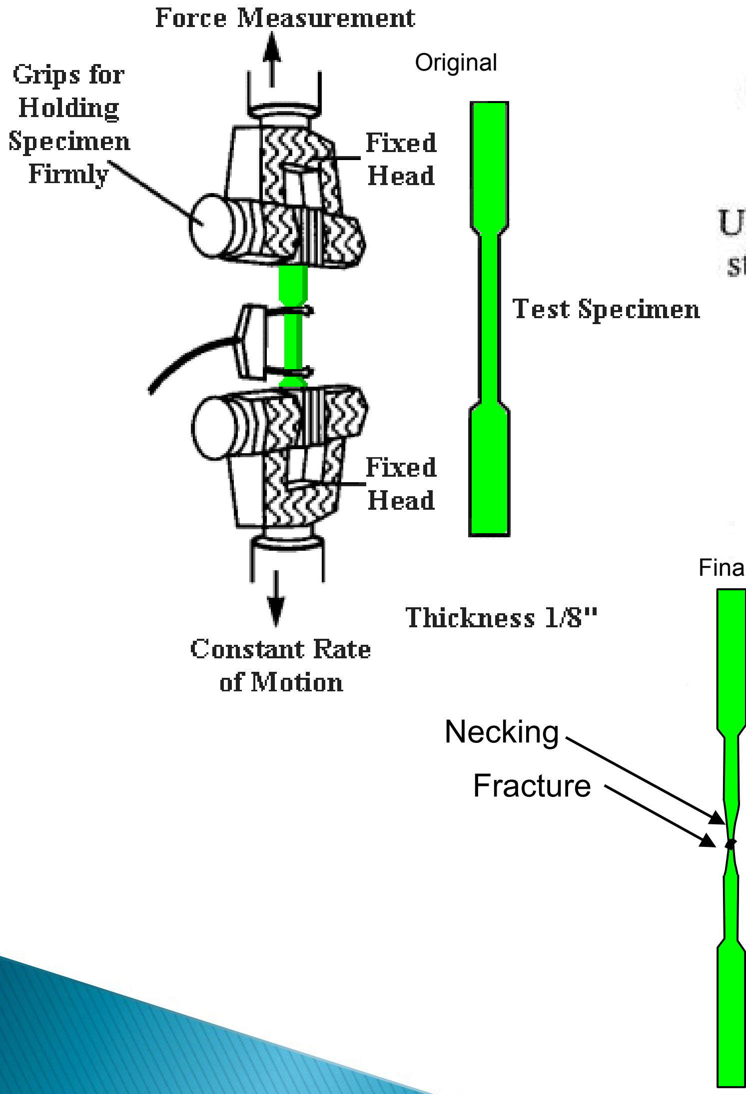
Failure in Tension, Young's modulus and Tensile strength

