MSE 170: Introduction to Materials Science & Engineering

Course Objective...

Introduce fundamental concepts in MSE

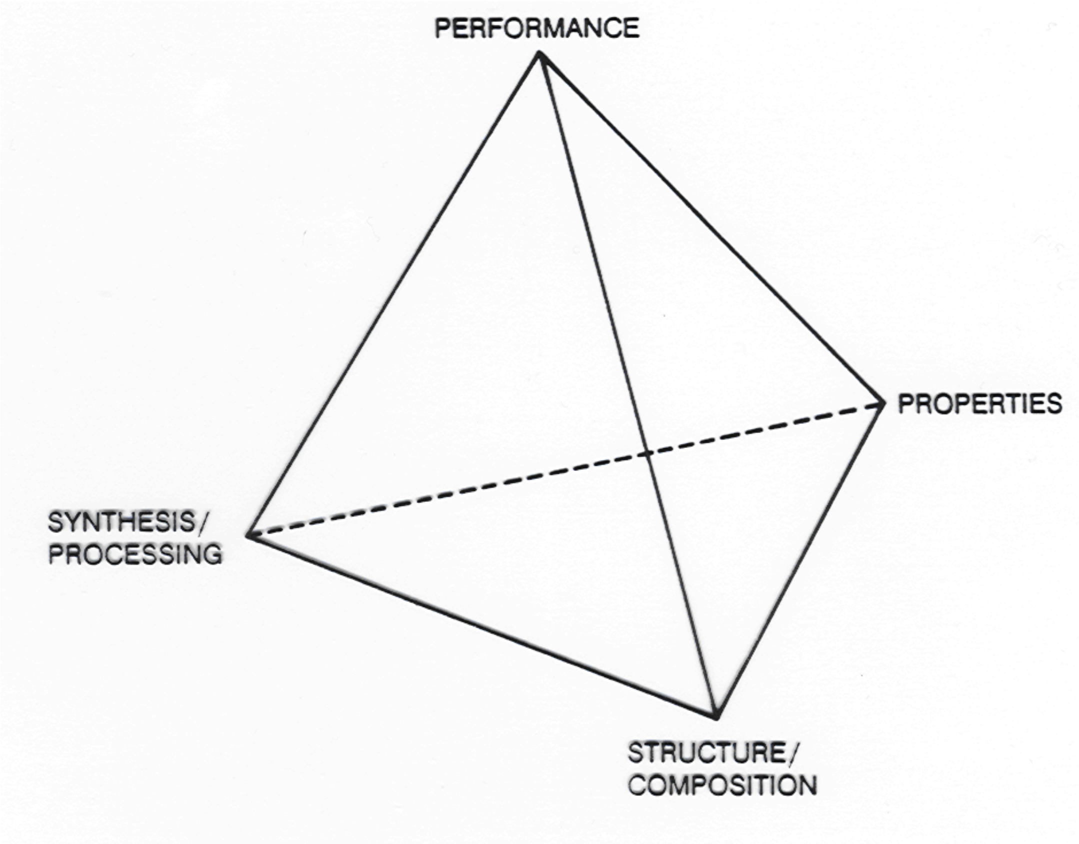
You will learn about:

- material structure
- how structure dictates properties
- how processing can change structure

This course will help you to:

- use materials properly
- realize new design opportunities with materials

What does Materials Science and Engineering do?



LECTURES

Lecturer: Fumio S. Ohuchi

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Time/Location: Mue 153, M/W/Th

COURSE MATERIAL

Required text:

- ***Materials Science and Engineering: An Introduction*** **W.D. Callister, Jr., 6th edition, John Wiley and Sons, Inc. (2003). Both book and accompanying CD-ROM are needed.**

Optional Material:

GRADING

Midterm	**25%**
Tentatively scheduled for:	July 17 (Thursday)
Material covered:	TBA
Final	**35%**
Homework/Labs	**15%**
Project	**25%**

CHAPTER 1: MATERIALS SCIENCE & ENGINEERING

Materials are...

