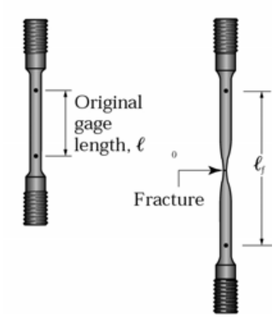
Review of Mechanical Properties of Materials

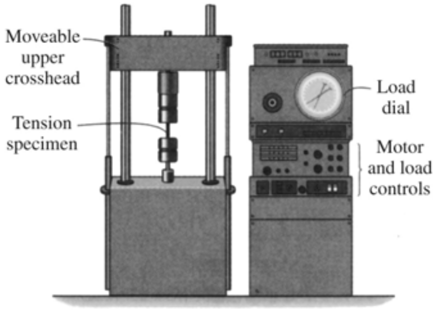
Outline

- Tensile test
- True stress - true strain (flow curve)
- mechanical properties:
  - - *Resilience*
  - - *Ductility*
  - - *Toughness*
  - - *Hardness*

Tensile-Test Specimen and Machine



A standard tensile-test specimen before and after pulling, showing original and final gage lengths

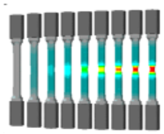


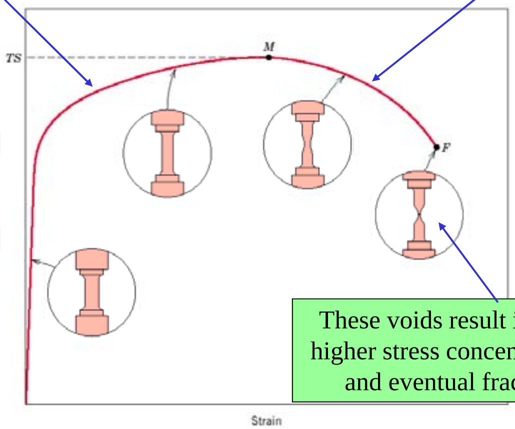
A typical tensile-testing machine

Mechanical Behaviour

As plastic deformation proceeds, the force increases due to ……………….

As more of the stress becomes concentrated in the neck, formation of ……… occur





These voids result in even higher stress concentrations and eventual fracture

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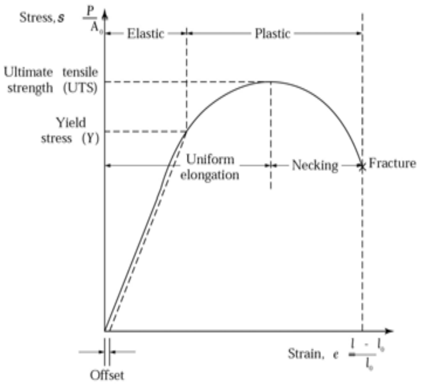
Stress-Strain Curve



A typical stress- strain curve obtained from a tension test, showing various features.

- Engineering stress
  $\sigma = P/A_o$
- Engineering strain
  $e = (l - l_o) / l_o$
- Measures of ductility
  % elongation
  $(l_f - l_o) / l_o \times 100$

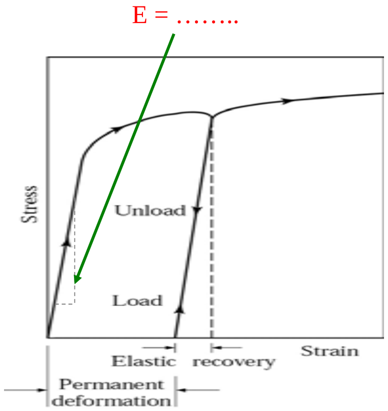
  % Reduction area
  $(A_f - A_o) / A_o \times 100$

Loading and Unloading of Tensile-Test Specimen

Elastic behaviour: stretching of bonds between atoms (like springs)

- Stronger bonds = less stretch, so stiffer material and ……..….. E
- E is temperature dependent –
  - *- Atoms vibrate more as T rises so bonds are less strong thus E↓*

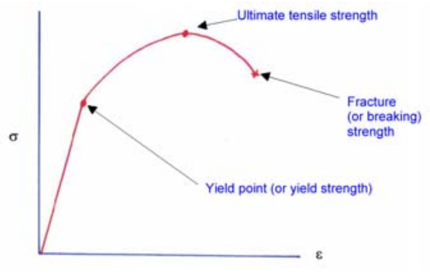
Note that, during unloading, the curve follows a path parallel to the original elastic slope.