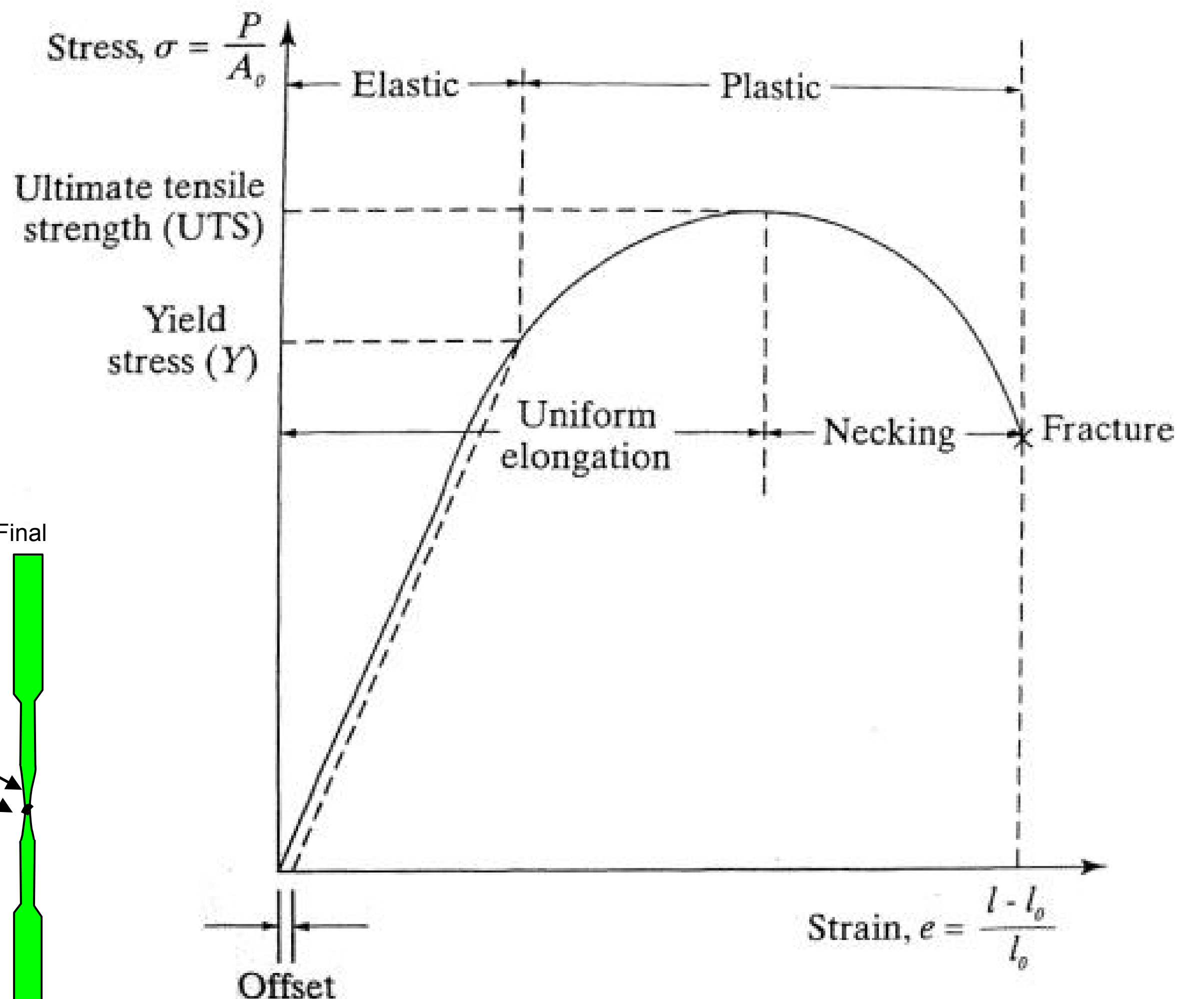


Engineering stress = $\sigma = P/A_o$

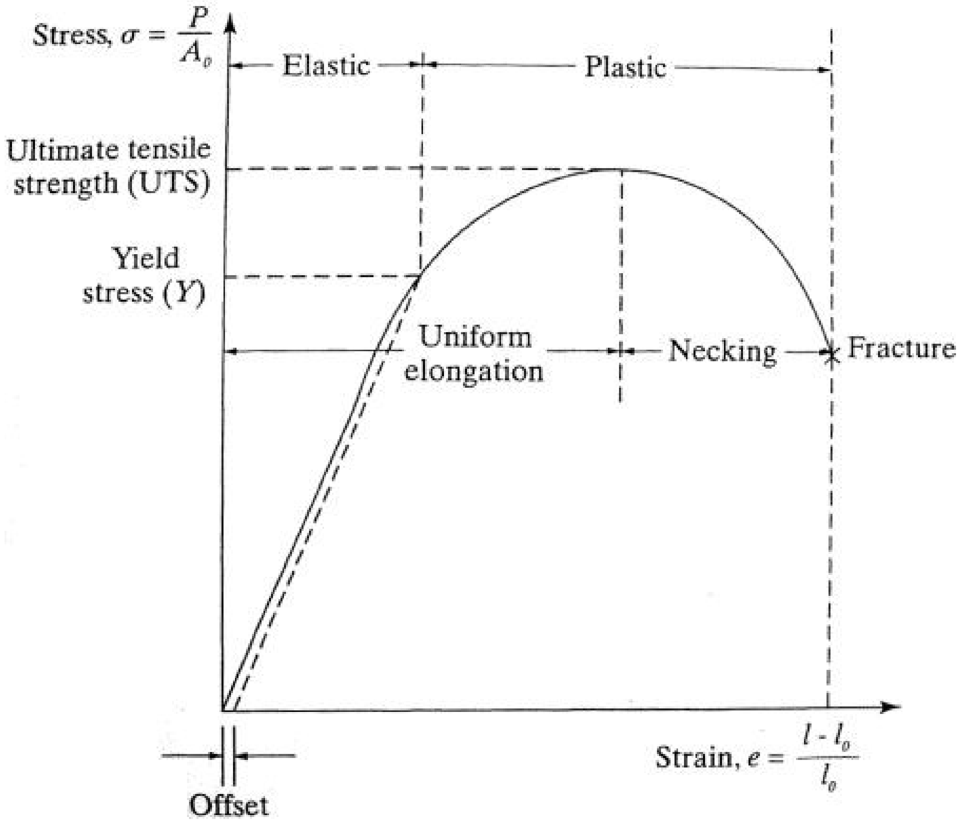
Engineering strain = $e = (L - L_o)/L_o = \delta/L_o$

