Chapter 13: Applications and Processing of Ceramics

ISSUES TO ADDRESS...

- General categories of ceramics
- What are common applications of ceramics?
- How are ceramic materials processed?

Classification of Ceramics

Ceramic Materials

- **Glasses**
  - -optical
  - -composite reinforce
  - -containers/ household
- **Clay products**
  - -whiteware
  - -structural
- **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 13.2-8, *Callister & Rethwisch 8e.*

Ceramics Application: Refractories

- Materials to be used at high temperatures (e.g., in high temperature furnaces).
- Consider the Silica (SiO_2) - Alumina (Al_2O_3) system.
- Silica refractories - silica rich - small additions of alumina depress melting temperature (phase diagram):

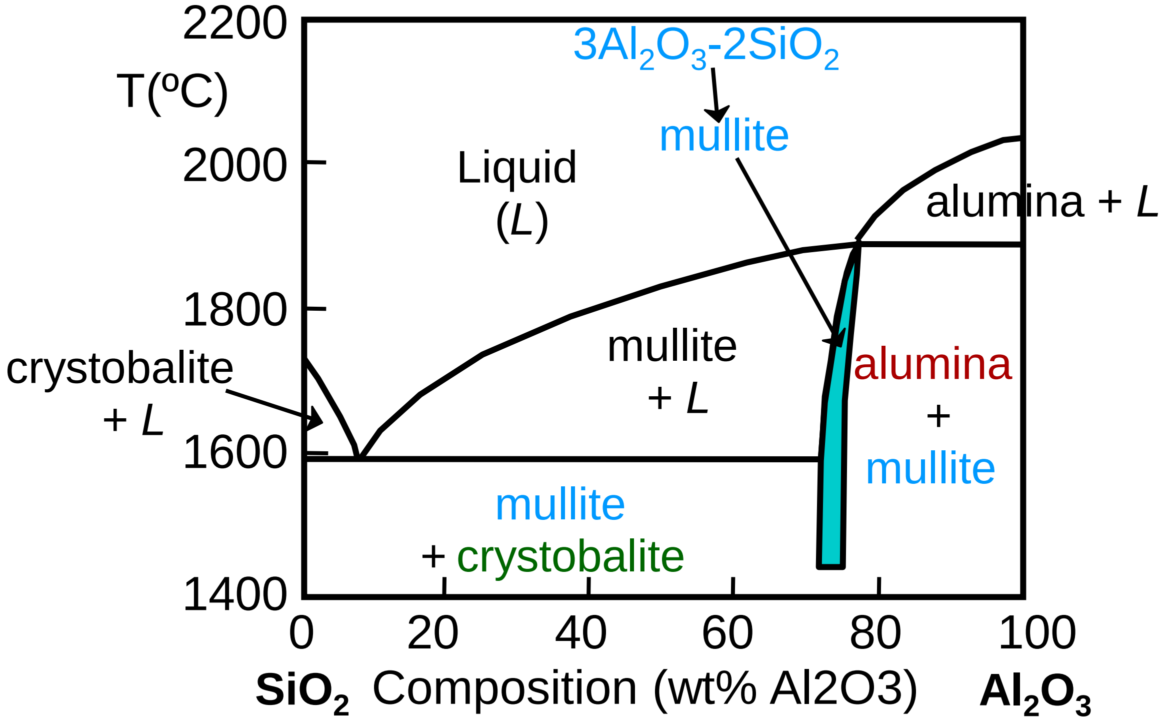


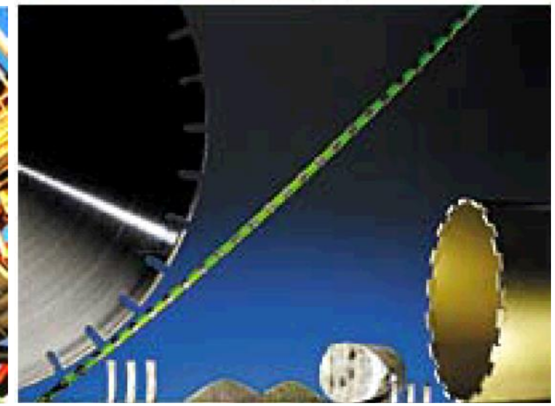
Fig. 12.27, *Callister & Rethwisch 8e.* (Fig. 12.27 adapted from F.J. Klug and R.H. Doremus, *J. Am. Cer. Soc.* **70**(10), p. 758, 1987.)

