AML 883 Properties and selection of engineering materials

LECTURE 8. Plasticity

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Problem Sheet 3

Problems on strength-limited design are up on the homepage.

Hardness

Resistance of a material to plastic deformation, measured usually by indentation

Measuring harndess

- Mohs
- Brinell
- Rockwell
- Vickers
- Knoop
- Nanoindentation

Historical interest

Macro tests

Micro tests

Mohs scale

- Very ancient
- Idea is simple – Softest material that can scratch the given material or the hardest mineral on which the given material can produce a scratch
- It is really just a way of ordering
- All the images in the following ten slides are courtesy: wiki

Mohs scale 1

- Talc

Mohs scale 2

- Gypsum

Mohs scale 3

- Calcite

Mohs scale 4

- Fluorite

Mohs scale 5

- Apatite

Mohs scale 6

- Feldspar

Mohs scale 7

- Quartz

Mohs scale 8

- Topaz

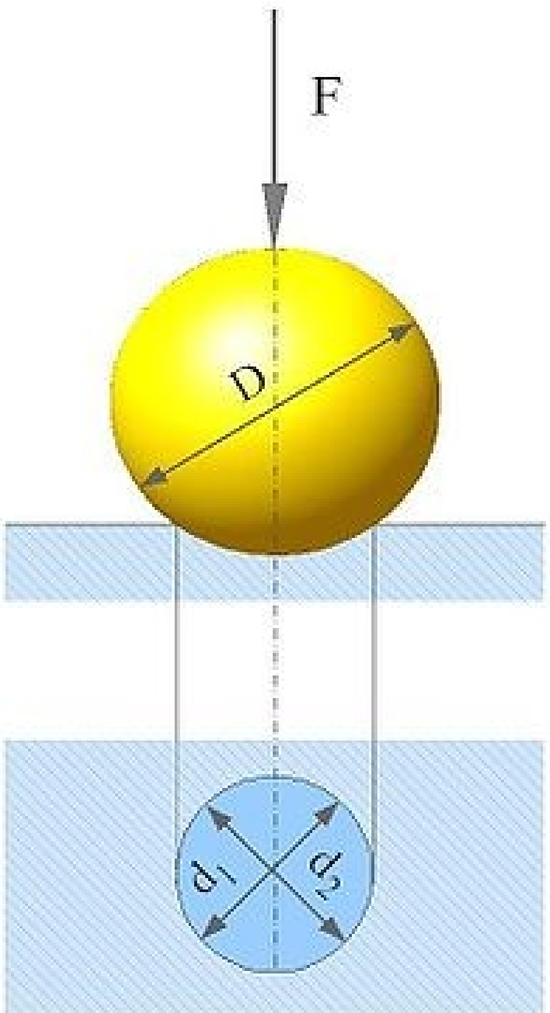
Mohs scale 9

- Corundum

Mohs scale 10

- Diamond

Brinell hardness tester



- 10 mm dia steel ball
- 29 kN force (3000 kgf)
- Softer – less force
- Harder – Tungsten carbide ball
- Image courtesy: wiki

Brinell hardness number

- Using the formula

$$BHN = 2P/\pi D\left(D-\left(D^2-d^2\right)^{1/2}\right)$$

- "d" -- indentation diameter (mm)
- "P" -- force in kgf
- "D" -- indentor diameter (mm)