Failure in Tension, Young's modulus and Tensile strength..





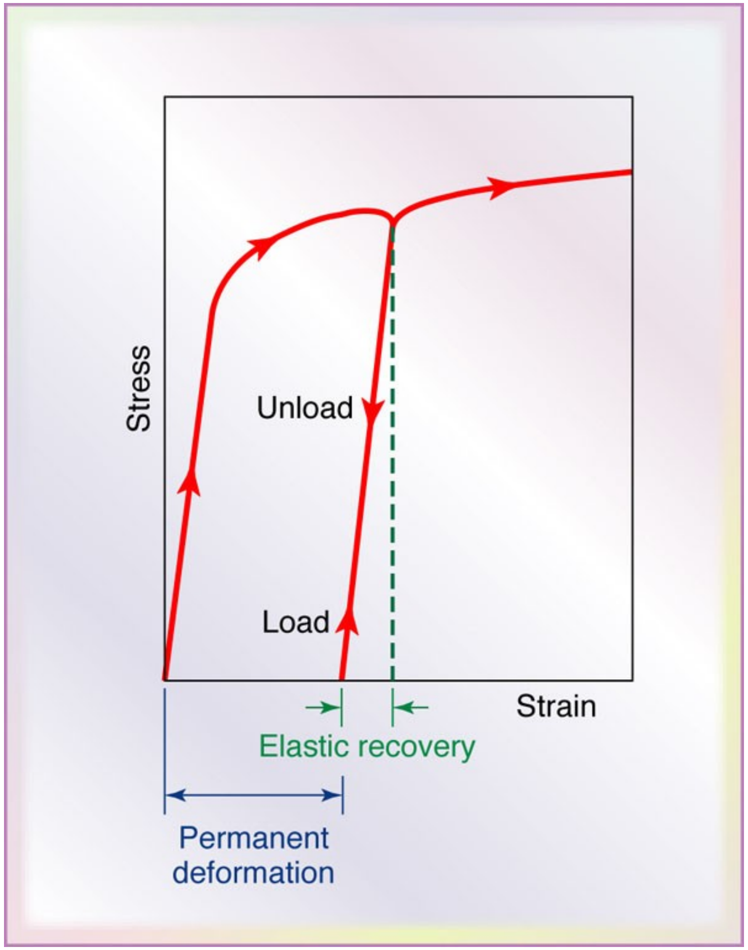
Failure in Tension, Young's modulus and Tensile strength…



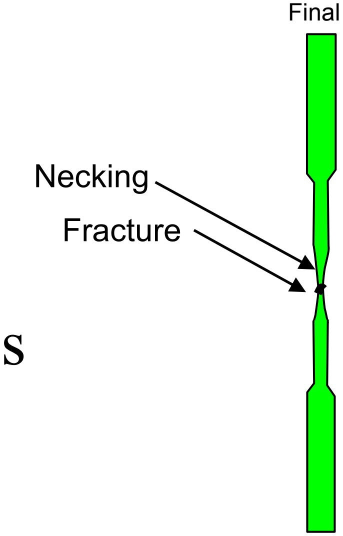
In the linear elastic range: *Hooke's law*: $\sigma = E\,e$ or, $E = \sigma/e$

