

MAT 214: Processing and Properties of Ceramic Materials

History of Ceramic Materials

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Materials Science and Engineering
Lehigh University

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Learning Objectives:

- An appreciation for the historic origins and applications of ceramic materials
- Understanding of processes and considerations for structural ceramic materials (cements)
- A working knowledge of industrial applications of ceramic materials
- An appreciation for the diversity of modern applications of ceramic materials



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- When chipped leave a sharp edge



Clay

- The oldest samples of baked clay include more than 10,000 fragments of statuettes dated as far back as 23,000 BCE



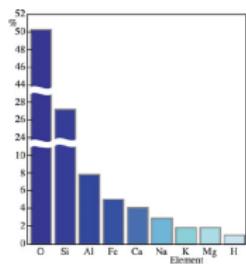
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 - The high strength of the Si–O bond

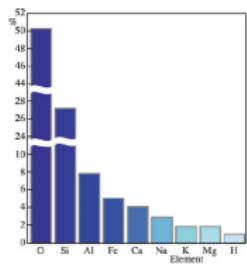


TABLE 2.1 Bond Strengths with Oxygen

Bond	Strength (kJ/mol)
Ti-O	674
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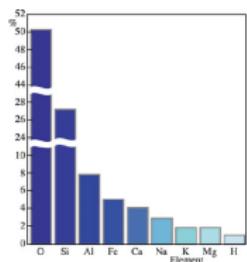


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- Their abundance makes them found in all parts of the world

Types of Pottery - Earthenware



- Red “earthenware clay”
- Porous when not glazed, not vitreous (glassy)
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- Bricks, tiles, and terra cotta vessel
- Earthenware dating back to between 7,000 and 8,000 BCE

Types of Pottery - Stoneware



- Fired to a higher temperature (around 1,200–1,300°C)
- At least partially vitrified, and so it is nonporous and stronger
- Traditional stoneware was gray or buffcolored, although the color can vary, ranging from black—through red, brown, and gray—to white

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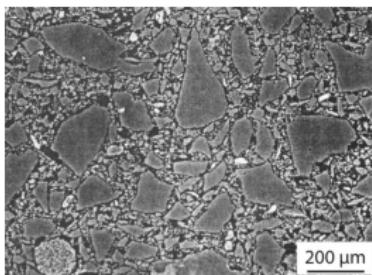
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- Color comes from metal-oxides, called jasper
- Fine white stoneware was made in China as early as 1,400 BCE

Types of Pottery - Porcelain



- It is a white, thin, and translucent ceramic that possesses a metal-like ringing sound when tapped
- Porcelain is made from kaolin (also known as china clay), quartz, and feldspar
- Fired at 1,250–1,300°C, it is an example of vitreousware
- Porcelain 618–907 BCE

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- Complex microstructure containing many large grains immersed in a glass phase

Cement

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- World production of hydraulic cement is about 1.5 billion tons per year
- When mixed with sand and gravel, we obtain concrete, the most widely utilized construction material in industrialized nations
- Ancient Romans and Greeks, 2,000 years ago, pioneered the use of cement which consisted of a mixture of powdered lime (CaO) and volcanic ash (a mixture of mainly SiO_2 , Al_2O_3 , and iron oxide)—called *pozzolana*

Portland Cement

- Modern cement is mainly Portland Cement a specific surface area of $300 \text{ m}^2/\text{kg}$ and grains between 20 and 30 mm

Chemistry is described in a reduced nomenclature



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Reduced Nomenclature for Cement Chemistry

Lime $\text{CaO} = \text{C}$

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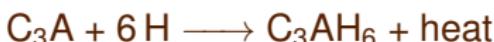
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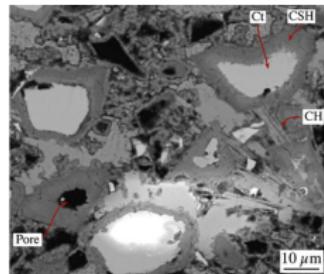
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2 Tobermorite gel ($\text{Ca}_3\text{Si}_2\text{O}_7 \cdot 3\text{H}_2\text{O}$) formation 10h-100 days



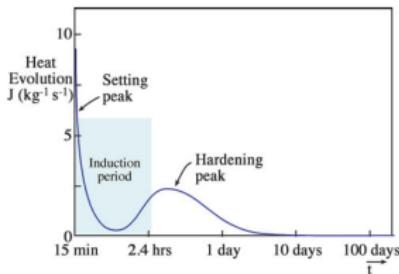
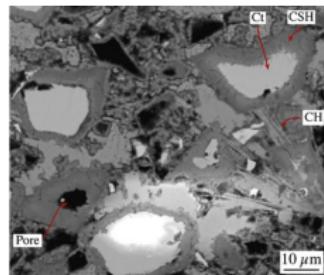
This bonds everything together