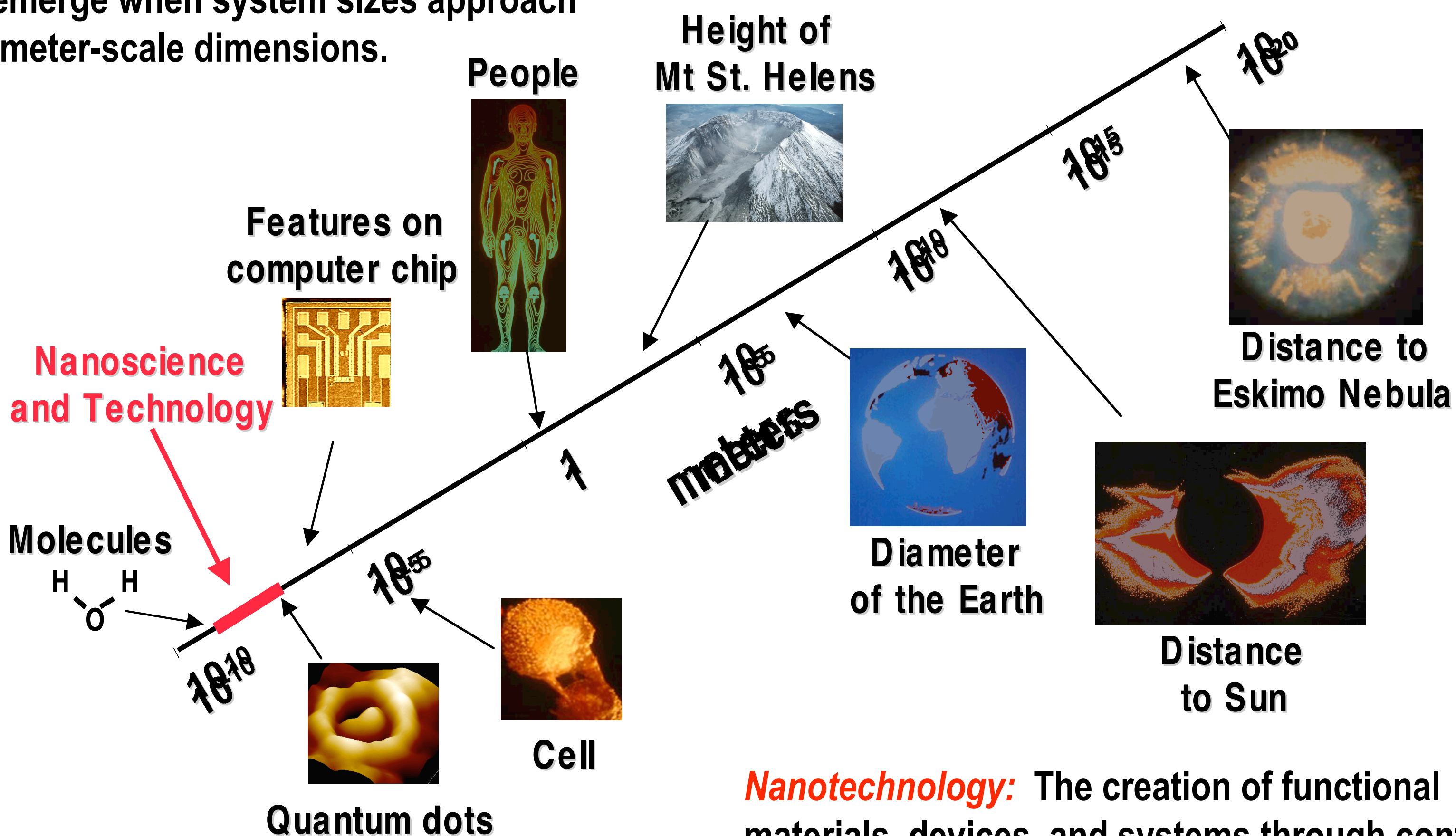
engineered structures...not blackboxes!

Structure...has many dimensions...

Structural feature	Dimension (m)
atomic bonding	$< 10^{-10}$
missing/extra atoms	10^{-10}
crystals (ordered atoms)	10^{-8}-10^{-1}
second phase particles	10^{-8}-10^{-4}
crystal texturing	$> 10^{-6}$

Nanoscience and Nanotechnology

Nanoscience: The study of the many unique and potentially useful properties that emerge when system sizes approach nanometer-scale dimensions.



Nanotechnology: The creation of functional materials, devices, and systems through control of matter at the scale of 1 to 100 nanometers, and the exploitation of novel properties and phenomena at the same scale.