E: ***Young's modulus***

Elastic recovery after plastic deformation



True Stress, True Strain, and Toughness

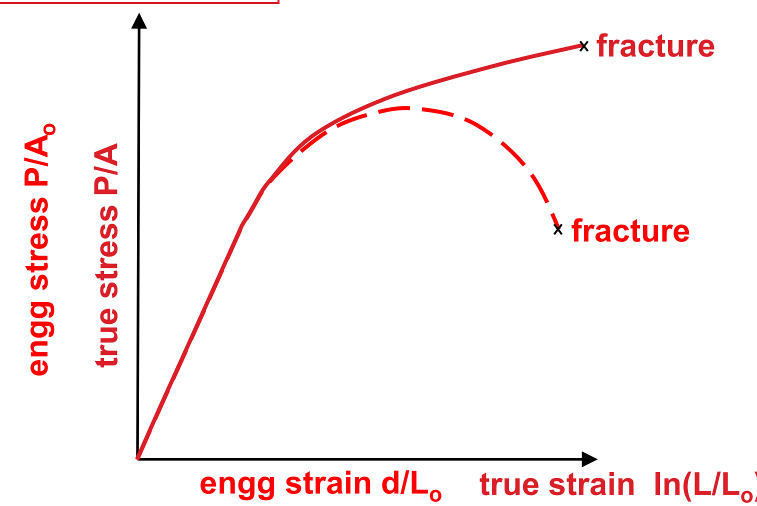


Engg stress and strain are “gross” measures:

$\sigma = F/A \Rightarrow \sigma$ is the average stress $\neq$ local stress

$e = \delta/L_o \Rightarrow e$ is average strain

Toughness = energy used to fracture
= area under true stress-strain curve



Ductility

Measures how much the material can be stretched before fracture

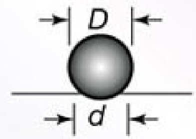
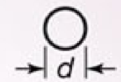
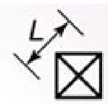
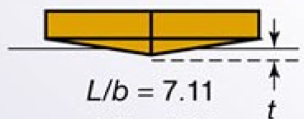
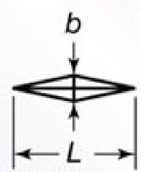
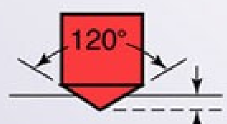
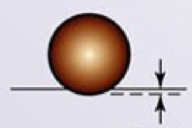
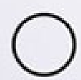
$$\text{Ductility} = 100 \times (L_f - L_o)/L_o$$

High ductility: platinum, steel, copper
Good ductility: aluminum
Low ductility (brittle): chalk, glass, graphite

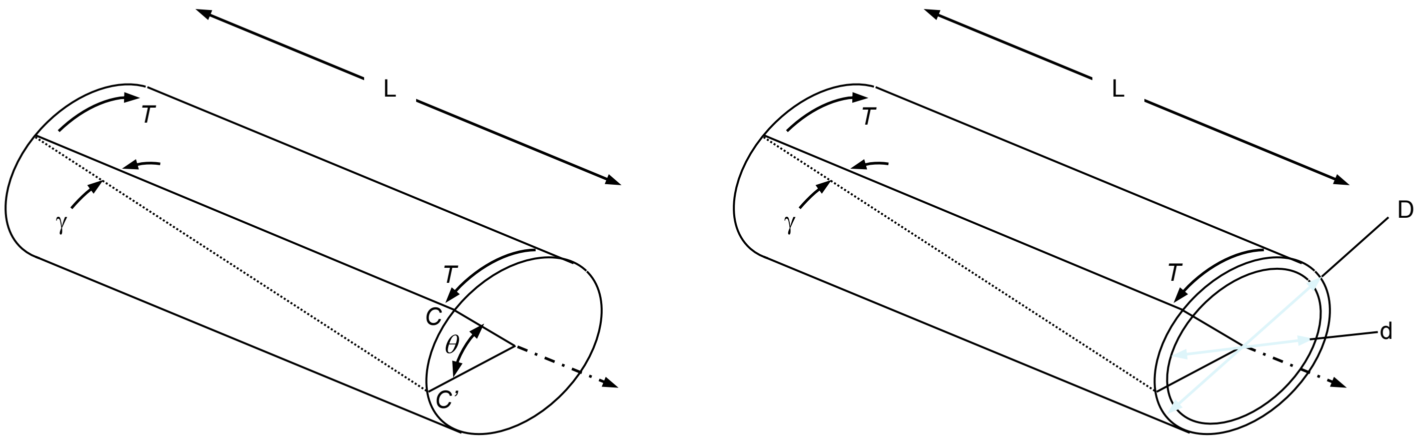
- Walkman headphone wires: Al or Cu?

