Materials Science and Engineering

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Posted Presentation (useful for the quiz):
Introduction to Materials Science and Engineering Concepts

Demonstrations and Discussion (fun for the day):
Scanning Electron Microscopy
Frozen Marshmallows

Supersaturation of Water with CO₂
Nucleation of CO₂ Bubbles

Shape Memory Alloys
???
Materials Science and Engineering

Materials Engineers work to understand and control the properties and performance of “solids”
Materials Science and Engineering

Materials Scientists and Engineers produce “solids” with controlled properties for use in all engineered devices and structures.

Materials technologies have always influenced civilization.

Stone Age, Bronze Age, Iron Age, Silicon Age, ???

All technologies are based around some material. Can you think of something, anything, that does not require a material?
Carnegie Mellon Materials Engineers created InP solar panels for the ISS that have greater efficiency and longer life.
The International Space Station: Energy is a Materials Challenge

Materials Engineers created InP solar panels for the ISS that have greater efficiency and longer life.
Materials Science and Engineering is Interdisciplinary

Materials Science and Eng. has only been around as a formal discipline for 50+ years. The discipline exists at the interface of:

- Metallurgy, Ceramics, Mineralogy
- Physics, Chemistry, Biology, Mathematics
- Engineering:
  - Chemical, Mechanical, Civil, Environmental, Biomedical, Electrical, Computer

Materials Science and Engineering involves the discovery and application of fundamental principles.
Biomaterials and Tissue Engineering

Materials Engineers work with medical researchers to develop new implant and tissue replacement materials
Recently the steel industry has developed an optimized automotive steel structure which is 24% lighter, 34% stronger, and $154 less expensive than auto body structures on the road today. (>3 years old)

Materials Engineering in Automobiles

Fuel cells : Energy / Environment
Electric generation : Energy / Environment
Catalytic converters : Environment
**Materials Science**

**Tetrahedron**

**Structure:**

arrangement of internal components on something
(ranges from atomic to and macroscopic shape)
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**Properties:**

the kind and magnitude of a response to an external stimulus.
**Materials Science Tetrahedron**

**Structure:**
arrangement of internal components on something
(ranges from atomic to and macroscopic shape)

**Processing:**
the methods used to prepare materials for application

**Properties:**
the kind and magnitude of a response to an external stimulus.
**Materials Science Tetrahedron**

**Structure:**
arrangement of internal components on something
(ranges from atomic to and macroscopic shape)

**Processing:**
the methods used to prepare materials for application

**Properties:**
the kind and magnitude of a response to an external stimulus.

**Performance:**
how a material achieves the requirements of a specific applications
Materials Science and Engineering

Internal Structure:
- Electronic
- Atomic
- Molecular arrangement
- Microstructure
- Grain Size
- Precipitate Size

Properties:
- Electrical
- Thermal
- Mechanical
- Optical
- Magnetic
- Deteriorative

Performance:
- Service Life
- Failure Mode
- Environmental Compatibility
- Recycling
- Quality
- Cost

Processing:
- Synthesis
- Purification
- Annealing
- Forming
- Polishing
- Time
# Materials Science and Engineering

<table>
<thead>
<tr>
<th>Processing</th>
<th>How do you make a material?</th>
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<tbody>
<tr>
<td></td>
<td>How do you make it in a specific shape?</td>
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<td>How do you make it do what you want?</td>
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<table>
<thead>
<tr>
<th>Structure (Composition)</th>
<th>What and How do you get the structure you want?</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Every material has a hierarchy of structural levels.</td>
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<tr>
<td></td>
<td>How do you characterize these?</td>
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<tr>
<td></td>
<td>How do you get the structure you want?</td>
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<table>
<thead>
<tr>
<th>Properties</th>
<th>Why do materials have the properties they do?</th>
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<tbody>
<tr>
<td></td>
<td>How can you exploit these?</td>
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<td>How do you ensure these get transferred to technologies?</td>
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<table>
<thead>
<tr>
<th>Performance</th>
<th>How to ensure that materials don’t limit technology?</th>
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<tbody>
<tr>
<td></td>
<td>How long do materials last?</td>
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<tr>
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<td>How do materials fail?</td>
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<td>How do you ensure that materials do not limit technology?</td>
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</tbody>
</table>
Materials Engineers Work Across Length Scales
Structure of Solids
Two types of Atomic Order

Disordered
(Amorphous)

Ordered
(Crystalline)
Demonstration: Metallic Glass vs Nanocrystalline

Discussion / Notes

Structure  Processing  Properties  Performance

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Atomic Arrangements: The crystal structures of Iron

*Face Centered Cubic*

*Body Centered Cubic*

Atomic Arrangements:
The crystal structures of Iron

Face Centered Cubic

Body Centered Cubic

Atomic Arrangements:
The crystal structures of Iron

Face Centered Cubic

Body Centered Cubic

Demonstration: Piano Wire Phase Change

Discussion / Notes

Demonstration:
Shape Memory Alloys

Discussion / Notes

http://webdocs.cs.ualberta.ca/~database/MEMS/sma_mems/sma.html

Structure  Processing  Properties  Performance
Properties are Length Scale Dependent

Scale of our material world, from galaxies to atoms

1 nanometer =
1 billionth of a meter

http://invsee.asu.edu/Modules/size&scale/unit3/unit3.htm
http://www.powersof10.com/
Properties are Length Scale Dependent

What Color are Gold and Silver?

