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?**

TAXONOMY OF CERAMICS

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

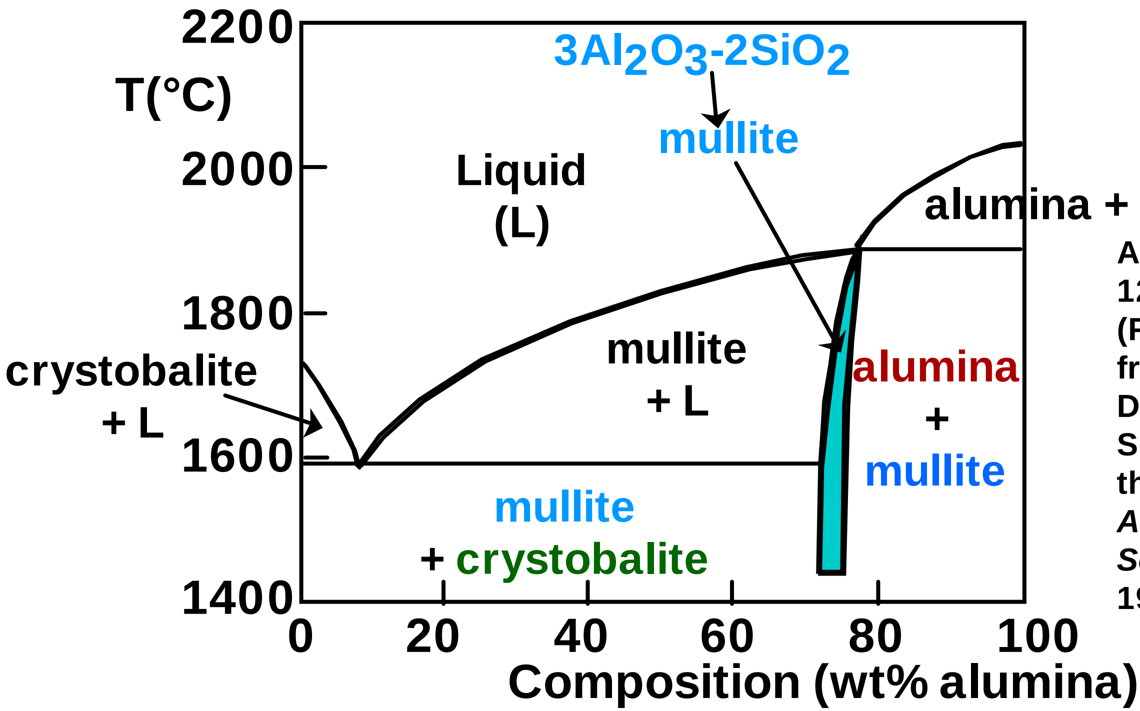
Adapted from Fig. 13.1 and discussion in Section 13.2-6, *Callister 6e.*

- **Properties:**
  - --T_{melt} 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
  - --other ceramics can not be formed or cast.

APPLICATION: REFRACTORIES

- Need a material to use in high temperature furnaces.
- Consider Silica (SiO_2) - Alumina (Al_2O_3) system.
- Phase diagram shows:

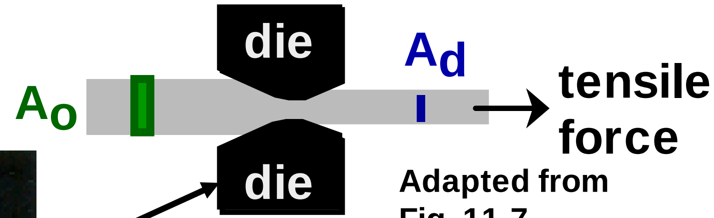
mullite, alumina, and crystobalite (made up of SiO_2) tetrahedra as candidate refractories.



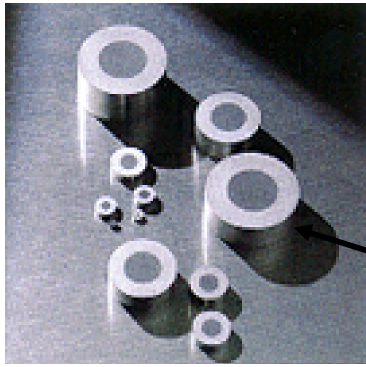
Adapted from Fig. 12.27, *Callister 6e.* (Fig. 12.27 is adapted from F.J. Klug and R.H. Doremus, "Alumina Silica Phase Diagram in the Mullite Region", *J. American Ceramic Society* **70**(10), p. 758, 1987.)