Schematic illustration of the loading and the unloading of a tensile- test specimen.

Plastic deformation

What happens if we continue to apply tensile loading beyond the yield point? (*i.e., stretching atomic bonds to the point of breaking*)



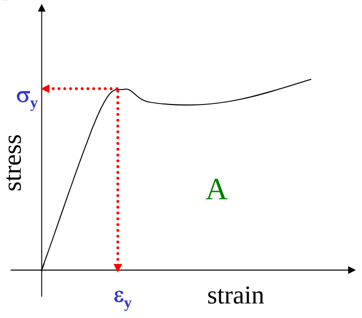
Plastic deformation:

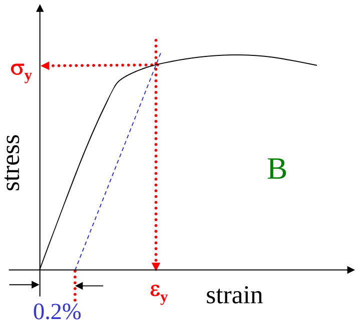
- stress and strain are not proportional
- the deformation is not reversible
- deformation occurs by breaking and re-arrangement of atomic bonds (*in crystalline materials primarily by motion of dislocations, next lecture*)

- *For structural applications, the yield stress is usually a more important property than the tensile strength, since once it is passed, the structure has deformed beyond acceptable limits.*

Yield Strength

- The yield point corresponds to the point where the material begins to have permanent deformation.



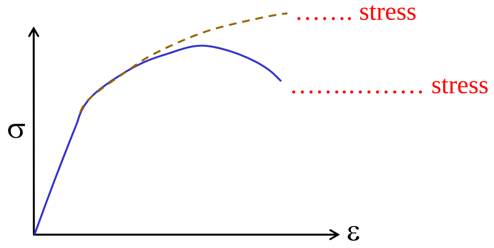


- Some materials have a well-defined yield region (A), others (B) do not.
- In the absence of a distinct yield point, a 0.2% offset is used to obtain an approximate yield point.
- *Although the **yield** and the **proportional** limit points **are close** to each other, they **do not correspond** to the same location on the stress-strain curve.*

Engineering Stress vs. True Stress

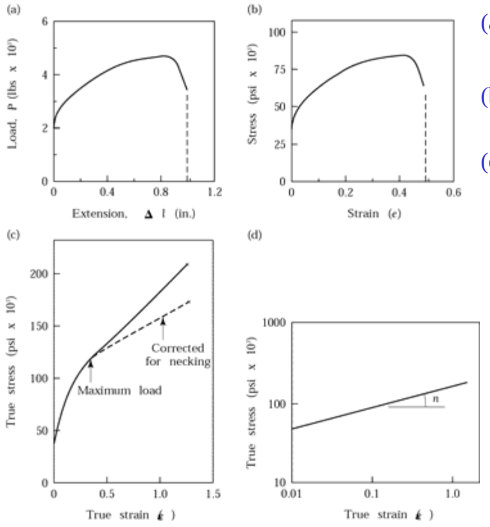
Since the actual cross-sectional area is reduced, use of the initial area gives a lower value than the actual one (the ratio is A_o/A_c).

