“INTRODUCTION”

MSE-225

INTRODUCTION TO MATERIALS SCIENCE
Why Material Science for Industrial Engineers???

Industrial Engineer?

**Optimize** complex processes or systems

Especially system engineering depend on the development of new materials, which in turn alter the economics.
Why Study Materials Science & Engineering

- **Economics**: What will the finished product cost? A material may be found that has the ideal set of properties but is prohibitively expensive.
- The cost of a finished piece also includes any expense incurred during fabrication to produce the desired shape.
- **Production and processing** of materials constitute a large part of our economy.
Why Study Materials Science & Engineering

• Designing of new materials might be needed for some new applications.

• Improvement or modification of properties might be needed for some applications.

• To understand existing materials so that new ones with desired properties can be designed.
Materials Science
- Investigating relationships that exist between the structure and properties of materials

Materials Engineering
- Is, on the basis of these structure-property correlations, designing or engineering the structure of a material to produce a pre-determined set of properties
The Materials Selection Process

1. Pick **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.
Property

Mechanical property
relates deformation to an applied load or force.
Such as elastic modulus, strength, stiffness, ductility, hardness

Thermal property
refers to the responses of a material to a heat.
Such as heat capacity, heat conductivity

Electrical property
refers to the responses of a material to an applied electric field.
Such as electrical conductivity, dielectric constant

Optical property
refers to the responses of a material to electromagnetic or light radiation.
Such as index of refraction and reflectivity

Deteriorative property
is related to the chemical reactivity of materials.
Electrical Properties

- **Electrical Resistivity of Copper:**

![Graph showing the electrical resistivity of copper alloys and pure copper as a function of temperature.]

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

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.)
Property

Thermal Properties

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

- Thermal Conductivity of Copper:
  - It decreases when zinc is added.

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.)

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 Properties

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

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

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**Property**

**Optical Properties**

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

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

Deteriorative Properties

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

- Heat treatment: slows crack speed in salt water!

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

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.)
Boeing 737-200 commercial aircraft (Aloha Airlines flight 243) that experienced an explosive decompression and structural failure on April 28, 1988
The structure of a material will depend on how it is processed. Furthermore, a material’s performance will be a function of its properties.

**Processing**

- Chemical Synthesis
- Melting
- Casting
- Annealing
- Sintering
- Diffusion

**Performance**

- Cost
- Reliability
- Efficiency
- Service Life
The **structure** of a material will depend on how it is **processed**. Furthermore, a material’s performance will be a function of its **properties**.

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

- **Processing can change structure**
  
  *ex: structure vs cooling rate 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 & Rethwisch 8e*. Micrographs adapted from (a) Fig. 10.19; (b) Fig. 9.30; (c) Fig. 10.33; and (d) Fig. 10.21, *Callister & Rethwisch 8e*. 
WHAT ARE MATERIALS?
What are Materials?

MATERIALS are the stuff that we see everywhere

By a dictionary meaning; material is anything made of a matter, constituted of one or more substances.
What are Materials?

MATERIALS

- Can be anything: a finished product in its own right or an unprocessed raw material.

- There is natural stuff - wood, bone, straw, wool, cotton - and there is man-made stuff - steel, pottery, plastic, semiconductors, concrete, textiles, paper.
METALS
Types of Materials

 Metals and Alloys:
 Metallic bonding;
 • Cu, Al, Ni, Fe, Au, bronze (Cu-Sn), steel (Fe-C) etc.
 • They are grouped as ferrous (steels) and non-ferrous (copper, magnesium, titanium and so on) metals

 An alloy is a metal that contains additions of one or more metals or non-metals in relatively small amounts.

