Imperial College London

Materials and Manufacturing

Mechanical properties of materials

Dr. Billy Wu

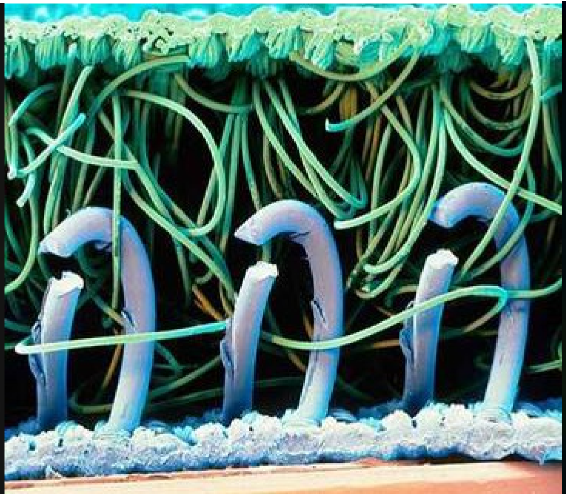
Module leader

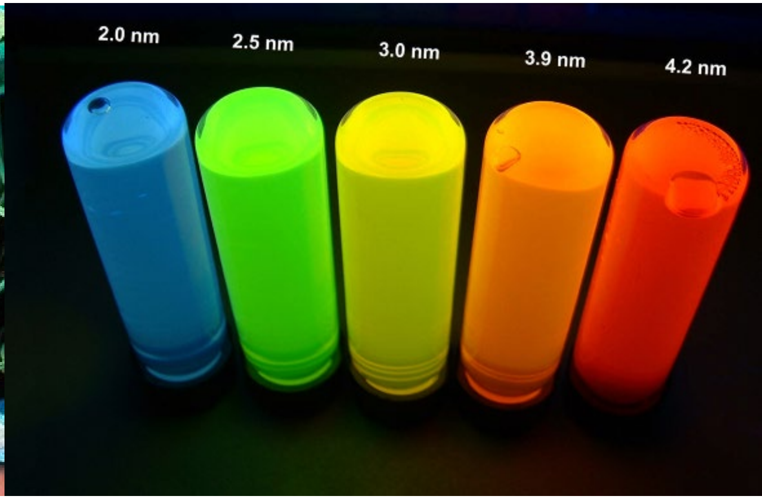
Reader (Associate Professor)

billy.wu@imperial.ac.uk

Dyson School of Design Engineering

Last time on M&M…



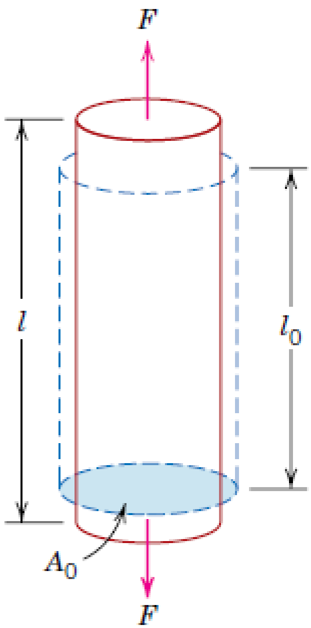


Learning objectives

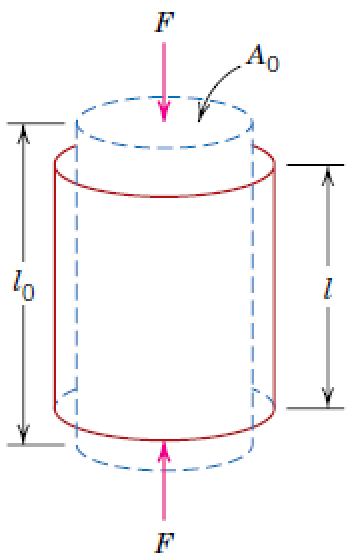
- Define engineering stress and engineering strain
- Explain the concept of Hooke's law and Poisson's ratio
- Evaluate common engineering metrics from an engineering stress-strain diagram
- Define the common material testing techniques

Loading

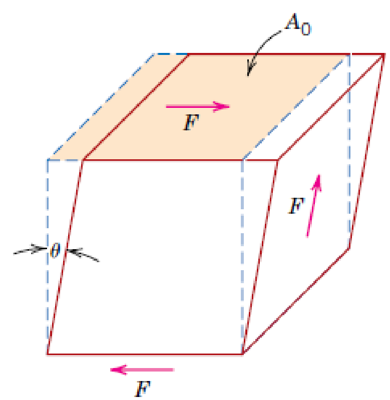
There are four principle ways load to applied to an object:



