MID TERM RESULTS - 2007

AVERAGE (%) 72

50 out of 55 obtained a score better than their tutorial quiz average!

2 perfect marks, 17 A's

Of course it was not all good…

By the end of this course, students will be able to:

- Classify materials based on their properties.
- Explain how properties are measured.
- Explain how structure is characterized at different length scales.
- Recognize links between structure and properties for a variety of materials.
- Illustrate the use of different materials in the field of electrical engineering.
- Apply their knowledge of materials in their chosen field of electrical engineering.

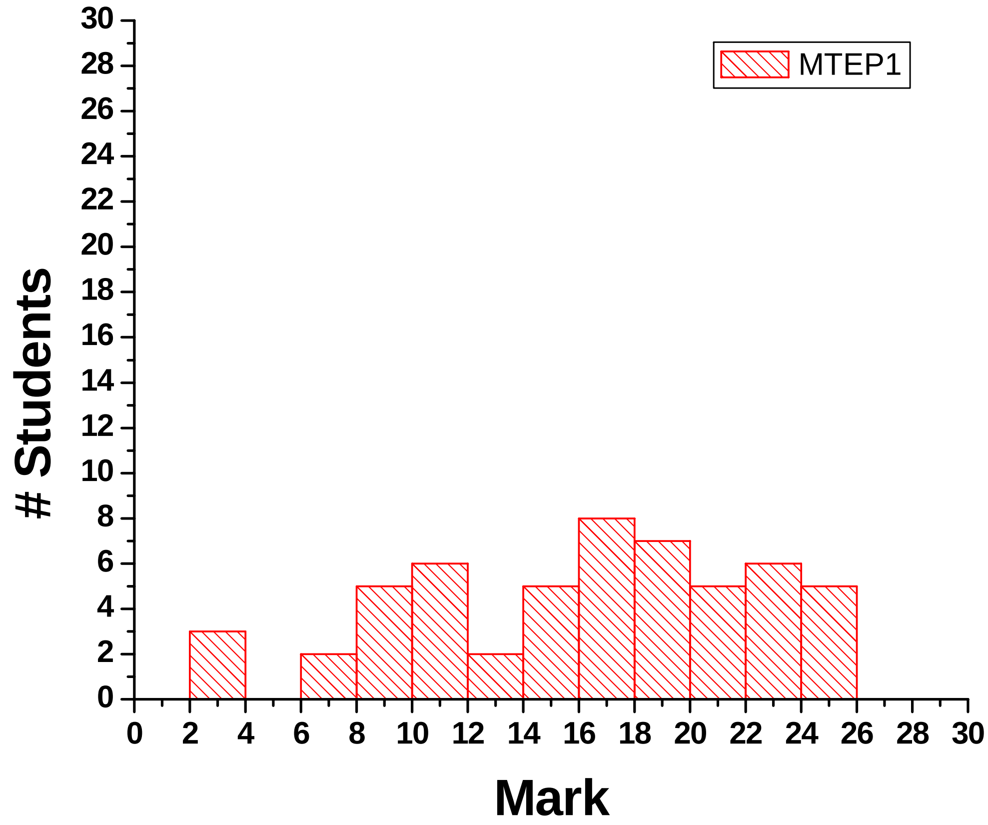
The course has many components to help you reach these learning outcomes…

1) Lecture
2) Tutorials
3) Callister
4) Recommended homework sets
5) Office hours
6) Extra files placed on WebCT

	Average
Problem 1: Basic phase diagram, Hume-Rothery, microstructure, lever rule	**63%**
Problem 2: Complex phase diagram, conversion of at% to wt%	**78%**
Problem 3: Diffusion coefficient, erfc(z) problem	**73%**
Problem 4: Crystalline planes, atomic packing (planar density)	**70%**

Problem 1

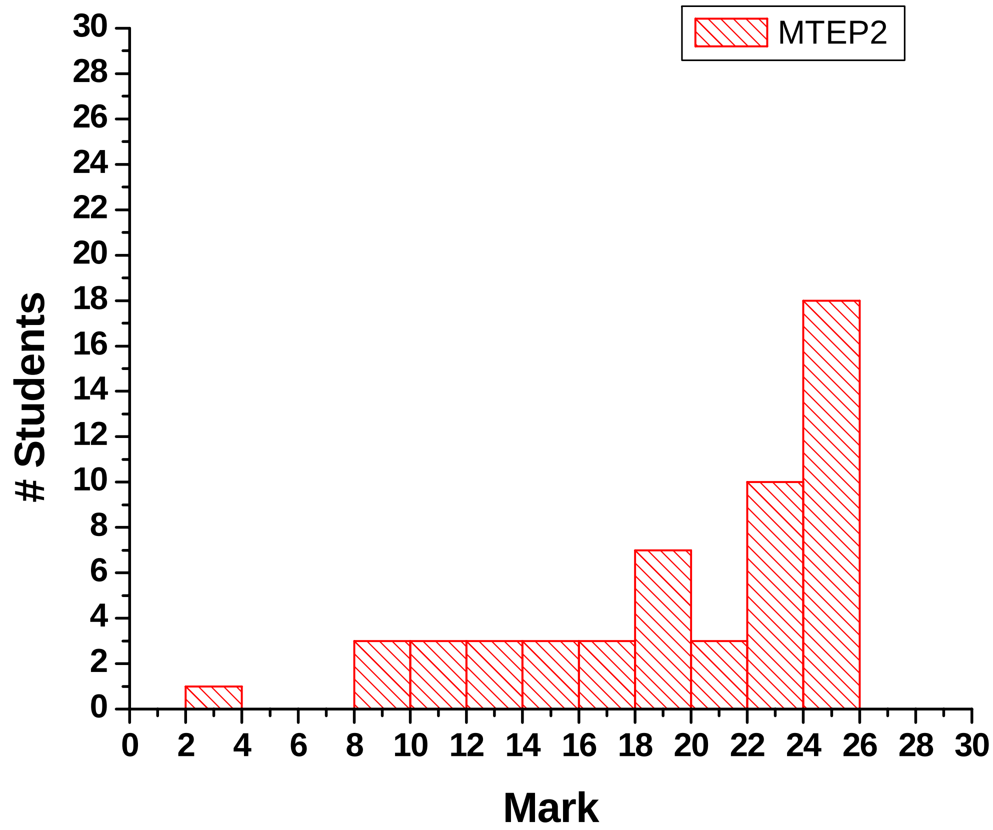
- **Basic phase diagram**
  - **Every component**
- **Hume-Rothery**
  - **Lecture, but more Callister and homework**
- **Microstructure**
  - **Lecture, Callister**
- **Lever rule**
  - **Every component**



- Explain how structure is characterized at different length scales.
- Apply their knowledge of materials in their chosen field of electrical engineering.

Problem 2

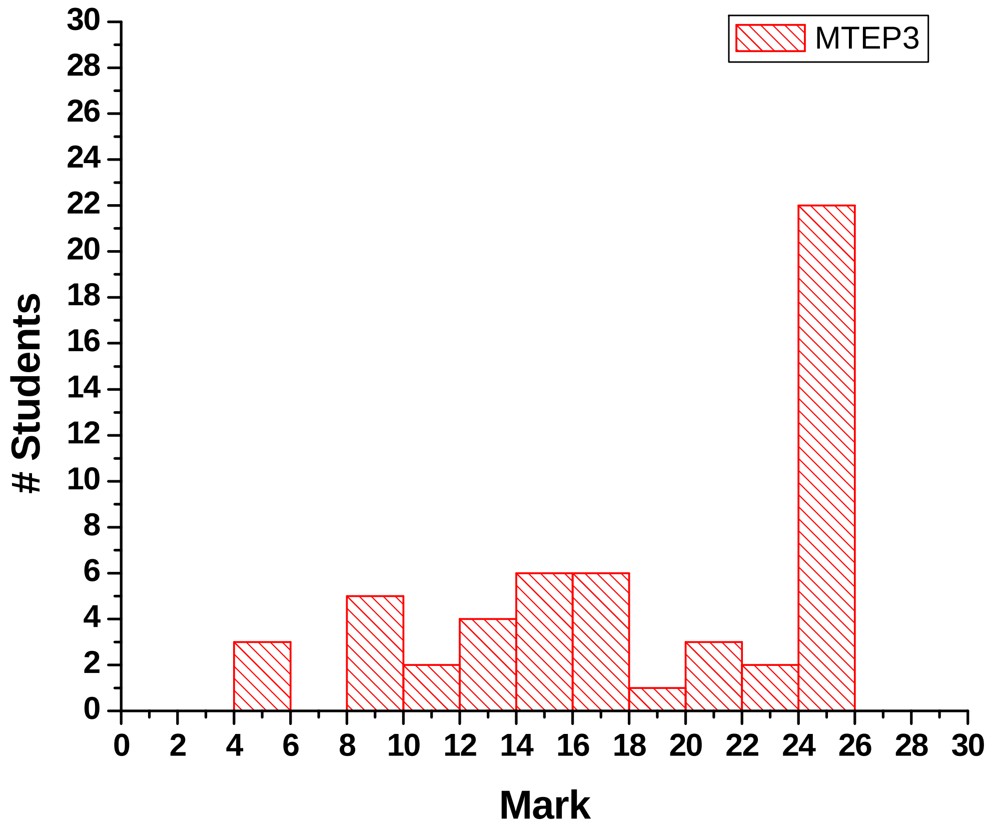
- Complex phase diagram
  - All components
- Conversion of at% to wt%
  - All components



- Apply their knowledge of materials in their chosen field of electrical engineering.

