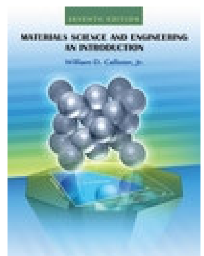
EGN 3365 Materials Engineering



Lecturer: Dr. Chunlei Wang

Chapter 1 - 1

EGN 3365 MATERIALS ENGINEERING

Course Objective...

Learn the materials behavior and function through their internal structures.

You will learn about:

- internal structure of the materials
- their corresponding properties
- how processing can change structure
- applications in engineering

This course will help you to:

- use materials properly
- realize new design opportunities with materials

Chapter 1 - 2

COURSE WEBSITES

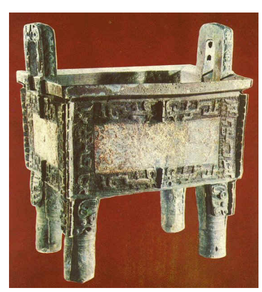
http://web.eng.fiu.edu/wangc/EGN3365.htm

Text Website: http://www.wiley.com/college/callister

- Additional Chapters (Chapters 19-23)
- Complete solutions to selected problems
- Links to other web resources
- Extended learning objectives
- Self-assessment exercises

Chapter 1 - Introduction

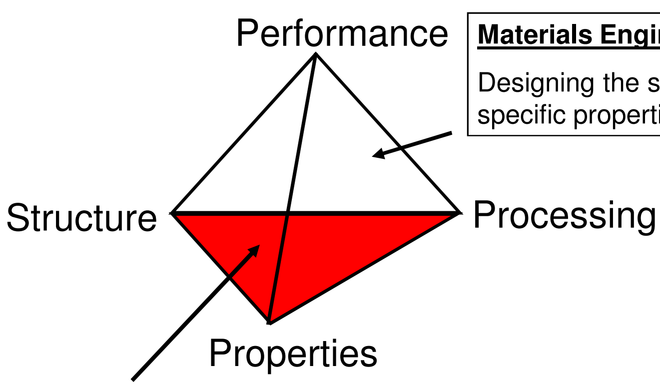
- **What is materials science and materials engineering?**
- **Why should we know about it?**
- Materials drive our society
  - **Stone Age**
  - **Bronze Age**
  - **Iron Age**
  - **Now?**
    - **Silicon Age?**
    - **Polymer Age?**



Simuwu Ding, Shang Dynasty, China.
Dated to: 1400-1100 B.C.
Cu: 84.77, Sn: 11.44, Pb: 2.76 others: 0.9.
H x L x W (cm): 133.2 x 110 x 78
Weight: 875 kg

Brief Historical Overview

- **Paleolithic** (40,000 to 100,000 yrs ago): Stone tools and clay pots
- **Mesolithic** (10,000 to 40,000 yrs ago): Extensive use of stone tools and clay, stone statues, ochre (pigment)
- **Copper Age** (5,000 to 10,000 yrs ago): Copper ornaments, earthenware, metal smelting
- **Bronze Age** (3,000 to 5,000 yrs ago): Bronze (Cu/Sn), glass, iron smelting
- **Iron Age** (1000 – 3000 yrs ago): Carburized Iron, improved forging, porcelain
- **Steel and concrete** (100 – 1000 yrs ago)
- **Polymers** (beginning early 1900s)
- **Silicon** (60s –)
- **The present**: Age of biomaterials and nanomaterials?



Materials Engineering

Designing the structure to achieve specific properties of materials.

Materials Science

Investigating the relationship between structure and properties of materials.

- Processing
- Structure
- Properties
- Performance

Classification of Materials

Metals:
Elemental metal (iron, copper etc), steel, Alloys, Intermetallic compounds

Ceramics:
Structural Ceramics (high-temperature load bearing), Refractories (corrosion-resistant, insulating), Whitewares (e.g. porcelains), Glass, Electrical Ceramics (capacitors, Insulators, transducers, etc.), Chemically Bonded Ceramics (e.g. cement and concrete)…

Polymers:
Plastics, Adhesives, liquid crystals…

Semiconductors: Group IV elements (Si, Ge…), III-V (GaAs, InP…) , II-VI (CdSe, ZnS…), IV-VI (PbS, PbSe…)…

Composites:
Particulate composites, (small particles embedded in a different material), Laminate composites (golf club shafts, tennis rackets, Damascus sword blades), Fiber reinforced composites (e.g. fiberglass)

Biomaterials
Nanoscale materials

Engineering Materials:
Controlling Processing - Structure - Properties - Performance

- **Realistic engineering materials:**

  Trade-off between

  - properties (what do we need or want?)
  - deterioration (how long will it last?)
  - cost (what's the biggest bang for the buck?)
  - Resources depletion (how to find new reserves, develop new environmentally-friendly materials, and increase recycling)