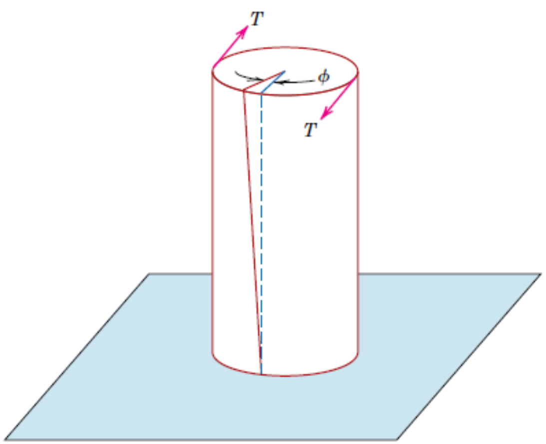
Tension



Compression



Shear



Torsion

Engineering stress and strain

Engineering stress

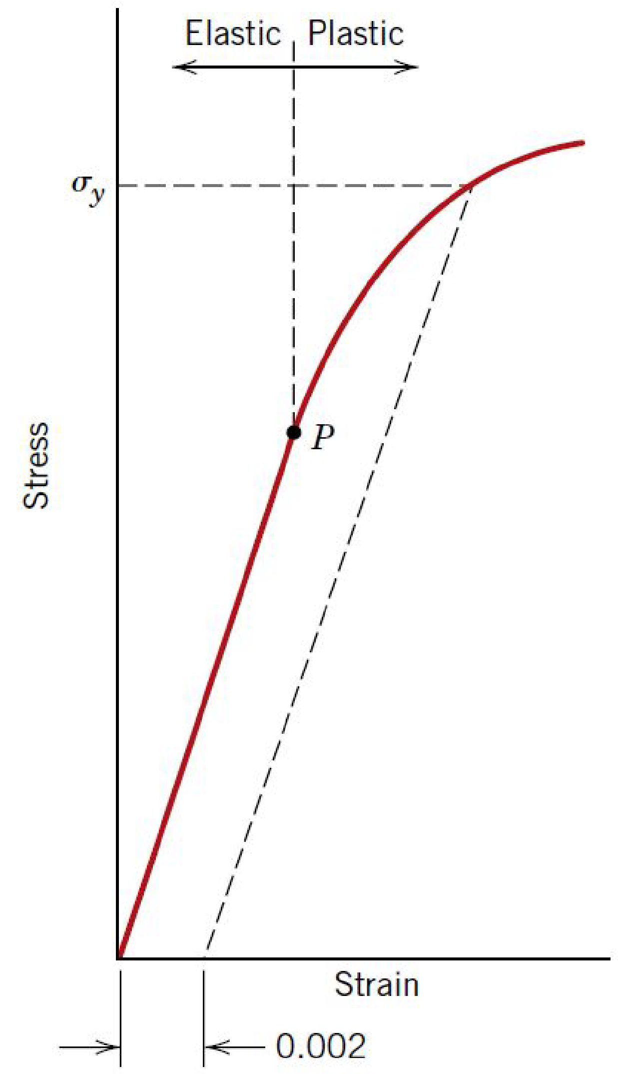
The stress on an object is define as the ratio between the force (F) and the original cross-sectional area (A_0). The stress is typically expressed in units of MPa

$$\sigma = \frac{F}{A_0}$$

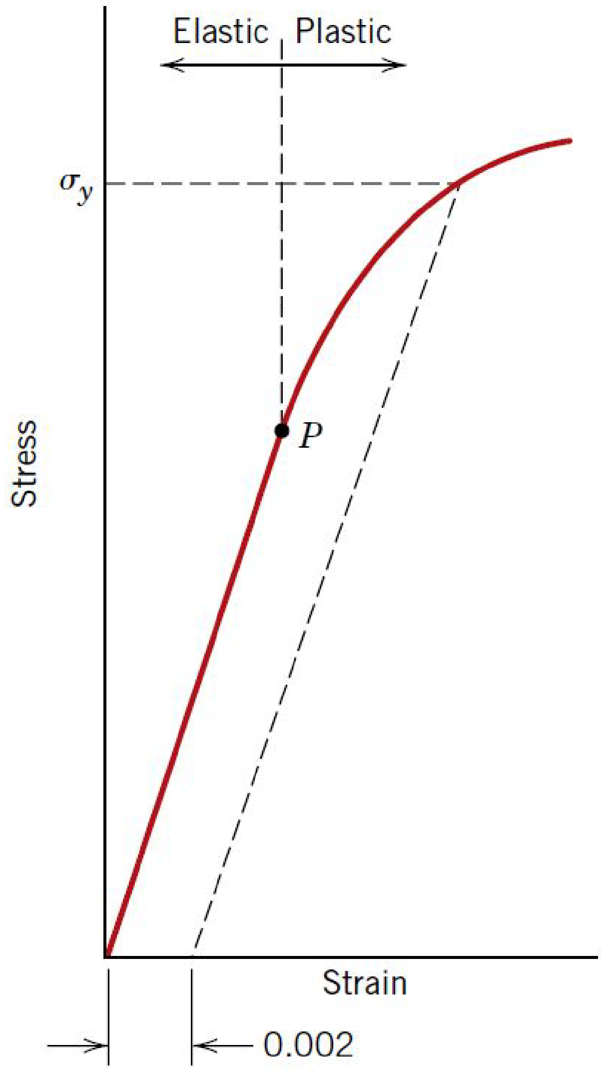
Strain

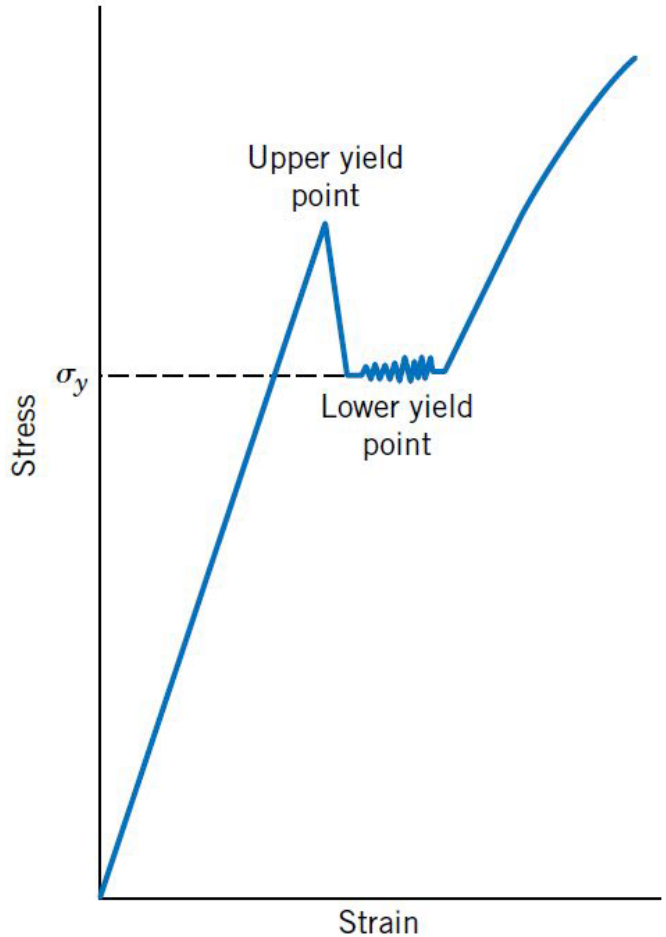
Engineering Strain. Strain (ε) is the ratio of elongation to original length, where l_0 is the initial length, l_i is the instantaneous length and Δl is the change in length.