The Materials Selection Process

1. Pick Application ⟶ Determine required Properties

   Properties: mechanical, electrical, thermal, magnetic, optical, deteriorative.

2. Properties ⟶ Identify candidate Material(s)

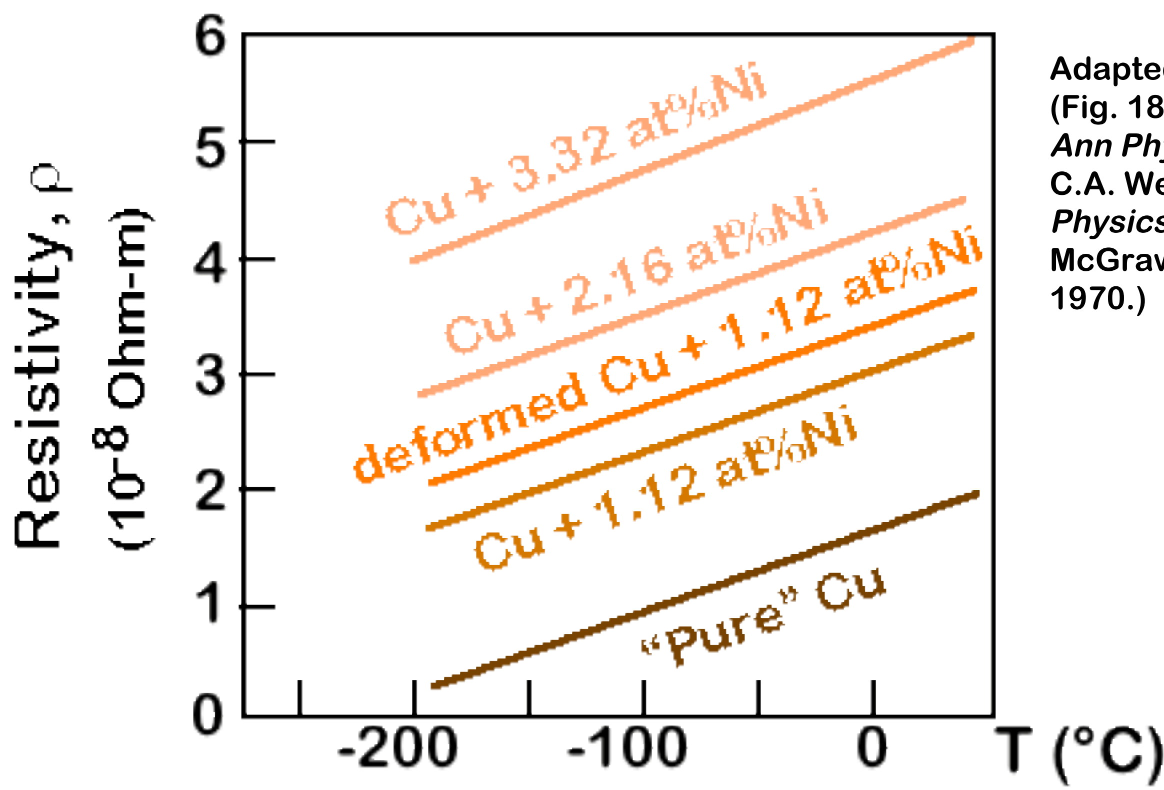
   Material: structure, composition.

3. Material ⟶ Identify required Processing

   Processing: changes *structure* and overall *shape*
   ex: casting, sintering, vapor deposition, doping
   forming, joining, annealing.

ELECTRICAL

- Electrical Resistivity of Copper:



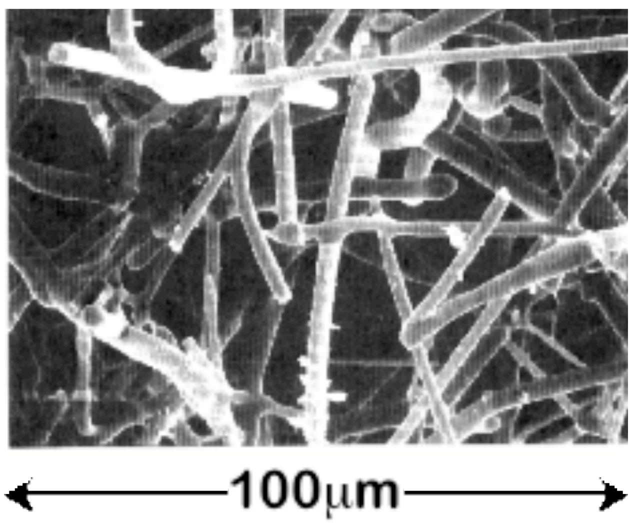
Adapted from Fig. 18.8, *Callister 6e.* (Fig. 18.8 adapted from: J.O. Linde, *Ann Physik* 5, 219 (1932); and C.A. Wert and R.M. Thomson, *Physics of Solids*, 2nd edition, McGraw-Hill Company, New York, 1970.)

