KMÜ 496
Materials Science and Technology III

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Hacettepe University
Department of Chemical Engineering

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Objective of This Course

- ✓ To build on fundamental concepts in Materials Science and Engineering.
- ✓ To introduce the students to thermodynamics in solid systems, mainly to solidification problems and alloy phase diagrams.
- ✓ Students will learn about:
  - Phase transformations in materials
  - Material structure and how structure determines properties
  - How processing, especially solidification can change structure

Materials Science and Technology III 2018/2019 Spring Semester

- Lecturer:
  - Dr. Damla Çetin Altındal
  - Office: Lab 4 / Assistant Office
  - e-mail address: damlacetin@hacettepe.edu.tr
- Class Schedule:
  - Wednesday: 13:00-15:50

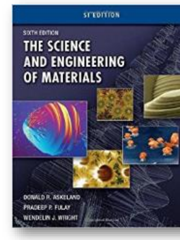
Objective of This Course

- ✓ This course will help to:
  - Use/select materials properly
  - Understand the mechanisms that affect material properties
  - Realize new design opportunities with materials
  - Instill technical competence in mathematics, science and materials engineering
  - Develop problem solving skills
  - Instill an ability to select the right materials when designing a component, unit, or process in the chemical/manufacturing industry that meets performance specifications
  - Instill an ability to use the techniques, skills, and modern engineering tools necessary for chemical engineering practice

Weeks	Topics
1	Review: Introduction to materials science and engineering; Classification of materials; Materials design and selection
2	Principles of solidification: Technological significance; Nucleation; Growth mechanisms; Cooling curves Casting: Structure; Solidification defects; Casting processes in manufacturing
3	Solid solutions and phase equilibrium: Phases and phase diagram; Solubility and solid solutions; Unlimited solid solubility; Solid solution strengthening
4	Isomorphous phase diagrams: Material properties and phase diagram; Solidification of a solidsolution alloy; Coring
5	Eutectic phase diagrams: Intermetallic compounds; Dispersion strengthening; Three phase reactions; Non-equilibrium freezing in the eutectic system
6	Strengthening by phase transformations and heat treatment: Nucleation in solid state transformations; Age or precipitation hardening
7	**Midterm**
8	Eutectoid reaction; Martensitic reaction; Tempering
9	Non-equilibrium solidification and segregation, solute trapping Solidification of polymers and inorganic glasses; Joining of metallic materials
10	Heat treatment of steels and cast irons
11	Nonferrous alloys: Aluminum, Magnesium, Copper, Nickel, Cobalt, Titanium alloys
12	Classes of materials: Metals; Ceramics; Polymers; Semiconductors; Composites
13	Classes of materials: Concrete and construction materials; Electronic materials; Magnetic materials; Photonic materials
14	Preparation to final exam
15	**Final exam**

Text Book:

Donald R. Askeland, Pradeep P. Fulay "The Science & Engineering of Materials", 6th Edition, 2011.



Reference Books:

- William D. Callister, Jr. "Materials Science and Engineering: An Introduction", 6th Edition, Wiley.
- William D. Callister, Jr. "Materials Science and Engineering: An Introduction", 7th Edition, Wiley.
- William D. Callister, Rethwisch, "Fundamentals of Materials Science and Engineering: An Integrate Approach", 3rd Edition, Wiley, 2008.
- J. F. Shackelford, "Introduction to Materials Science for Engineers, 6/E", 6th Edition, Prentice Hall, 2005.

Grading

Homeworks → 15%
Project → 20%
Midterm → 25%
Final exam → 40%

Historical Perspective

Stone → Bronze → Iron → Advanced materials

- Beginning of the Material Science - People began to make tools from stone. Start of the Stone Age was about two million years ago. Natural materials: stone, wood, clay, etc.
- The Stone Age ended about 5000 years ago with introduction of bronze in the Far East. Bronze is an **alloy** and it can be hammered or cast into a variety of shapes, can be made harder by alloying and corrode slowly.
- The Iron Age began about 3000 years ago and continues today. Use of iron and steel, a stronger and cheaper material changed drastically daily life of a common person.
- Age of Advanced materials: Throughout the Iron Age, many new types of materials have been introduced (ceramic, semiconductors, polymers, composites…).
  - Understanding of the **relationship among structure, properties, processing, and performance of materials** are important for the intelligent design of new materials.