Problem 3

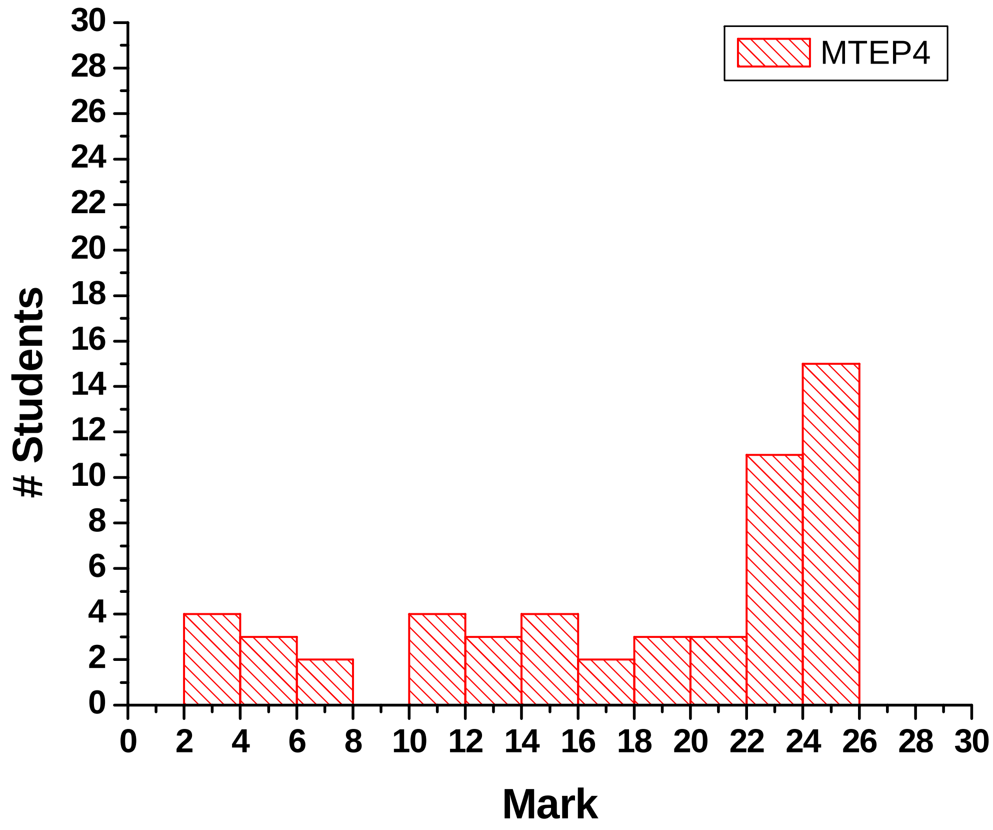
- **Diffusion coefficient**
  - **All components *lecture***
- **erfc(z) problem**
  - **All components (except WebCT)**



- Apply their knowledge of materials in their chosen field of electrical engineering.

Problem 4

- **Crystalline planes**
  - **All components (except WebCT)**
- **Atomic packing (planar density)**
  - **All components *tutorial***



- Explain how structure is characterized at different length scales.
- Apply their knowledge of materials in their chosen field of electrical engineering.

What wasn't tested?

- Recognize links between structure and properties for a variety of materials.
- Illustrate the use of different materials in the field of electrical engineering.

- Classify materials based on their properties.
- Explain how properties are measured.

- Ch. 1 – Materials classification
- Ch. 2 – Bonding

What’s coming?

28-02-07	Mechanical Properties I	6.1-6.12	NO QUIZ
05-03-07	Mechanical Properties II	7.1-7.13	
07-03-07	Mechanical Properties III	8.1-8.15	Tutorial Quizzes
12-03-07	Ceramics	12.1-12.11, 13.1-13.12	
14-03-07	Polymers	Chs. 14 & 15	WebCT Quiz Due 16-03-07
19-03-07	Electrical Properties I	18.1-18.12	
21-03-07	Electrical Properties II	18.12-18.25	Tutorial Quizzes
26-03-07	Magnetic Properties I	20.1-20.5 (Web)	
28-03-07	Magnetic Properties II	20.6-20.12 (Web)	Tutorial Quizzes & WebCT Quiz Due 30-03-07
02-04-07	Thermal Properties	19.1-19.5 (Web)	
04-04-07	Optical Properties	21.1-21.14 (Web)	Tutorial Quizzes
09-04-07	Phase Transformations	10.1-10.4	
11-04-07	*Review / Special Topic*		

24-04-07 **Final Exam**

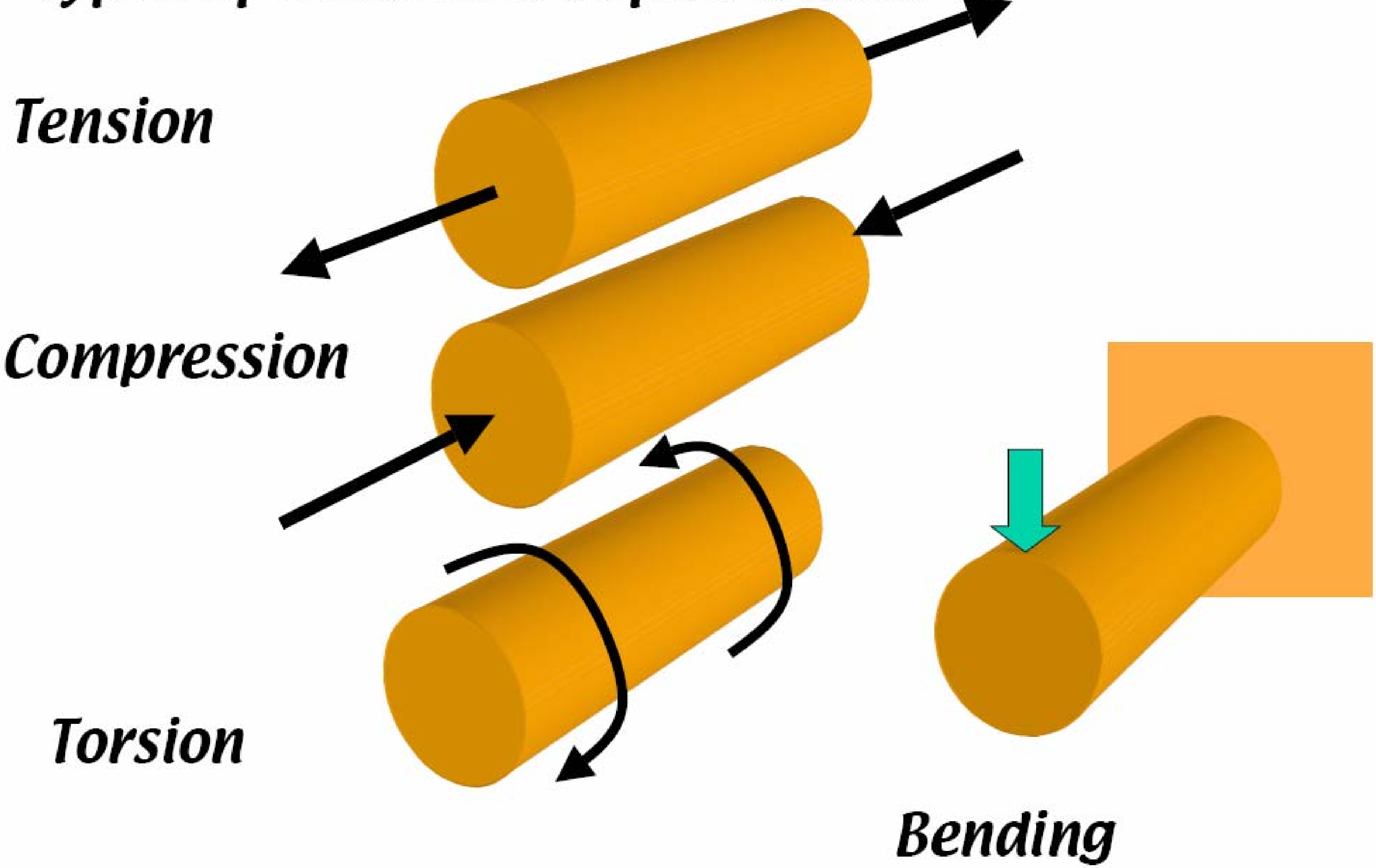
What went wrong?
What helped, what didn’t?
How did you study?

What could we do to help?

Changes that might help…

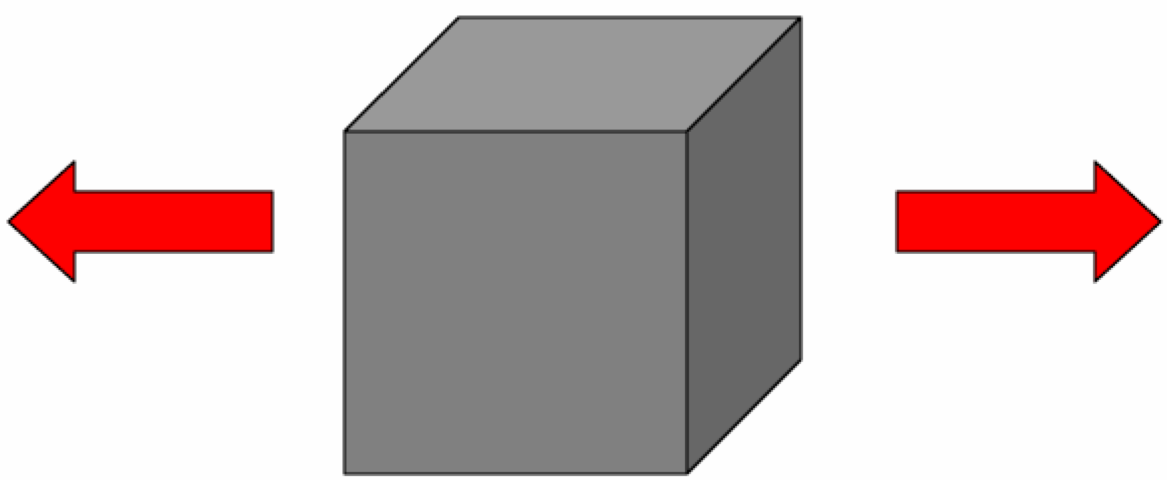
1. Fewer tutorial quizzes
   a. PRO – Allows for more learning in the tutorials
   b. CON – Fewer chances to bring up your quiz average
2. Same number of quizzes. Drop the lowest score (note: a zero from being absent not dropped)
   a. PRO – Helps everyone bring their quiz average up
   b. CON – Amount of learning in tutorials stays the same.