- Adding "impurity" atoms to Cu increases resistivity.
- Deforming Cu increases resistivity.

THERMAL

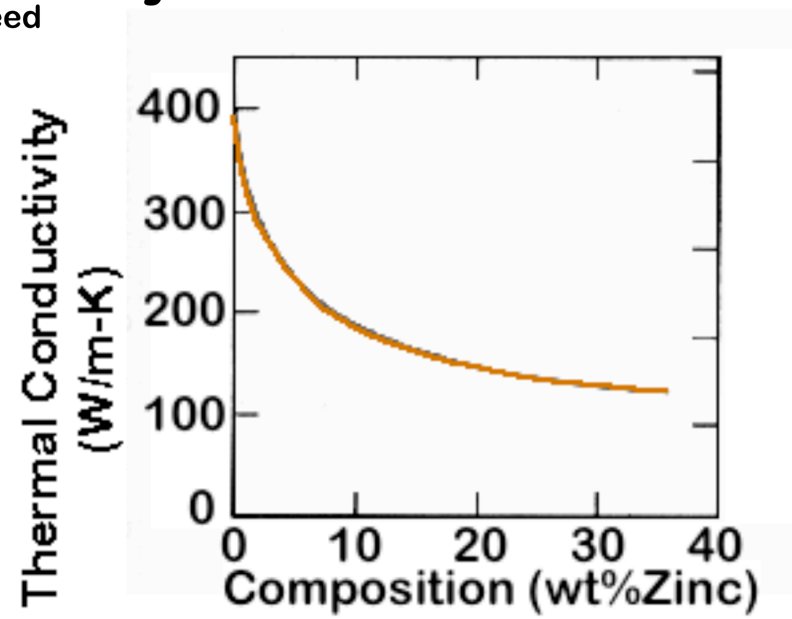
- Space Shuttle Tiles:
  --Silica fiber insulation offers low heat conduction.

Fig. 19.0, *Callister 6e.* (Courtesy of Lockheed Missiles and Space Company, Inc.)



Adapted from Fig. 19.4W, *Callister 6e.* (Courtesy of Lockheed Aerospace Ceramics Systems, Sunnyvale, CA) (Note: "W" denotes fig. is on CD-ROM.)