Hardness

resistance to plastic deformation by indentation

Test	Indenter	Shape of indentation: Side view	Shape of indentation: Top view	Load, P	Hardness number
Brinell	10-mm steel or tungsten carbide ball			500 kg 1500 kg 3000 kg	$HB = \frac{2P}{(\pi D)(D - \sqrt{D^2 - d^2})}$
Vickers	Diamond pyramid			1–120 kg	$HV = \frac{1.854P}{L^2}$
Knoop	Diamond pyramid	 $L/b = 7.11$ $b/t = 4.00$		25 g–5 kg	$HK = \frac{14.2P}{L^2}$
Rockwell A C D	Diamond cone	 t = mm		60 kg 150 kg 100 kg	HRA HRC HRD } $= 100 - 500t$
B F G	$\frac{1}{16}$ - in. diameter steel ball	 t = mm		100 kg 60 kg 150 kg	HRB HRF HRG } $= 130 - 500t$
E	$\frac{1}{8}$ - in. diameter steel ball			100 kg	HRE

Shear stress and Strain: the torsion test



Angle of twist: $\theta = TL/GJ$
Shear stress: $\tau = Tr/J$
Maximum shear stress = $\tau_{max} = TR/J$
Shear strain = $\gamma = r\theta/L$

T = torque,
J = polar moment of inertia
$J = \int r^2 \, dA$
Cylindrical shell: $J = \pi(D^4 - d^4)/32$

$$\tau = G\,\gamma$$

G: Modulus of rigidity

Shear strength and Tensile strength

[approximate relation between shear and tensile strengths]

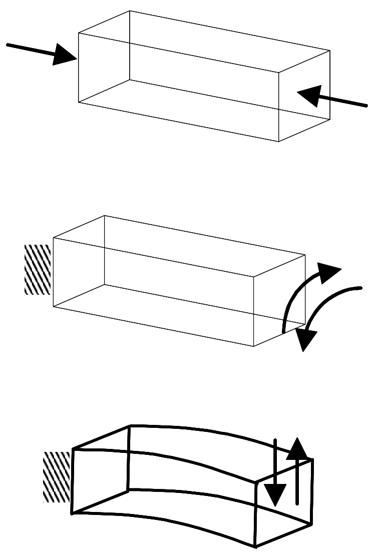
Ultimate Tensile Strength = S_u Ultimate Shear Strength = S_{su}
Tensile Yield Strength = S_{yp} Shear yield point = S_{syp}

Material	Tensile-Relation	Yield-Relation
Wrought Steel & alloy steel	$S_{su} \approx 0.75 \times S_u$	S_{syp} = Approx 0,58 x S_{yp}
Ductile Iron	$S_{su} \approx 0.90 \times S_u$	S_{syp} = Approx 0,75 x S_{yp}
Cast Iron	$S_{su} \approx 1.3 \times S_u$	-
Copper & alloys	$S_{su} \approx [0.6\text{-}0.9] \times S_u$	-
Aluminum & alloys	$S_{su} \approx 0.65 \times S_u$	S_{syp} = Approx 0,55 x S_{yp}