APPLICATION: DIE BLANKS

- **Die blanks:**
  --Need wear resistant properties!

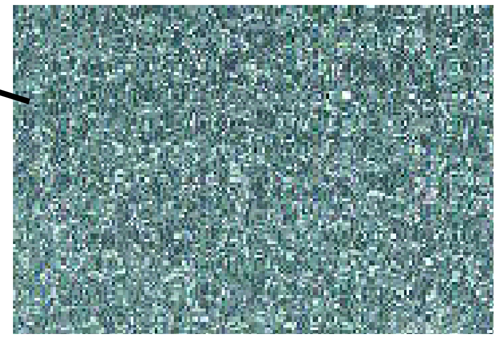


Adapted from Fig. 11.7, *Callister 6e*.



Courtesy Martin Deakins, GE Superabrasives, Worthington, OH. Used with permission.

- **Die surface:**
  --4 μm polycrystalline diamond particles that are sintered on to a cemented tungsten carbide substrate.
  --polycrystalline diamond helps control fracture and gives uniform hardness in all directions.



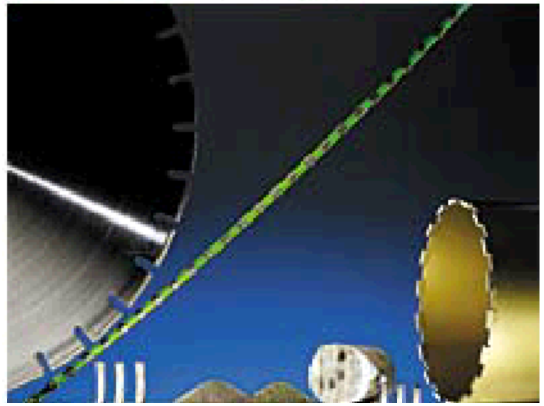
Courtesy Martin Deakins, GE Superabrasives, Worthington, OH. Used with permission.

APPLICATION: CUTTING TOOLS

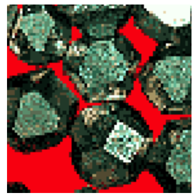
- **Tools:**
  --for grinding glass, tungsten, carbide, ceramics
  --for cutting Si wafers
  --for oil drilling

- **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.

oil drill bits



blades



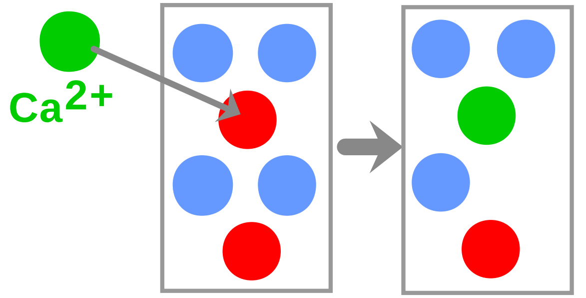
coated single crystal diamonds

polycrystalline diamonds in a resin matrix.

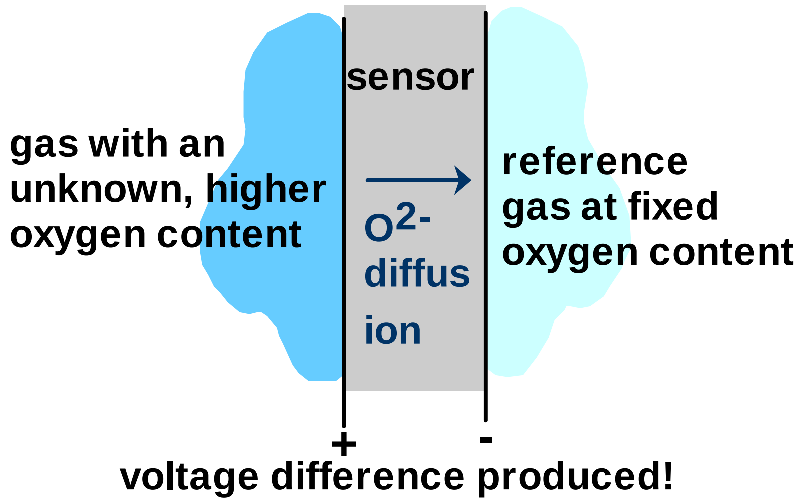
Photos courtesy Martin Deakins, GE Superabrasives, Worthington, OH. Used with permission.