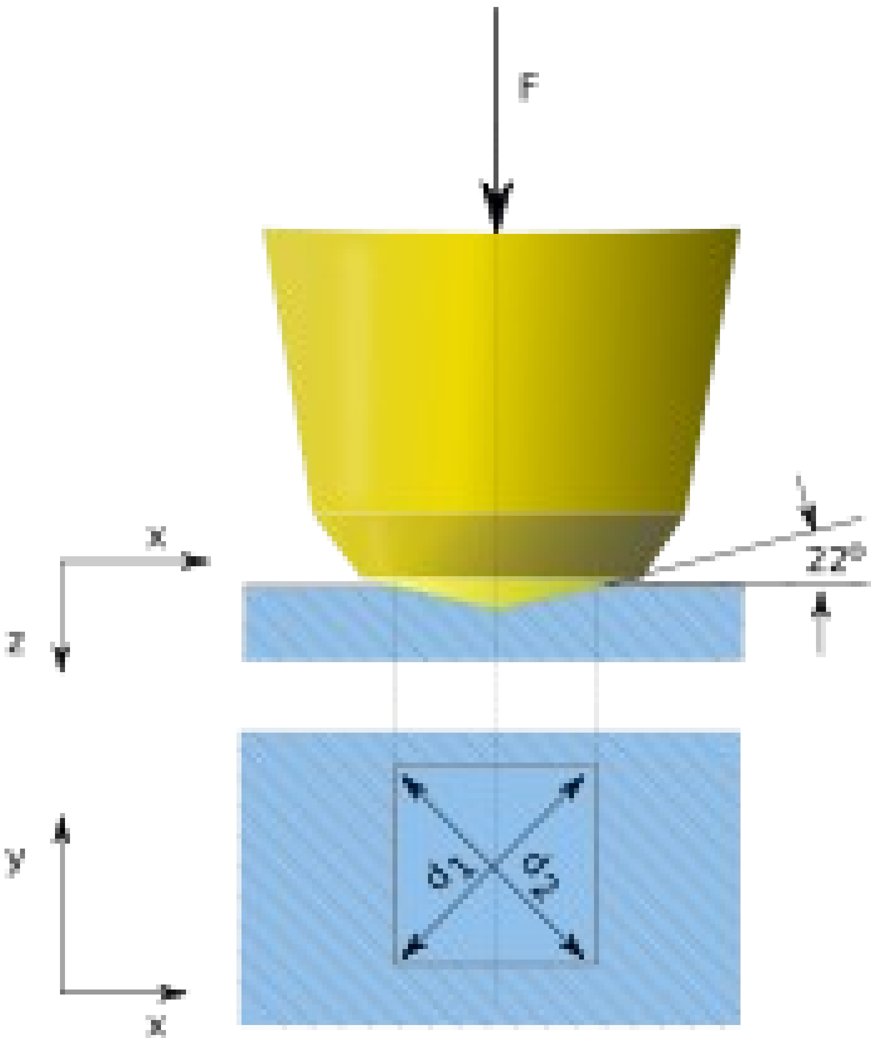
Rockwell hardness tester

- Brinell is not truly non-destructive test
- Rockwell – a minor load and then a major load; note the depth of penetration; read the hardness on a dial
- Indentor – cone or sphere

Vickers hardness test

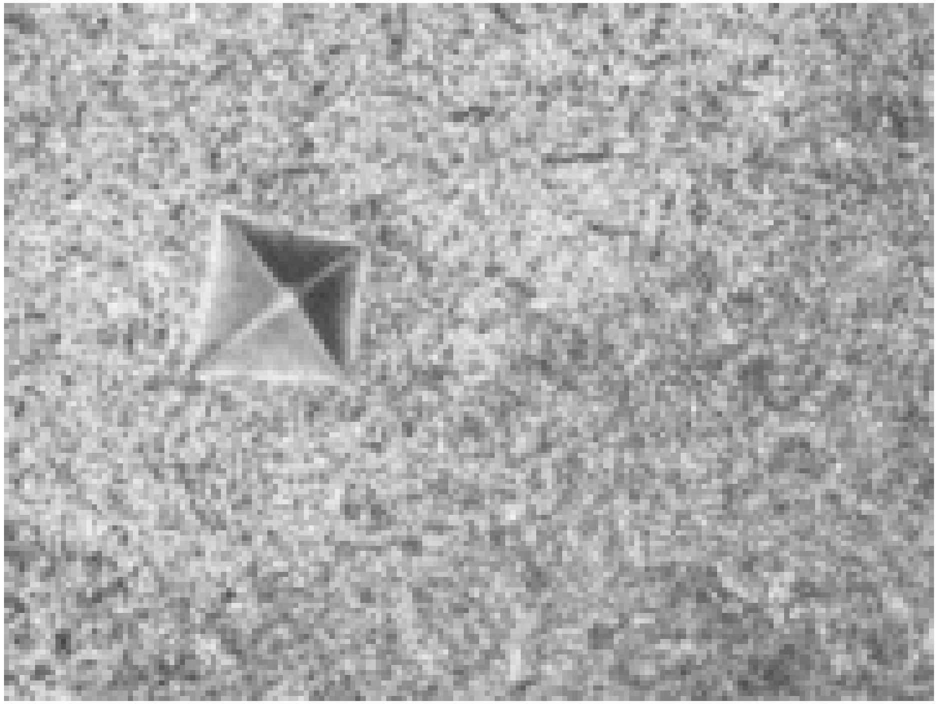
- Vickers hardness tester
- Vickers pyramid number (HV)
- Square based pyramidal diamond indentor
- Image courtesy:wiki