Types of loads and deformations



EXTREME example

Tensile loading of iron

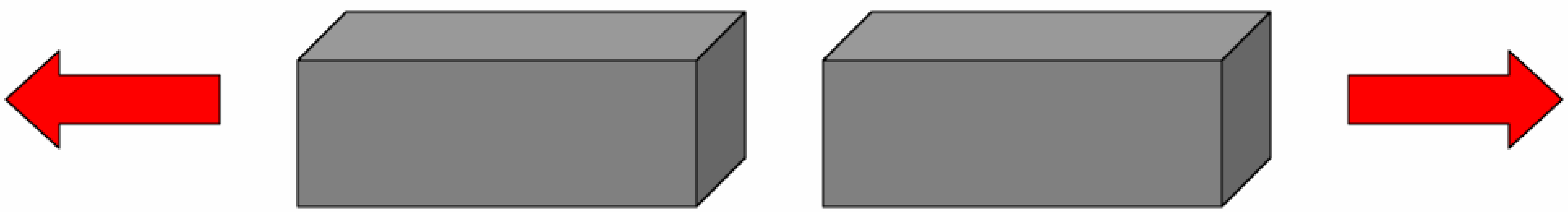


EXTREME example

Tensile loading of iron

EXTREME example

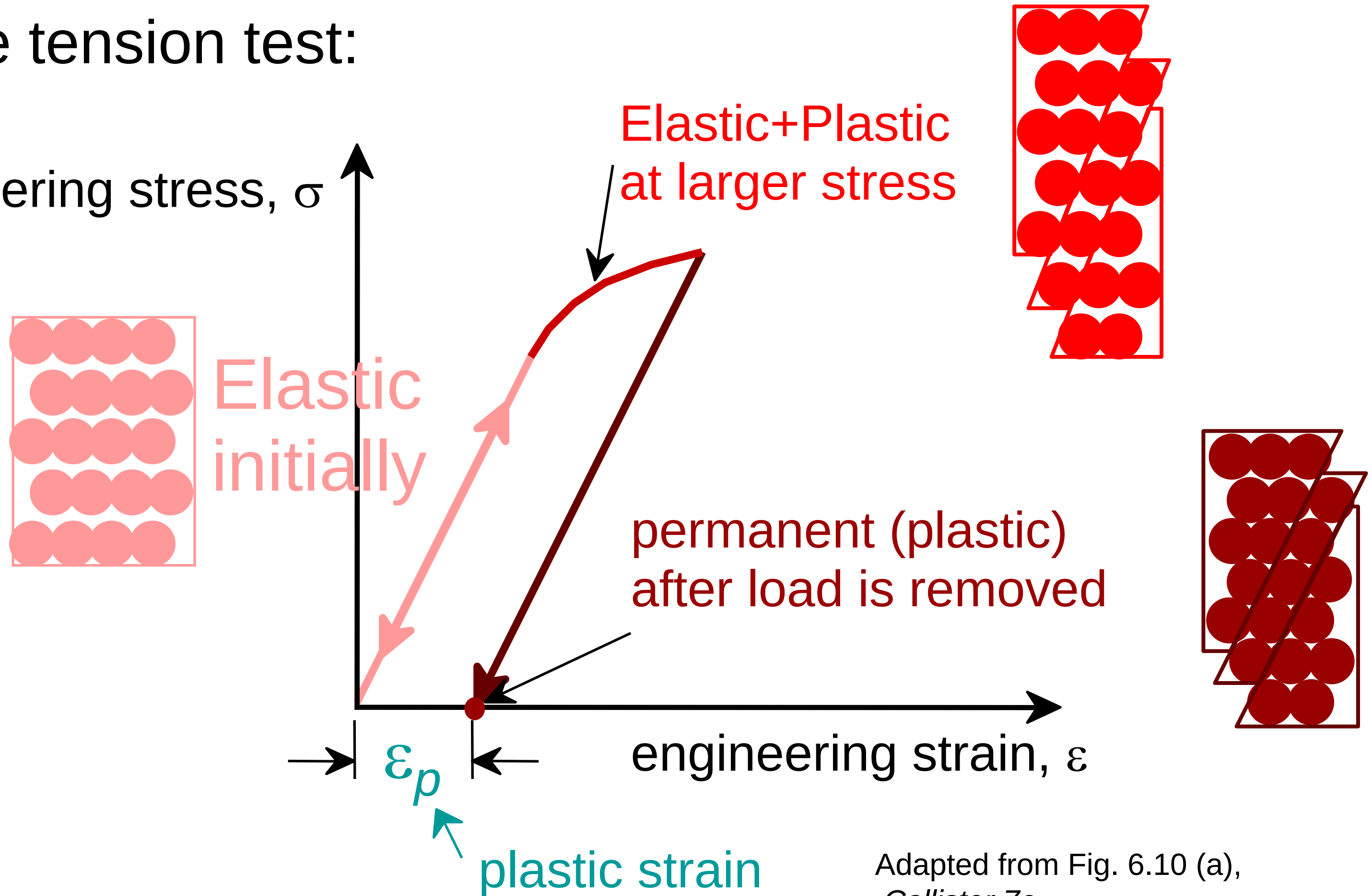
Tensile loading of iron



Plastic (Permanent) Deformation

(at lower temperatures, i.e. $T < T_{melt}/3$)

- Simple tension test:

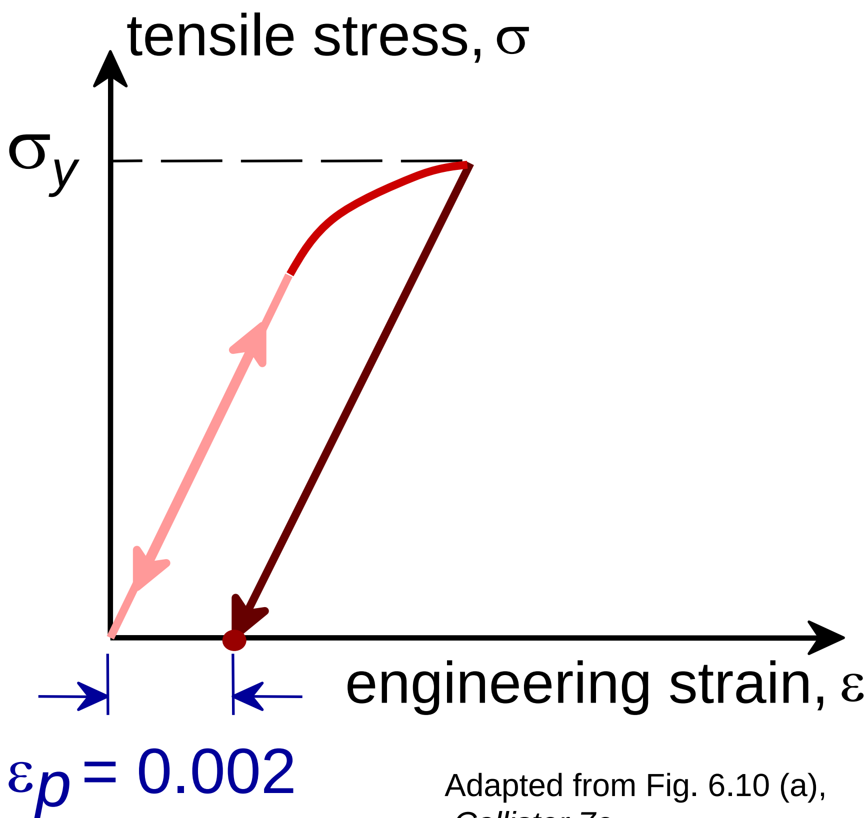


Adapted from Fig. 6.10 (a), *Callister 7e.*

Yield Strength, σ_y

- **Stress at which *noticeable* plastic deformation has occurred.**

when $\varepsilon_p = 0.002$



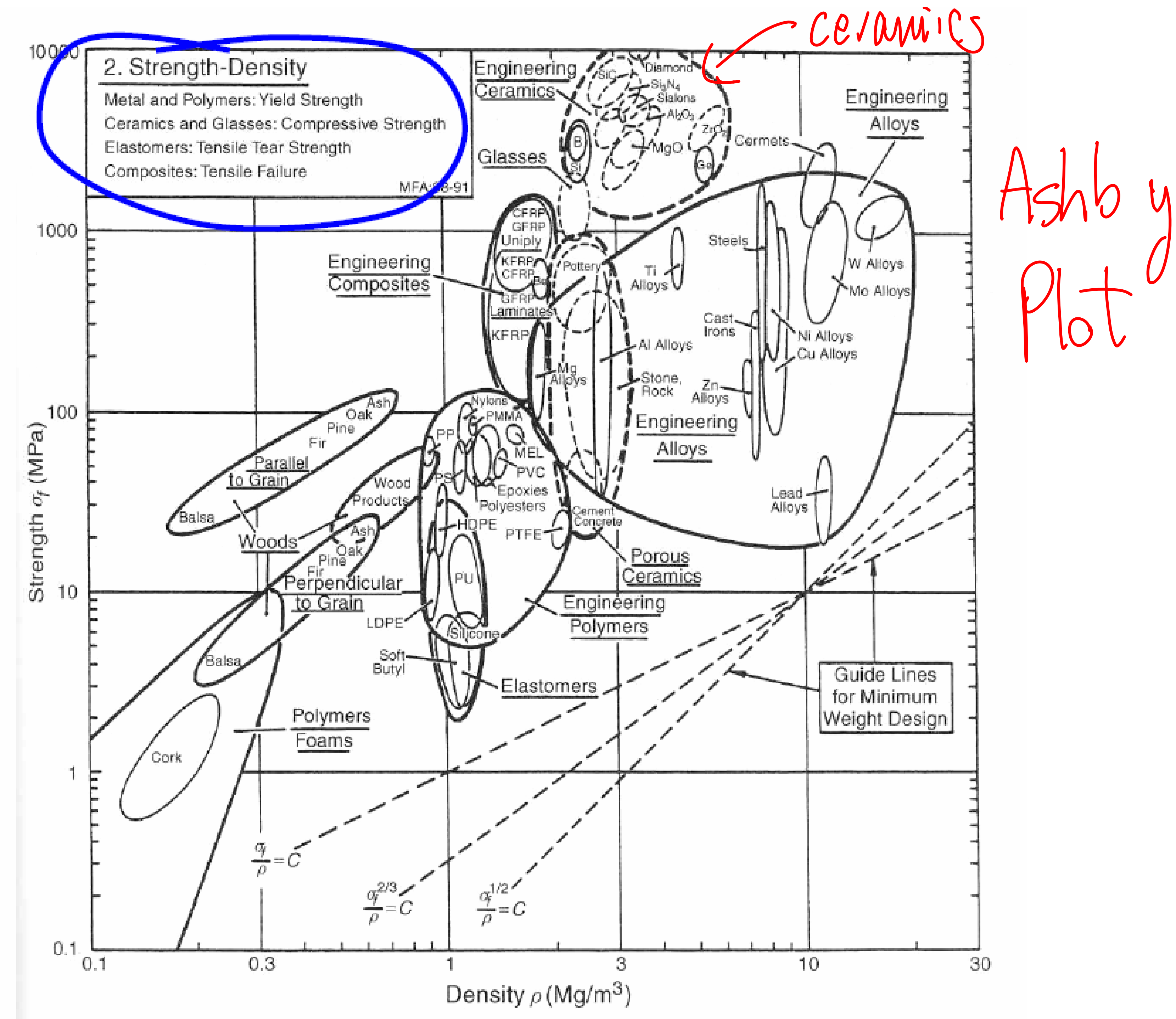
Adapted from Fig. 6.10 (a), *Callister 7e.*