 Properties:
 • Good conductors of heat and electricity
 • High strength
 • High stiffness
 • High ductility
 • High density
 • Not transparent to visible light
 • Resistance to fracture
• The more an element exhibits the physical and chemical properties of metals, the greater its **metallic character**.
• The metallic character **increases as we proceed down a column** of the periodic table and **decreases from left to right in a row**.
# Types of Materials

<table>
<thead>
<tr>
<th>METALS</th>
<th>NONMETALS</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Shiny luster, various colors, most are silvery</td>
<td></td>
</tr>
<tr>
<td>• Solids are malleable and ductile</td>
<td></td>
</tr>
<tr>
<td>• Good conductors of heat and electricity</td>
<td></td>
</tr>
<tr>
<td>• Tend to form cations in aqueous solution</td>
<td></td>
</tr>
<tr>
<td>• Most metal oxides are ionic solids that are basic</td>
<td></td>
</tr>
<tr>
<td>• Do not have a luster; various colors</td>
<td></td>
</tr>
<tr>
<td>• Solids are usually brittle; some are hard and some are soft</td>
<td></td>
</tr>
<tr>
<td>• Poor conductors of heat and electricity</td>
<td></td>
</tr>
<tr>
<td>• Tend to form anions or oxyanions in aqueous solutions</td>
<td></td>
</tr>
<tr>
<td>• Most nonmetal oxides are molecular that are acidic</td>
<td></td>
</tr>
</tbody>
</table>

**METALLOIDS**

• Have some properties between those of metals and nonmetals
**Ceramics:**
Combinations of metals or semimetals with oxygen, nitrogen, carbon and boron (oxides, nitrides, carbides, borides) \( \text{CaO}, \text{Al}_2\text{O}_3, \text{BN}, \text{SiC}, \text{TiB}_2 \)
Properties: hard but very brittle, Insulators of heat and electricity, resistant to high temperature and harsh environments,

1-TRADITIONAL CERAMICS
Pottery, porcelain, brick, glass

2-ADVANCED CERAMICS
*Structural:* bioceramics, cutting tools, engine components, armour.
*Electrical:* Capacitors, insulators, magnets and superconductors
The periodic table of the elements

CERAMICS IN PERIODIC TABLE

Metal + BCNO
Polymers: Organic compounds based on C, H and other nonmetallic elements. Large molecular structures (e.g. Epoxy, Nylon, PVC, Polystyrene, Plastics and rubber) Properties: weak, low density, ductile, extremely flexible, insulators.

Natural Polymers
Rubber, cotton, wool, leather, silk

Synthetic Polymers
PP, PS, PVC, PE
### Type of Polymer

**1-THERMOPLASTIC**
Chains of molecules are not connected to each other

- i.e. Polyethylene (PE), Polyvinyl chloride (PVC), polypropylene (PP)

**Property**
Can be softened or molten and reformed into new shape by reheating.

**2-THERMOSETTING**
Heavily cross-linked to produce a strong three-dimensional network structure

- i.e. Polyester, epoxies, silicone

**Property**
Cannot be softened or molten and reshaped

**3-ELASTOMERS**
Polymers that have an elastic deformation >200%

- Polyisoprene (vulcanized rubber)

**Property**
Gains its original shape when deformed and then released
**Composites:**
Engineered to consist of more than one type of material (metal+ceramic, polymer+ceramic, etc), so that display a combination of best characteristics.

Properties: strong, ductile, low density, conductors and insulators.

**Types of composites**

![Venn Diagram](image_url)
Composites:

- **Matrix**: metal, ceramic or polymer
- **Reinforcement**: metal, ceramic or polymer

### Reinforcement particles used in composites

- **MMC** = Metal Matrix Composite
- **CMC** = Ceramic Matrix Comp.
- **PMC** = Polymer Matrix Comp.
Examples

Concrete (CMC)
- Matrix: Hardened cement paste (H.C.P.)
- Reinforcement: Graded aggregate

Automobile tire (PMC)
- Matrix: Rubber (Compliant)
- Reinforcement: glass fiber
- Particle: Carbon (Stiffer)

Boats (PMC)
- Matrix: epoxy
- Reinforcement: glass fiber

Cutting tools (MMC)
- Matrix: Cobalt (ductile)
- V_m: 10-15 vol% •
- Particles: WC (brittle, hard)
- Used for shaping of hard materials
Structural Composites, i.e. Honeycomb structure

High strength to weight ratio
Advanced Materials
(Semiconductors, Biomaterials, smart materials, Nanoengineered materials)

Semiconductors
Electrical properties are intermediate between conductors and insulators (e.g. Silicon)

(a) Micro-Electrical-Mechanical Systems (MEMS), (b) Si wafer for computer chip devices.
Biomaterials

(Co-Cr alloys, Stainless steels, Ti&Ti-alloys)
Smart Materials

EXAMPLE – Shape Memory Alloys