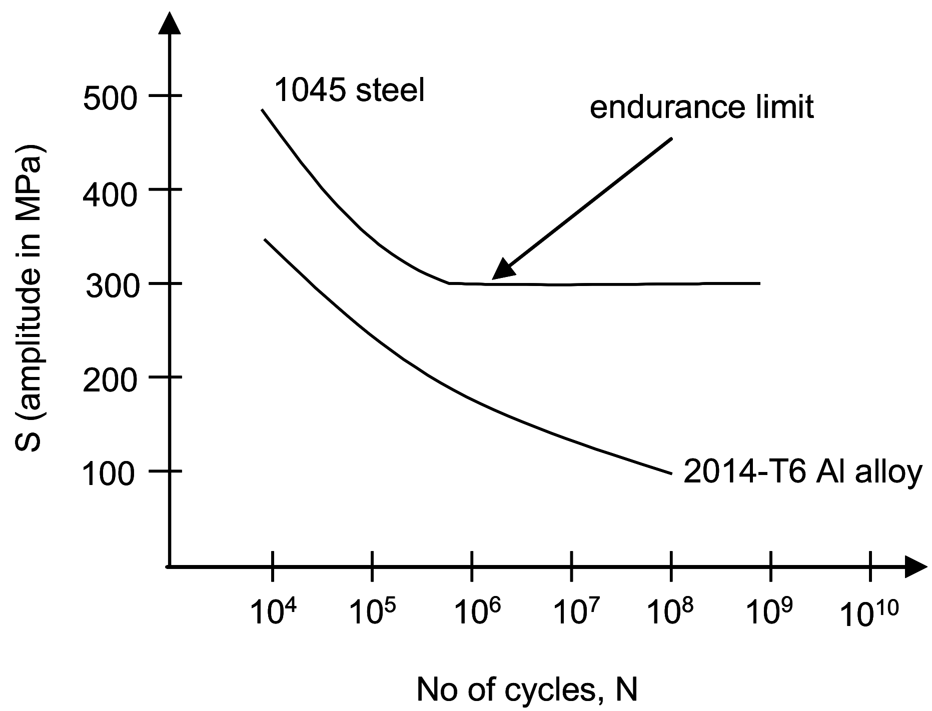
References: Machine design Theory and Practice .A.D.Deutschman, W.A Michels & C.E. Wilson.. MacMillan Publishing 1975.

