MAL 201E: Materials Science

Course Objective...

Introduce fundamental concepts in Materials Science

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

COURSE MATERIALS (with text)

Contributory texts:

- **Materials Science and Engineering: An Introduction, W.D. Callister, Jr. and D.G. Rethwisch, 8th edition, John Wiley and Sons, Inc. (2010).**
- Lawrence H. Van Vlack, Elements of Materials Science and Engineering, Literatür Yayıncılık Dağıtım Pazarlama.
- William F. Smith, Principles of Materials Science and Engineering, McGraw-Hill International Editions.
- Kaşif Onaran, Malzeme Bilimi, Bilim Teknik Yayınevi.
- Kaşif Onaran, Malzeme Bilimi Problemleri ve Çözümleri, Bilim Teknik Yayınevi.

GRADING

Midterm #1 30%

Tentatively scheduled for: 7th or 8th week

Material covered: Will be announced.

Midterm #2 30%

Tentatively scheduled for: 13th or 14th week

Material covered: Will be announced

Final: 40%

Material covered: All the course subjects discussed during the semester

COURSE SCHEDULE

Topic

Introduction
Atomic Bonding
Crystalline Structures and Imperfections
Applications & Processing of Metal Alloys
Diffusion Mechanism
Mechanical Properties

Electrical Properties/Conduction Materials
Dielectrical Properties
Optical Properties
Magnetic Properties
Thermal Properties

"Lectures will highlight important portions of each chapter."

Chapter 1 - Introduction

- What is materials science?
- Why should we know about it?
  - **Materials drive our society**
- Virtually every segment of our everyday lives (*Transportation, housing, clothing, communication, recreation, food production, …*) is influenced to one degree or another by materials.
- Historically, the development and advancement of societies have been intimately tied to the members' ability to produce and manipulate materials to fill their needs. In fact, early civilizations have been designated by the level of their materials development.
  - Stone Age

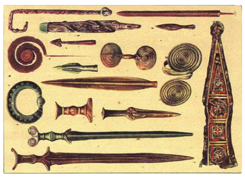
    During which human beeing widely used stone for tool making:

With time they discovered techniques for producing materials that had properties superior to those of the natural ones; these new materials included pottery and various metals. Furthermore, it was discovered that the properties of a material could be changed by heat treatments and by the addition of other substances.

- Bronze Age:

  During which the most advanced metal working in that culture used bronze.

  -88% Copper (Cu) and 12%Tin (Sn)-



- Iron Age:

  During which cutting tools and weapons were mainly made of iron or steel.

•It was not until relatively recent times that scientists came to understand the relationships between the structural elements of materials and their properties.

•This knowledge, which has been obtained over approximately the past 100 years, has qualified engineers to construct the characteristics of materials.

•Tens of thousands of different materials have evolved with rather specialized characteristics that meet the needs of our modern and complex society; **Metals, plastics, glasses, and fibers**.

•The development of many technologies that make our existence so comfortable has been intimately associated with the accessibility of suitable materials.

An advancement in the understanding of a material type is often the forerunner to the "stepwise progression of a technology".

- Automobiles would not have been possible without the availability of inexpensive steel or some other comparable materials.
- In our contemporary era, sophisticated electronic devices mostly rely on components that are made from what are called "**semiconducting materials**".

– Now?
  - Silicon Age?
  - Polymer Age?

Classification of Materials

- **Metals**
- **Ceramics**
- **Polymers (Plastics)**
- **Composites**



- **METALS**:
  - Strong, ductile
  - High thermal & electrical conductivity
  - Opaque, reflective.

•Metals are composed of one or more metallic elements (such as iron, aluminum, copper, titanium, gold, and nickel), and often also nonmetallic elements (for example, carbon, nitrogen, and oxygen) in relatively small amounts.

•Atoms in metals and their alloys are arranged in a **very orderly manner** and in comparison to the ceramics and polymers: Relatively dense.

•With regard to mechanical characteristics, these materials are relatively stiff - and strong, as well as ductile (i.e., capable of large amounts of deformation without fracture), which accounts for their widespread use in structural applications.

•Metallic materials have large numbers of nonlocalized electrons; that is, these electrons are not bound to particular atoms. Many properties of metals are directly attributable to these electrons. For example, metals are extremely good conductors of electricity and heat, and are not transparent to visible light.