$$\varepsilon = \frac{l_i - l_0}{l_0} = \frac{\Delta l}{l_0}$$

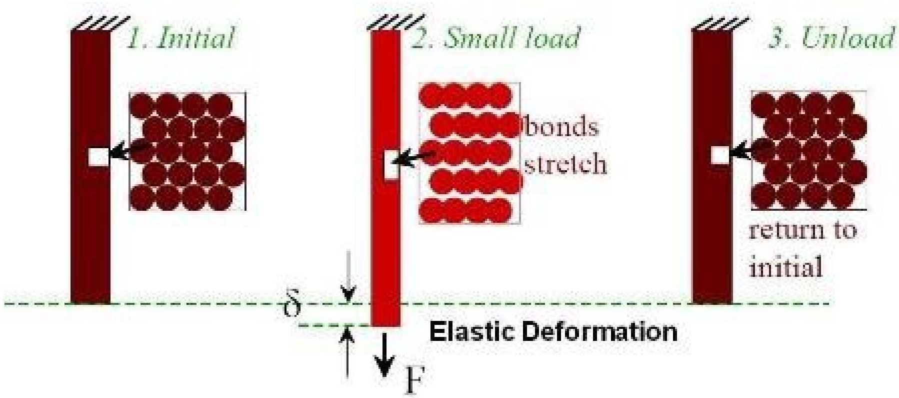


Yielding

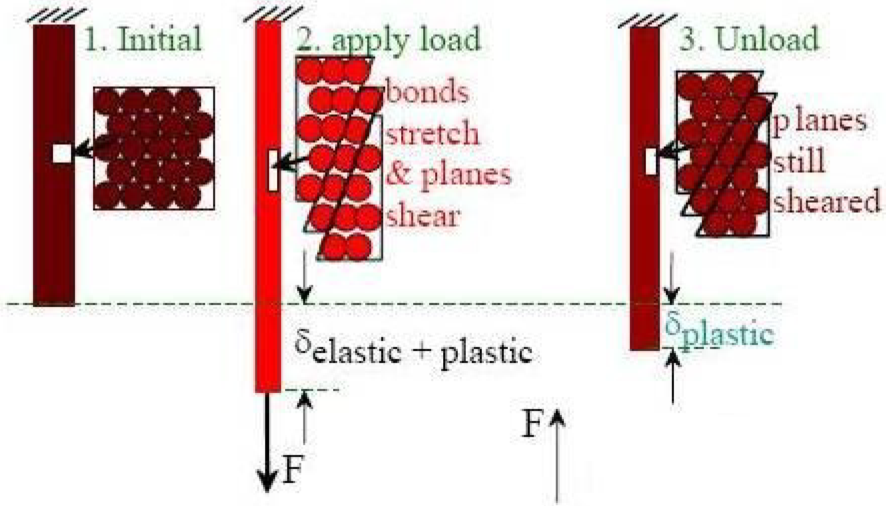

Elastic
Plastic
σ_y
P
Stress
Strain
0.002


Upper yield point
σ_y
Lower yield point
Stress
Strain

Plastic deformation

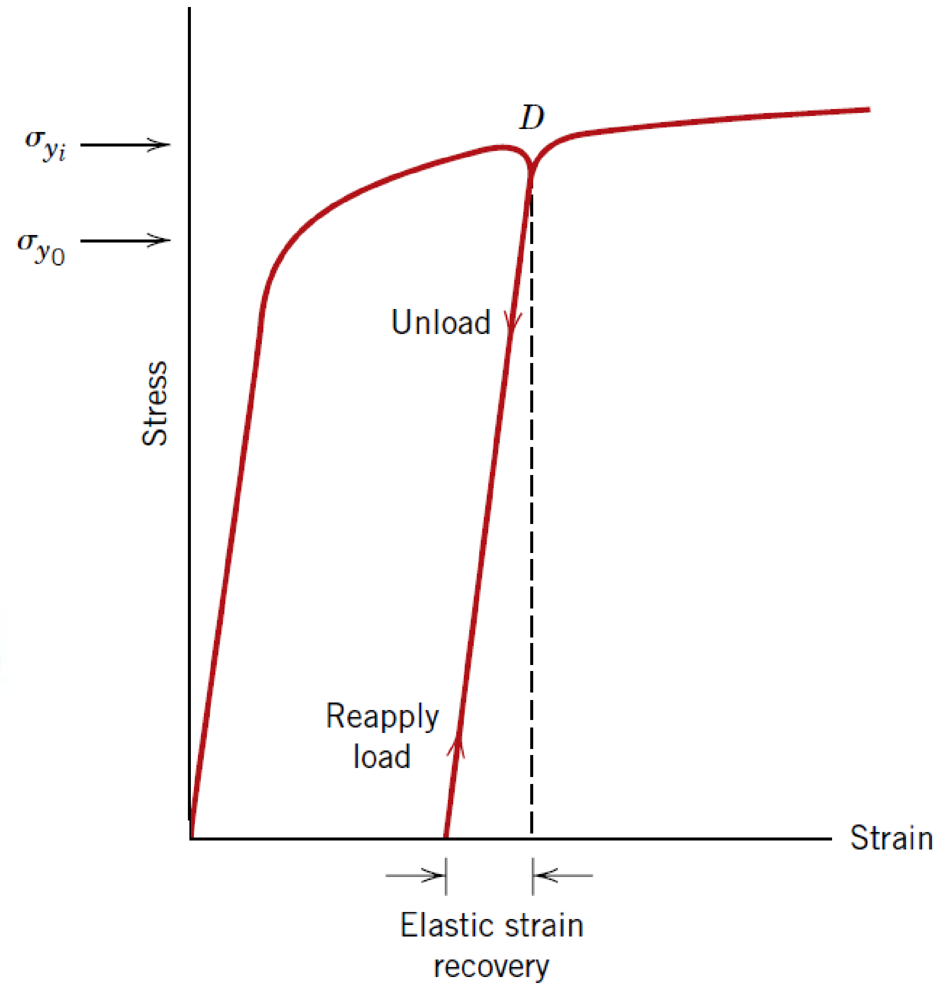


Elastic deformation



Schematic Representation of Plastic Deformation

Plastics deformation

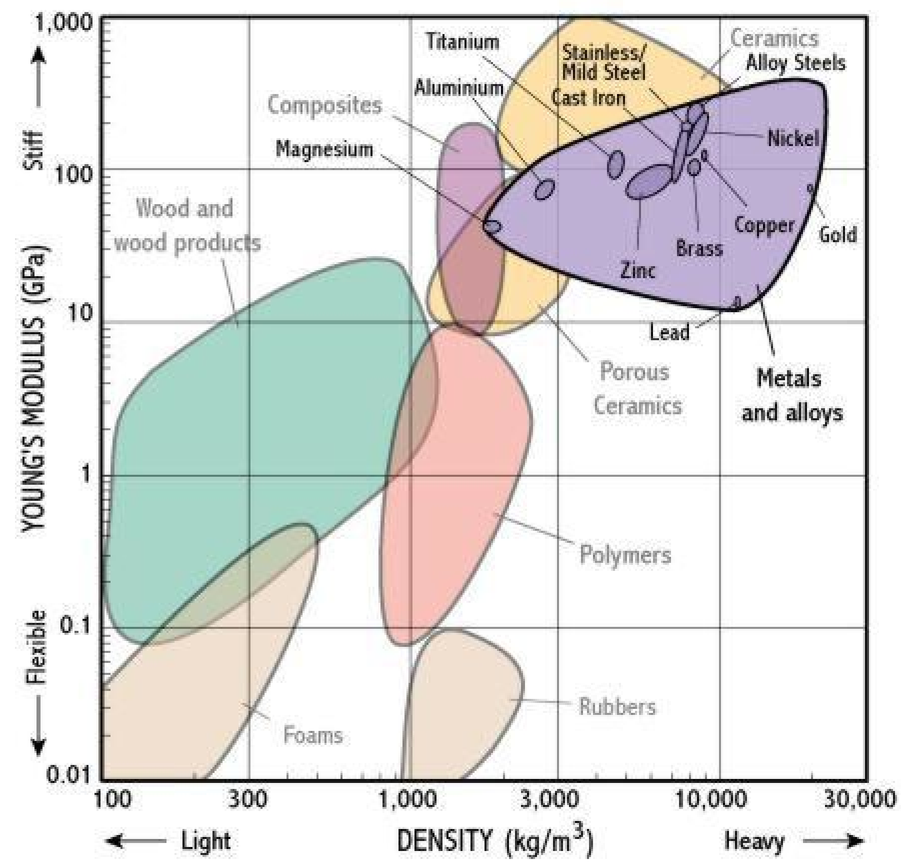


Young’s modulus

The Young’s modulus (E) is a measure of stiffness of an elastic material and is defined as the ratio between the tensile stress (σ) and the strain (ε).