Vickers hardness test



- Area measurement
- H = F/A
- Image courtesy:wiki

Vickers hardness test

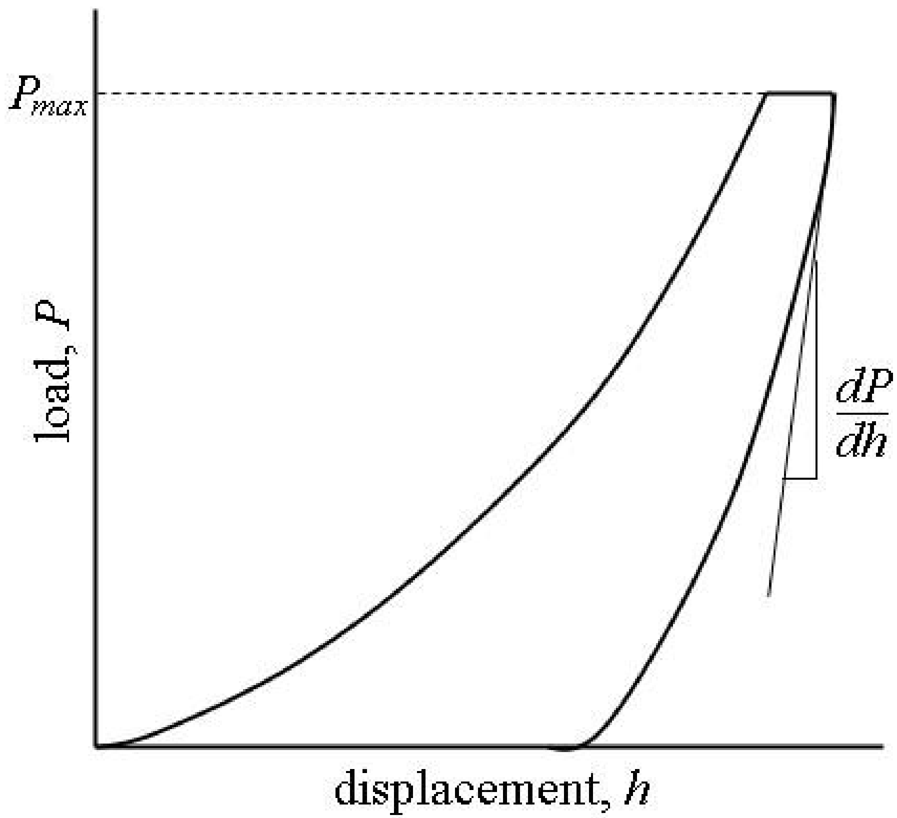


- Indentation on hardened steel
- Area measurement
- H = F/A
- Image courtesy:wiki

Knoop hardness test

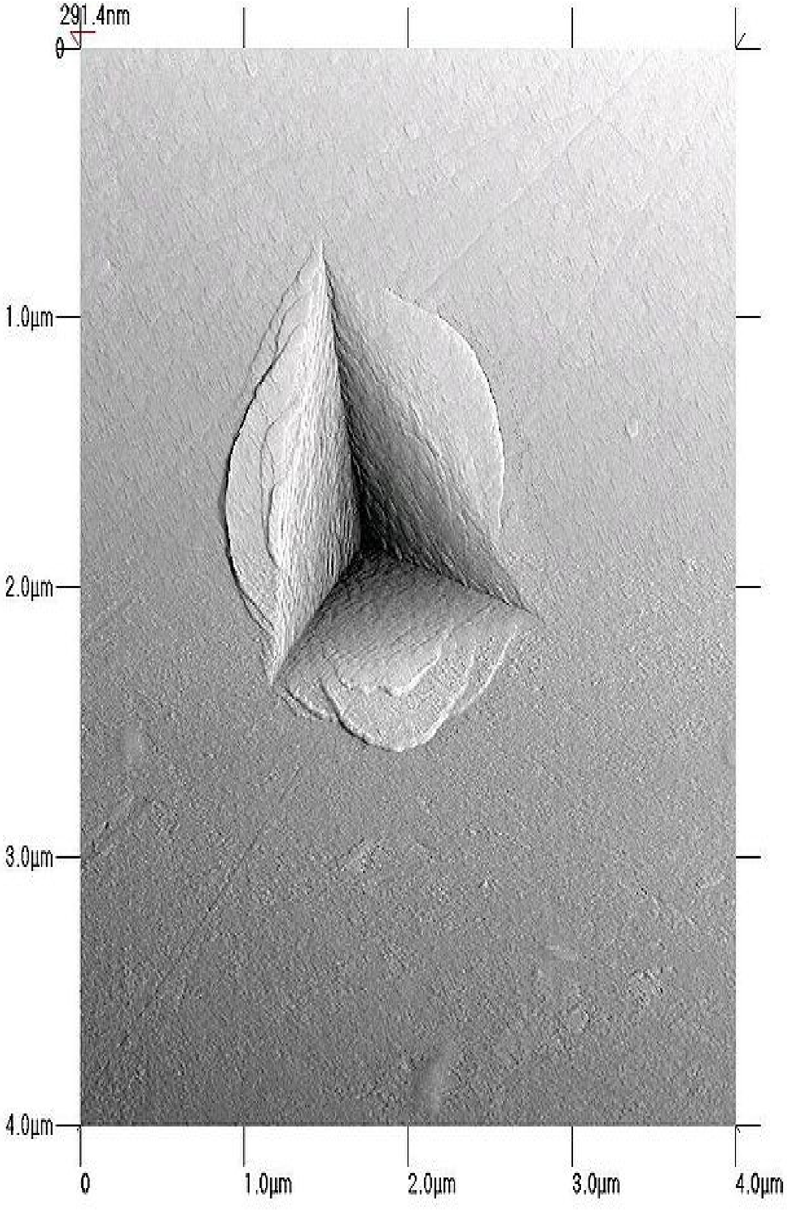
- For very brittle materials and thin sheets
- Requires a microscope to measure the indentation
- Pyramidal diamond point – press on surface!