APPLICATION: SENSORS

- **Ex: Oxygen sensor: ZrO_2**
- **Principle: Make diffusion of ions fast for rapid response.**
- **Approach:**
  Add Ca impurity to:
  --increase O^{2-} vacancies
  --increase O^{2-} diffusion
- **Operation:**
  --voltage difference produced when O^{2-} ions diffuse between external and references gases.



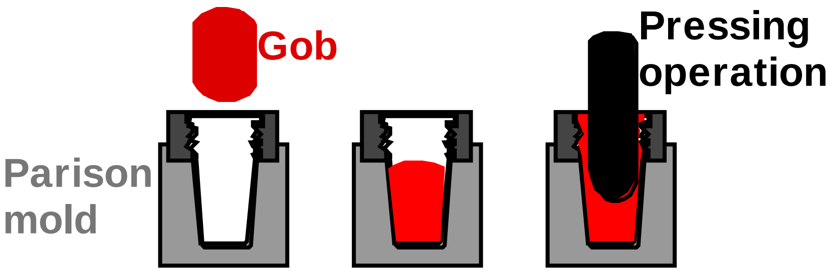
A Ca^{2+} impurity removes a Zr^{4+} and a O^{2-} ion.



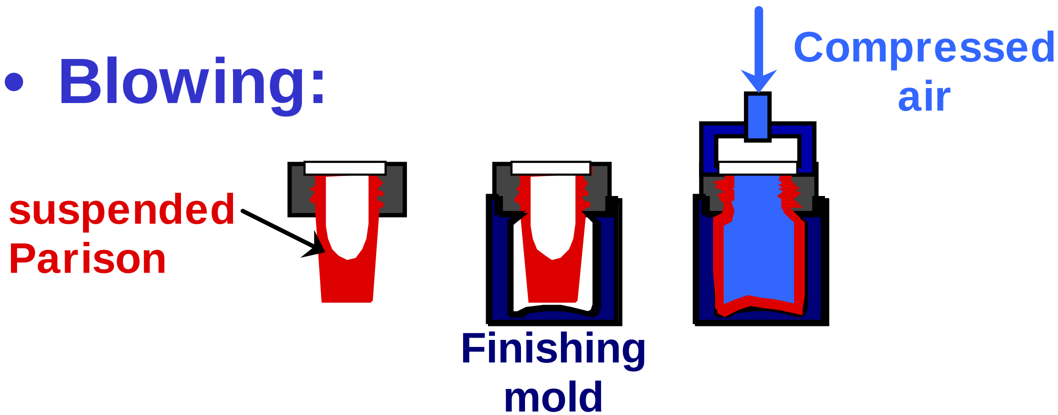
CERAMIC FABRICATION METHODS-I

GLASS FORMING | PARTICULATE FORMING | CEMENTATION

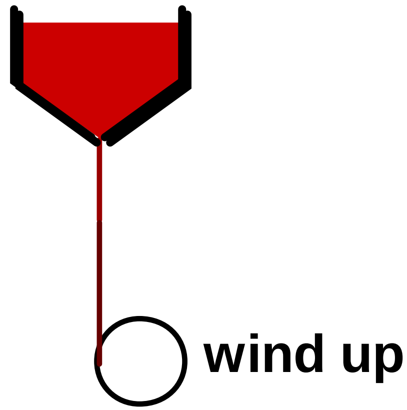
- **Pressing:**



- **Blowing:**



- **Fiber drawing:**

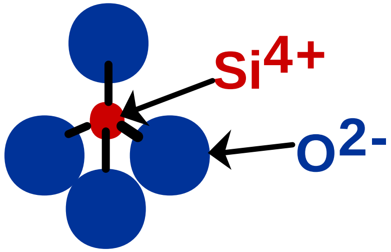


Adapted from Fig. 13.7, *Callister, 6e*. (Fig. 13.7 is adapted from C.J. Phillips, *Glass: The Miracle Maker*, Pittman Publishing Ltd., London.)