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

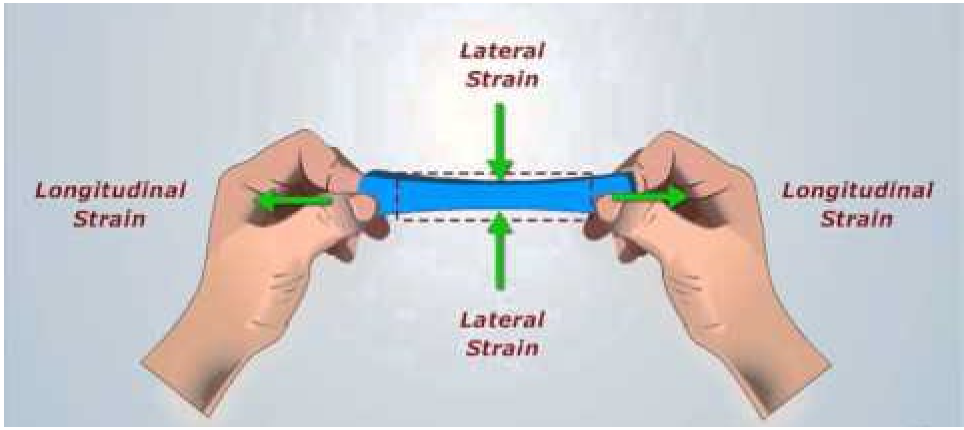
$$E = \frac{F/A_0}{\Delta L/L_0} = \frac{F L_0}{A_0 \Delta L}$$



Poisson's ratio

The ratio of the proportional decrease in a lateral measurement to the proportional increase in length in a sample of material that is elastically stretched

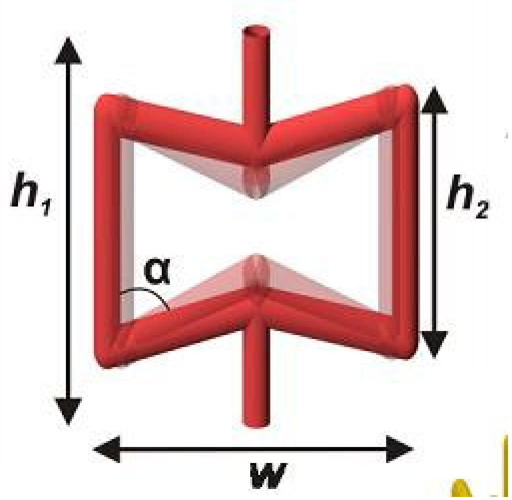
$$\nu = -\frac{d\varepsilon_{trans}}{d\varepsilon_{axial}} = -\frac{d\varepsilon_y}{d\varepsilon_x}$$