Nanoindentation



- Load versus displacement from an instrumented nanoindentor
- Image courtesy: wiki

Nanoindentation

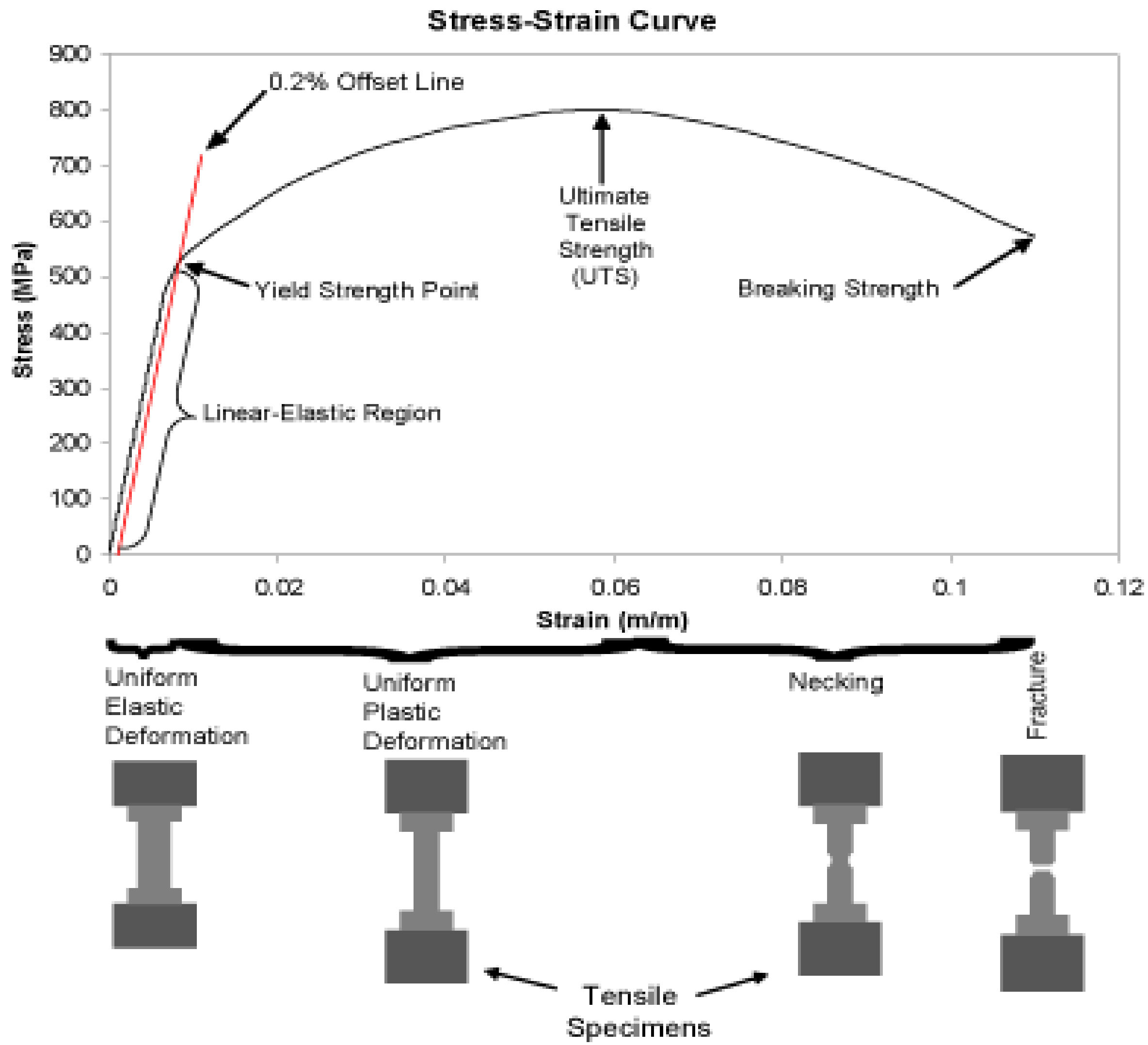


- AFM image of nanoindentation in Zr-Cu-Al metallic glass
- Berkovich indentor – triangular pyramid
- Image courtesy: wiki