Fatigue

Fracture/failure of a material subjected ***cyclic stresses***



Modes of fatigue testing

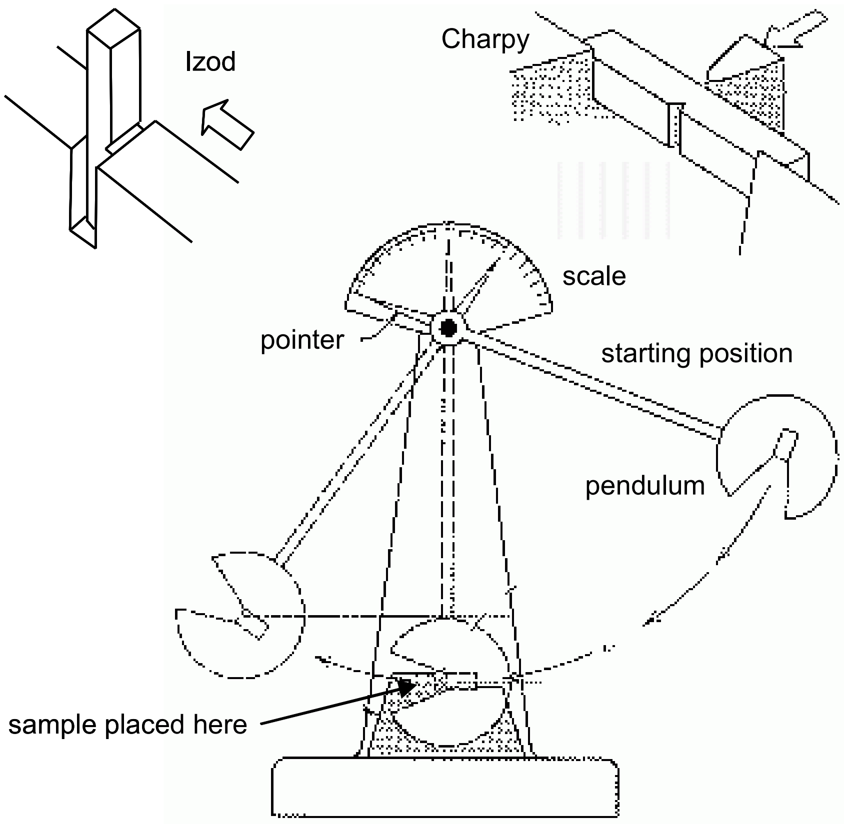


S-N curve for compressive loading

Failure under impact

Application: Drop forging

Testing for Impact Strength



Strain Hardening

- Metals microstructure: crystal-grains
- Under plastic strain, grains slipping along boundaries
- Locking up of grains => increase in strength
- We can see this in the true-stress-strain curve also

Applications:

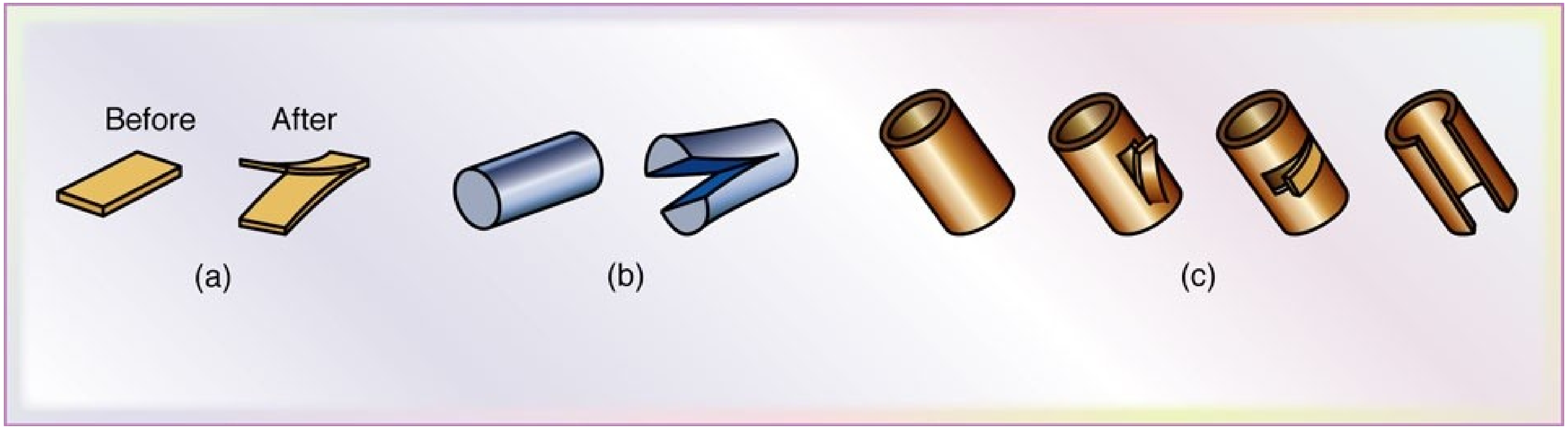
- Cold rolling, forging: part is stronger than casting

Residual stresses

Internal stresses remaining in material after it is processed

Causes:
- Forging, drawing, …: removal of external forces
- Casting: varying rate of solidification, thermal contraction

Problem: warping when machined, creep



Releasing residual stresses: annealing

Physical Properties

Property	Application (e.g.)
Density, ρ = mass/volume	Drop forging, hammering
Specific heat	Coolant in machining
Thermal conductivity	Cutting titanium
Coeff of linear thermal expansion, $\alpha = \Delta L/(L\,\Delta T)$	Compensation in Casting, …
Melting point	Brazing, Casting, …
Electrical conductivity	EDM, ECM, Plating
Magnetic properties	Magnetic chucking

Summary

Materials have different physical, chemical, electrical properties

Knowledge of materials' properties is required to

- Select appropriate material for design requirement
- Select appropriate manufacturing process
- Optimize processing conditions for economic manufacturing
- …