σ_y = yield strength

Note: for 2 inch sample

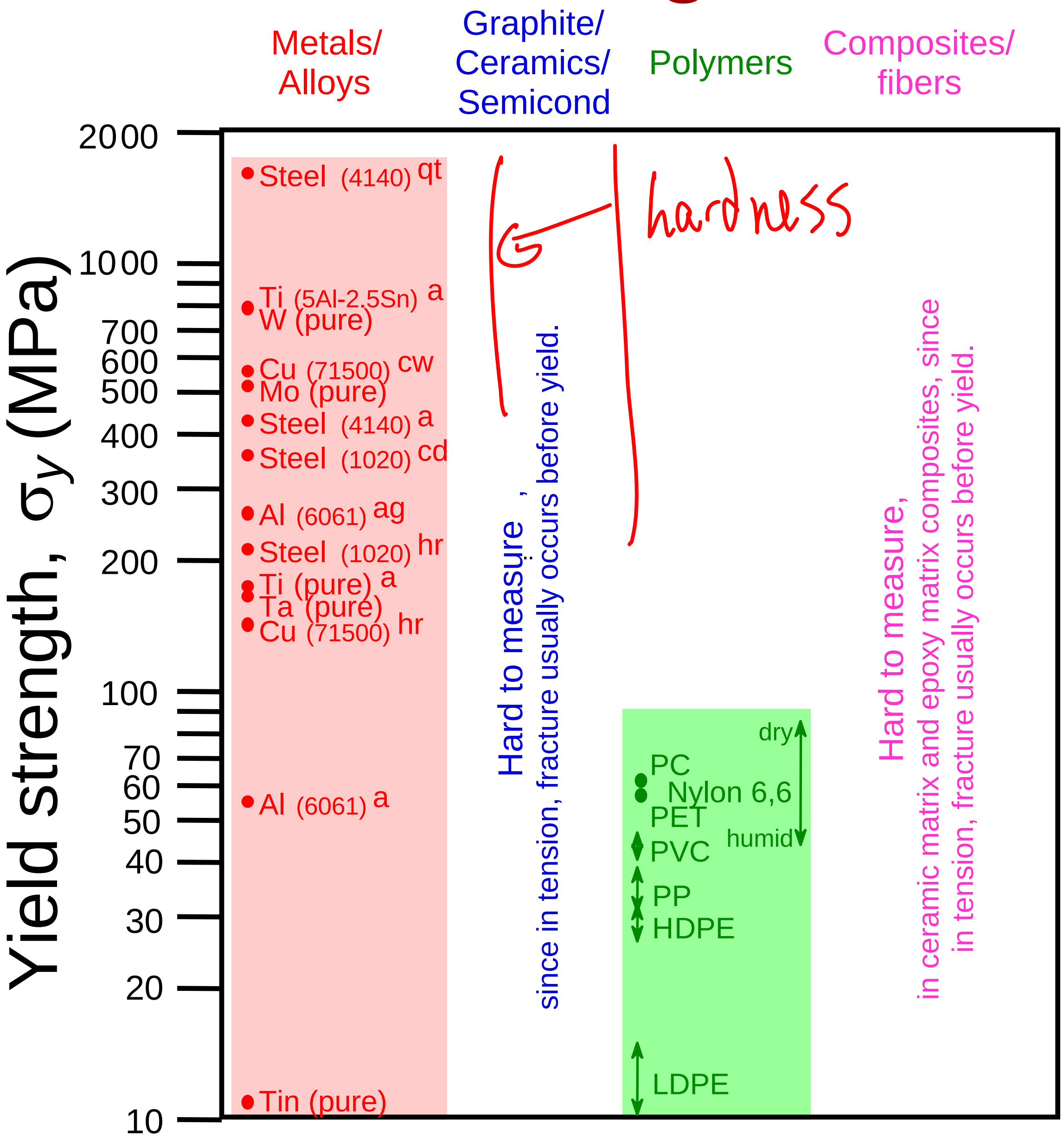
$\varepsilon = 0.002 = \Delta z/z$

$\therefore \Delta z = 0.004$ in



2. Strength-Density
Metal and Polymers: Yield Strength
Ceramics and Glasses: Compressive Strength
Elastomers: Tensile Tear Strength
Composites: Tensile Failure
MFA:88-91
ceramics
Ashby Plot
Engineering Ceramics
Diamond
SiC
Si_3N_4
Sialons
Al_2O_3
ZrO_2
MgO
B
Si
Ge
Glasses
Cermets
Engineering Alloys
Steels
W Alloys
Mo Alloys
Ti Alloys
Ni Alloys
Cu Alloys
Cast Irons
Al Alloys
Mg Alloys
Stone, Rock
Zn Alloys
Lead Alloys
Pottery
Be
Engineering Composites
CFRP
GFRP
Uniply
KFRP
Laminates
Nylons
PMMA
PP
PS
MEL
PVC
Epoxies
Polyesters
HDPE
PTFE
PU
LDPE
Silicone
Soft Butyl
Elastomers
Engineering Polymers
Cement Concrete
Porous Ceramics
Ash
Oak
Pine
Fir
Parallel to Grain
Balsa
Woods
Wood Products
Perpendicular to Grain
Polymers Foams
Cork
Guide Lines for Minimum Weight Design
$\frac{\sigma_f}{\rho} = C$
$\frac{\sigma_f^{2/3}}{\rho} = C$
$\frac{\sigma_f^{1/2}}{\rho} = C$
Strength σ_f (MPa)
Density ρ (Mg/m^3)
10000
1000
100
10
1
0.1
0.3
3
30

Yield Strength : Comparison



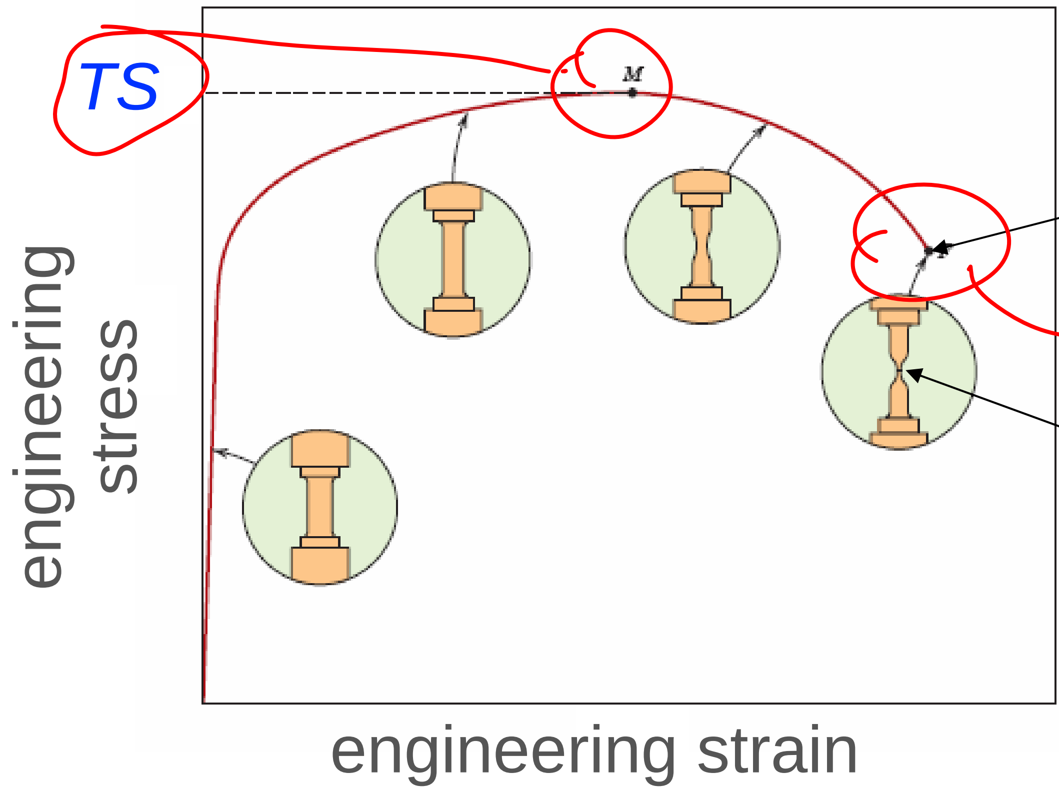
Room *T* values

Based on data in Table B4, *Callister 7e*.

a = annealed
hr = hot rolled
ag = aged
cd = cold drawn
cw = cold worked
qt = quenched & tempered

Tensile Strength, TS

- Maximum stress on engineering stress-strain curve.



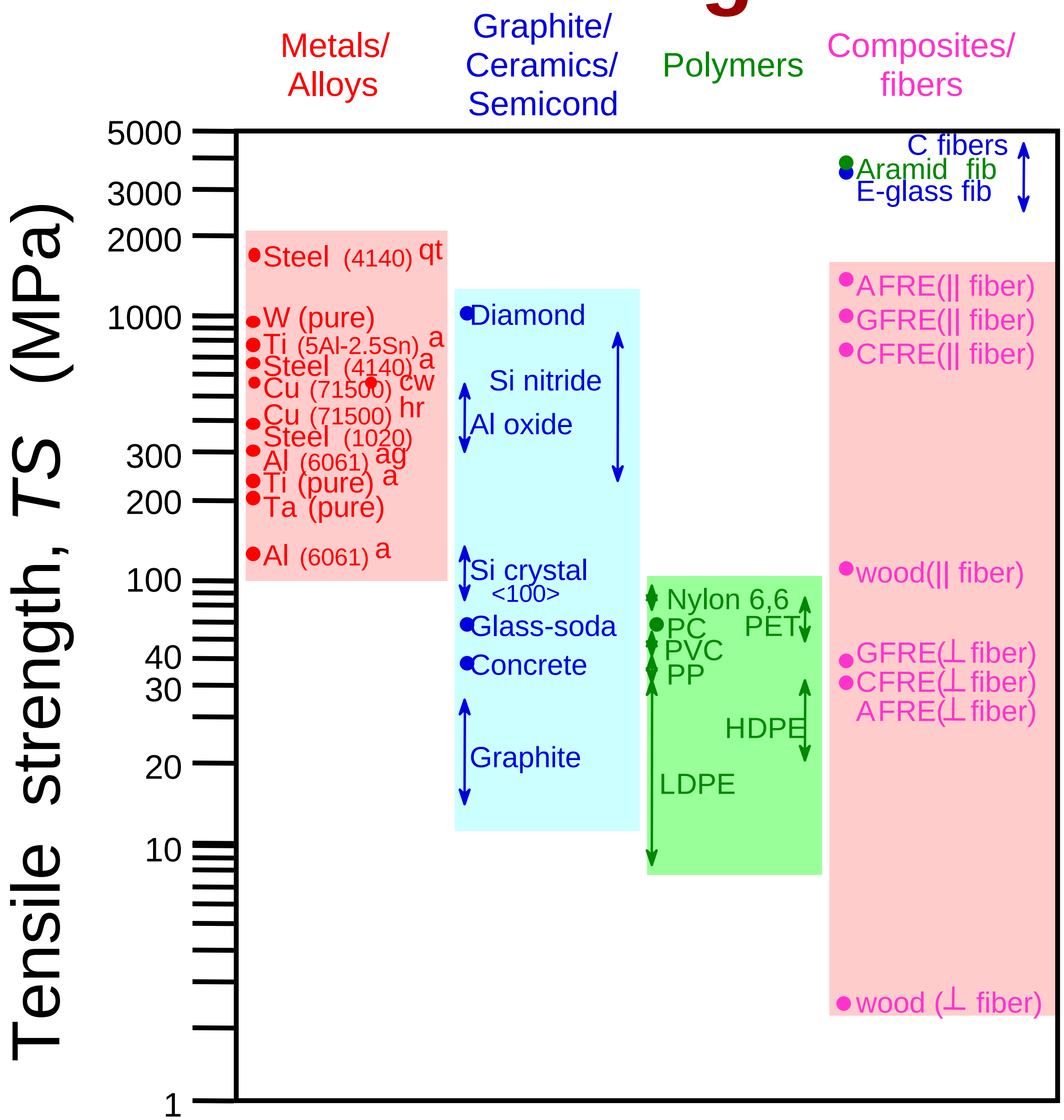
Adapted from Fig. 6.11, *Callister 7e.*

F = fracture or ultimate strength

Neck – acts as stress concentrator

- Metals: occurs when noticeable necking starts.
- Polymers: occurs when polymer backbone chains are aligned and about to break.