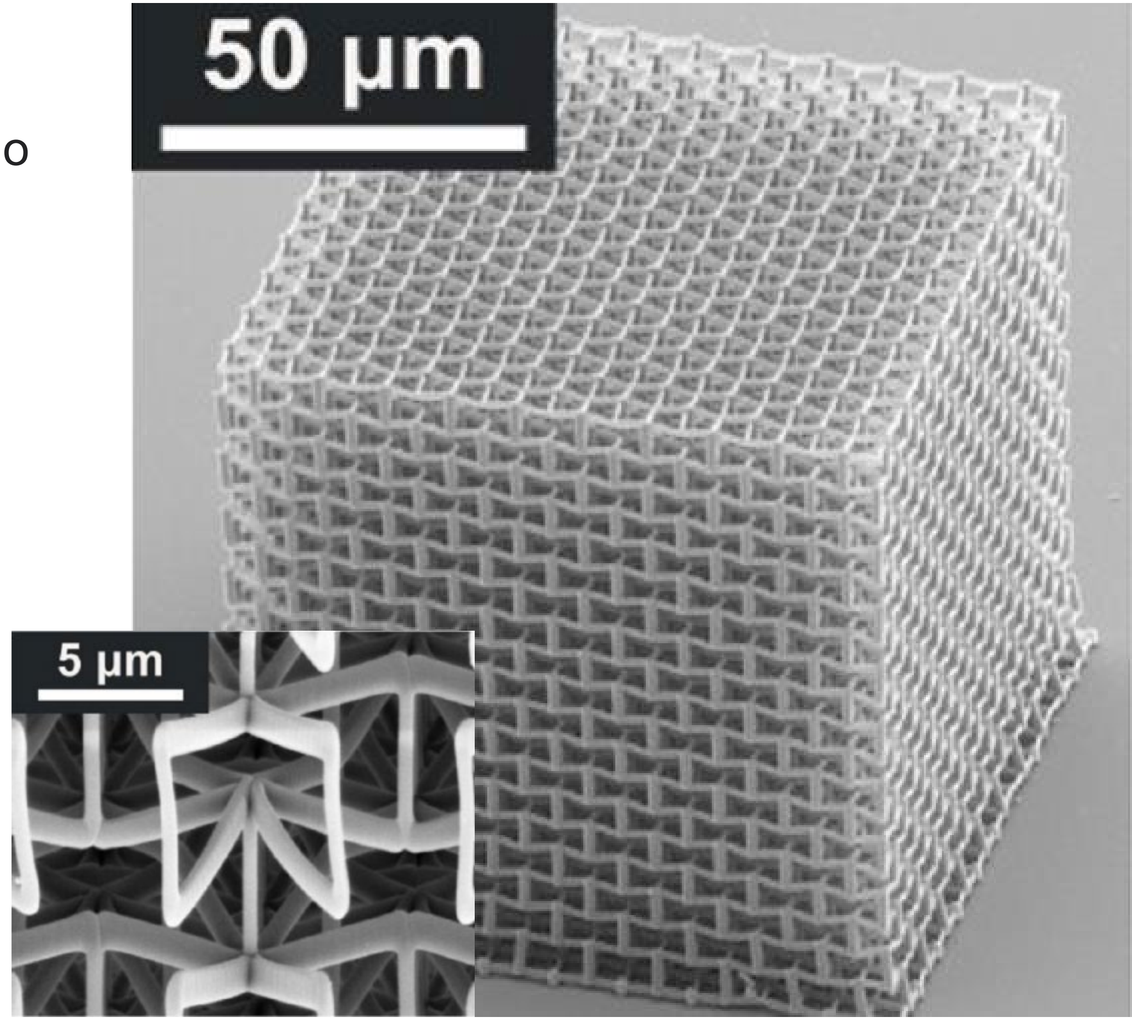


Metal alloy	Poisson's ratio
Aluminium	0.33
Brass	0.34
Copper	0.34
Magnesium	0.29
Nickel	0.31
Steel	0.30
Titanium	0.34
Tungsten	0.28

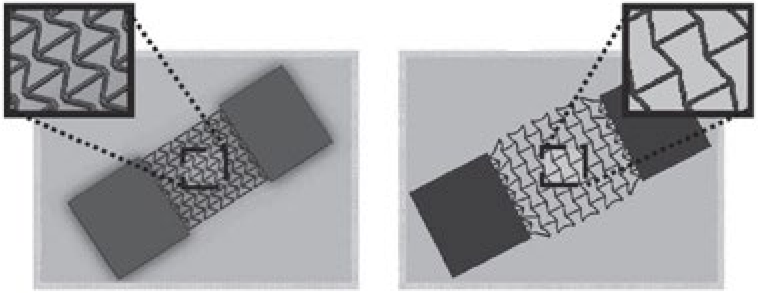
Poisson's ratio

- Auxetics:
  - Tuneable Poisson's ratio
  - -0.12 < v < +0.13



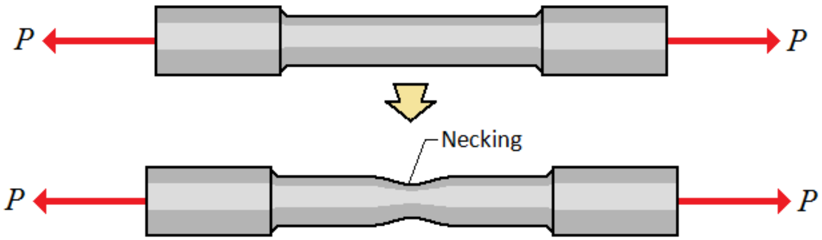


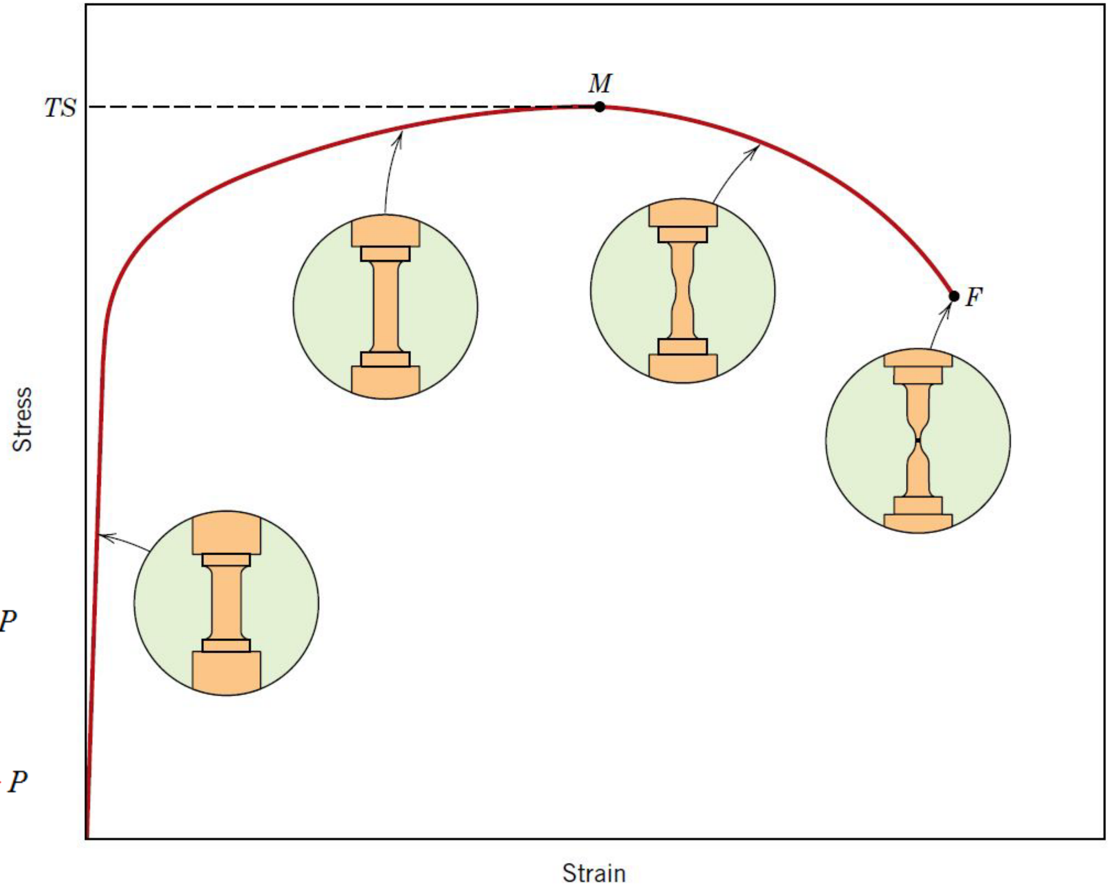
T. Bueckmann et al., Advanced Materials 24 , 2710 (2012)