- A better understanding of structure-composition properties relations has lead to a remarkable progress in properties of materials.
- Example is the dramatic progress in the strength to density ratio of materials, that resulted in a wide variety of new products, from dental materials to tennis racquets.

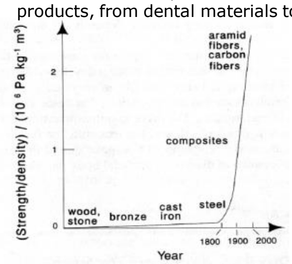
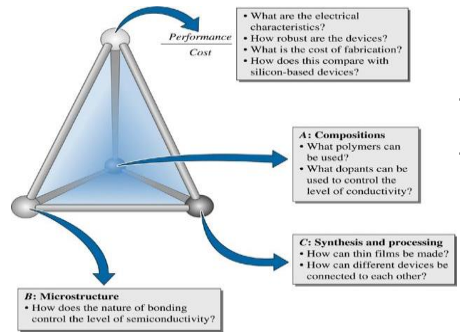
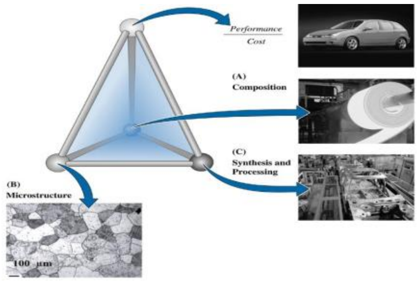


Figure from: M. A. White, Properties of Materials (Oxford University Press, 1999)

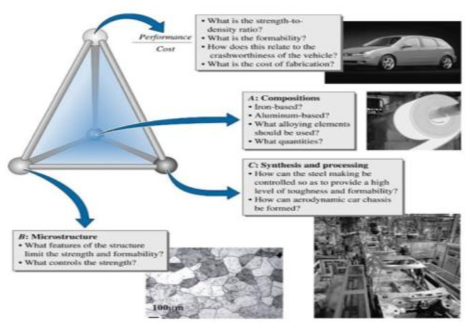


Example of the application of the tetrahedron of materials science and engineering to semiconducting polymers for microelectronics.

WHAT IS MATERIALS SCIENCE?



Material science is the investigation of the relationship among processing, structure, composition and performance of materials.



Another example of the application of the tetrahedron of materials science and engineering to sheet steels for automative chassis.

Example: Hip Implant

- **Requirements**
  - mechanical strength
  - roughness
  - biocompatibility

Length Scales

Angstrom = 1Å = 1/10,000,000,000 meter = 10^{-10} m

Nanometer = 10 nm = 1/1,000,000,000 meter = 10^{-9} m

Micrometer = 1μm = 1/1,000,000 meter = 10^{-6} m

Millimeter = 1mm = 1/1,000 meter = 10^{-3} m

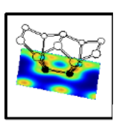
Interatomic distance ~ a few Å

A human hair is ~ 50 μm

Materials are...

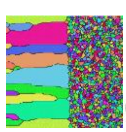
engineered structures

- **Subatomic level**
  Electronic structure of individual atoms that defines interaction among atoms (interatomic bonding).



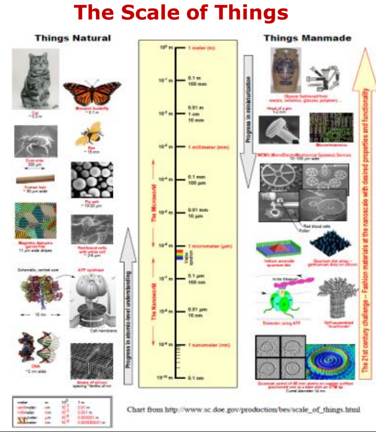
- **Atomic level**
  Arrangement of atoms in materials (for the same atoms can have different properties, e.g. two forms of carbon: graphite and diamond)

- **Microscopic structure**
  Arrangement of small grains of material that can be identified by microscopy.



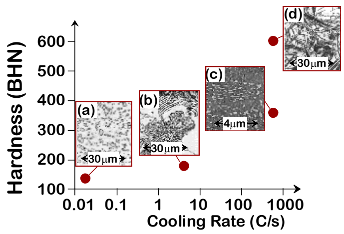
- **Macroscopic structure**
  Structural elements that may be viewed with the naked eye.

The Scale of Things



Structure and processing affect the properties of materials.