Tensile Strength : Comparison



Room Temp. values

Based on data in Table B4, *Callister 7e*.

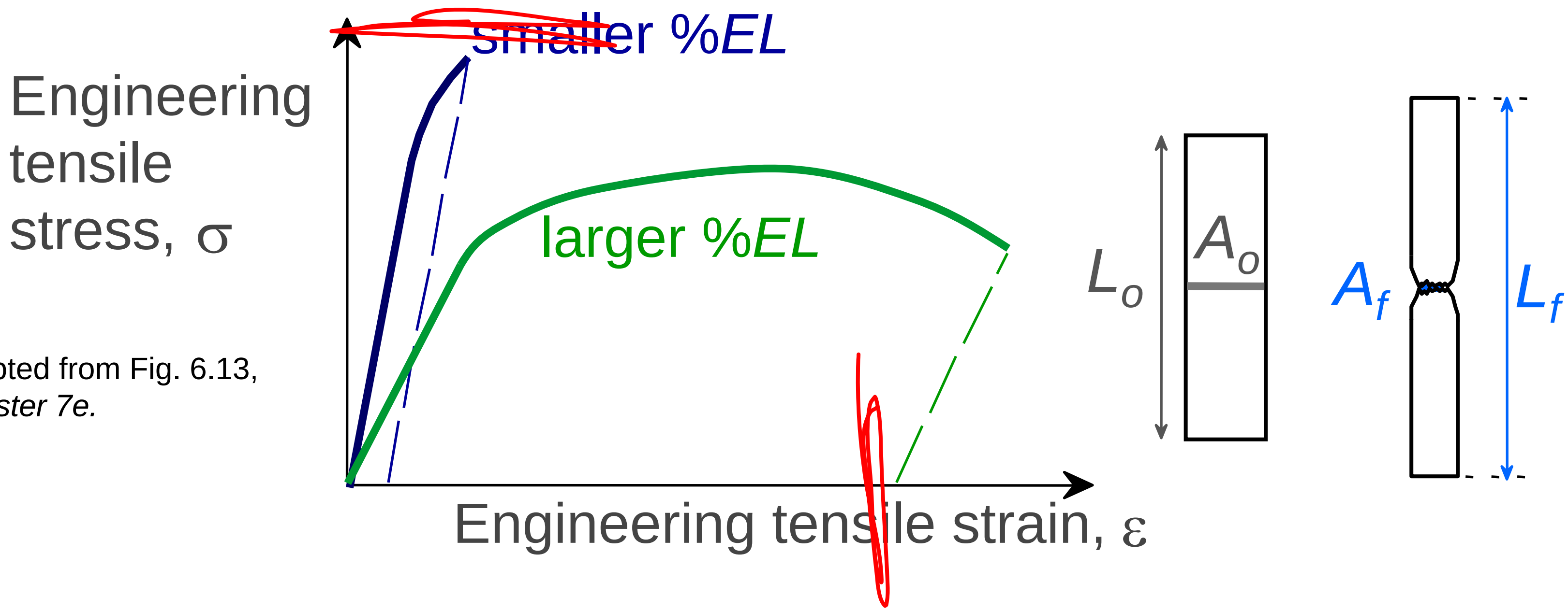
a = annealed
hr = hot rolled
ag = aged
cd = cold drawn
cw = cold worked
qt = quenched & tempered

AFRE, GFRE, & CFRE = aramid, glass, & carbon fiber-reinforced epoxy composites, with 60 vol% fibers.

Ductility

- Plastic tensile strain at failure:

$$\%EL = \frac{L_f - L_o}{L_o} \text{ x } 100$$



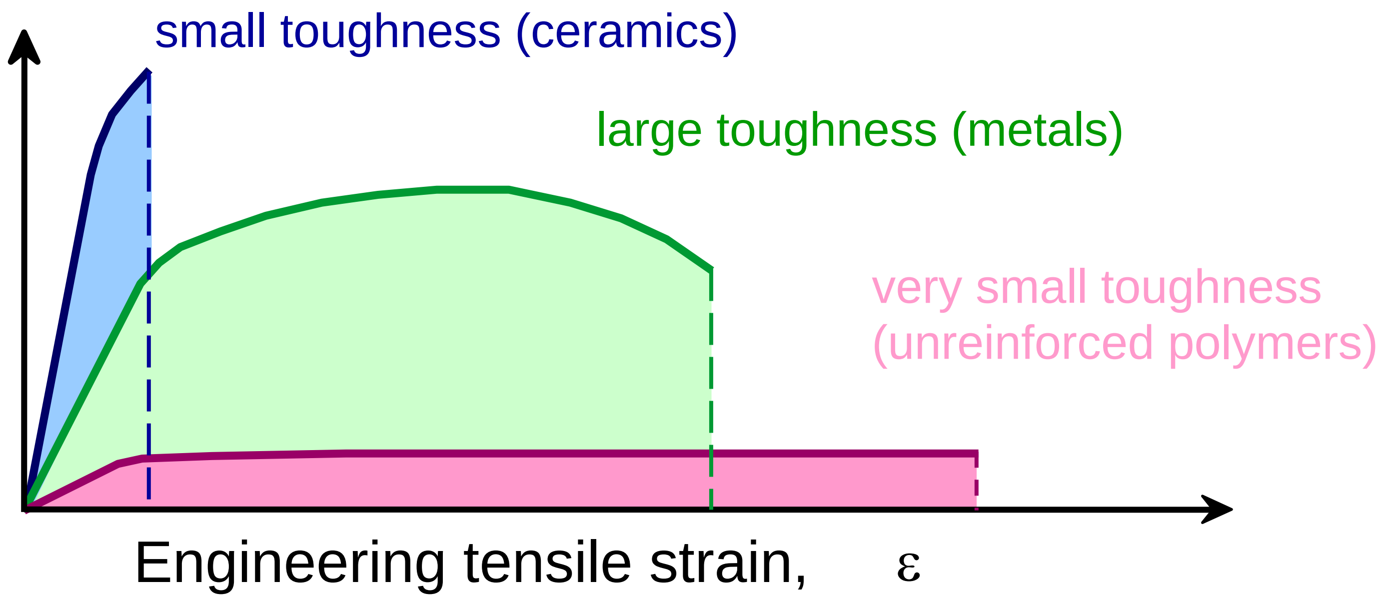
Adapted from Fig. 6.13, *Callister 7e.*

- Another ductility measure:

$$\%RA = \frac{A_o - A_f}{A_o} \text{ x } 100$$

Toughness

- Energy to break a unit volume of material
- Approximate by the area under the stress-strain curve.



Adapted from Fig. 6.13, *Callister 7e.*

Brittle fracture: elastic energy
Ductile fracture: elastic + plastic energy

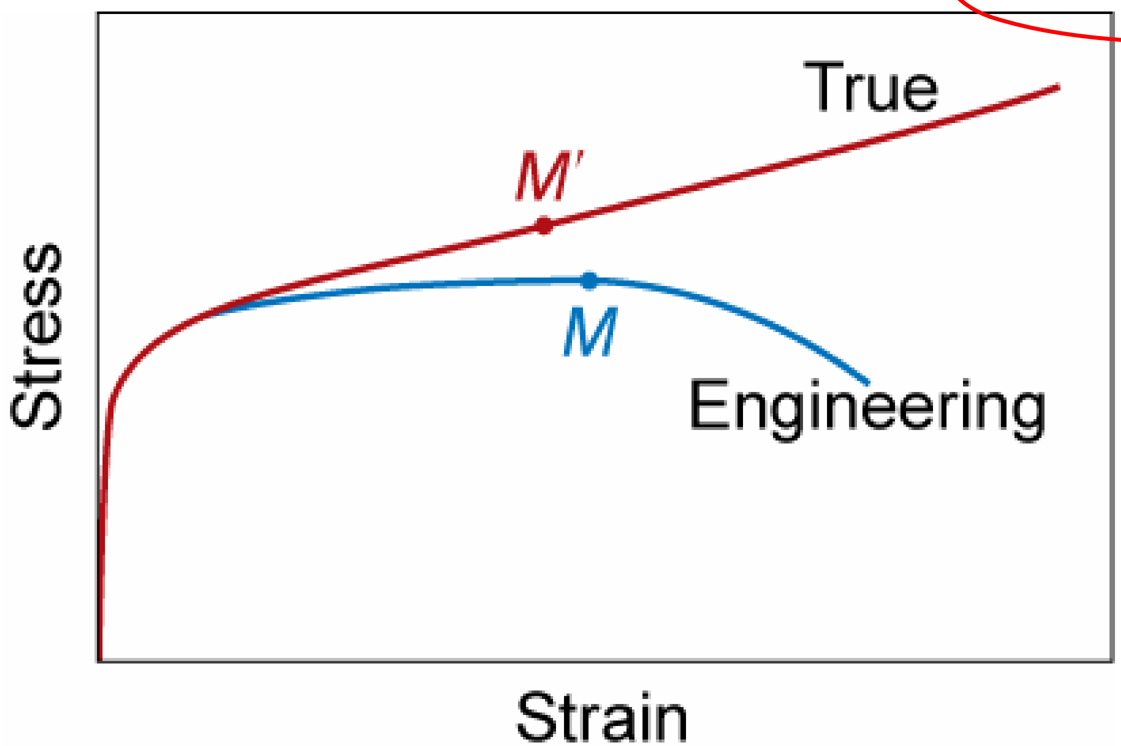
True Stress & Strain

Note: S.A. changes when sample stretched

- True stress $\sigma_T = F/A_i$ → instantaneous
- True Strain $\varepsilon_T = \ln(\ell_i/\ell_o)$ instantaneous