•In addition, some of the metals (Fe, Co, and Ni) have desirable magnetic properties.

- **POLYMERS/PLASTICS**: Covalent bonding → sharing of e's
  - Soft, ductile, low strength, low density
  - Thermal & electrical insulators
  - Optically translucent or transparent.

•Many of them are organic compounds that are chemically based on carbon, hydrogen, and other nonmetallic elements.

•These materials typically have low densities, whereas their mechanical characteristics are generally dissimilar to the metallic and ceramic materials: They are not as stiff nor as strong as these other material types.

•However, on the basis of their low densities, many times *their stiffnesses and strengths on a per mass basis are comparable to the metals and ceramics*.

•In addition, many of the polymers are extremely ductile, which means they are easily formed into complex shapes.

•One major **drawback** to the polymers is their tendency to soften and/or decompose at modest temperatures, which, in some instances, limits their use.

•Furthermore, they have low electrical conductivities and are nonmagnetic.

- **CERAMICS:** ionic bonding – compounds of metallic & non-metallic elements (oxides, carbides, nitrides, sulfides)
  - Brittle, glassy, elastic
  - Non-conducting (insulators)

•Ceramics are compounds between metallic and nonmetallic elements.

•With regard to mechanical behavior, ceramic materials are relatively stiff and strong : stiffnesses and strengths are comparable to those of the metals.

•In addition, ceramics are typically very hard. On the other hand, they are extremely brittle (lack ductility), and are highly susceptible to fracture.

•These materials are typically insulative to the passage of heat and electricity (i.e., have low electrical conductivities), and are more resistant to high temperatures and harsh environments than metals and polymers.

•With regard to optical characteristics, ceramics may be transparent, translucent, or opaque.

•Some of the oxide ceramics exhibit magnetic behavior.

- **COMPOSITES:**

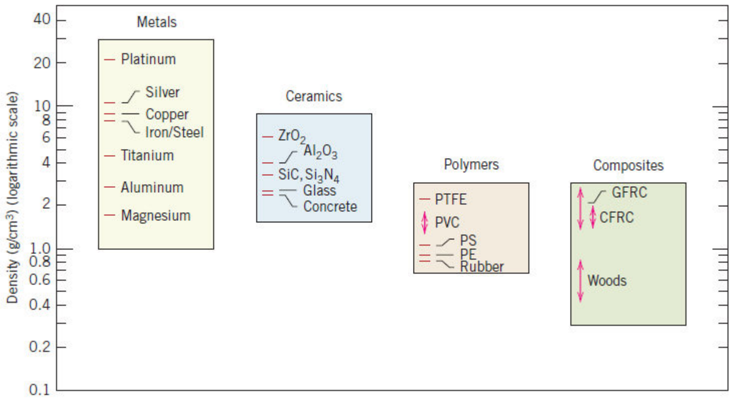
•A composite is composed of two (or more) individual materials, which come from the categories: metals, ceramics, and polymers.

•The design goal of a composite is to achieve a combination of properties that is not displayed by any single material, and also to incorporate the best characteristics of each of the component materials.

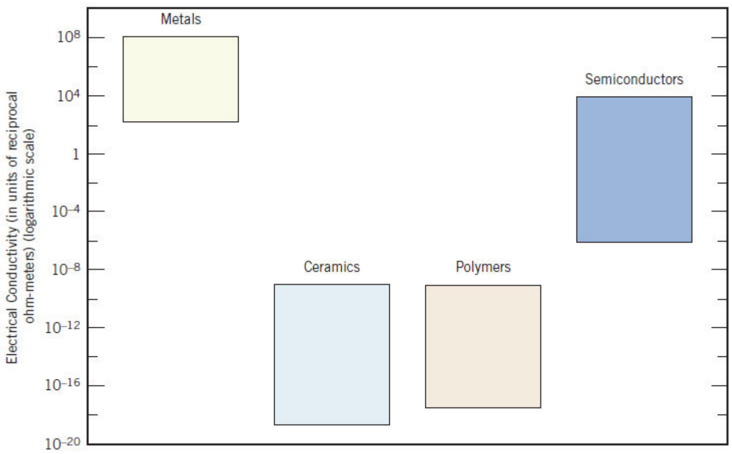
•A large number of composite types exist that are represented by different combinations of metals, ceramics, and polymers.