Hardness to yield strength

- Vickers – one third of yield strength
- Other hardness numbers – can similarly be converted
- Information from hardness tests – less accurate and less complete
- Not used for design

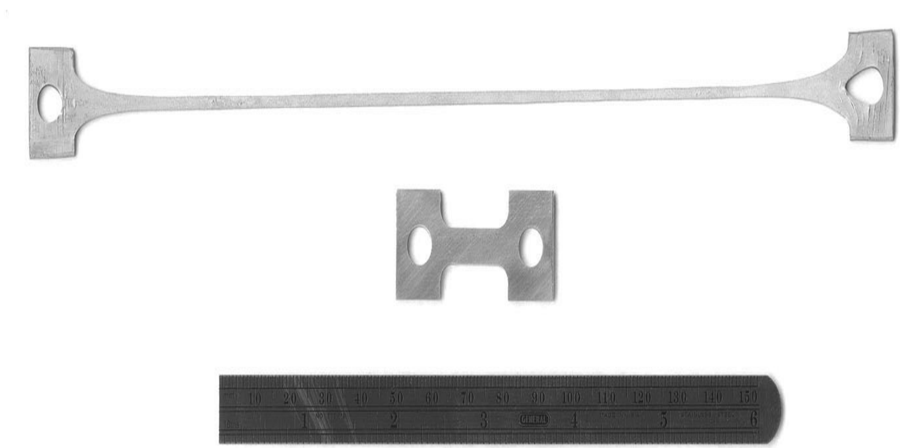
Stress-strain curve



Plastic strain

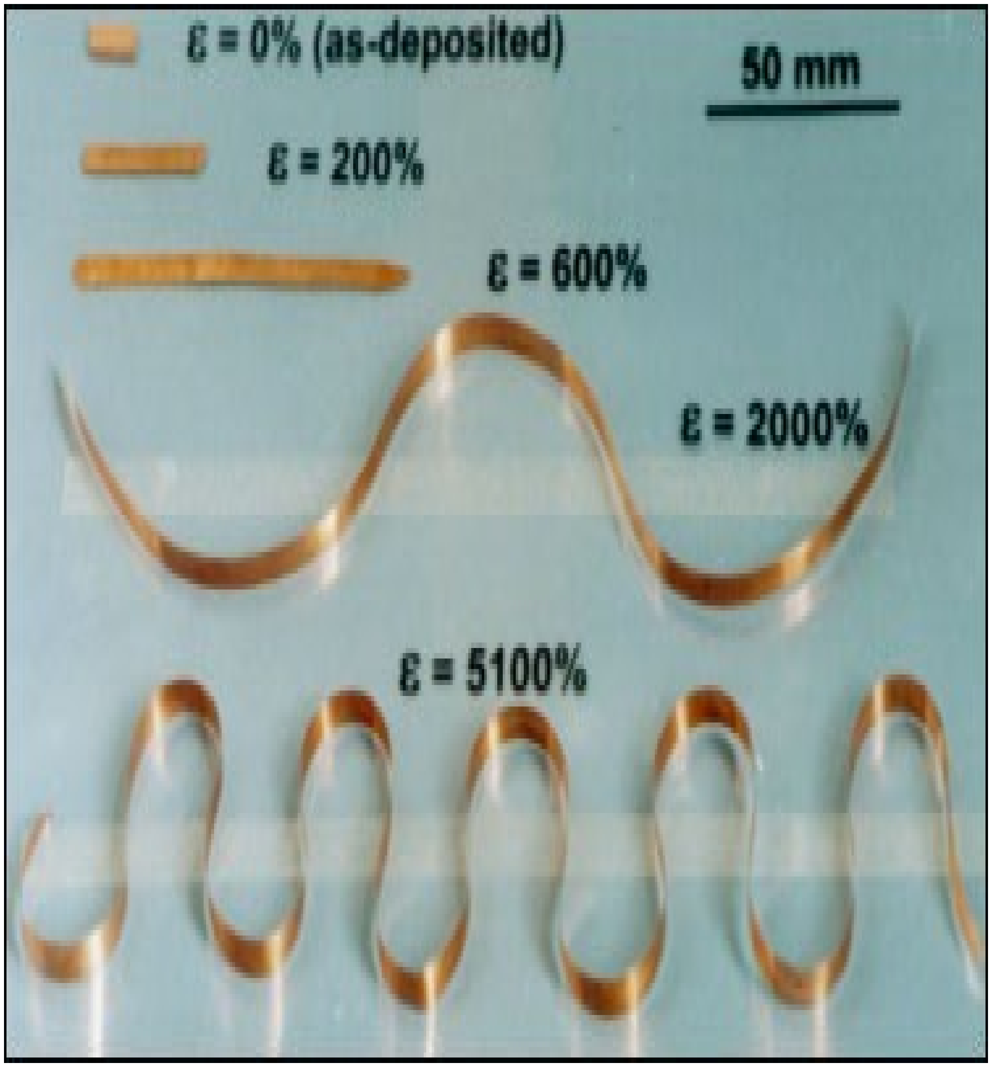
- By definition, permanent strain resulting from plasticity
- Total strain – elastic strain
- Plastic work – area under the stress-strain curve in the plastic regime
- Ductility – how much plastic strain can a material take
- Super-ductile materials -- superplastic!