GLASS STRUCTURE

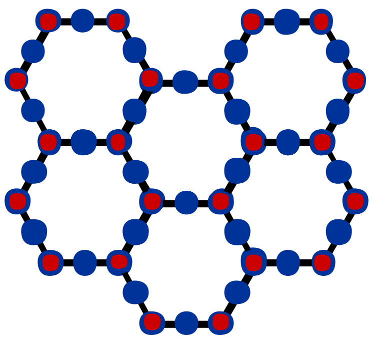
- **Basic Unit:**

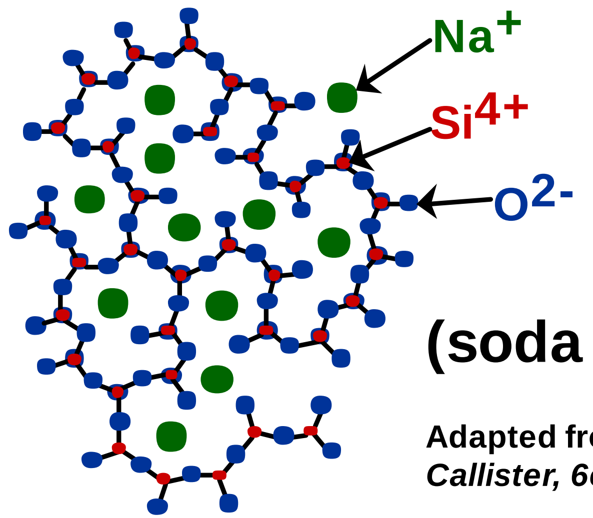
SiO_4^{4-} tetrahedron



- **Glass is amorphous**
- **Amorphous structure** occurs by adding impurities (Na^+, Mg^{2+}, Ca^{2+}, Al^{3+})
- **Impurities:** interfere with formation of crystalline structure.

- **Quartz is crystalline SiO_2:**



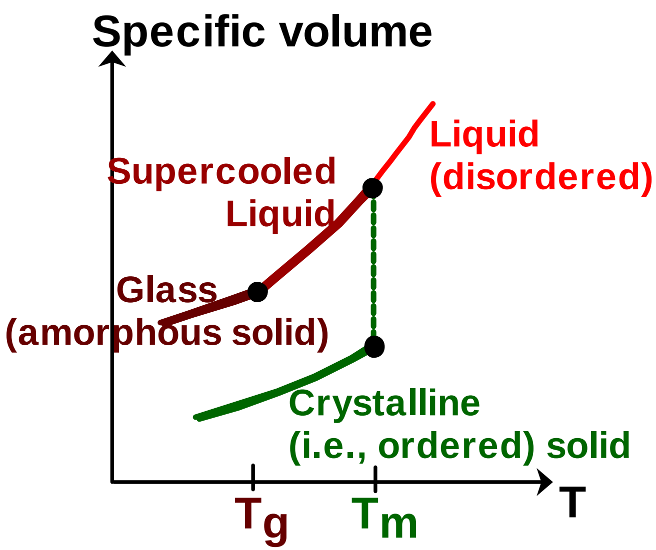


(soda glass)

Adapted from Fig. 12.11, *Callister, 6e*.

GLASS PROPERTIES

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



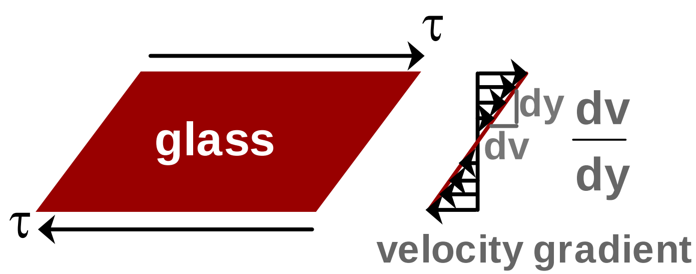
Adapted from Fig. 13.5, *Callister, 6e.*

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

- **Glasses:**
  - --do not crystallize
  - --spec. vol. varies smoothly with T
  - --Glass transition temp, T_g