- True stress, $\sigma = P/A_c$
  - – P: load
  - – A_c: current area
- True strain, $\varepsilon = \ln(l_c/l_o)$
  - - l_c: current length
  - - l_o: original length



- Even though the true stress-strain curve gives a more accurate picture of the breaking strength of a material, it is difficult to obtain measurements of *the actual area in real-time*.
- Usually, the reported values are the engineering stress.
- True fracture strength > tensile strength
  - ✓ *but the engineering σ - ε diagram does not show this*

Construction of True Stress-True Strain Curve



(a) Load-elongation curve in tension testing of a stainless steel specimen.

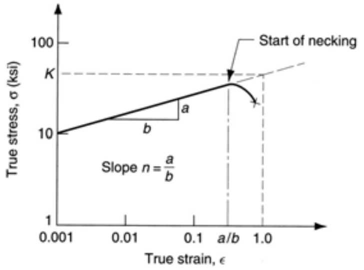
(b) Engineering stress-engineering strain curve, drawn from the data in Fig. a.

(c) True stress-true strain curve, drawn from the data in Fig. b.

Note that this curve has a positive slope, indicating that the material is becoming stronger as it is strained.

(d) True stress-true strain curve plotted on log-log paper and based on the corrected curve in Fig. c. The correction is due to the triaxial state of stress that exists in the necked region of a specimen.

True Stress-True Strain Curve



True stress-strain curve plotted on log-log scale

Material	n	K MPa	K psi
Low-carbon steel (annealed)	0.26	530	77,000
Alloy steel (Type 4340, annealed)	0.15	640	93,000
Stainless steel (Type 304, annealed)	0.45	1275	185,000
Aluminum (annealed)	0.20	180	26,000
Aluminum alloy (Type 2024, heat treated)	0.16	690	100,000
Copper (annealed)	0.54	315	46,000
Brass (70Cu–30Zn, annealed)	0.49	895	130,000

$\sigma = K\varepsilon^n$

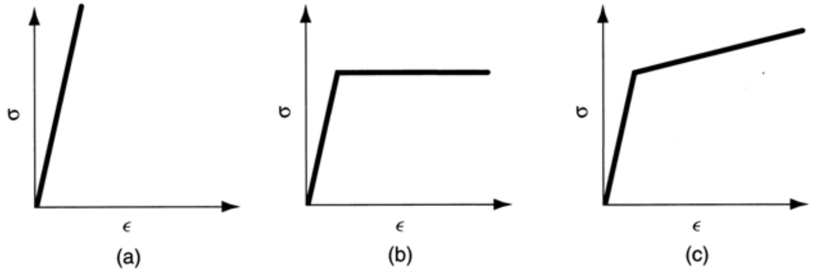
Because it is a straight line in a log-log plot

K: strength coefficient

n: strain-hardening exponent

- The ……… the slope the stronger when material is strained

Categories of Stress-Strain Relationship



Perfectly elastic

- Mech. behavior ↔ *E*
- No plastic flow
- Brittle materials:
- ceramics, many cast irons, and thermosetting polymers

Elastic and perfectly plastic

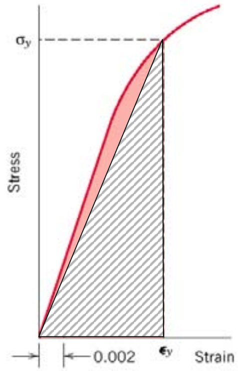
- *Stiffness defined by E*
- *Once Y reached, deforms plastically at same stress level*
- *Flow curve: K = Y, n = 0*
- *Metals behave like this when heated to sufficiently high temp. (above recrystallization)*

Elastic and strain hardening

- *Hooke's Law in elastic region, yields at Y*
- *Flow curve: K > Y, n > 0*
- *Most ductile metals behave this way when cold worked*

Resilience

Ability of material to absorb energy during **elastic** deformation and then to **give it back** when unloaded.