Superplasticity



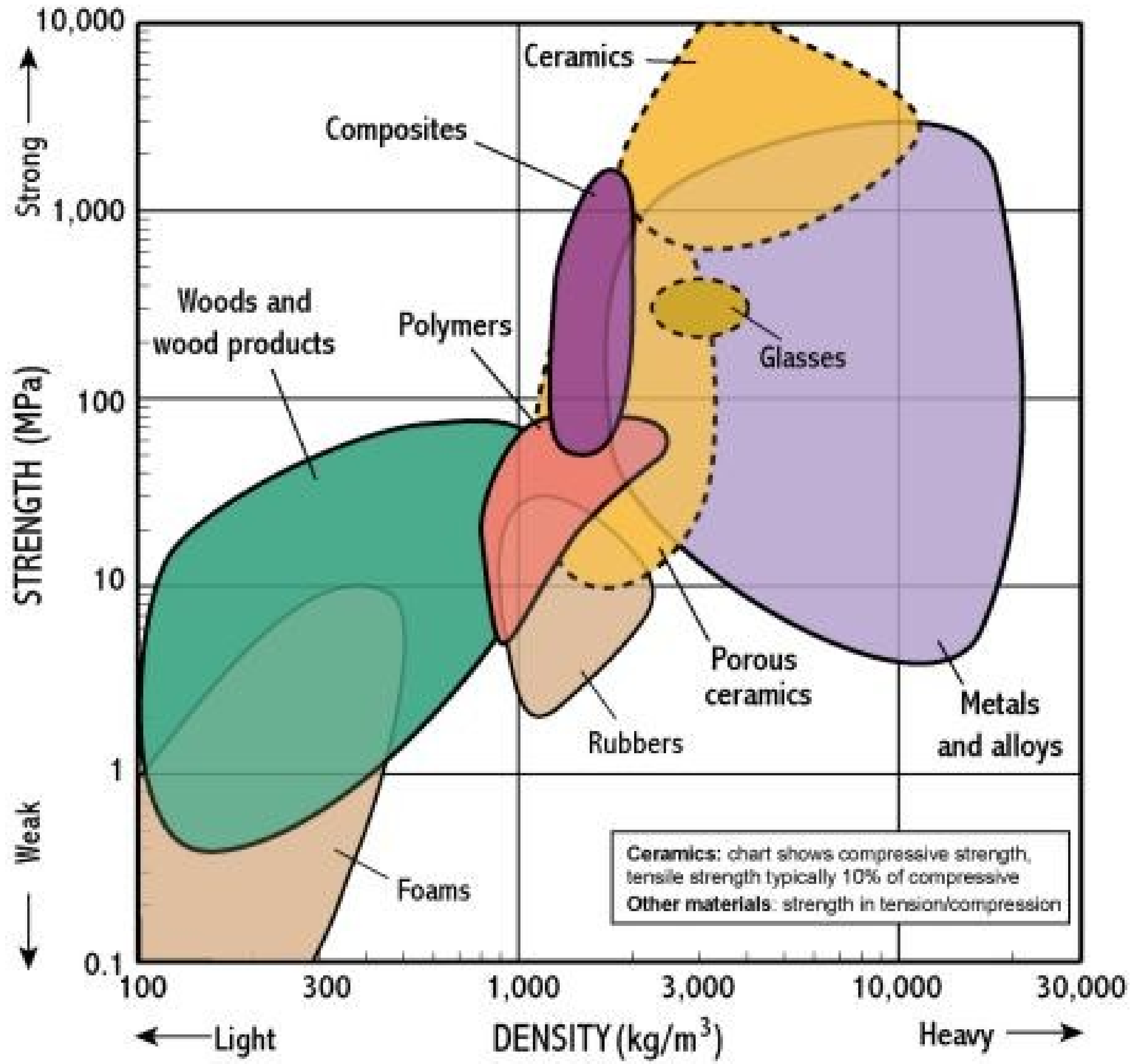
- Deformation amounting to 1000% or even more (8000% is the largest reported?)
- UCDavis, ChemEngg-MatSci site