Process of Portland Cement



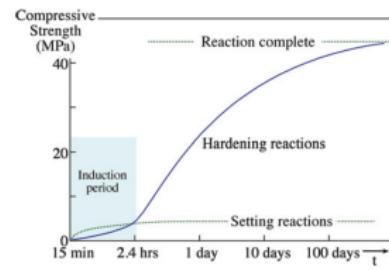
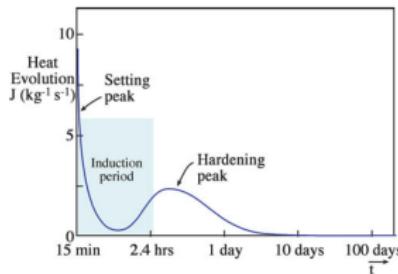
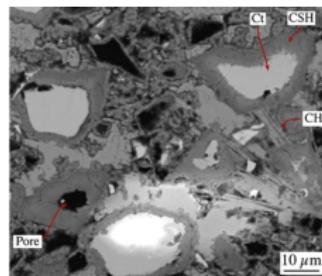
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Process of Portland Cement



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- Hardening happens over many days to reach final compressive strength

Plaster of Paris



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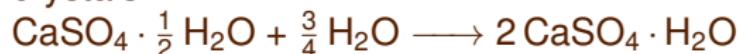


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- $$\text{CaSO}_4 \cdot \frac{1}{2} \text{H}_2\text{O} + \frac{3}{4} \text{H}_2\text{O} \longrightarrow 2 \text{CaSO}_4 \cdot \text{H}_2\text{O}$$

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- 1880: Magnesite with a typical composition in a ratio of MgO 83–93%/ Fe_2O_3 2–7%
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- Refractory materials have complex chemistry and microstructures

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Uranium Dioxide Nuclear Fuel



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 - 3 Fluorite crystal structure, which can accommodate ion fission products (He) without straining the lattice

Pore-Free Ceramics



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- Can be used to improve mechanical properties

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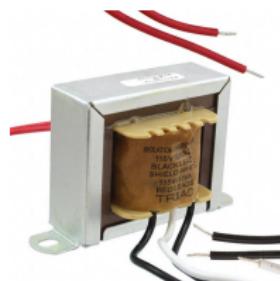
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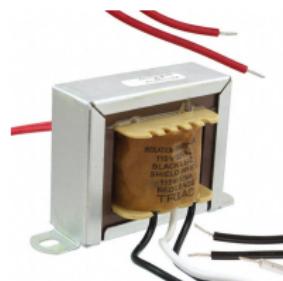
- Most common is silicon nitride Si_3N_4 is a chemical compound of the elements silicon and nitrogen
- Good high-temperature, chemically inert material
- Very good electrical resistance
- Is harder than metal but has good shock resistance, this makes it good for ball bearing and abrasives.

Magnetic Ferrites



- Commercial applications of magnetic ferrites started in 1930s → used for signal processing (e.g., inductors and transformers)

Magnetic Ferrites



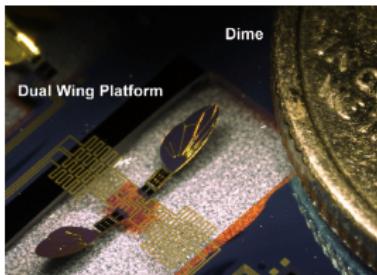
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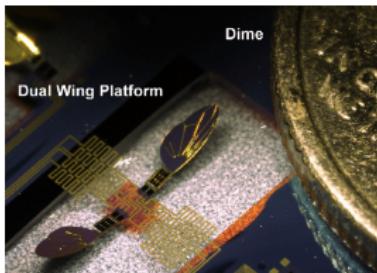
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- About 1-million tons of ceramic ferrites are produced a year.

Ferroelectric Titanates



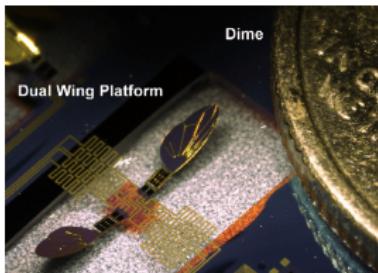
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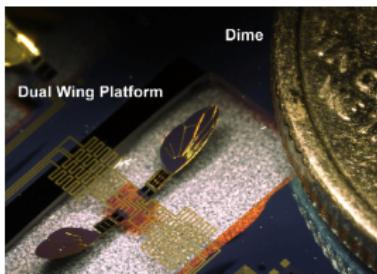
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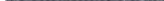
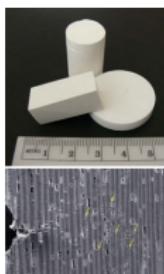
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- Tons of interesting modern applications in micro-electro-mechanical systems (MEMS) and quantum computing

Tough Ceramics



- Ceramics are inherently brittle with low toughness
- Zirconia (ZrO_2) can increase the strength and toughness of ceramics by utilizing the tetragonal to monoclinic phase transformation induced by the presence of a stress field ahead of a crack.