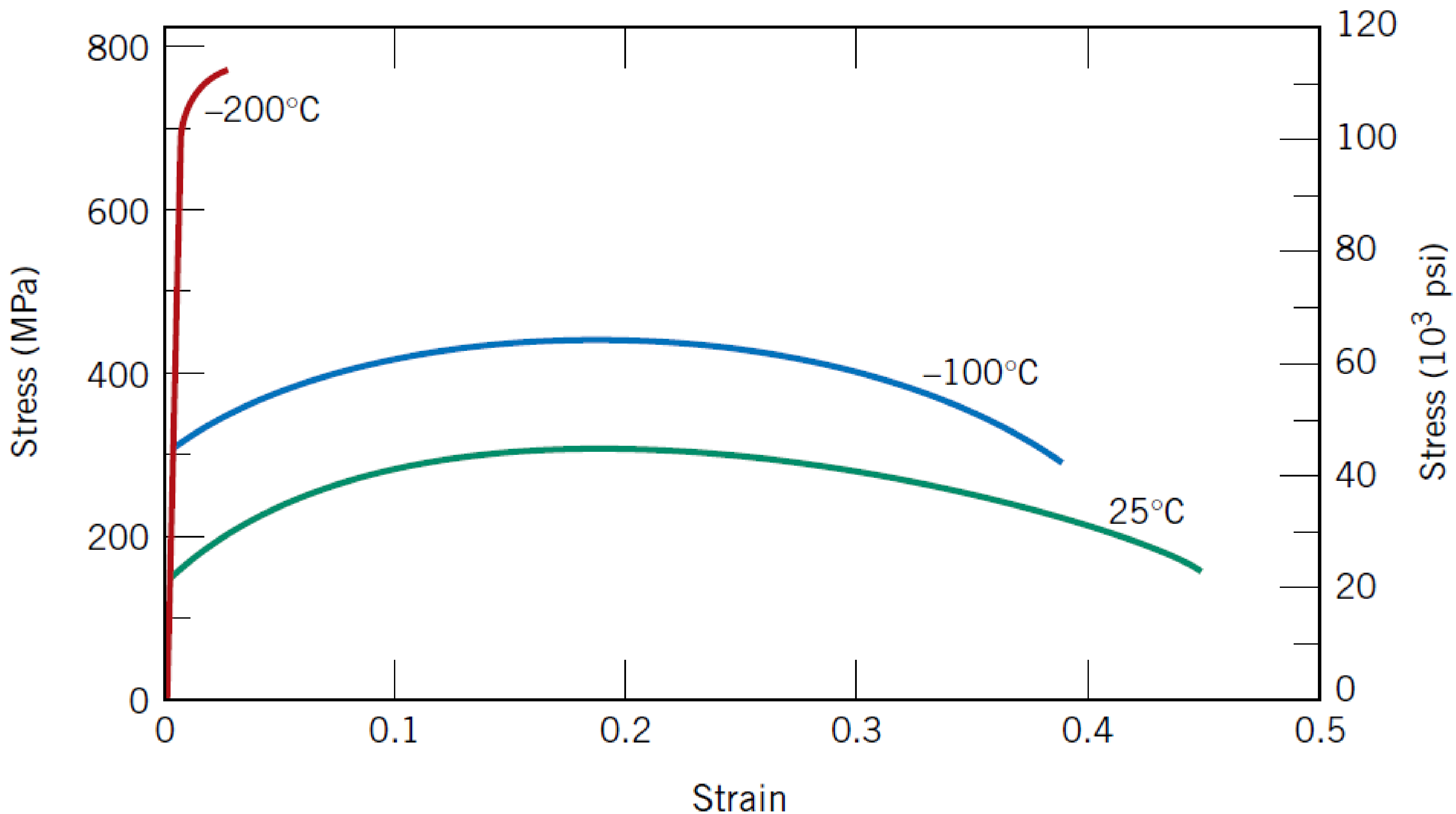
Tensile strength

1. Linear elastic region
2. Non-linear plastic deformation
3. Beyond the tensile strength, the sample thins at the neck
4. Necking continues and eventually causes failure of the sample





Tensile strength

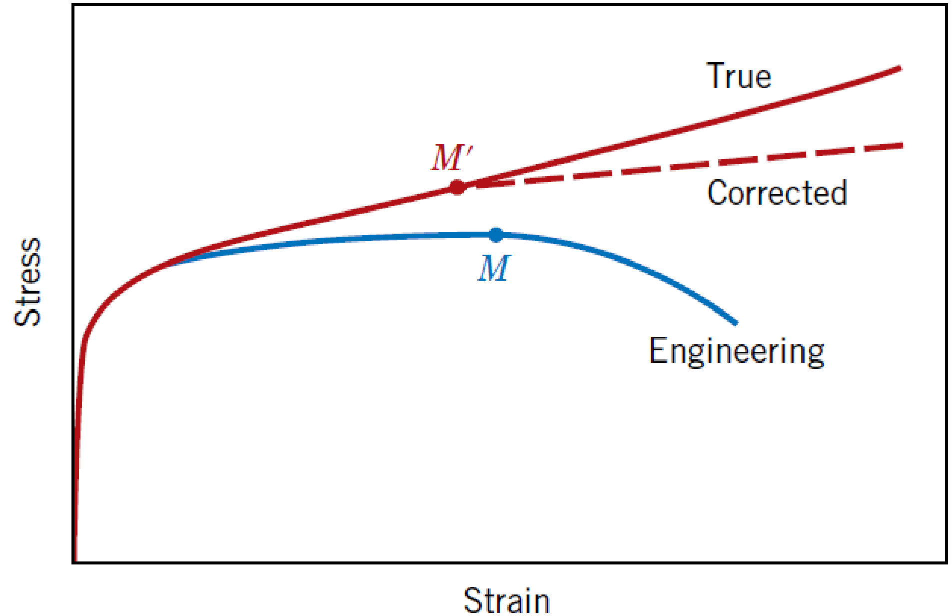


Engineering stress-strain behaviour for iron at three temperatures

True stress and strain

True stress σ_T is the load (F) divided by the instantaneous cross-sectional area A_l over which deformation is occurring (i.e., the neck, past the tensile point)