$$\boxed{\begin{aligned}\sigma_T &= \sigma(1+\varepsilon)\\ \varepsilon_T &= \ln(1+\varepsilon)\end{aligned}}$$

not really important

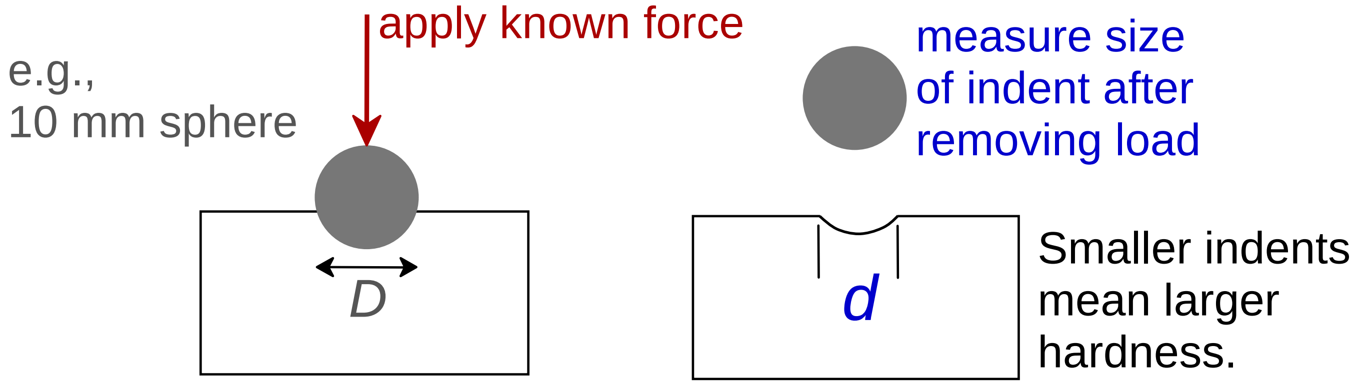


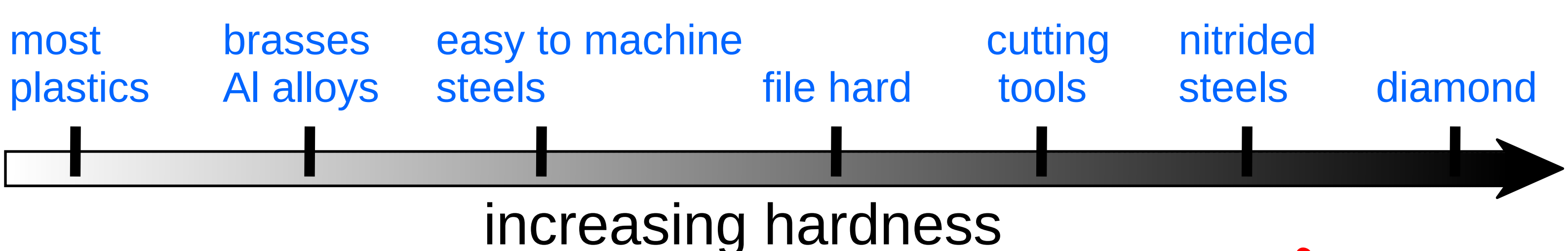
Adapted from Fig. 6.16, *Callister 7e.*

Hardness

- Resistance to permanently indenting the surface.
- Large hardness means:
  --resistance to plastic deformation or cracking in compression.
  --better wear properties.

$$H = \frac{F}{A}$$

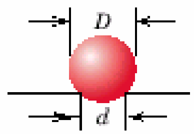
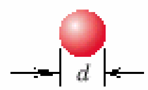
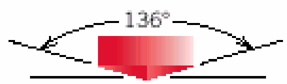
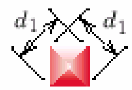
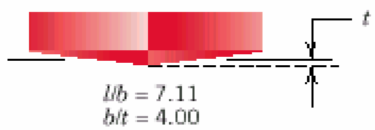
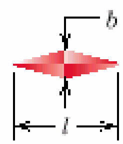
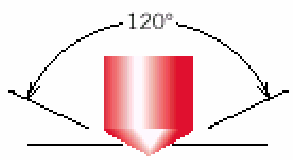
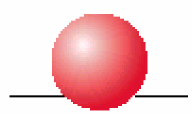
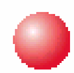
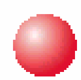




vague

Hardness: Measurement

Table 6.5 **Hardness Testing Techniques**

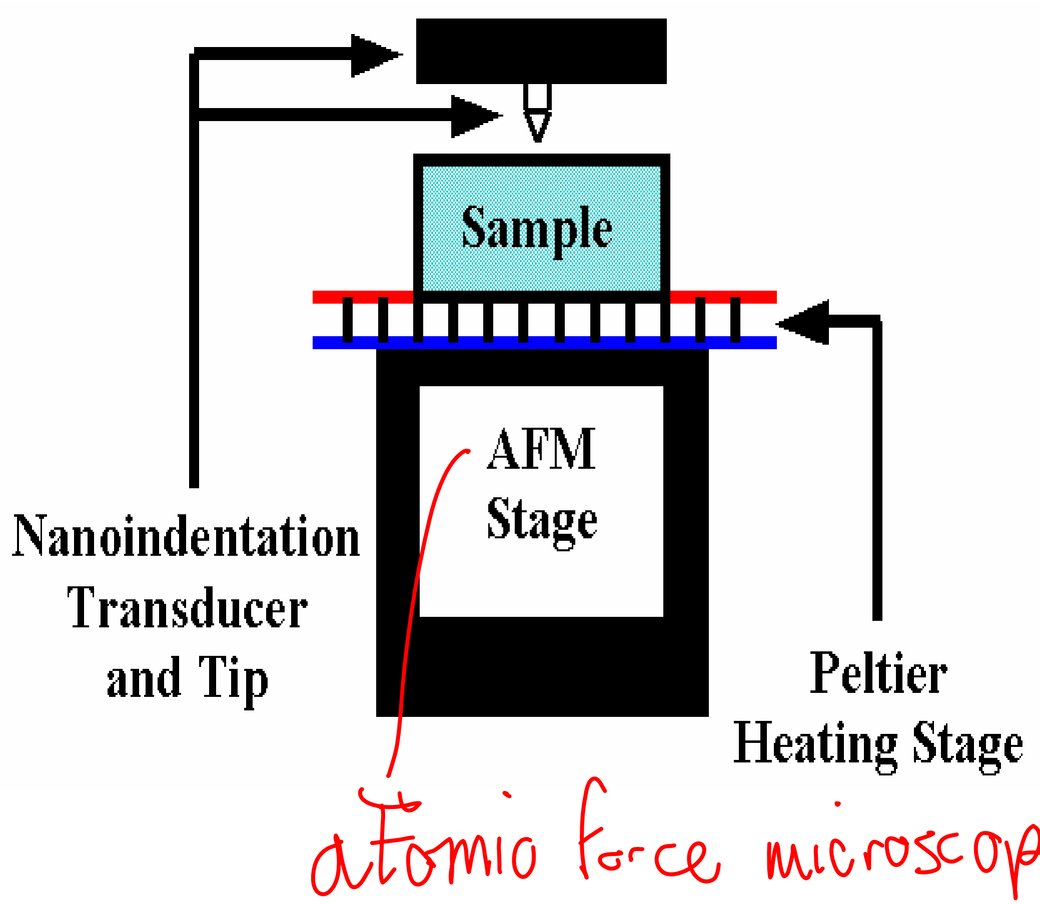
		Shape of Indentation			
Test	***Indenter***	***Side View***	***Top View***	***Load***	***Formula for Hardness Number***[a]
Brinell	10-mm sphere of steel or tungsten carbide			P	$\mathrm{HB} = \dfrac{2P}{\pi D[D - \sqrt{D^2 - d^2}]}$
Vickers microhardness	Diamond pyramid			P	$\mathrm{HV} = 1.854P/d_1^2$
Knoop microhardness	Diamond pyramid			P	$\mathrm{HK} = 14.2P/l^2$
Rockwell and Superficial Rockwell	Diamond cone; $\frac{1}{16}$, $\frac{1}{8}$, $\frac{1}{4}$, $\frac{1}{2}$ in. diameter steel spheres	 	 	60 kg, 100 kg, 150 kg } Rockwell 15 kg, 30 kg, 45 kg } Superficial Rockwell	

[a] For the hardness formulas given, P (the applied load) is in kg, while D, d, d_1, and l are all in mm.

Source: Adapted from H. W. Hayden, W. G. Moffatt, and J. Wulff, *The Structure and Properties of Materials,* Vol. III, *Mechanical Behavior.* Copyright © 1965 by John Wiley & Sons, New York. Reprinted by permission of John Wiley & Sons, Inc.