Superplasticity

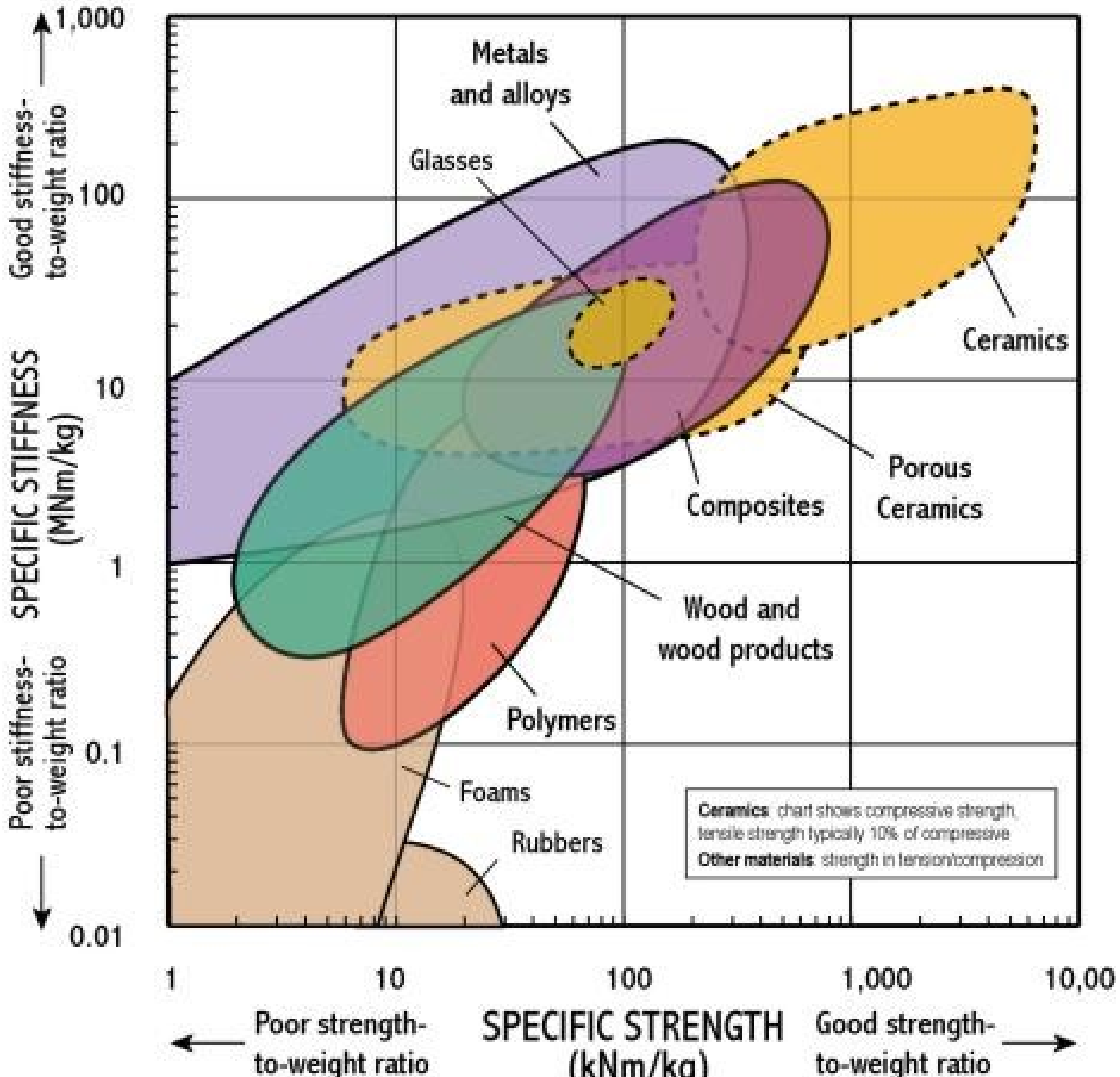


- Image courtesy: Chinese National Science Foundation webpage
- Rate of straining is important!
- Slow strain rates so that system can adjust