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



True strain ε_T defined by:

$$\varepsilon_T = ln\frac{l_l}{l_0}$$

If no volume change occurs then:

$$A_l l_l = A_0 l_0$$

True and engineering stress and strain are then related according to the below which is valid only to the onset of necking

$$\sigma_T = \sigma(1 + \varepsilon) \qquad \varepsilon_T = ln(1 + \varepsilon)$$

Ductility

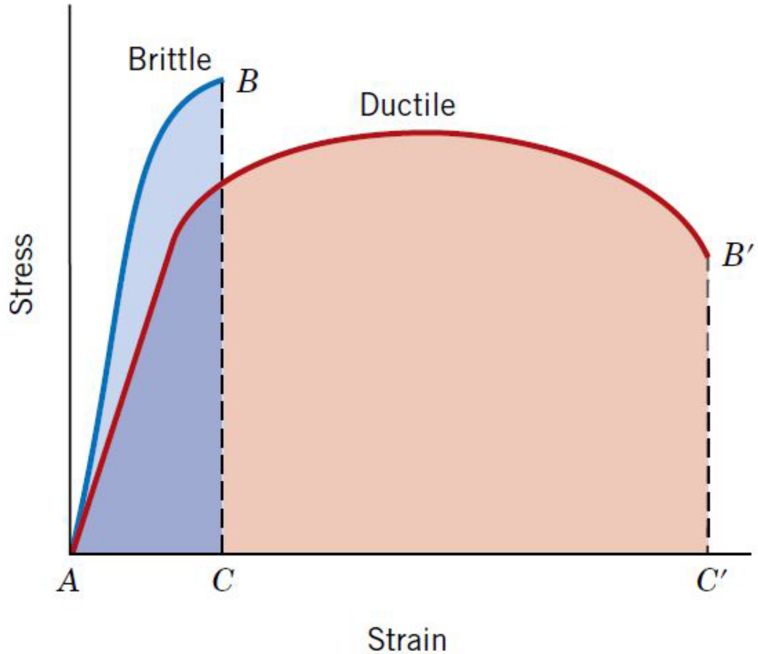
Ductility is a measure of plastic deformation that has been sustained at fracture

- A material that experiences very little or no plastic deformation upon fracture is called brittle
- 2 ways of defining ductility: %elongation or %reduction in area
- The %elongation (*%EL)* is the percentage of plastic strain at fracture. l_f is the fracture length and l_0 is the original length:

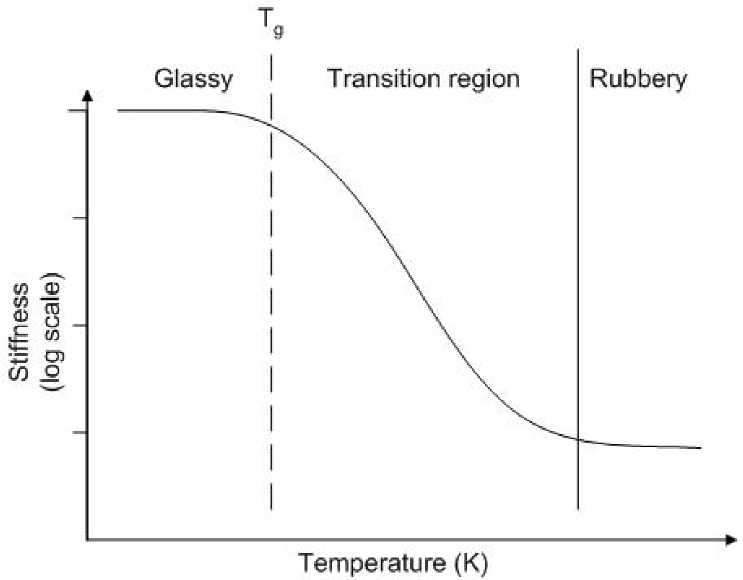
$$\%EL = \frac{l_f - l_0}{l_0} \times 100$$

- %area reduction. A_0 is the original area and A_f is the area at failure:

$$\%RA = \frac{A_0 - A_f}{A_0} \times 100$$

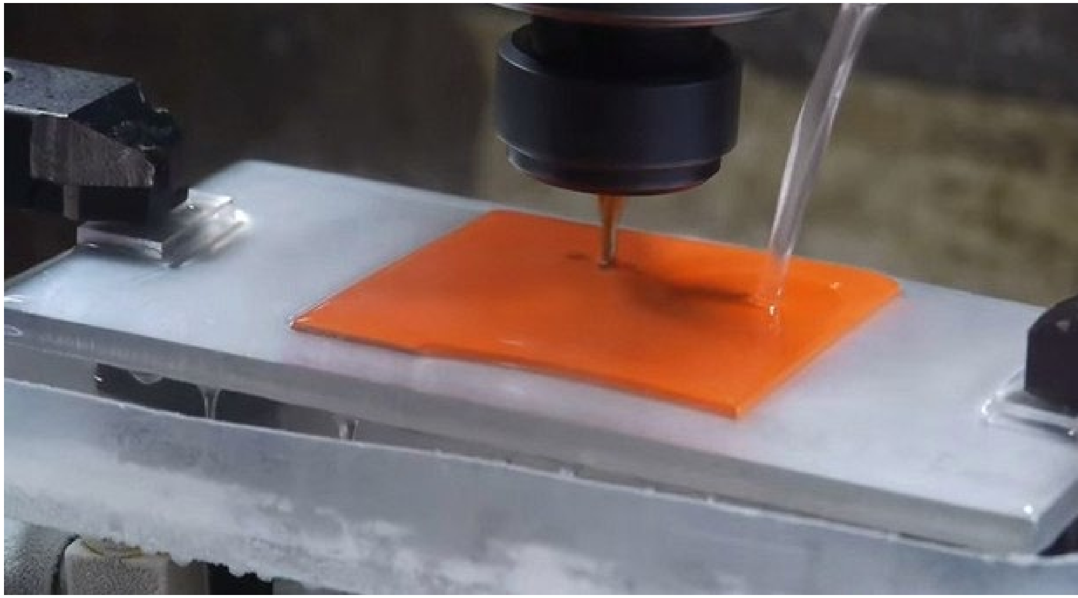


Ductility



T_g
Glassy
Transition region
Rubbery
Stiffness (log scale)
Temperature (K)