Better tool for “small” materials

Nanoindentation



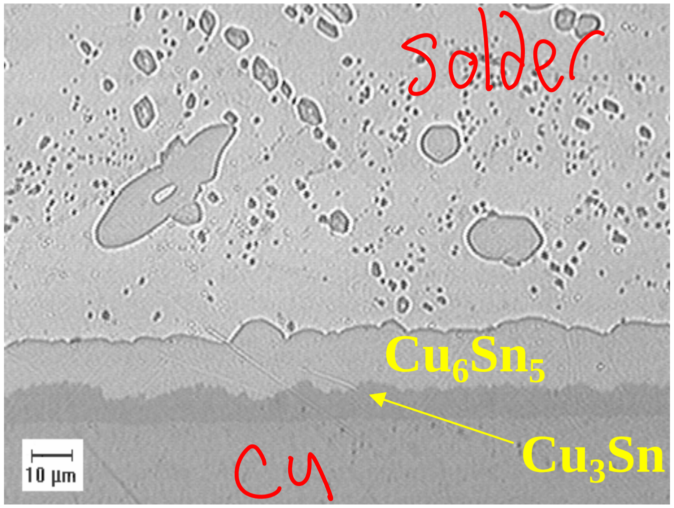
- *Loading:* 1 μN to 10 mN with 100 nN sensitivity
- *Tip displacement:* 5 μm full scale with 0.2 nm sensitivity
- *Indenter geometry:* Three-sided pyramid (Berkovich), 150 nm tip radius
- *Heating stage:* 15^{o}C to 150^{o}C
- *Imaging:* Coupled to atomic force microscope (AFM)