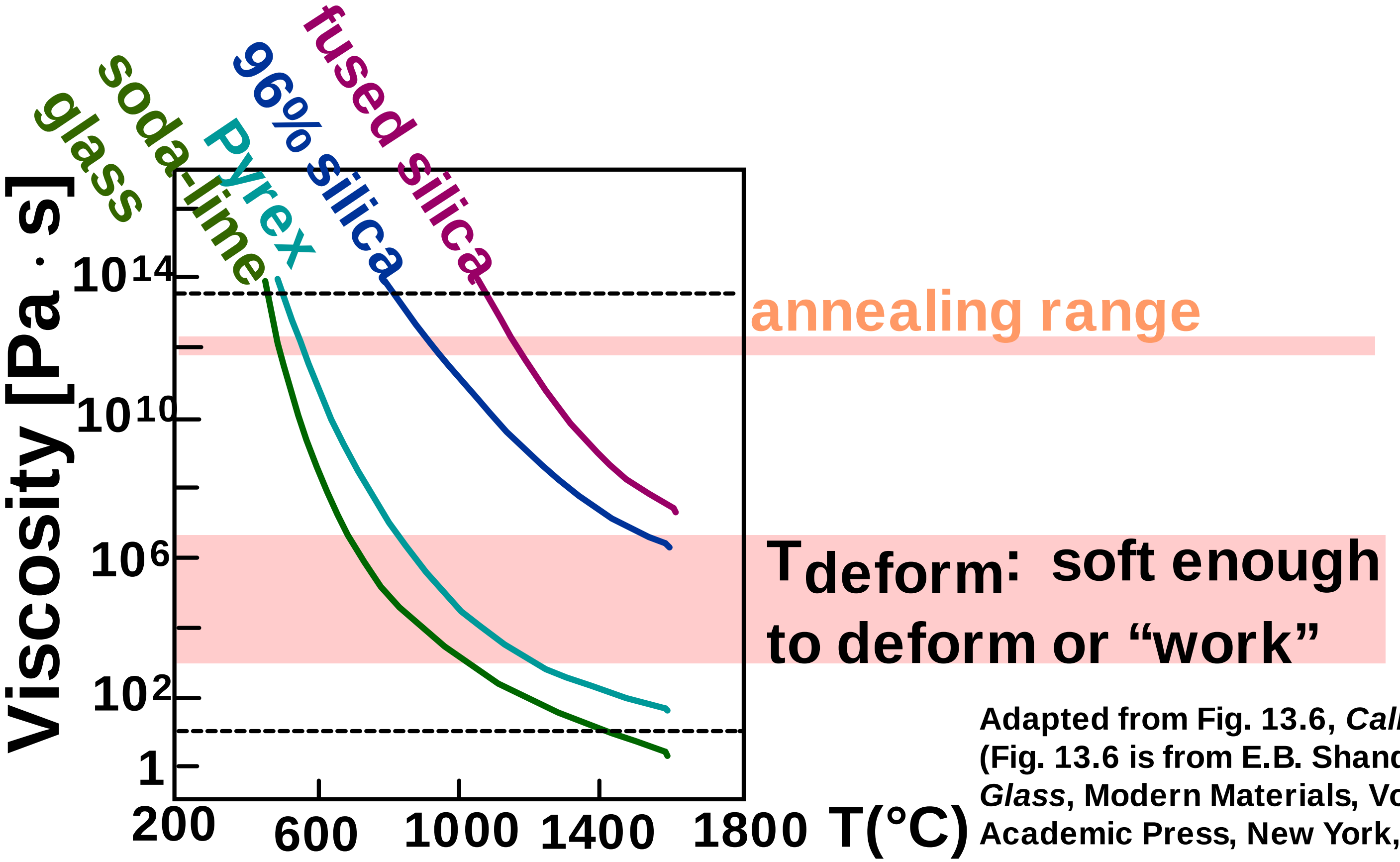
- **Viscosity:**
  - --relates shear stress & velocity gradient:
  - --has units of (Pa-s)

$$\tau = \eta \frac{dv}{dy}$$



GLASS VISCOSITY VS T AND IMPURITIES

- **Viscosity decreases with T**
- **Impurities lower T_{deform}**



Adapted from Fig. 13.6, *Callister, 6e*. (Fig. 13.6 is from E.B. Shand, *Engineering Glass*, Modern Materials, Vol. 6, Academic Press, New York, 1968, p. 262.)

HEAT TREATING GLASS

- **Annealing**:

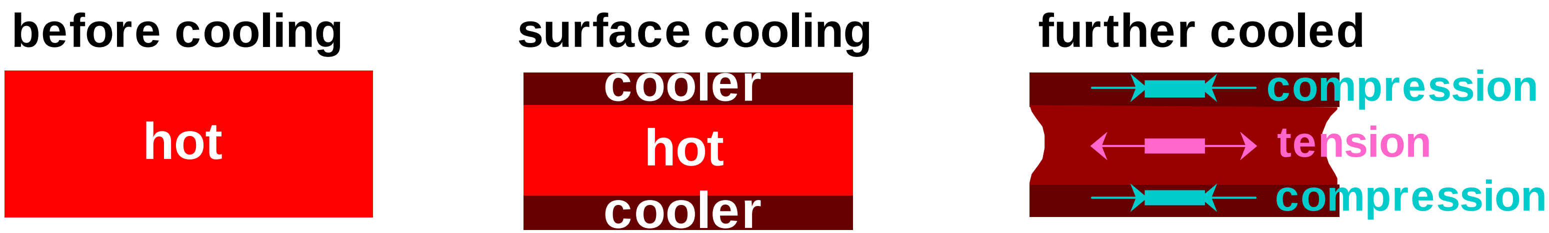
  --removes internal stress caused by uneven cooling.

- **Tempering**:

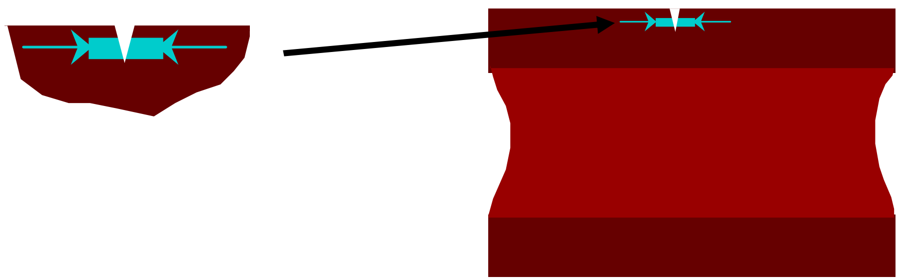
  --puts surface of glass part into compression

  --suppresses growth of cracks from surface scratches.

  --sequence:



--Result: surface crack growth is suppressed.

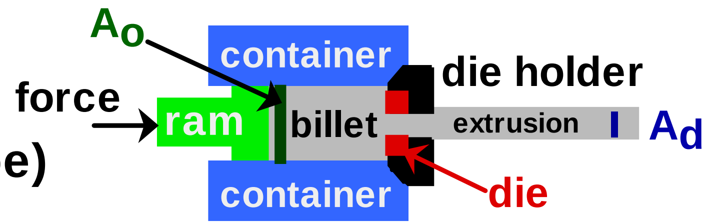


CERAMIC FABRICATION METHODS-IIA

GLASS FORMING | **PARTICULATE FORMING** | CEMENTATION

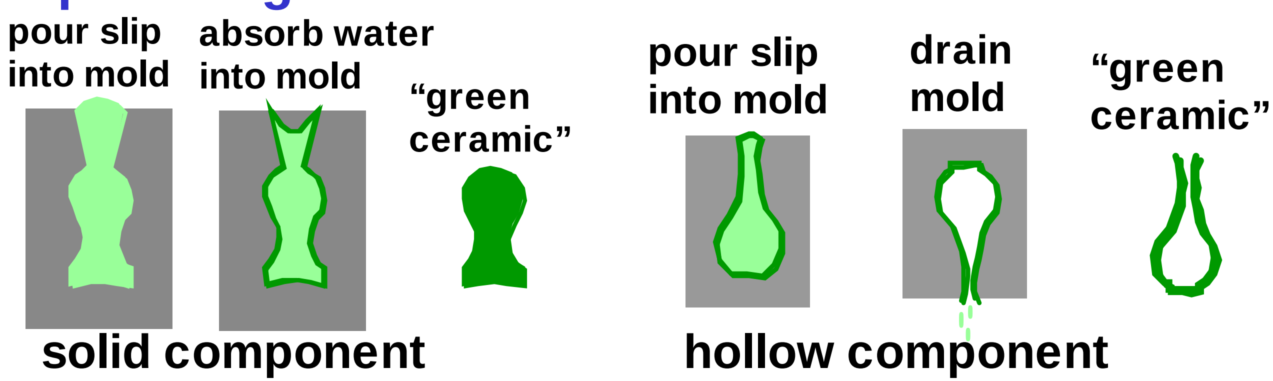
- Milling and screening: desired particle size
- Mixing particles & water: produces a "slip"
- Form a "green" component

  --Hydroplastic forming:
  extrude the slip (e.g., into a pipe)



Adapted from Fig. 11.7, *Callister 6e*.

