Chapter 13: Applications and Processing of Ceramics

ISSUES TO ADDRESS...

• How do we classify ceramics?

• What are some applications of ceramics?

• How is processing different than for metals?
13.1-13.8 Taxonomy of Ceramics

- Glasses
  - optical
  - composite
  - reinforce
  - containers/household
- Clay products
- Refractories
  - bricks
  - for high $T$ (furnaces)
- Abrasives
  - sandpaper
  - cutting
  - polishing
- Cements
  - composites
  - structural
- Advanced ceramics
  - engine
  - rotors
  - valves
  - bearings
  - sensors

Adapted from Fig. 13.1 and discussion in Section 13.2-6, Callister 7e.

• Properties:
  -- $T_m$ for glass is moderate, but large for other ceramics.
  -- Small toughness, ductility; large moduli & creep resist.

• Applications:
  -- High $T$, wear resistant, novel uses from charge neutrality.

• Fabrication
  -- some glasses can be easily formed
  -- some ceramics can not be formed or cast.
Application: Refractories

- Need a material to use in high temperature furnaces.
- Consider the Silica (SiO\textsubscript{2}) - Alumina (Al\textsubscript{2}O\textsubscript{3}) system.
- Phase diagram shows: mullite, alumina, and crystobalite as candidate refractories.

Adapted from Fig. 12.27, Callister 7e. (Fig. 12.27 is adapted from F.J. Klug and R.H. Doremus, "Alumina Silica Phase Diagram in the Mullite Region", J. American Ceramic Society \textbf{70}(10), p. 758, 1987.)
• 20wt%Al$_2$O$_3$-80wt%SiO$_2$ and 25wt%Al$_2$O$_3$-75wt%SiO$_2$
Which is more desirable for refractory?
Application: Cutting Tools

• Tools:
  -- for grinding glass, tungsten, carbide, ceramics
  -- for cutting Si wafers
  -- for oil drilling

• Solutions:
  -- manufactured single crystal or polycrystalline diamonds in a metal or resin matrix.
  -- optional coatings (e.g., Ti to help diamonds bond to a Co matrix via alloying)
  -- polycrystalline diamonds resharpen by microfracturing along crystalline planes.
**Application: Sensors**

- **Example:** Oxygen sensor ZrO$_2$
- **Principle:** Make diffusion of ions fast for rapid response.
- **Approach:**
  Add Ca impurity to ZrO$_2$:
  -- increases O$^{2-}$ vacancies
  -- increases O$^{2-}$ diffusion rate
- **Operation:**
  -- voltage difference produced when O$^{2-}$ ions diffuse from the external surface of the sensor to the reference gas.
Ceramic Fabrication Methods-I

GLASS FORMING

PARTICULATE FORMING

CEMENTATION FORMING

Fracture
Release stress in 15 min
Hold shape
Easily deformed
Liquid

Chapter 13 - 7
13.9 Ceramic Fabrication Methods-I

GLASS FORMING

- Pressing:
  - Gob
  - Parison mold

- Blowing:
  - Suspended Parison
  - Compressed air
  - Finishing mold

PARTICULATE FORMING

- Fiber drawing:
  - Wind up
  - Plates, dishes, cheap glasses

CEMENTATION

Adapted from Fig. 13.8, Callister, 7e. (Fig. 13.8 is adapted from C.J. Phillips, Glass: The Miracle Maker, Pittman Publishing Ltd., London.)
Glass Properties

- **Specific volume** \((1/\rho)\) vs Temperature \((T)\):

  - **Crystalline materials:**
    - crystallize at melting temp, \(T_m\)
    - have abrupt change in spec. vol. at \(T_m\)

  - **Glasses:**
    - do not crystallize
    - change in slope in spec. vol. curve at glass transition temperature, \(T_g\)
    - transparent
      - no crystals to scatter light

Adapted from Fig. 13.6, *Callister, 7e.*
Glass Viscosity vs. T and Impurities

- Viscosity decreases with $T$
- Impurities lower $T_{\text{deform}}$

- soda-lime glass: 70% SiO$_2$ balance Na$_2$O (soda) & CaO (lime)
- borosilicate (Pyrex): 13% B$_2$O$_3$, 3.5% Na$_2$O, 2.5% Al$_2$O$_3$
- Vycor: 96% SiO$_2$, 4% B$_2$O$_3$
- fused silica: > 99.5 wt% SiO$_2$

Adapted from Fig. 13.7, Callister, 7e. (Fig. 13.7 is from E.B. Shand, Engineering Glass, Modern Materials, Vol. 6, Academic Press, New York, 1968, p. 262.)
Heat Treating Glass

- **Annealing:**
  --removes internal stress caused by uneven cooling.