- **How do you decide what materials to use?**

  - Pick Your Application ⇒ Required Properties

  (mechanical, electrical, thermal, magnetic, optical, deteriorative)

  - Properties ⇒ Required Materials (type, structure, composition)
  - Material ⇒ Required Processing (changes to structure and desired shape via casting, annealing, joining, sintering, mechanical, …)

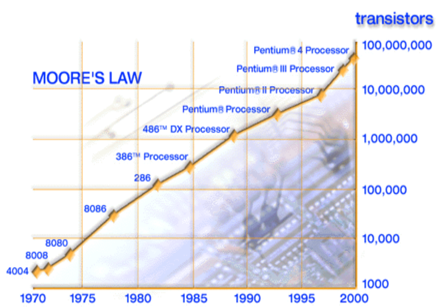
Needs for Materials (i.e. Final Performance)

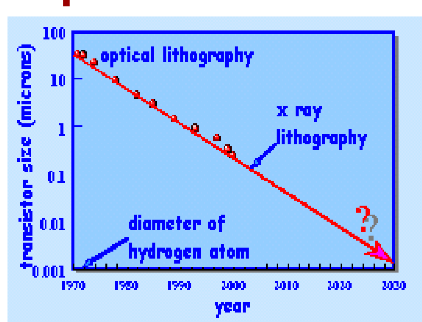
- Microelectronics: **ICs, packaging, photoresists...**
- Infrastructure: **Concrete, metal beams…**
- Environmental control: **biodegradable polymers, ion exchange…**
- Communication/Information: **fiber optics, LEDs…**
- Energy: **solar cells, Li ion batteries, fuel cells…**
- Automotive: **chassis, engine parts…**
- Defense: **night vision, light weight/high strength composites for aircrafts…**
- Biotechnology: **medical implants, biocompatible polymers, biosensors…**
- Sporting goods: **bicycle frames, golf clubs…**
- Homeland Security: **Sensor materials for explosive and biohazards…**

and more… (no engineering without materials).

Chapter 1 - 9

New Needs for "Future" Materials: an example





Pentium 4 Processor has 42,000,000 transistors!

DRAM half-pitch of 35 nm will be needed by 2014.

Nanoscale materials and molecular electronics?

To achieve **performance** needs, an understanding of materials' **properties** is necessary!

Chapter 1 - 10

Properties of Materials

	Stimulus	Response (e.g.)
Mechanical	**Applied load**	**Deformation**
Electrical	**Electric field**	**Electrical conduction**
Magnetic	**Magnetic field**	**Magnetization**
Thermal	**Heat**	**Heat conduction**
Optical	**Light**	**Reflection, absorption**
Deterioration **(Chemical)**	**Chemicals**	**Oxidation, corrosion**

many materials needs combine different properties (e.g. piezoelectric materials).

Characterization methods: microscopy (optical, SEM, TEM, STM, AFM…), spectroscopy (uv-vis, FTIR…), crystallography, light scattering, mechanical testing, etc…

To obtain desired **properties**, the material must have the appropriate **structure**.

Structure

- **Types of atoms.**
- **Arrangement of atoms/molecules.**
  - **e.g. crystal structure, polymer chain length, crosslinking…**
- **Defects and impurities.**
- **Grain size.**
- **Etc…**

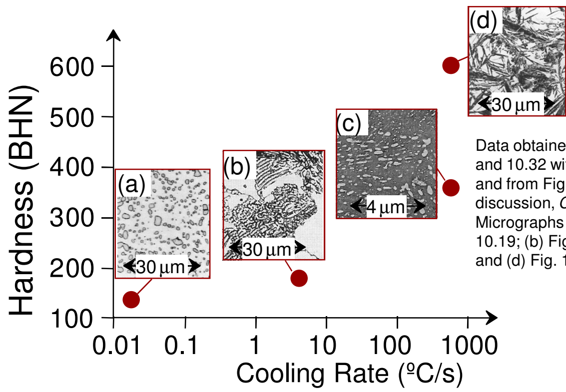
Structure at different length scales:

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}

Structure will depend on **processing** conditions.