  --Slip casting:



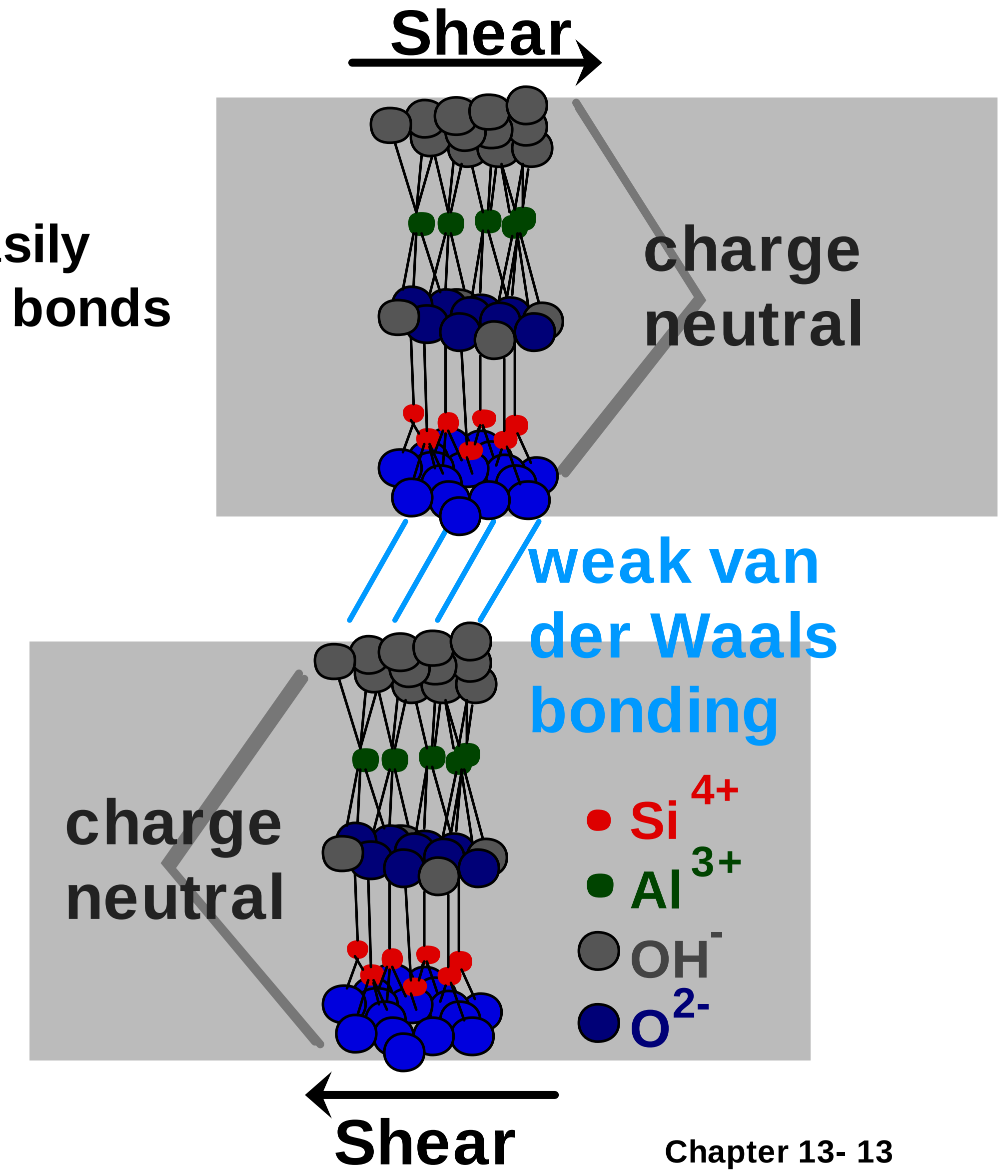
Adapted from Fig. 13.10, *Callister 6e*. (Fig. 13.10 is from W.D. Kingery, *Introduction to Ceramics*, John Wiley and Sons, Inc., 1960.)