Bioceramics



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Bioceramics



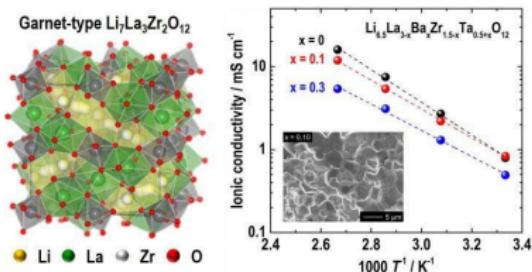
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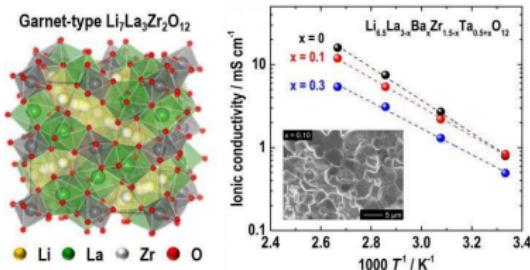
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- Some ceramics can be bioactive and used for bone growth

Fast-Ion Conductors



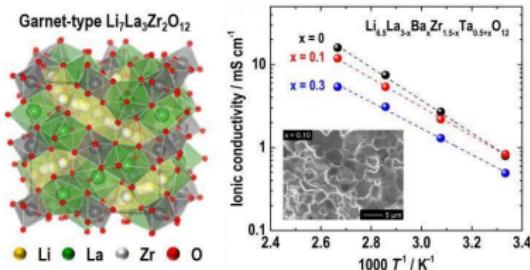
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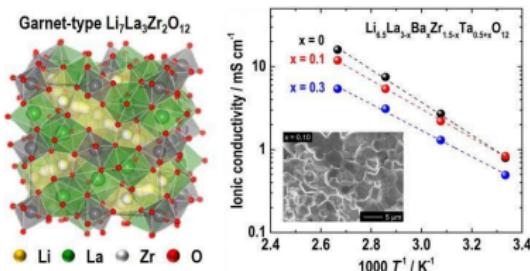
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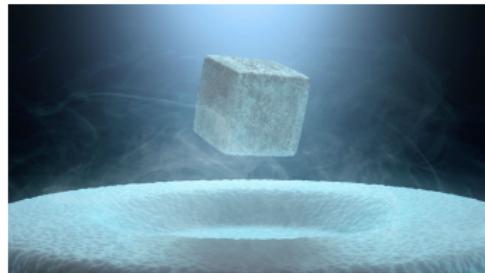
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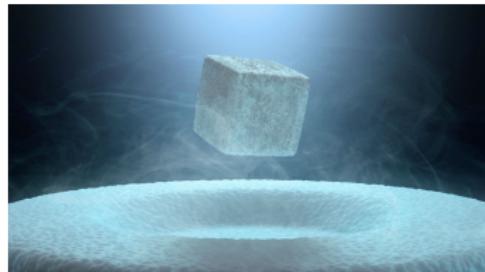
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- Majority of effort is on reducing cost, and improving reliability, and electrical mobility.

High-Temperature Superconductors



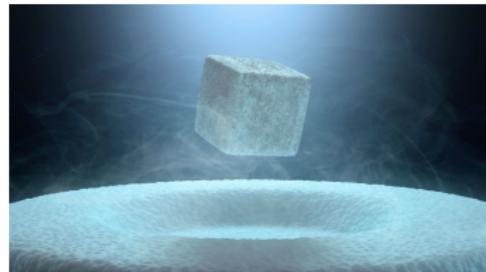
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High-Temperature Superconductors



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- All high-temperature superconductors are ceramics
- The most common are 123 $\text{YBa}_2\text{Cu}_3\text{O}_7$

Important Concepts to Master

- Why clay is so common on earth?
- Chemistry and thermal and mechanical evolution of cement
- Materials design - given an application be able to suggest a candidate ceramic materials
- High-level understanding of why ceramic materials are useful for specific modern applications

Things you should not attend to:

- Specific complex chemical structures of materials
- Specific dates, common names (flint), or regions where specific materials were discovered
- Specific numbers provided in text or tables, important relative values should be considered.