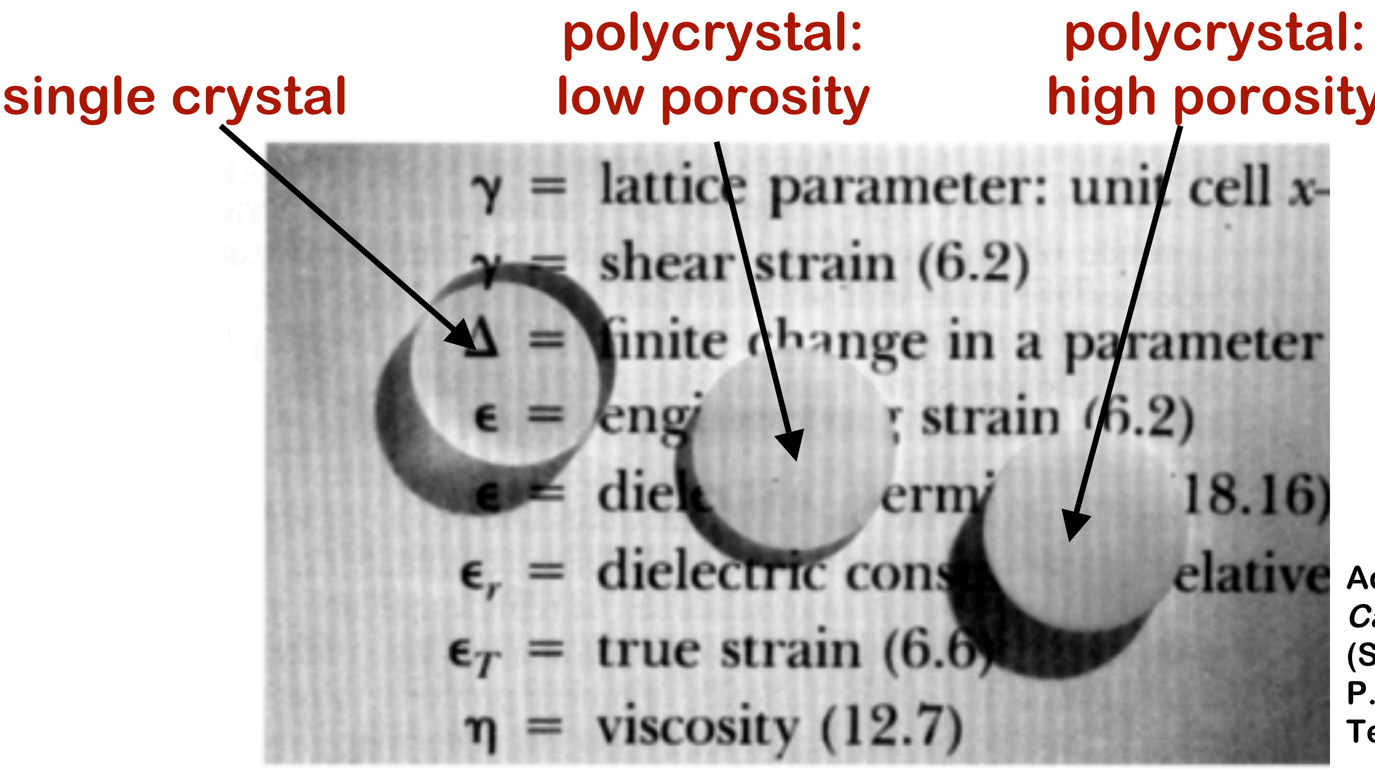
- Thermal Conductivity of Copper:
  --It decreases when you add zinc!



Adapted from Fig. 19.4, *Callister 6e.* (Fig. 19.4 is adapted from *Metals Handbook: Properties and Selection: Nonferrous alloys and Pure Metals*, Vol. 2, 9th ed., H. Baker, (Managing Editor), American Society for Metals, 1979, p. 315.)

OPTICAL

- **Transmittance**:
  --Aluminum oxide may be transparent, translucent, or opaque depending on the material structure.



Adapted from Fig. 1.2, *Callister 6e.* (Specimen preparation, P.A. Lessing; photo by J. Telford.)

MAGNETIC

- **Magnetic Storage**:
  --Recording medium is magnetized by recording head.

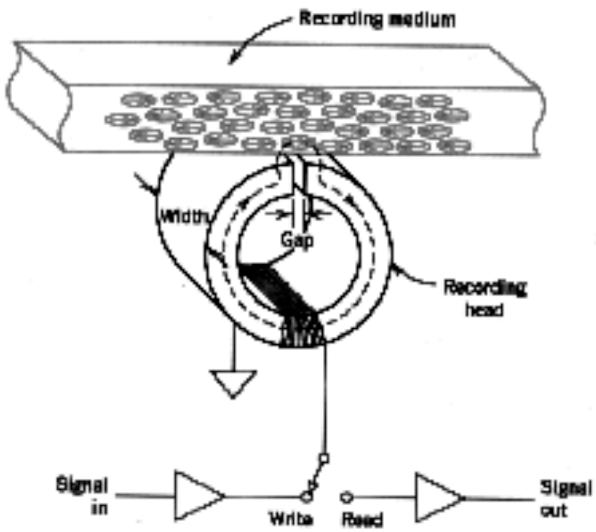
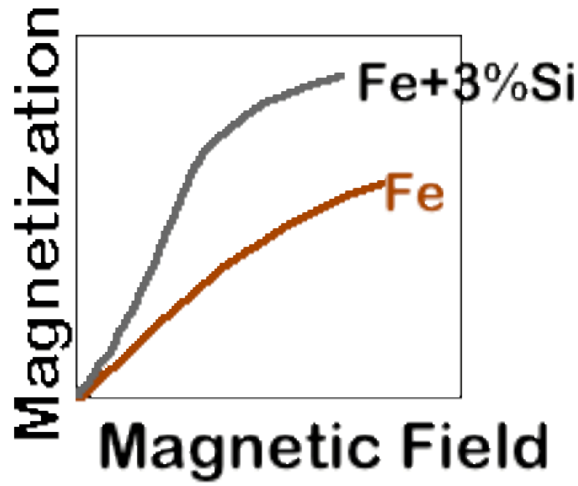