- Dry and Fire the component

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

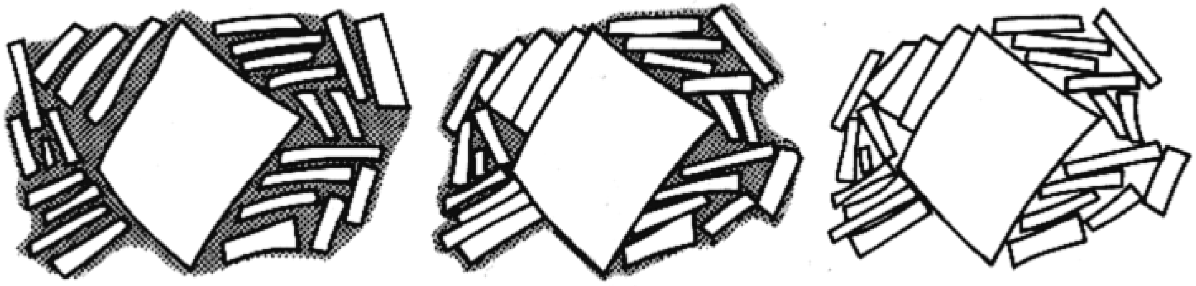
- Structure of Kaolinite Clay:



Adapted from Fig. 12.14, *Callister 6e*. (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.**

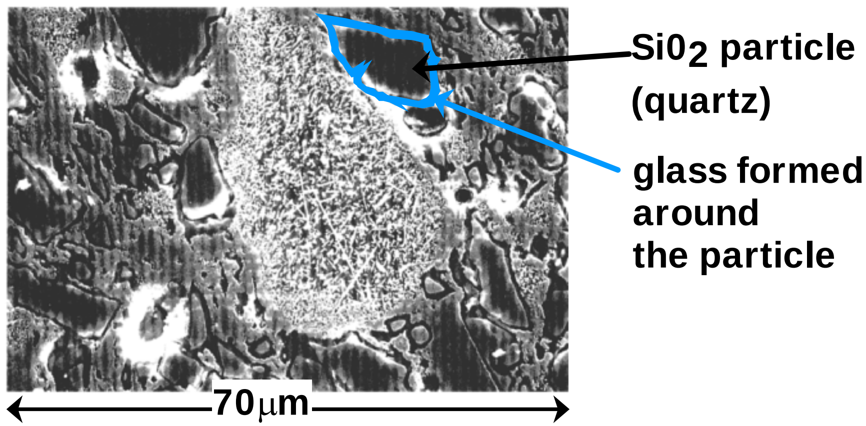


Adapted from Fig. 13.11, *Callister 6e*. (Fig. 13.11 is from W.D. Kingery, *Introduction to Ceramics*, John Wiley and Sons, Inc., 1960.)

wet slip | **partially dry** | **"green" ceramic**

- **Firing:**
  --T raised to (900-1400 C)
  --vitrification: glass forms from clay and flows between SiO_2 particles.

micrograph of porcelain



Adapted from Fig. 13.12, *Callister 6e*. (Fig. 13.12 is courtesy H.G. Brinkies, Swinburne University of Technology, Hawthorn Campus, Hawthorn, Victoria, Australia.)

CERAMIC FABRICATION METHODS-IIB

GLASS FORMING | **PARTICULATE FORMING** | CEMENTATION

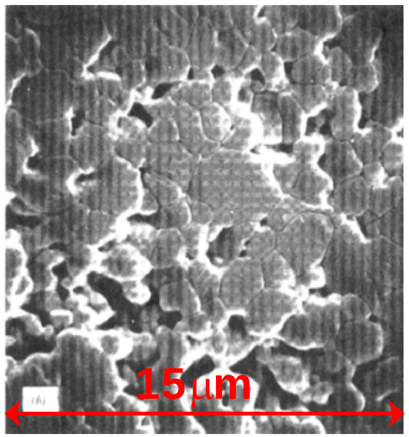
- **Sintering: useful for both clay and non-clay compositions.**
- **Procedure:**

  --grind to produce ceramic and/or glass particles

  --inject into mold

  --press at elevated T to reduce pore size.
- **Aluminum oxide powder:**

  --sintered at 1700C for 6 minutes.



Adapted from Fig. 13.15, *Callister 6e*. (Fig. 13.15 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.)

CERAMIC FABRICATION METHODS-III

GLASS FORMING | PARTICULATE FORMING | **CEMENTATION**

- **Produced in extremely large quantities.**
- **Portland cement:**
  - **--mix clay and lime bearing materials**
  - **--calcinate (heat to 1400C)**
  - **--primary constituents:**
    - **tri-calcium silicate**
    - **di-calcium silicate**
- **Adding water**
  - **--produces a paste which hardens**
  - **--hardening occurs due to hydration (chemical reactions with the water).**
- **Forming: done usually minutes after hydration begins.**

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.