- **Tempering:**
  --puts surface of glass part into compression
  --suppresses growth of cracks from surface scratches.
  --sequence:

  before cooling  surface cooling  further cooled
  ![Diagram with hot, cooler, and tension/compression arrows]

  --Result: surface crack growth is suppressed.
13.10 Ceramic Fabrication Methods-IIA

GLASS FORMING

- Milling and screening: desired particle size
- Mixing particles & water: produces a "slip"
- Form a "green" component
  -- Hydroplastic forming: extrude the slip (e.g., into a pipe)
  -- Slip casting:
    - pour slip into mold
    - absorb water into mold
    - "green ceramic"
    - pour slip into mold
    - drain mold
    - "green ceramic"

PARTICULAT FORMING

- Form a "green" component
  -- Hydroplastic forming: extrude the slip (e.g., into a pipe)
  -- Slip casting:
    - pour slip into mold
    - absorb water into mold
    - "green ceramic"
    - pour slip into mold
    - drain mold
    - "green ceramic"

CEMENTATION

- Dry and fire the component

Adapted from Fig. 11.8 (c), Callister 7e.
Adapted from Fig. 13.12, Callister 7e.
(Fig. 13.12 is from W.D. Kingery, Introduction to Ceramics, John Wiley and Sons, Inc., 1960.)
Clay Composition

A mixture of components used

(50%) 1. Clay
(25%) 2. Filler – e.g. quartz (finely ground)
(25%) 3. Fluxing agent (Feldspar)
   binds it together
   aluminosilicates + K\(^+\), Na\(^+\), Ca\(^+\)
Features of a Slip

• Clay is inexpensive
• Adding water to clay
  -- allows material to shear easily
    along weak van der Waals bonds
  -- enables extrusion
  -- enables slip casting

• Structure of Kaolinite Clay:

Adapted from Fig. 12.14, Callister 7e.
(Fig. 12.14 is adapted from W.E. Hauth,
"Crystal Chemistry of Ceramics", American
Ceramic Society Bulletin, Vol. 30 (4), 1951,
p. 140.)
Drying and Firing

- **Drying**: layer size and spacing decrease.

  - Wet slip
  - Partially dry
  - "Green" ceramic

  Drying too fast causes sample to warp or crack due to non-uniform shrinkage.

- **Firing**:
  - $T$ raised to (900-1400°C)
  - Vitrification: liquid glass forms from clay and flows between SiO$_2$ particles. Flux melts at lower $T$.

Adapted from Fig. 13.13, *Callister 7e*. (Fig. 13.13 is from W.D. Kingery, *Introduction to Ceramics*, John Wiley and Sons, Inc., 1960.)

Adapted from Fig. 13.14, *Callister 7e*. (Fig. 13.14 is courtesy H.G. Brinkies, Swinburne University of Technology, Hawthorn Campus, Hawthorn, Victoria, Australia.)
Sintering: useful for both clay and non-clay compositions.

- Procedure:
  -- produce ceramic and/or glass particles by grinding
  -- place particles in mold
  -- press at elevated $T$ to reduce pore size.

- Aluminum oxide powder:
  -- sintered at 1700°C for 6 minutes.

Adapted from Fig. 13.17, *Callister 7e.*
(Fig. 13.17 is from W.D. Kingery, H.K. Bowen, and D.R. Uhlmann, *Introduction to Ceramics*, 2nd ed., John Wiley and Sons, Inc., 1976, p. 483.)
Powder Pressing

Sintering - powder touches - forms neck & gradually neck thickens
  – add processing aids to help form neck
  – little or no plastic deformation

Uniaxial compression - compacted in single direction

Isostatic (hydrostatic) compression - pressure applied by fluid - powder in rubber envelope

Hot pressing - pressure + heat

Adapted from Fig. 13.16, Callister 7e.
Powder Pressing

Compressed pellet sintering

Hot pressing
13.12 Tape Casting

- thin sheets of green ceramic cast as flexible tape
- used for integrated circuits and capacitors
- cast from liquid slip (ceramic + organic solvent)

Adapted from Fig. 13.18, Callister 7e.
• Produced in extremely large quantities.
• Portland cement:
  -- mix clay and lime bearing materials
  -- calcinate (heat to 1400°C)
  -- primary constituents:
    tri-calcium silicate (3CaO-SiO₂)
    di-calcium silicate (2CaO-SiO₂)
• Adding water
  -- produces a paste which hardens
  -- hardening occurs due to hydration (chemical reactions with the water e.g. (2CaO-SiO₂+xH₂O= 2CaO-SiO₂-xH₂O)).
• Forming: done usually minutes after hydration begins.
Applications: Advanced Ceramics

Electronic Packaging

• Chosen to securely hold microelectronics & provide heat transfer
• Must match the thermal expansion coefficient of the microelectronic chip & the electronic packaging material. Additional requirements include:
  – good heat transfer coefficient
  – poor electrical conductivity
• Materials currently used include:
  • Boron nitride (BN)
  • Silicon Carbide (SiC)
  • Aluminum nitride (AlN)
    – thermal conductivity 10x that for Alumina
    – good expansion match with Si
Summary

• Basic categories of ceramics:
  -- glasses
  -- clay products
  -- refractories
  -- cements
  -- advanced ceramics

• Fabrication Techniques:
  -- glass forming (impurities affect forming temp).
  -- particulate forming (needed if ductility is limited)
  -- cementation (large volume, room T process)

• Heat treating: Used to
  -- alleviate residual stress from cooling,
  -- produce fracture resistant components by putting surface into compression.
Homework

13.4
13.10
13.11