Fig. 20.18, *Callister 6e.*
(Fig. 20.18 is from J.U. Lemke, *MRS Bulletin*, Vol. XV, No. 3, p. 31, 1990.)

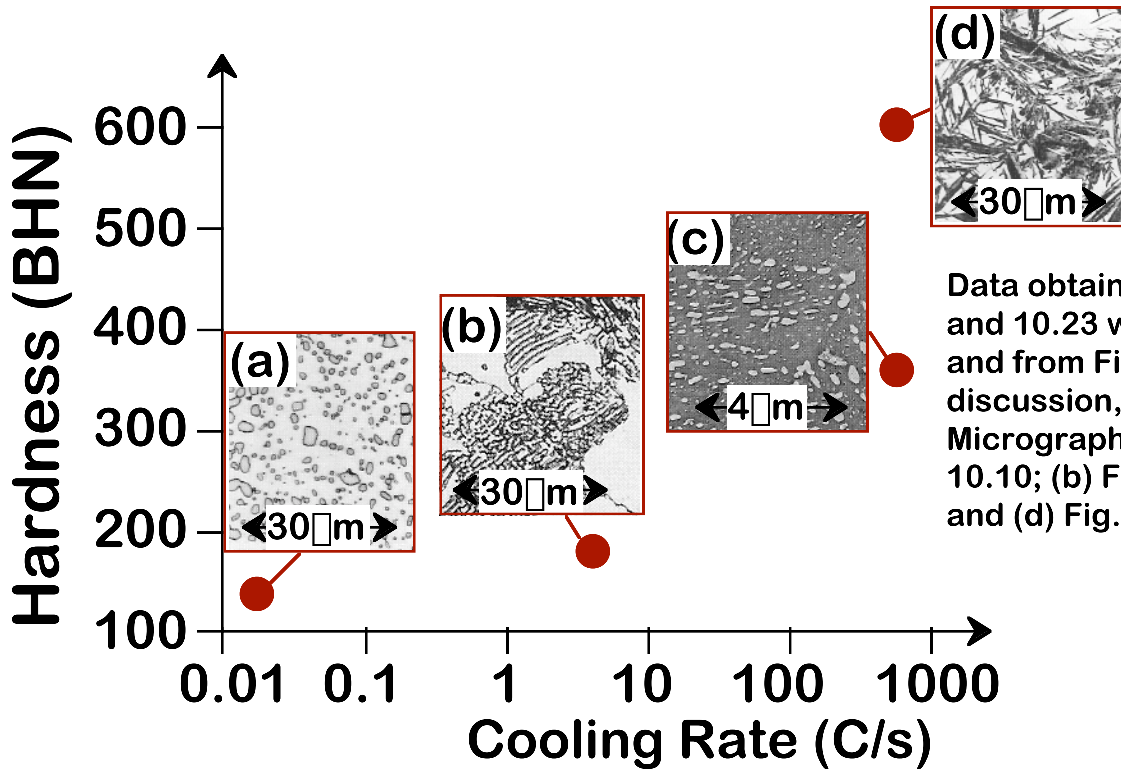
- **Magnetic Permeability** vs. Composition:
  --Adding 3 atomic % Si makes Fe a better recording medium!



Adapted from C.R. Barrett, W.D. Nix, and A.S. Tetelman, *The Principles of Engineering Materials*, Fig. 1-7(a), p. 9, 1973. Electronically reproduced by permission of Pearson Education, Inc., Upper Saddle River, New Jersey.