- Measured with **Modulus of Resilience, U_r**
- **U_r,** is area under **σ - ε** curve up to yielding:

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

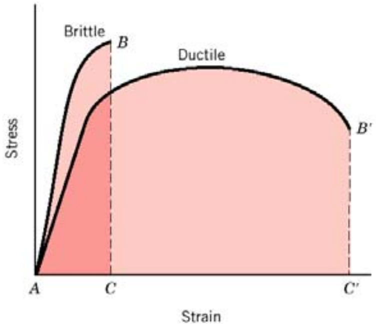
- Assuming a **linear elastic** region:

$$U_r = \frac{1}{2}\sigma_y\varepsilon_y = \frac{1}{2}\sigma_y\left(\frac{\sigma_y}{E}\right) = \frac{\sigma_y^2}{2E}$$

- Units are J/m^3

TOUGHNESS

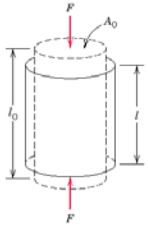
Toughness is the material's ability to absorb energy before **fracture**

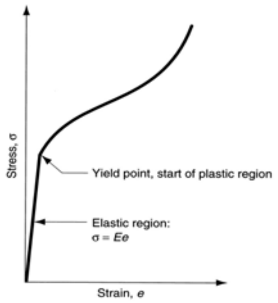


- Toughness is the **area under σ - ε curve up to fracture**.
  - *- Similar to Resilience (same units J/m*^{3}*).*
  - *- Larger area ⇒* ***tougher*** *material*.
- So tough materials have a **combination of ………... and …………**
- Can be measured by an impact test *(MECH 321-lab)*.

Compression Test

- by convention, stress and strain are negative
- used for measuring strength of *brittle materials* and for calculating *forces required in manufacturing processing* which involve compressive deformation



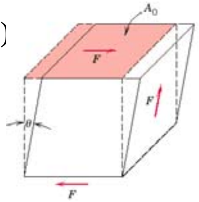


Typical engineering stress-strain curve for a compression test

- Shape of plastic region is different from tensile test because cross-section increases
- Calculated value of eng. stress is ……..
- Although differences exist between eng. σ-ε curves in tension and compression, the true σ-ε curves are *nearly identical*
- Since tensile test results are more common, flow curve values (*K* and *n*) from tensile test data can be applied to compression operations

Shear Test

- Shear stress is τ = F/A$_o$ and γ (shear strain) is tangent of shear angle, θ
- τ = G γ, G is shear modulus
- Shear tests are often used to measure adhesive bonding, riveted joints etc

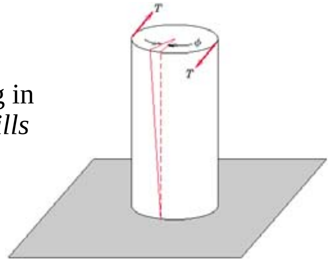


Also, shear stress and strain can be obtained using a torsion test

Torsion Test

- *Torsion* is a variation of shear occurring in *machine axles, drive shafts and twist drills*
- T = f(τ) and γ = f (ϕ)

Details - *next lecture*

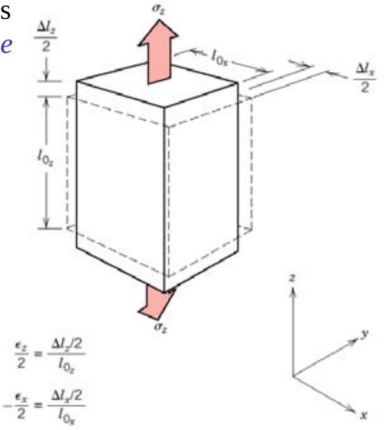


Poisson's Ratio

- When pulled in tension (Z), a sample gets longer and thinner, i.e., *a contraction in the width (X) and breadth (Y)*
  - *if compressed gets fatter*
- **Poisson's ratio** defines how much strain occurs in the lateral directions (x & y) when strained in the (z) direction:

$$\upsilon = -\frac{\text{lateral strain}}{\text{longitudinal strain}}$$

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



- Typical values = 0.2 to 0.5
- For isotropic materials

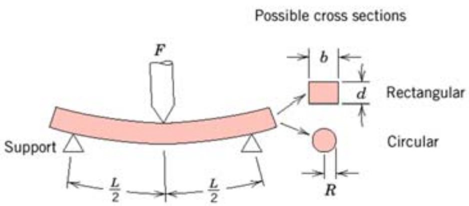
$$E = 2G(1+\nu)$$

Some materials are anisotropic so E & G vary with direction (*e.g. composite materials and single crystals*)