Stained-Glass as Ancient Nanotechnology

Gold and silver salts were used in medieval times to color glass used in church windows. For example, silver particles were used to stain glass yellow, while gold particles were used to stain glass red. The aggregation of metal into nanoparticles with surface-plasmon resonances which variously affected their spectral transmissivity is only today's 20-20 hindsight analysis of archaic technology.
New biocompatible quantum dots are set to revolutionize biological imaging. In (a) a frog embryo has been imaged using conventional organic-dye techniques, and the signal is seen to fade in time. (b) Specially prepared quantum dots that were injected into another frog embryo at the same time fluoresce brightly for much longer.
Properties are Length Scale Dependent
Classification of Materials
Classification of Materials

Metals:

Solids or compounds composed of metallic elements
Classification of Materials

Metals:
   Solids or compounds composed of metallic elements

Polymers:
   Materials having large molecules whose basic repeating unit
   is based upon carbon, hydrogen, other non-metallics
Classification of Materials

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Ceramics:
Compounds between metallic and non-metallic elements
(and covalently bonded elements at the boundary)

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Composites:
Materials that contain a number of different materials designed to get the best combined property / performance/
### Periodic Table of the Elements

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<tbody>
<tr>
<td><strong>1H</strong></td>
<td><strong>2He</strong></td>
<td><strong>3Li</strong></td>
<td><strong>4Be</strong></td>
<td><strong>5B</strong></td>
<td><strong>6C</strong></td>
<td><strong>7N</strong></td>
<td><strong>8O</strong></td>
<td><strong>9F</strong></td>
<td><strong>10Ne</strong></td>
<td><strong>11Na</strong></td>
<td><strong>12Mg</strong></td>
<td><strong>13Al</strong></td>
<td><strong>14Si</strong></td>
<td><strong>15P</strong></td>
<td><strong>16S</strong></td>
</tr>
<tr>
<td>hydrogen</td>
<td>helium</td>
<td>lithium</td>
<td>beryllium</td>
<td>boron</td>
<td>carbon</td>
<td>nitrogen</td>
<td>oxygen</td>
<td>fluorine</td>
<td>neon</td>
<td>sodium</td>
<td>magnesium</td>
<td>aluminium</td>
<td>silicon</td>
<td>sulphur</td>
<td>chlorine</td>
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<tr>
<td>1.008</td>
<td>4.003</td>
<td>6.941</td>
<td>9.012</td>
<td>10.81</td>
<td>12.01</td>
<td>14.01</td>
<td>16.00</td>
<td>19.00</td>
<td>20.18</td>
<td>22.99</td>
<td>24.31</td>
<td>27.36</td>
<td>30.97</td>
<td>35.45</td>
<td>45.38</td>
</tr>
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### Classification of Materials

- **Lanthanide Series**: lanthanum to lutetium
- **Actinide Series**: actinium to lawrencium
Classification of Materials

Primary Material Classification
- Metal
- Ceramic
- Polymer
- Composite

Alternate (application oriented)
- Electronic
- Biomedical
- Nanomaterials
- Aerospace
- Glasses
- etc…

Property Classification
- Electrical
- Magnetic
- Optical
- Thermal
- Mechanical
- Deteriorative

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General Features of Materials

Metals

- Electrical Conductors
- Thermal Conductors
- Opaque
- Ductile
- Strong
- Crystalline except under conditions of rapid cooling
General Features of Materials

Ceramics

• Oxides, Carbides, sulfides and nitrides
• Insulating to heat and electricity (most)
• Resistant to High Temperatures
• Resistant to Corrosive Atmospheres
• Hard
• Brittle
• Crystalline but can form glasses easily under condition of rapid cooling
Classification of Materials

Polymers

• Low Density
• Low temperature applications
• Ductile to brittle transitions as temperature decreases
• Visco-elastic at higher temperatures
• Large molecular structures
• Glasses but can form crystals
Classification of Materials

Composites

- Metal-Ceramic
- Ceramic-ceramic
- Crystalline-amorphous
- Emulsion (liquid-liquid)
- Wood

Tailored properties
Directional properties

Polymer-ceramic
Metal-polymer
Foams (gas -solid)
Concrete
Strong but light
Fiber-glass
Nanocomposite TiO$_2$-glass coating

Self Cleaning Windows

Researchers have developed these windows and they are now available for sale. One of a few companies selling windows with this technology is Pilkington. The glass is covered with a thin film of a special compound that does the actual cleaning.