Structure, Processing, & Properties

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

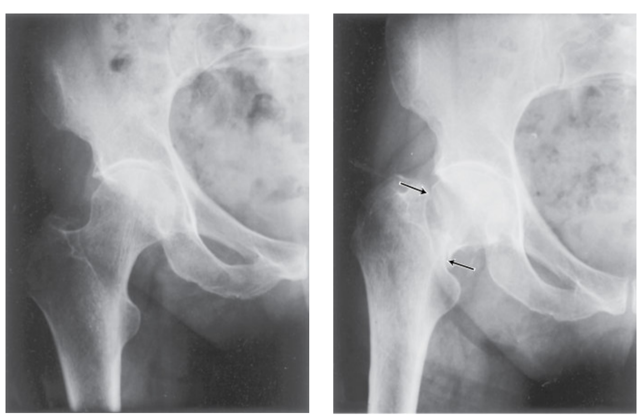


Data obtained from Figs. 10.30(a) and 10.32 with 4 wt% C composition, and from Fig. 11.14 and associated discussion, *Callister 7e.* Micrographs adapted from (a) Fig. 10.19; (b) Fig. 9.30;(c) Fig. 10.33; and (d) Fig. 10.21, *Callister 7e.*

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

Example – Hip Implant

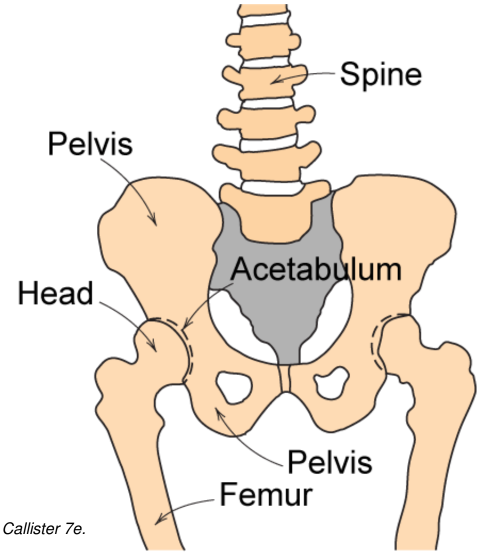
- With age or certain illnesses joints deteriorate. Particularly those with large loads (such as hip).



Adapted from Fig. 22.25, *Callister 7e.*

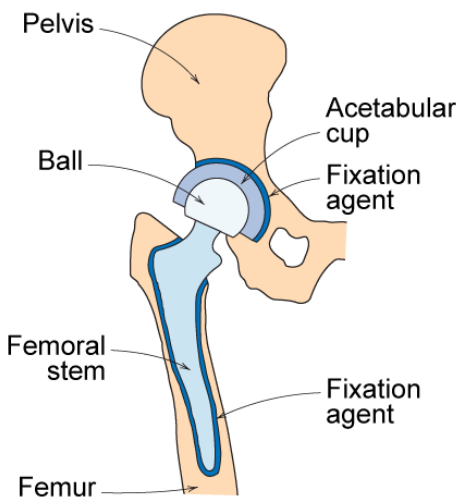
Example – Hip Implant

- Requirements
  - mechanical strength (many cycles)
  - good lubricity
  - biocompatibility



Adapted from Fig. 22.24, *Callister 7e.*

Example – Hip Implant



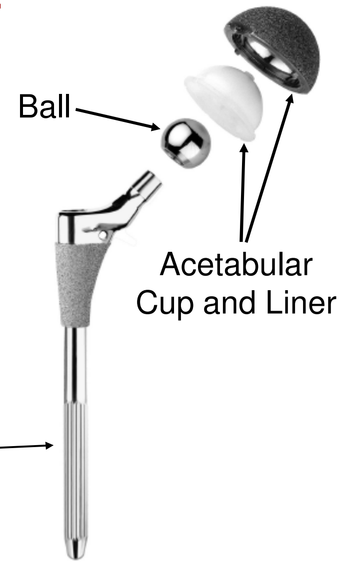
(a)

(b)

Adapted from Fig. 22.26, *Callister 7e.*

Hip Implant

- Key problems to overcome
  - fixation agent to hold acetabular cup
  - cup lubrication material
  - femoral stem – fixing agent (“glue”)
  - must avoid any debris in cup



Adapted from chapter-opening photograph, Chapter 22, *Callister 7e.*

Chapter 1 - 17

Example – Develop New Types of Polymers

- Commodity plastics – large volume ca. \$0.50 / lb
  Ex. Polyethylene
  Polypropylene
  Polystyrene
  etc.

- Engineering Resins – small volume > \$1.00 / lb
  Ex. Polycarbonate
  Nylon
  Polysulfone
  etc.

Can polypropylene be “upgraded” to properties (and price) near those of engineering resins?

Chapter 1 - 18

The Materials Selection Process

1. Pick Application ⟶ Determine required Properties

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

2. Properties ⟶ Identify candidate Material(s)

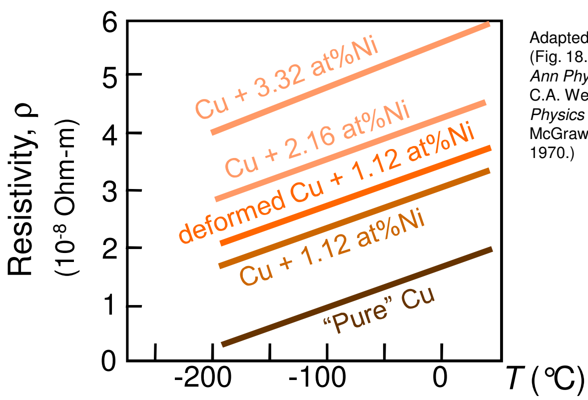
   Material: structure, composition.