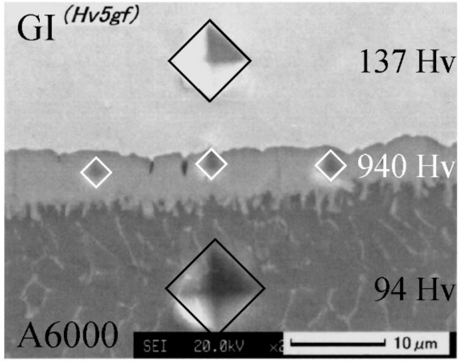
Frozen banana



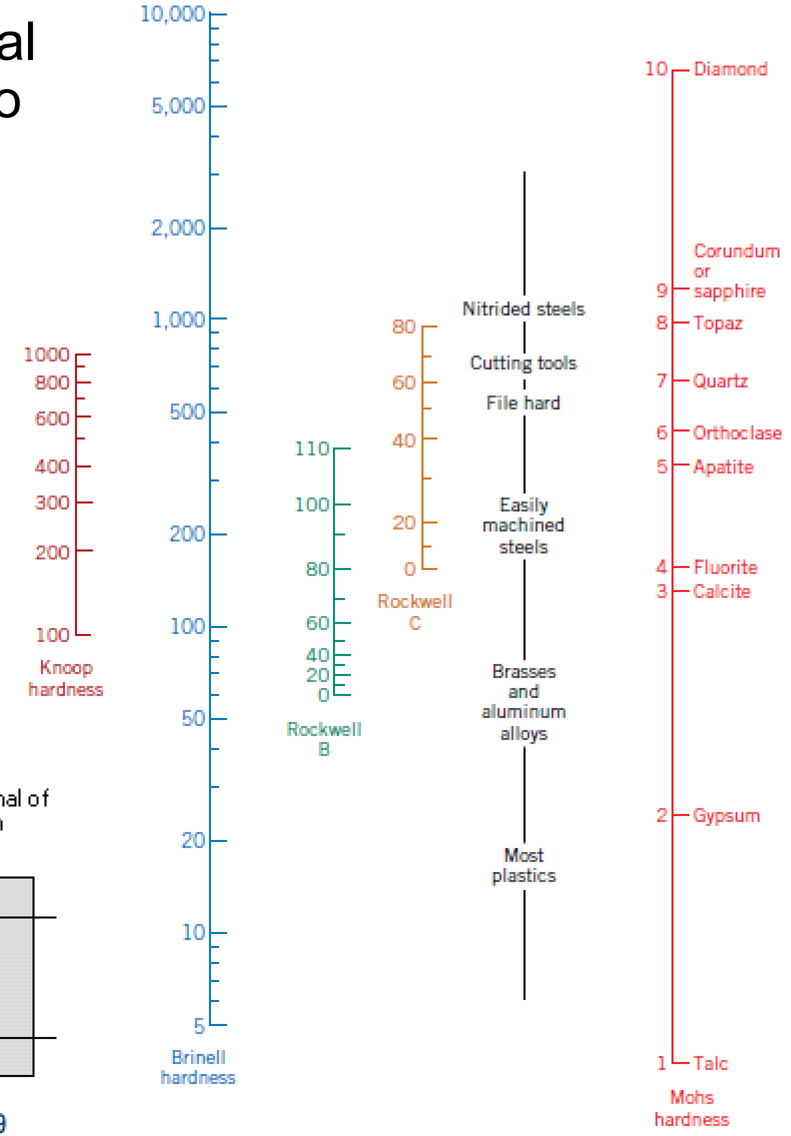
Hardness

The hardness of a material is a mechanical property which measures the resistance to localised plastic deformation
(e.g. scratches or dents)

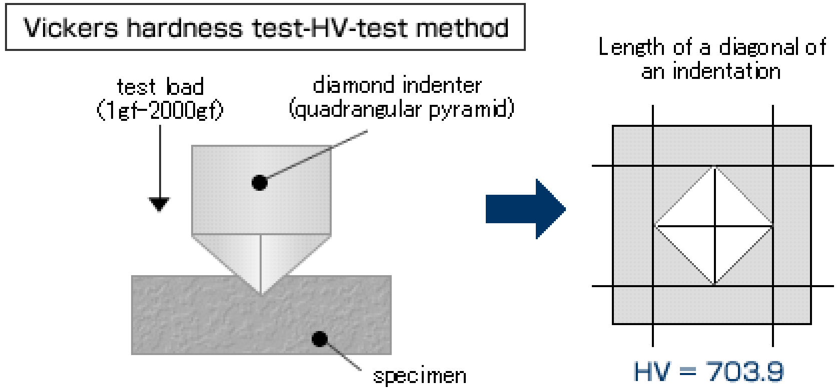
- Brinell hardness
- Vickers hardness



$$TS(MPa) = 3.45 \times HB$$



standard model



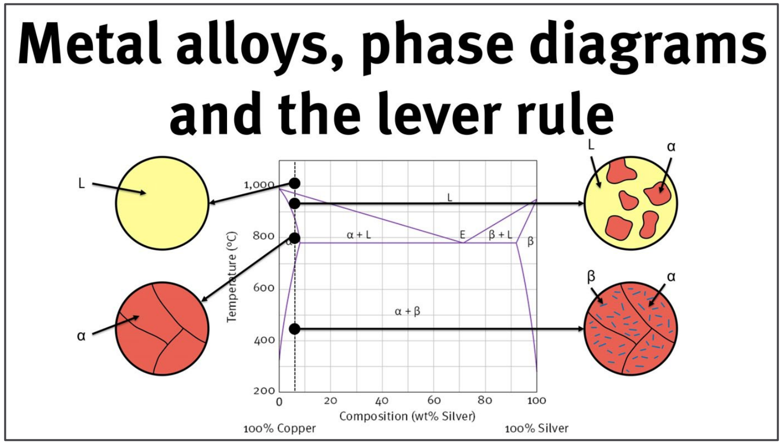
Summary

- Define engineering stress and engineering strain
- Explain the concept of Hooke's law and Poisson's ratio
- Evaluate common engineering metrics from an engineering stress-strain diagram
- Define the common material testing techniques

Time to flip

Please watch this short video on equilibrium phase diagrams and the Lever rule before the next lecture

"How to use phase diagrams and the lever rule to understand metal alloys"
https://youtu.be/huvtkdn_keY



Next time on M&M…