The windows are powered by UV light, which helps the compound break down any dirt that accumulates on the glass. The compound is also hydrophilic which causes the water to sheet off the window instead of forming beads of water.

Autonomous Windows Due to their special Coating these windows stay clean without much outside interference.

Sheeting Water The hydrophilic coating causes water to sheet off the window and take all the dirt with it.
The Space Shuttle: Protection is a Materials Challenge

Materials Engineers created Ceramic Panels for the Shuttle that higher heat resistance and mechanical strength
The Space Shuttle: Protection is A Materials Challenge

Materials Engineers created Ceramic Panels for the Shuttle that higher heat resistance and mechanical strength
Clothing / Insulation: Protection is A Materials Challenge

Bob Gore invented GORE TEX in frustration
Structure Determination: Scanning Electron Microscopy

High Magnification
Large Depth of Field
Relatively Simple
More information than Topography
Sample (environment) must conduct
Vacuum Technique

http://www.mse.iastate.edu/microscopy/proimage.html
Structure Determination: Scanning Electron Microscopy

http://www.mse.iastate.edu/microscopy/proimage.html
Demonstration: Scanning Electron Microscopy

Marshmallows: A Materials Challenge?
Demonstration: Scanning Electron Microscopy

Marshmallows: A Materials Challenge?

Discussion / Notes
Demonstration
Frozen Marshmallows

Discussion / Notes

http://brands.kraftfoods.com/Jetpuffed

Structure      Processing      Properties      Performance
Processing Affects Structure

Nucleation and Growth

• Nucleation:
  the initial formation of a new phase from
  an environment that does not contain that phase

• Growth
  the increase in size of existing nuclei into a different medium

Video Demonstration
Nucleation and Growth

http://www.youtube.com/watch?v=aC-KOYQsIvU&NR=1
Microstructure of Materials

Microstructure is defined in two ways:
the structure you observe when viewing a material under a microscope
the structure of a material on the micron-scale (0.5 to 100)

Polycrystal
Most Materials

Single Crystal
Gem Stones
GaAs Laser
Si wafers
NiAl Turbine Blades
Processing Affects Structure
Fe-Fe₃C (Steel)

Adapted from Fig. 10.5, *Callister 6e.*
(Fig. 10.5 adapted from H. Boyer (Ed.) *Atlas of Isothermal Transformation and Cooling Transformation Diagrams*, American Society for Metals, 1997, p. 28.)

Processing Affects Structure
Fe-Fe₃C (Steel)

- Smaller ΔT: colonies are larger
- Larger ΔT: colonies are smaller

Adapted from Fig. 10.6 (a) and (b), Callister 6e. (Fig. 10.6 from R.M. Ralls et al., An Introduction to Materials Science and Engineering, p. 361, John Wiley and Sons, Inc., New York, 1976.)
Dendrite Formation in Tin
Nucleation Demonstration: CO$_2$ Injection into Water and Release

Watch During Set-Up

http://www.youtube.com/watch?v=hKoB0MHVBvM

http://www.youtube.com/watch?v=LjbJELjLgZg&feature=related

Define

Supersaturation
Supercooling

Structure      Processing      Properties      Performance

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Nucleation Demonstration: CO$_2$ Injection into Water and Release

Discussion / Notes

- Nucleation:

- Growth

Turbine Blades

Figure 8.41  (a) Polycrystalline turbine blade that was produced by a conventional casting technique. High-temperature creep resistance is improved as a result of an oriented columnar grain structure (b) produced by a sophisticated directional solidification technique. Creep resistance is further enhanced when single-crystal blades (c) are used. (Courtesy of Pratt & Whitney.)
In aircraft engines, a nickel-based alloy called Alloy 718 is used extensively for compressor and turbine parts.
Engineering Materials of the Future

• To understand the fundamentals of Materials' Structure, Properties, Processing, and Performance.

• To understand the relationship between these items, and how they are exploited for sample engineering applications.
Careers in Materials Engineering

- Automotive
- Aeronautical
- Biological
- Electronic
- Environmental
- Athletic Equipment
- Chemical
- Mining/refining

Mean starting salary, class of 2009 = $64.2 K

2008: (MSE = 59K, CEE = 54k, ME = 58k, BME = 63k, ChE = 66.5k, ECE = 68.5k)
Mean Starting Salaries

Every year, roughly half of our students enter doctoral programs
Data for CMU, Class of 2008, Bachelors Degree
Source: CMU career center

2009 MSE Values:

<table>
<thead>
<tr>
<th></th>
<th>Maximum</th>
<th>Mean</th>
<th>Median</th>
<th>Minimum</th>
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<tbody>
<tr>
<td></td>
<td>$85,000</td>
<td>$64,182</td>
<td>$63,397</td>
<td>$50,000</td>
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