Testing of Brittle Materials

- Recall: Hard brittle materials (*e.g., ceramics*) possess elasticity but little or no plasticity.
- Ceramics are not normally tested in tension because:
  - it is difficult to machine to the required geometry
  - it is difficult to grip brittle materials without inducing fracture
  - ceramics typically fail after only ~ 0.1% strain

For these reasons, the mechanical properties are determined using a different approach, the ………………………….:



- specimen geometry is either circular or rectangular cross section
- during the test, the top surface is under compression while the bottom surface is under tension
- maximum tensile stress occurs on the bottom surface, just below the top loading point

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HARDNESS

Hardness is a measure of the material's resistance to localized plastic deformation (e.g. dent or scratch)

Qualitative Hardness:

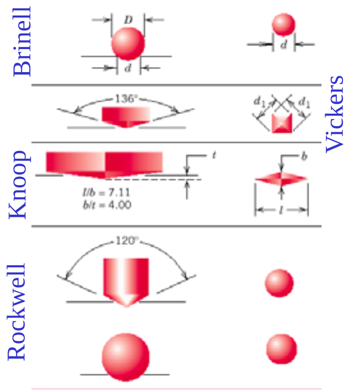
- Moh's scale, determined by the ability of a material to scratch another material:

from 1 (softest = talc) to 10 (hardest = diamond)

Quantitative Hardness:

- Different types of quantitative hardness test has been designed
  - Rockwell
  - ……….
  - ……….
  - ……….

HARDNESS



- Usually a small indenter (*sphere, cone, or pyramid*) is forced into the surface of a material under conditions of controlled magnitude and rate of loading.
- The depth or size of indentation is measured.
- The tests somewhat approximate, but popular because they are easy and non-destructive (except for the small dent).

$$HB = \frac{2P}{\pi D[D - \sqrt{D^2 - d^2}]}$$

Where,
P (the applied load) is in kg,
D is the indenter's diameter
d is the diameter of the resulted indentation

Correlation between Hardness and Tensile Strength

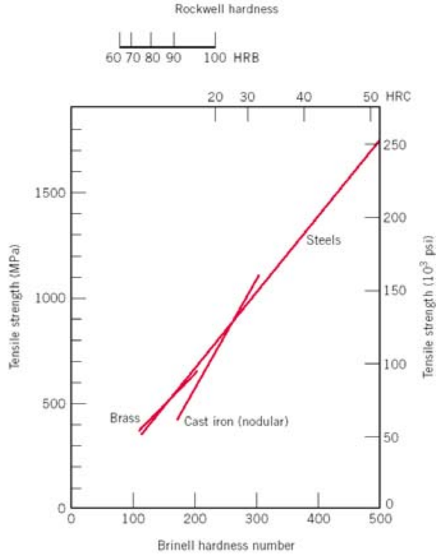
- Both tensile strength and hardness are a measure of a materials resistance to ……………………….

⇒ expect a correlation

- *usually TS and HB scale*

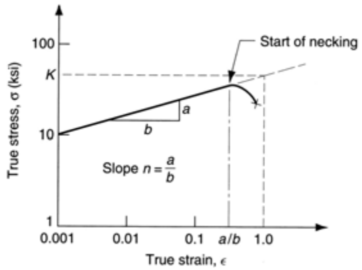
TS (MPa) = 3.45 x HB

TS (psi) = 500 x HB



Example

A metal obeys the Hollomon relationship and has a UTS of 300 MPa.
To reach maximum load requires an elongation of 35%. Find K and n.



True stress-strain curve plotted on log-log scale

Next time:

Continue Mechanical Properties:

Torsion test

Plastic deformation

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