Structure, Processing, & Properties

- Properties depend on structure
  ex: hardness vs structure of steel

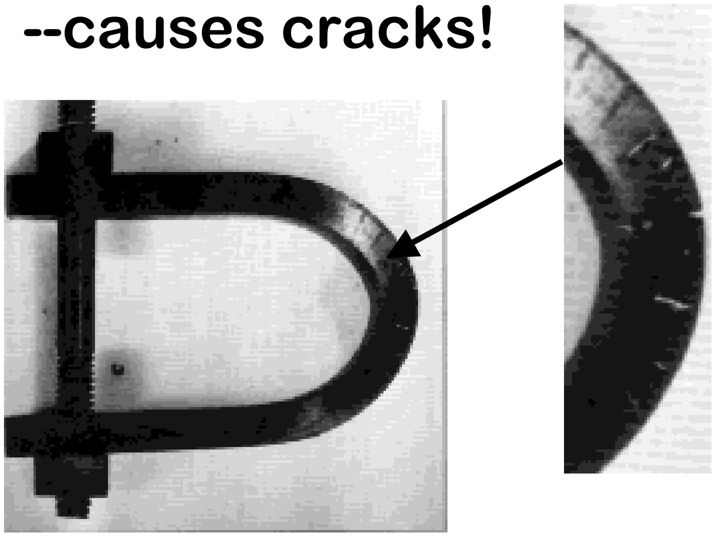


Data obtained from Figs. 10.21(a) and 10.23 with 4wt%C composition, and from Fig. 11.13 and associated discussion, *Callister 6e*. Micrographs adapted from (a) Fig. 10.10; (b) Fig. 9.27;(c) Fig. 10.24; and (d) Fig. 10.12, *Callister 6e*.

- Processing can change structure
  ex: structure vs cooling rate of steel

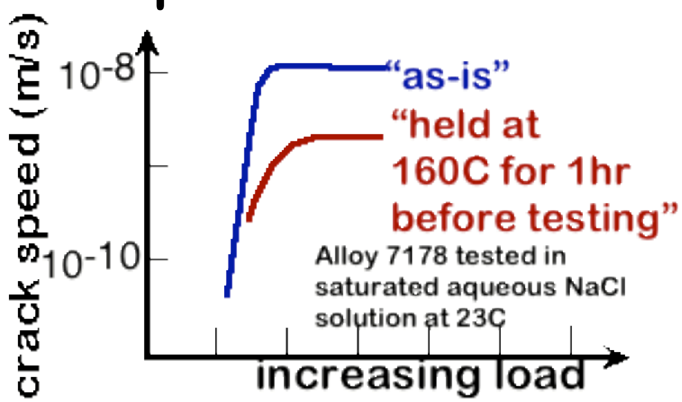
DETERIORATIVE

- **Stress & Saltwater...**
  --causes cracks!



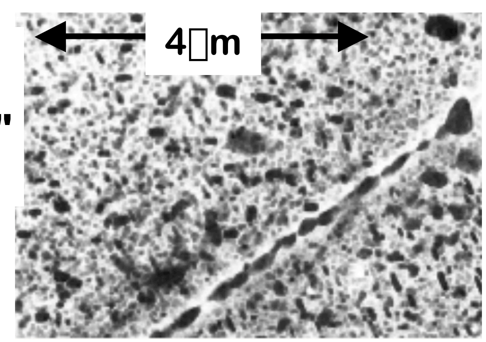
Adapted from Fig. 17.0, *Callister 6e.*
(Fig. 17.0 is from *Marine Corrosion, Causes, and Prevention*, John Wiley and Sons, Inc., 1975.)

- **Heat treatment: slows crack speed in salt water!**



Adapted from Fig. 11.20(b), R.W. Hertzberg, "Deformation and Fracture Mechanics of Engineering Materials" (4th ed.), p. 505, John Wiley and Sons, 1996. (Original source: Markus O. Speidel, Brown Boveri Co.)

--material:
7150-T651 Al "alloy" (Zn,Cu,Mg,Zr)



Adapted from Fig. 11.24, *Callister 6e.* (Fig. 11.24 provided courtesy of G.H. Narayanan and A.G. Miller, Boeing Commercial Airplane Company.)

