A fly-by during deployment of the aircraft carrier USS Stennis. The pilot was grounded for 30 days, but he likes the picture and thinks it was worth it.
Materials Science and Engineering

- **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
Structure

• Sub atomic – electrons and nuclei (protons and neutrons)
• Atomic – organization of atoms or molecules
• Microscopic – groups of atoms that are normally agglomerated together
• Macroscopic – viewable with the un-aided eye
Terminology

mil = 1 / 1000 inch = 25.4 µm
micrometer = 1 / 1,000,000 meter = 1µm
Angstrom = 1 / 10,000,000,000 meter = 1Å

1 MICROMETER IS TWO WAVELENGTHS OF GREEN LIGHT LONG

A 1 MICRON WIDE LINE ON A CD
IS THE SAME SCALE AS A 100 FOOT
WIDE ROAD ON NORTH AMERICA

A HAIR IS 100 MICROMETERS
THE SCALE OF THINGS

**Things Natural**

- **Cat** ~ 0.3 m
- **Monarch butterfly** ~ 0.1 m
- **Dust mite** 300 µm
- **Fly ash** ~ 10-20 µm
- **Human hair** ~ 50 µm wide
- **Cell membrane**
- **Red blood cells with white cell** ~ 2-5 µm
- **Magnetic domains garnet film** 11 µm wide stripes Schematic, central core
- **DNA** ~2 nm wide
- **ATP synthase**

**Things Manmade**

- **Head of a pin** 1-2 mm
- **MEMS (MicroElectroMechanical Systems) Devices** 10 -100 µm wide
- **Red blood cells**
- **Pollen grain**
- **Human hair** ~ 50 µm wide
- **Indium arsenide quantum dot**
- **Quantum dot array** - germanium dots on silicon
- **Indium arsenide quantum dot**

**Progress in atomic-level understanding**

- **1 nanometer (nm)**
- **10 nm**
- **100 nm**
- **1 micrometer (µm)**
- **10 µm**
- **10 µm**
- **10 mm**
- **1 cm**
- **100 mm**
- **1 meter (m)**

**The Microworld**

- **Visible spectrum**

**The Nanoworld**

- **Magnetic domains garnet film**
- **Red blood cells with white cell**
- **DNA**
- **Cell membrane**

**The 21st century challenge** -- Fashion materials at the nanoscale with desired properties and functionality.
Structure, Processing, & Properties

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

  ![Hardness vs Cooling Rate](image)

  - Data obtained from Figs. 10.21(a) and 10.23 with 4wt%C composition, and from Fig. 11.13 and associated discussion, *Callister 6e*. Micrographs adapted from (a) Fig. 10.10; (b) Fig. 9.27; (c) Fig. 10.24; and (d) Fig. 10.12, *Callister 6e*.

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

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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.
Composition, Bonding, Crystal Structure and Microstructure DEFINE Materials Properties

- Composition
- Bonding
- Crystal Structure

Thermomechanical Processing

Microstructure

- Mechanical Properties
- Electrical & Magnetic Properties
- Optical Properties
- Thermal Properties
ELECTRICAL

- Electrical Resistivity of Copper:

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

Adapted from Fig. 18.8, Callister 6e. (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.)
• Magnetic Storage:
  --Recording medium is magnetized by recording head.

  Fig. 20.18, *Callister 6e.*
  (Fig. 20.18 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!

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

Adapted from Fig. 1.2, *Callister 6e.*
(Specimen preparation, P.A. Lessing; photo by J. Telford.)
DETERIORATIVE

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

• Heat treatment: slows crack speed in salt water!

Adapted from Fig. 11.24, Callister 6e. (Fig. 11.24 provided courtesy of G.H. Narayanan and A.G. Miller, Boeing Commercial Airplane Company.)

--material:
7150-T651 Al "alloy" (Zn,Cu,Mg,Zr)

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.)

Alloy 7178 tested in saturated aqueous NaCl solution at 23C

increasing load

10^-10

10^-8

crack speed (m/s)

“as-is”

“held at 160C for 1hr before testing”

4µm

Adapted from Fig. 17.0, Callister 6e. (Fig. 17.0 is from Marine Corrosion, Causes, and Prevention, John Wiley and Sons, Inc., 1975.)
Types of Materials

Metals: strong, ductile, tough, high density, conductors.
Ceramics: strong, brittle, low density, insulators.
Polymers: weak, ductile, low density, insulators.
Semiconductors: weak, brittle, low density, semi-conductors.
Composites: strong, ductile, low density, conductors, insulators.

Crystals: atoms have long range periodic order (a).
Glasses: atoms have short range order only (b).
Types of Materials

Let us classify materials according to the way the atoms are bound together (Chapter 2).

**Metals:** valence electrons are detached from atoms, and spread in an 'electron sea' that "glues" the ions together. Strong, ductile, conduct electricity and heat well, are shiny if polished.

**Semiconductors:** the bonding is covalent (electrons are shared between atoms). Their electrical properties depend strongly on minute proportions of contaminants. Examples: Si, Ge, GaAs.

**Ceramics:** atoms behave like either positive or negative ions, and are bound by Coulomb forces. They are usually combinations of metals or semiconductors with oxygen, nitrogen or carbon (oxides, nitrides, and carbides). Hard, brittle, insulators. Examples: glass, porcelain.

**Polymers:** are bound by covalent forces and also by weak van der Waals forces, and usually based on C and H. They decompose at moderate temperatures (100 – 400 C), and are lightweight. Examples: plastics rubber.
Several uses of steel and pressed aluminum.
Examples of ceramic materials ranging from household and lab products to high performance combustion engines which utilize both Metals and ceramics.

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Crystalline ceramics (a) and non-crystalline glasses (b) yield inherently different properties for applications. Open circles represent nonmetallic atoms, solids represent metal atoms.
Examples of glasses. Depending on the material structure, the glass can be opaque, transparent, or translucent. Glasses can also be processed to yield high thermal shock resistance.
Polymers or commercially called “Plastics” need no intro.
Polymer composite materials, reinforcing glass fibers in a polymer matrix.

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Semiconductors

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

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<table>
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<th>Applications</th>
<th>Properties</th>
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<tr>
<td><strong>Ceramics</strong></td>
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<td></td>
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<td>Phenolics</td>
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<td>Carbide cutting tools for machining</td>
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<td>Titanium-clad steel</td>
<td>Reactor vessels</td>
</tr>
</tbody>
</table>
SUMMARY

- Use the right material for the job.

- Understand the relation between properties, structure, and processing.

- Recognize new design opportunities offered by materials selection.