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:



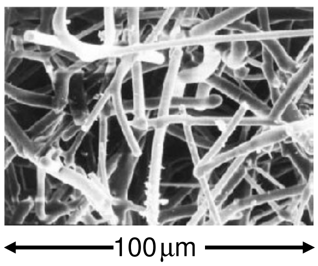
Adapted from Fig. 18.8, *Callister 7e.* (Fig. 18.8 adapted from: J.O. Linde, *Ann Physik* **5**, 219 (1932); and C.A. Wert and R.M. Thomson, *Physics of Solids*, 2nd edition, McGraw-Hill Company, New York, 1970.)

- Adding “impurity” atoms to Cu increases resistivity.
- Deforming Cu increases resistivity.

THERMAL

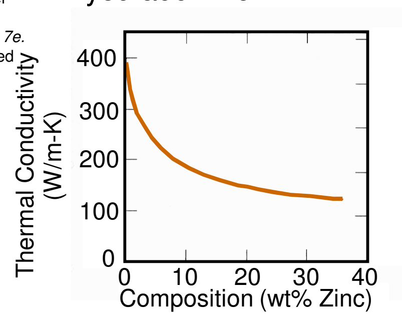
- Space Shuttle Tiles:
  --Silica fiber insulation offers low heat conduction.

Adapted from chapter-opening photograph, Chapter 19, *Callister 7e.* (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 7e.* (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.)

MAGNETIC

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

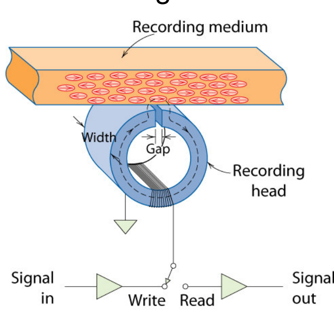
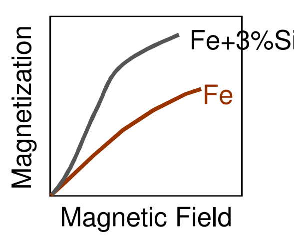


Fig. 20.23, *Callister 7e.*
(Fig. 20.23 is from J.U. Lemke, *MRS Bulletin*, Vol. XV, No. 3, p. 31, 1990.)

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

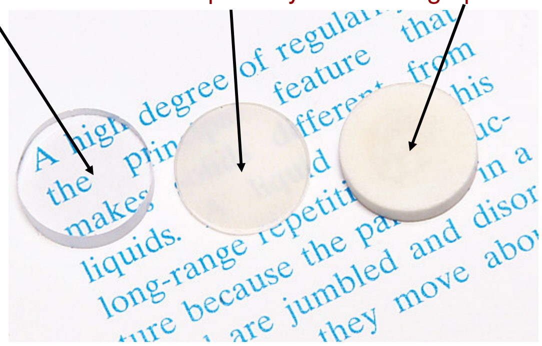


Adapted from C.R. Barrett, W.D. Nix, and A.S. Tetelman, *The Principles of Engineering Materials*, Fig. 1-7(a), p. 9, 1973. Electronically reproduced by permission of Pearson Education, Inc., Upper Saddle River, New Jersey.

OPTICAL

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

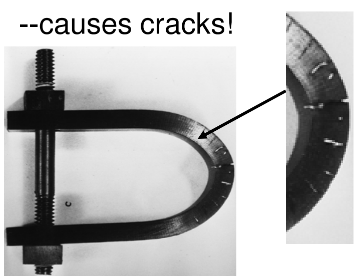
single crystal | polycrystal: low porosity | polycrystal: high porosity



Adapted from Fig. 1.2, *Callister 7e.* (Specimen preparation, P.A. Lessing; photo by S. Tanner.)

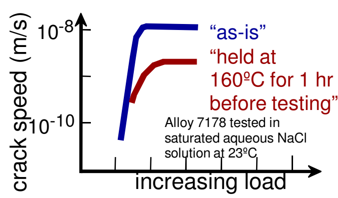
DETERIORATIVE

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



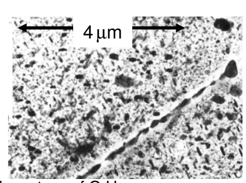
Adapted from chapter-opening photograph, Chapter 17, *Callister 7e.* (from *Marine Corrosion, Causes, and Prevention*, John Wiley and Sons, Inc., 1975.)

- 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. 11.26, *Callister 7e.* (Fig. 11.26 provided courtesy of G.H. Narayanan and A.G. Miller, Boeing Commercial Airplane Company.)

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.