•Furthermore, some naturally-occurring materials are also considered to be composites :Wood and bone.

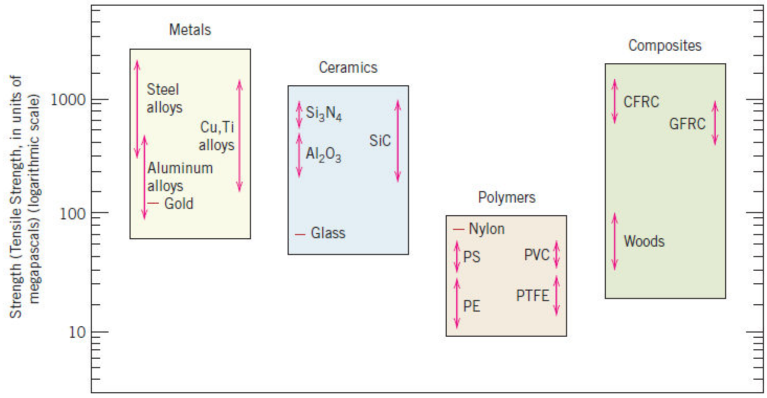
Bar-chart of room temperature **density** values for various metals, ceramics, polymers and composite materials.



Bar-chart of room temperature **electrical conductivity** ranges for metals, ceramics, polymers and semiconducting materials.



Bar-chart of room temperature **tensile strength** values for various metals, ceramics, polymers and composite materials.



The Materials Selection Process

1. Pick Application ⟶ Determine required Properties

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

2. Properties ⟶ Identify candidate Material(s)

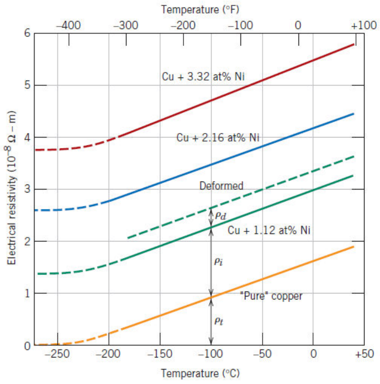
   Material: structure, composition.

3. Material ⟶ Identify required Processing

   Processing: changes *structure* and overall *shape*

ELECTRICAL

- Electrical Resistivity of Copper:

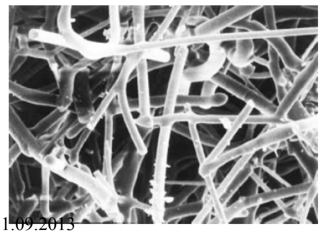


•The electrical resistivity versus temperature for copper and three copper–nickel alloys, one of which has been deformed.

Temperature effect: The increase in thermal vibrations and other lattice irregularities serve as electron-scattering centers.

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

THERMAL



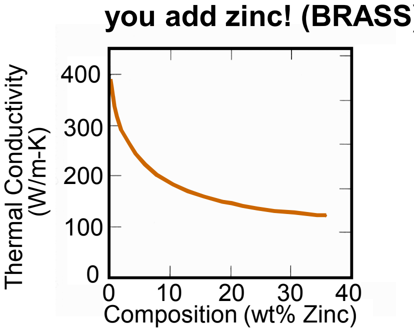
100 µm

Silica fiber insulation
offers low heat conduction

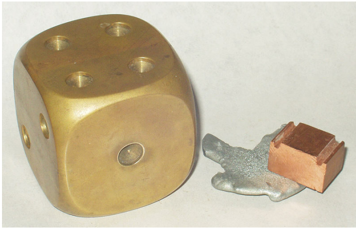
•This photograph shows a white hot cube of a **silica fiber insulation material**, which, only seconds after having been removed from a hot furnace, can be held by its edges with the bare hands.

•Initially, the heat transfer from the surface is relatively rapid; however, the thermal conductivity of this material is so small that heat conduction from the interior [**maximum temperature approximately 1250 °C**] is extremely slow.

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



A plot of thermal conductivity versus composition for copper–zinc alloys



•Alloying metals with impurities results in a reduction in the thermal conductivity, for the same reason that the electrical conductivity is diminished;

•The impurity atoms, especially if in solid solution, act as **scattering centers**, lowering the efficiency of electron motion.

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OPTICAL

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

single crystal

polycrystal: low porosity

polycrystal: high porosity

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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.