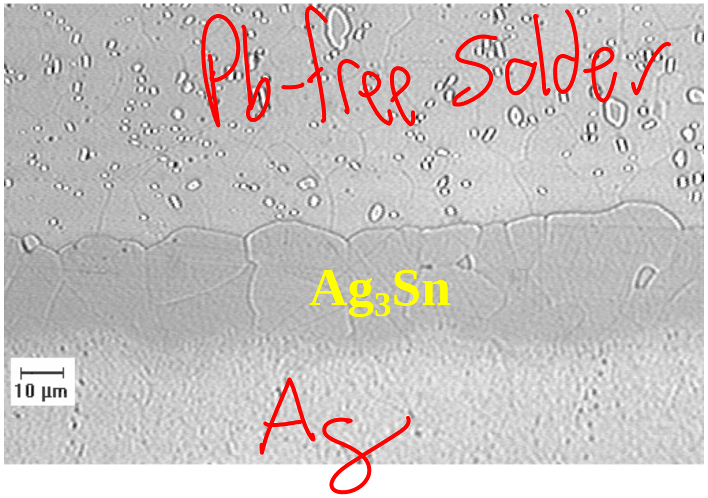
Nanoindentation

Ag_3Sn, Cu_3Sn, and Cu_6Sn_5

- **Samples formed by solid state aging of diffusion couples**

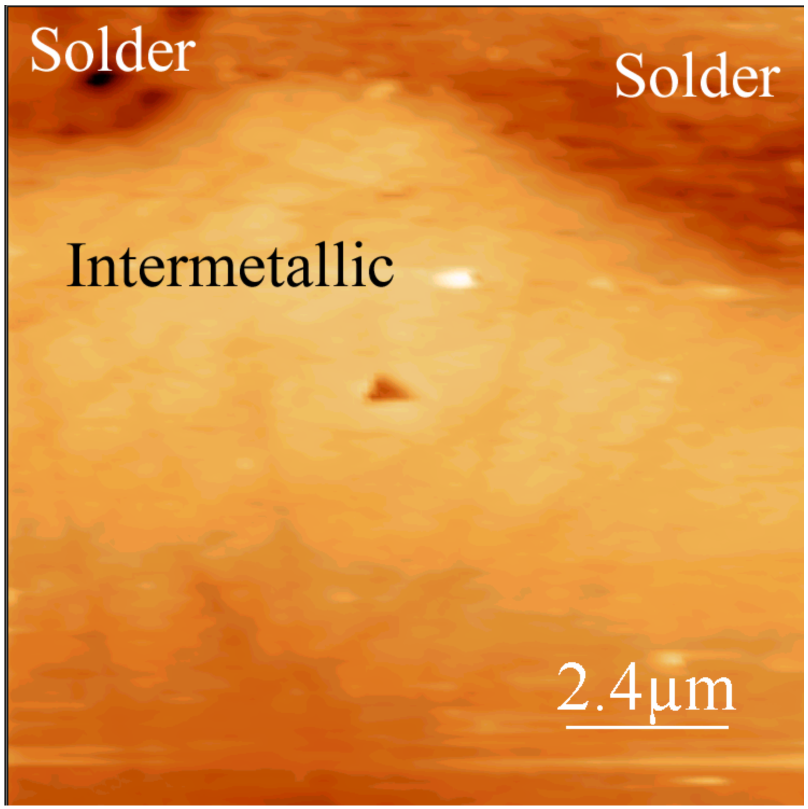
- **Layers of 5 μm or more obtained**





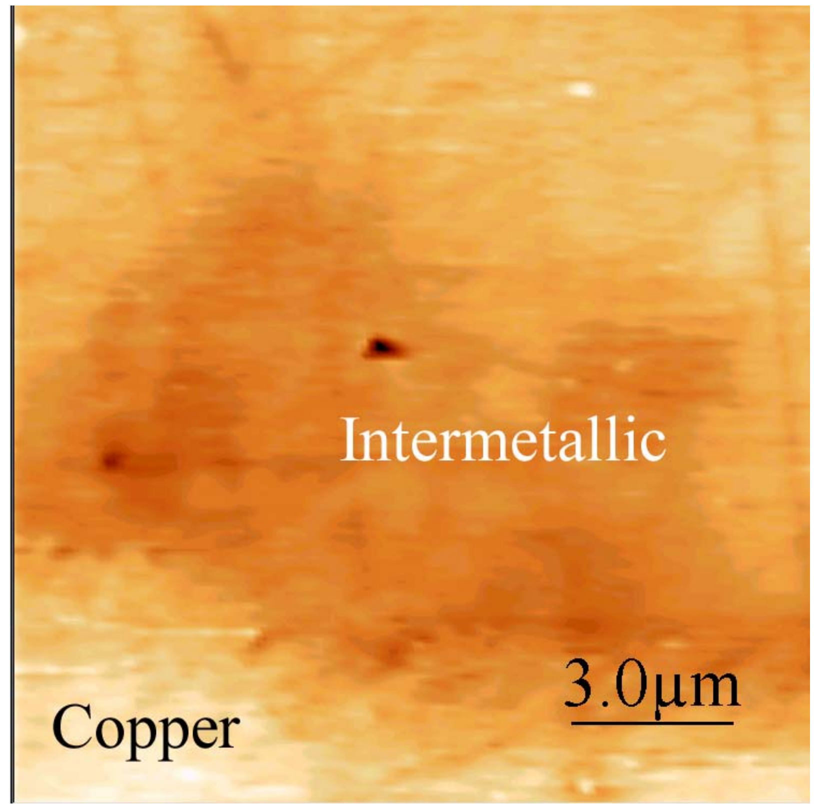
Nano-Indents in Intermetallic Layers

AFM

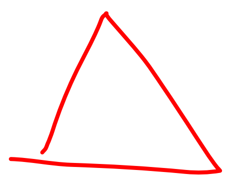


Cu_6Sn_5

AFM



Cu_3Sn



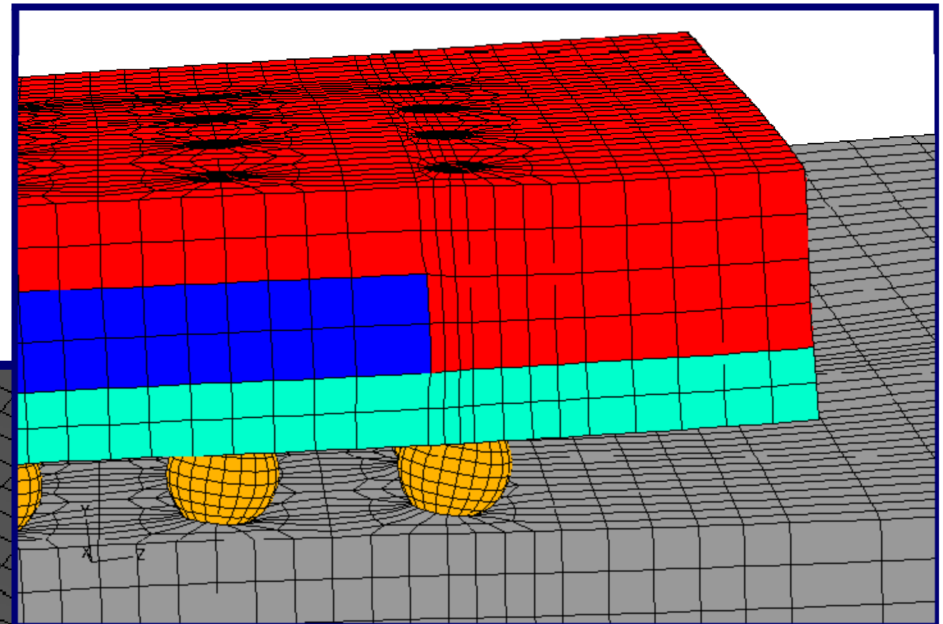
Berkovich

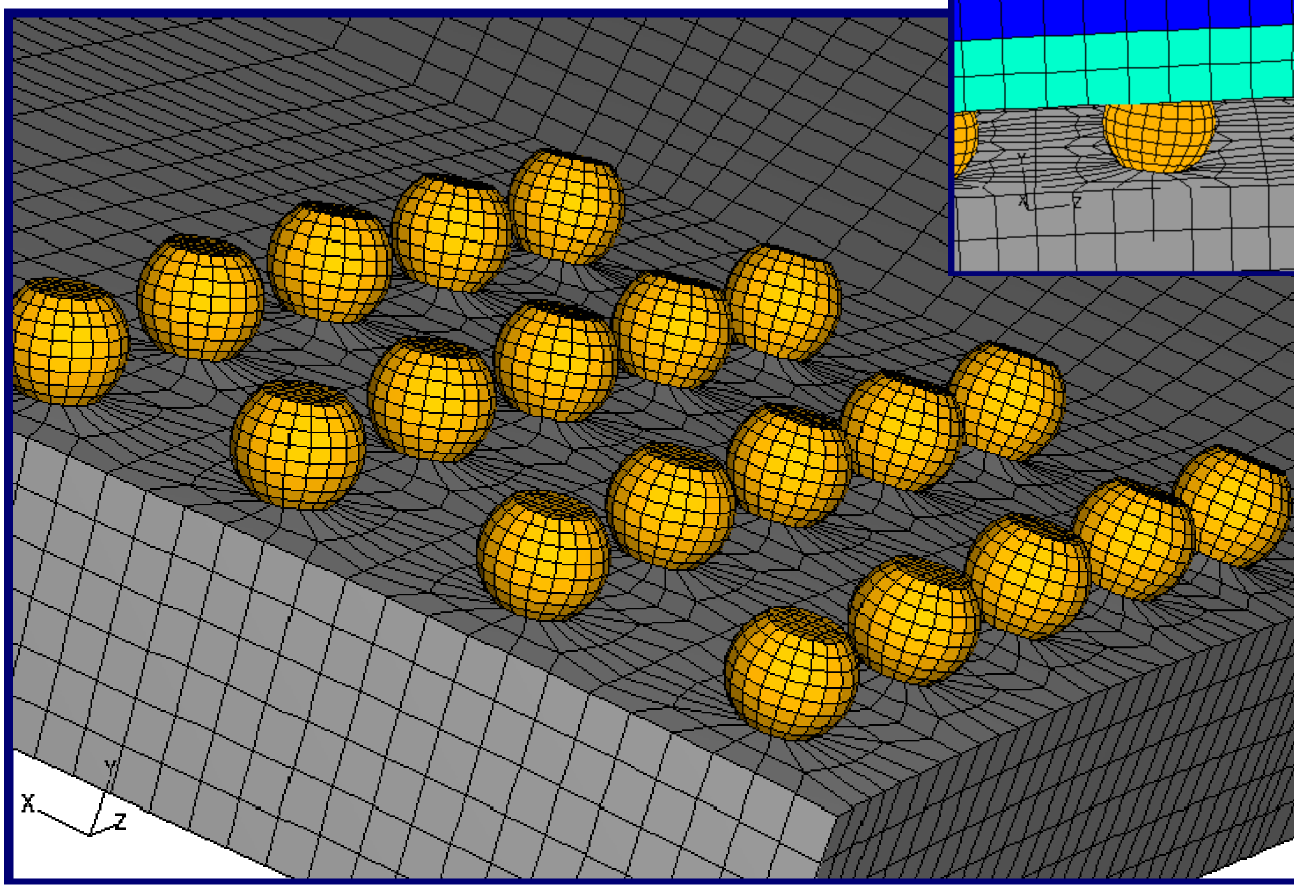
Nanoindentation

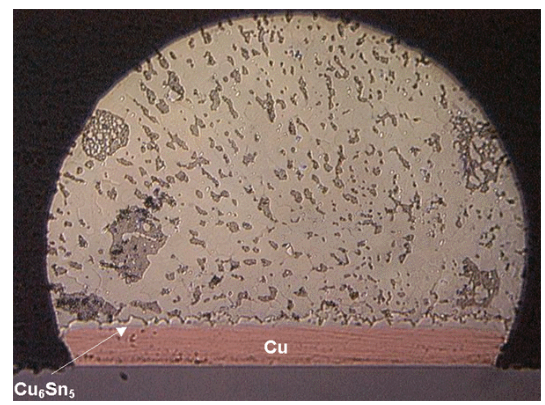
Solder Joint Materials

Material	~~Reduced~~ Modulus (GPa)	Hardness (GPa)
Ag_3Sn	91±5	2.9±0.2
Cu_6Sn_5	120±5	6.5±0.3
Cu_3Sn	140±6	6.2±0.4
Cu	124±7	1.7±0.2
Sn	49±5	0.11±0.05
Sn-Ag-Cu solder	45±8	0.16±0.06

Reliability Modeling
Pb-Sn Solders







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What was not covered from Ch. 6

- Don’t worry about
  - ‘Resilience’
  - The gory details for hardness tests
  - Section 6.11
- Do worry about
  - Rest of chapter, including anelasticity
  - What a hardness test tells you

Vickers

Next time

- More about what actually happens in the material
- Strengthening (Ch. 7)
- More on behavior for specific materials
- Failure (Ch. 8)
  - Fracture
  - Creep
  - Fatigue

Hardness: Measurement

- Rockwell
  - No major sample damage
  - Each scale runs to 130 but only useful in range 20-100.
  - Minor load 10 kg
  - Major load 60 (A), 100 (B) & 150 (C) kg
    - A = diamond, B = 1/16 in. ball, C = diamond

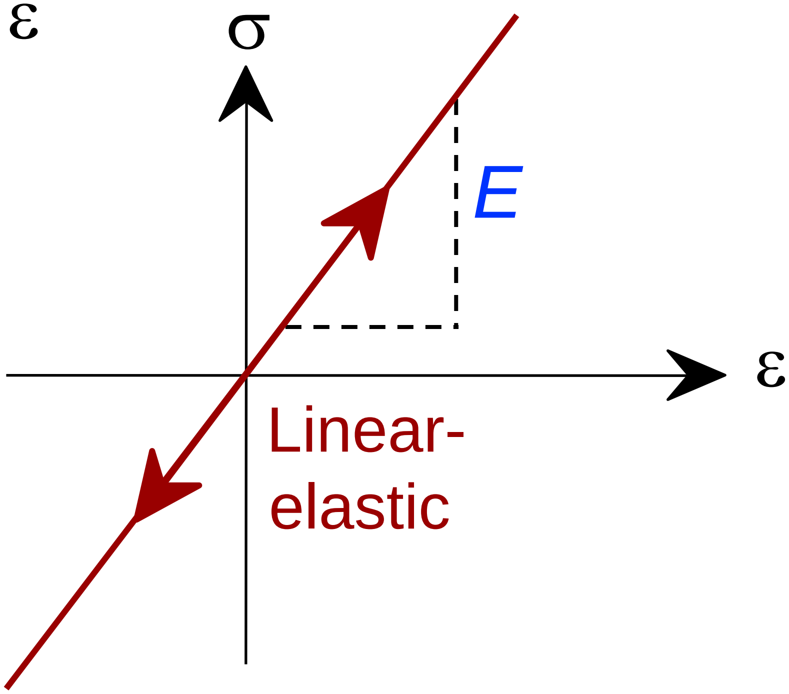
- HB = Brinell Hardness
  - *TS* (psia) = 500 x HB
  - *TS* (MPa) = 3.45 x HB

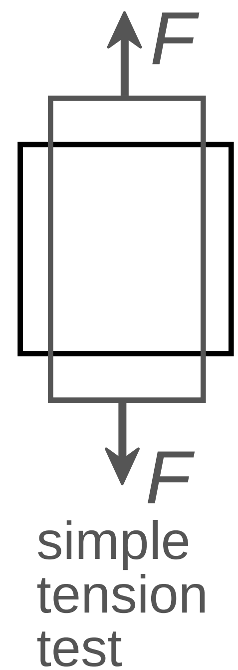
Linear Elastic Properties

- **Modulus of Elasticity, *E*:**
  (also known as Young's modulus)

- **Hooke's Law:**

$$\sigma = E\,\varepsilon$$

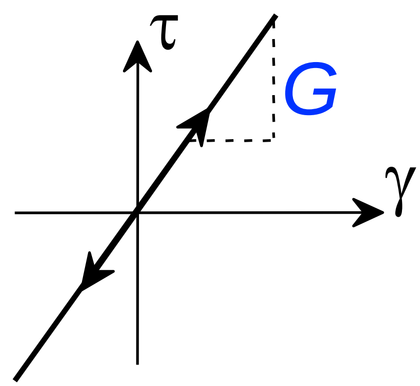


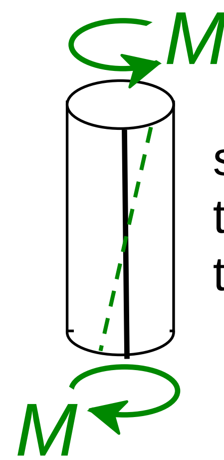


Other Elastic Properties

- **Elastic Shear modulus, *G*:**

$$\tau = G\gamma$$

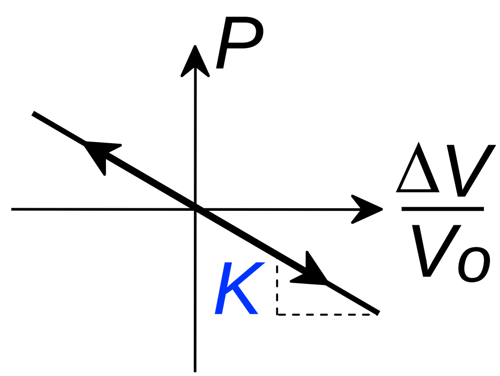


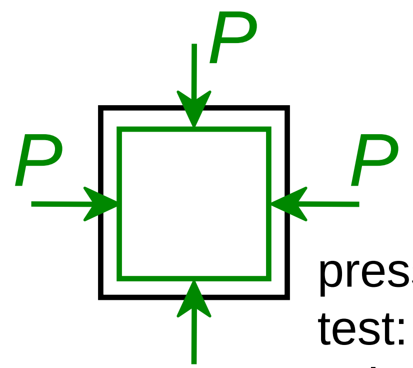


simple torsion test

- **Elastic Bulk modulus, K:**

$$P = -K\frac{\Delta V}{V_o}$$





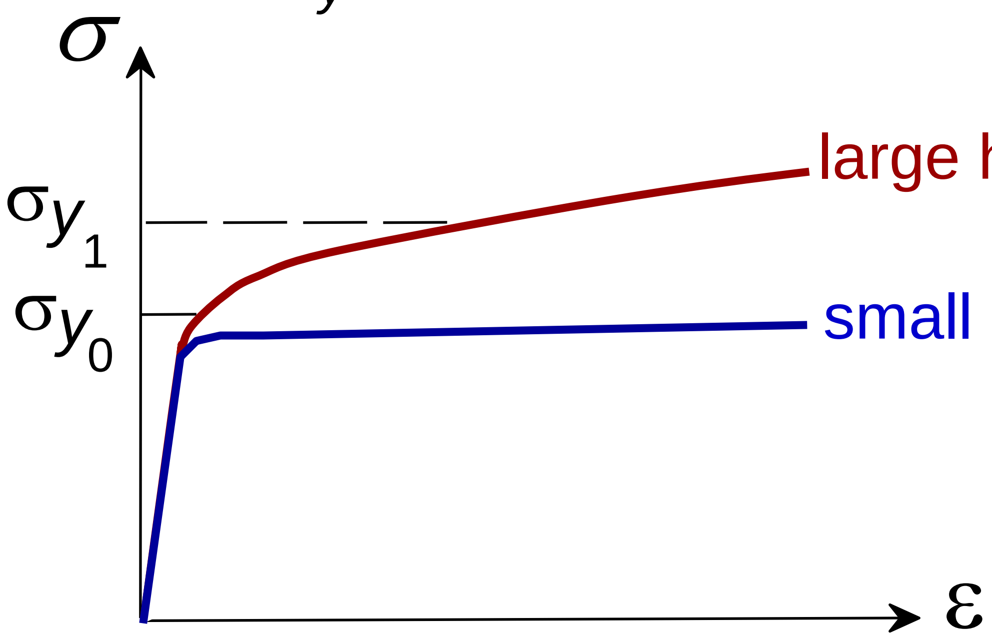
pressure test: Init. vol $=V_o$. Vol chg. $=\Delta V$

- **Special relations for isotropic materials:**

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

Hardening

- An increase in σ_y due to plastic deformation.



- Curve fit to the stress-strain response:

$$\boxed{\sigma_T} = K\left(\boxed{\varepsilon_T}\right)^n$$

hardening exponent:
n = 0.15 (some steels)
to n = 0.5 (some coppers)

"true" stress (F/A)

"true" strain: $\ln(L/L_o)$

Summary

- Stress and strain: These are size-independent measures of load and displacement, respectively.
- Elastic behavior: This reversible behavior often shows a linear relation between stress and strain. To minimize deformation, select a material with a large elastic modulus (E or G).
- Plastic behavior: This permanent deformation behavior occurs when the tensile (or compressive) uniaxial stress reaches σ_y.
- Toughness: The energy needed to break a unit volume of material.
- Ductility: The plastic strain at failure.