Strength-Density chart



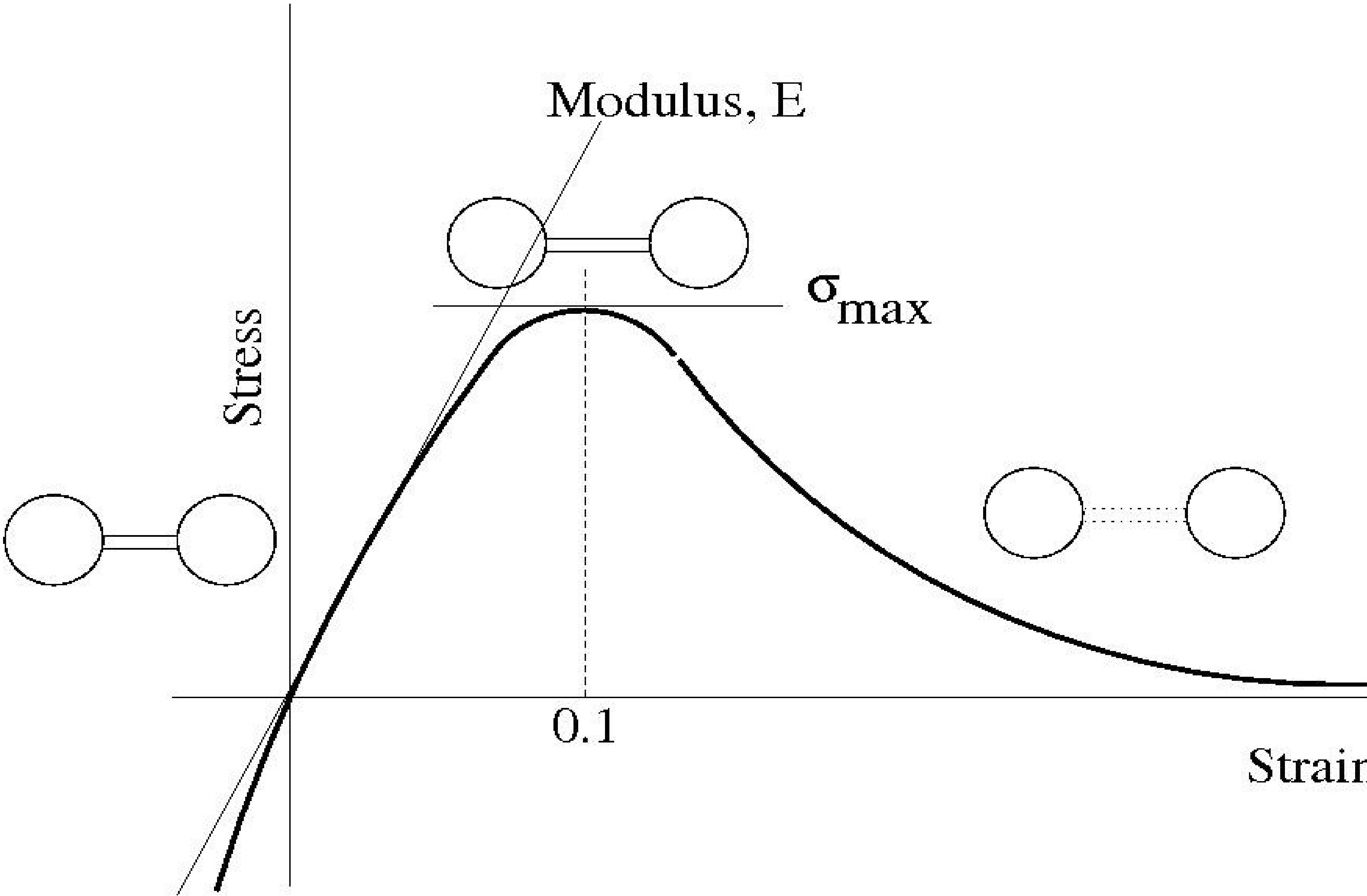
Stiffness—Strength (specific) chart



Ideal strength of crystals

- Atoms in a crystal – connected via bonds (springs)
- The springs have a breaking point!
- Connect the breaking point with the material constant – namely, modulus!

Ideal strength of crystals



Ideal strength of crystals

- Let the strain at which the bond is broken be 0.1
- Let the initial interatomic distance be “a”
- The force needed to break the bond is then (roughly) Sa/10
- S – bond stiffness
- The ideal strength is then
$$\sigma_{max} = Sa/10\mathrm{a}^2 = S/10\mathrm{a} = E/10$$
- More refined estimate (including curvature of force-distance curve): E/15

Theory versus practice

In theory, there is no difference between theory and practice. But, in practice, there is.
-- Attributed to Jan L. A. van de Snepscheut/Yogi Berra

Observed versus theoretical

- Copper:
  Yield strength: 70 M Pa
  Young's modulus: 110-130 G Pa
- Aluminium alloy:
  Yield strength: 400 M Pa
  Young's modulus: 69 G Pa

Why the discrepancy?

Defects!