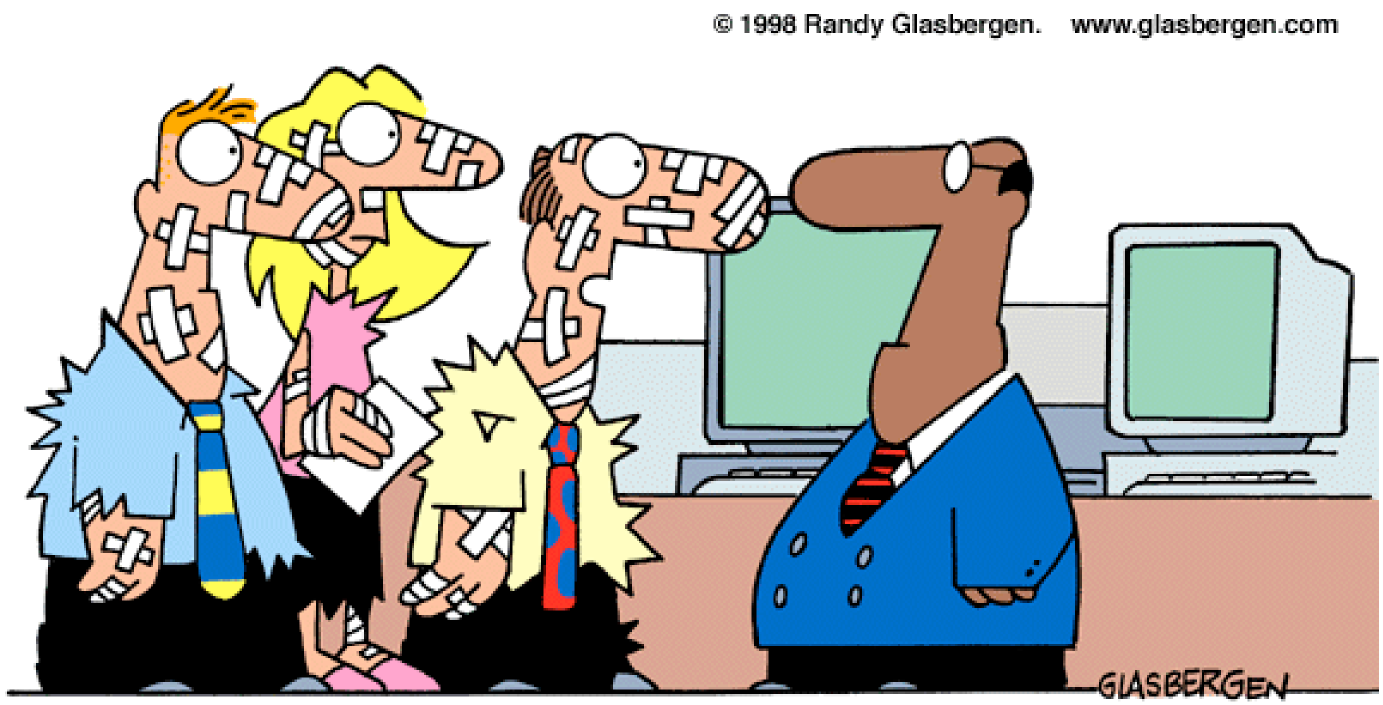
Roadmap for Semiconductors

YEAR TECHNOLOGY NODE	2008 70 nm	2011 50 nm	2014 35 nm
DRAM			
Half pitch (nm)	70	50	35
Contacts (nm)	100	70	50
Overlay (nm, mean + 3 sigma)	25	20	15
CD control (nm, 3 sigma, post-etch)	7	5	4
MPU			
Half pitch	80	55	40
Gate length (nm, in resist)	45	30	20
Gate length (nm, post-etch)	45	30	20
Contacts (nm, in resist)	80	55	40
Gate CD control (nm, 3 sigma, post-etch)	4	3	2
ASIC (SoC)			
Half pitch	80	55	40
Gate length (nm, in resist)	70	50	35
Gate length (nm, post-etch)	70	50	35
Contacts (nm, in resist)	80	55	40
Gate CD control (nm, 3 sigma, post-etch)	7	5	4

Solutions being pursued (yellow) — No known solutions (red)

Yellow cells: DRAM Half pitch and Contacts (all years); MPU Half pitch, Gate lengths (all years), Contacts 2008 and 2011; ASIC Half pitch, Gate lengths (all years), Contacts 2008 and 2011, Gate CD control 2008. Red cells: all others.

The Challenge?



"Frankly, sir, we're tired of being on the cutting edge of technology."

SUMMARY

Course Goals:

- Use the right material for the job.
- Understand the relation between properties, structure, and processing.
- Recognize new design opportunities offered by materials selection.