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



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

Categories of Materials

	Category	Applications	Properties
Metals & Alloys	Alloy steels	Automobile chassis	Strengthened by heat treatment
Ceramics & Glasses	Silica	Optical fibers for transfer of information	Refractive index, low optical losses
Polymers	Epoxy	Encapsulation of integrated circuits	Electrically insulating and moisture resistant
Semiconductors	Silicon	Transistors and integrated circuits	Unique electrical behavior
Composites	Titanium-clad steel	Reactor vessels	Corrosion resistant (due to titanium) low cost and high strength (due to steel)

Categories of Materials

- Metals & Alloys
- Ceramics & Glasses
- Polymers
- Semiconductors
- Composites

Categories of Materials

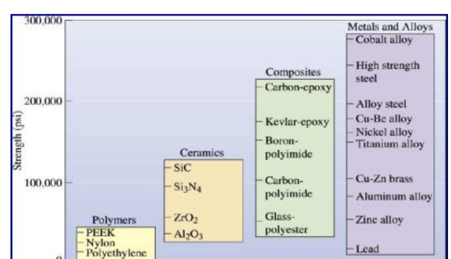


Figure 1-3 Representative strengths of various categories of materials.

D. Askeland and P. Phule, The Science and Engineering of Materials, 5th Ed., Thomson Learning, London, 2006, pg.9

Types of Materials

- Metals:
  - Strong
  - High thermal & electrical conductivity
  - Opaque, reflective

- Polymers:
  - Soft, ductile, low strength, low density
  - Thermal & electrical insulators
  - Optically translucent or transparent

- Ceramics:
  - Brittle, glassy
  - Non-conducting (insulators)

The Materials Selection Process

1. Application ⟶ Determine required Properties

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

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.

3

Properties of Materials

Properties are the way the material responds to the environment and external forces.

Mechanical properties – response to mechanical forces, strength, etc.

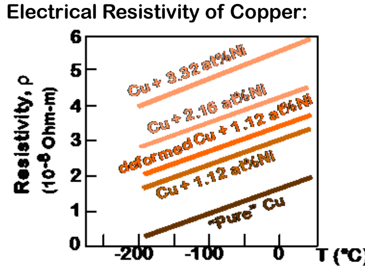
Electrical and **magnetic** properties - response electrical and magnetic fields, conductivity, etc.

Thermal properties are related to transmission of heat and heat capacity.

Optical properties include to absorption, transmission and scattering of light.

Electrical Properties

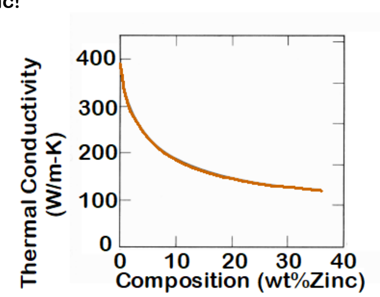
- Electrical Resistivity of Copper:



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

Thermal Properties

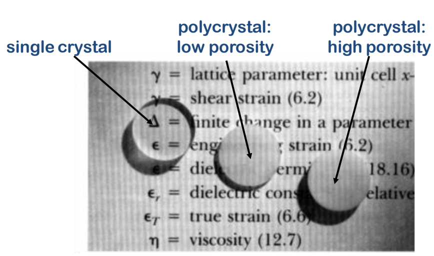
- **Thermal Conductivity of Copper:**
  - **- It decreases when you add zinc!**



- The goals of Materials Science and Technology
  - Use the right material for the job
  - Understand the relation between properties, structure, and processing
  - Recognize new design opportunities offered by materials selection

Optical Properties

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



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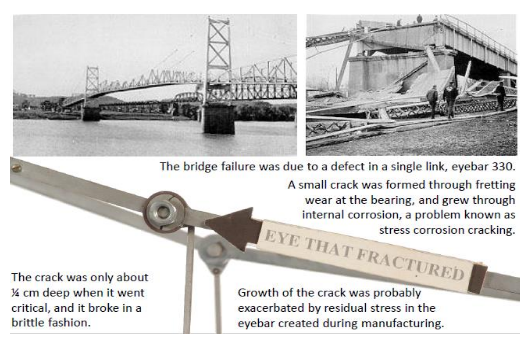
Silver Bridge (1928-1967, USA): Material fault and corrosion



Tacoma Narrows Bridge (1940-1940, USA):
Aerodynamically poor design resulted in aeroelastic flutter