Ceramics Application: Cutting Tools

- Tools:
  - -- for grinding glass, cutting other hard materials
  - -- for cutting Si wafers
  - -- for oil drilling

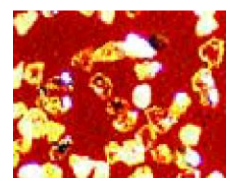
- Materials:
  - -- manufactured single crystal or polycrystalline diamonds in a metal or resin matrix.

oil drill bits



blades

Single crystal diamonds

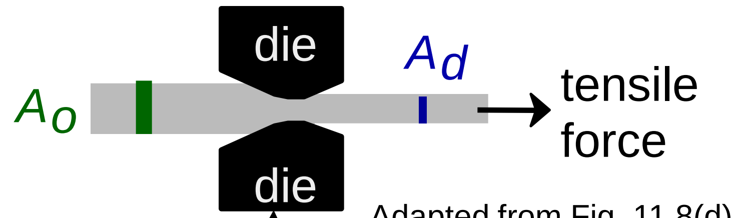


polycrystalline diamonds in a resin matrix.

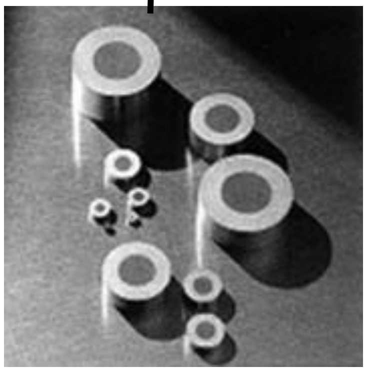
Photos courtesy Martin Deakins, GE Superabrasives, Worthington, OH. Used with permission.

Ceramics Application: Die Blanks

- Die blanks:
  -- Need hardness & wear resistant properties!
- Die surface:
  -- 4 μm polycrystalline diamond particles that are sintered onto a cemented tungsten carbide substrate.
  -- polycrystalline diamond gives uniform hardness in all directions to reduce wear.



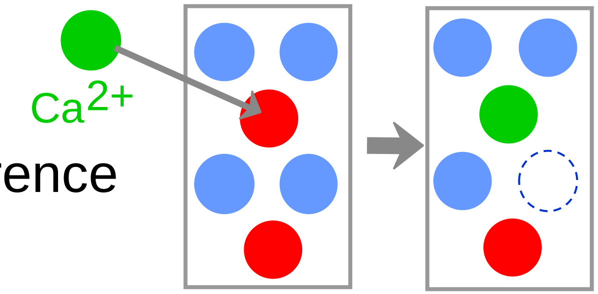
Adapted from Fig. 11.8(d), *Callister & Rethwisch 8e.*



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

Ceramics Application: Sensors

- Example: ZrO_2 as an oxygen sensor
- Principle: oxygen gas concentration difference is related to voltage difference on both sides



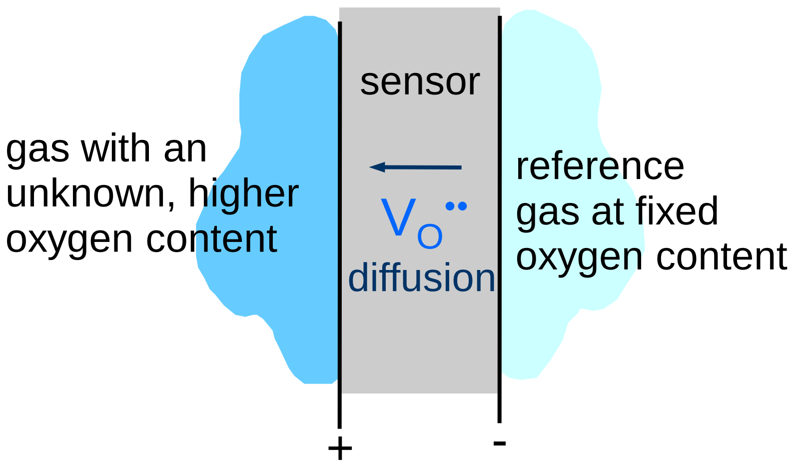
A substituting Ca^{2+} ion removes a Zr^{4+} ion while Creating an oxygen vacancy $V_O^{\bullet\bullet}$

- Approach:

  Add Ca or Y impurity to ZrO2

- Operation:

  -- magnitude of voltage difference $\propto$ the log of partial pressure difference of oxygen at the two external surfaces



Advanced Ceramics: Materials for Automobile & Jet Engines

- **Advantages:**
  - **Operate at higher temperatures – higher efficiencies**
  - **Low frictional losses**
  - **Operate without a cooling system**
  - **Lower weights than current engines**

- Disadvantages:
  - Ceramic materials are brittle
  - Difficult to remove internal voids (that weaken structures)
  - Ceramic parts are difficult to form and machine

- Potential candidate materials: Si_3N_4, SiC, & ZrO_2
- Possible engine parts: engine block & piston coatings or bulk (in form of composites)

https://www.youtube.com/watch?v=WgQNDcJrhDc

https://www.youtube.com/watch?v=nTZtHhqo7zU

Advanced Ceramics: Materials for Ceramic Armor

Armor components:
- -- Outer facing plates
- -- Backing sheet

http://uniarc.eu/military/229-reaction-bonded-armor

Properties/Materials:
- -- Outer facing plates -- hard and brittle
  - — fracture high-velocity projectile
  - — Al_2O_3, B_4C, SiC, TiB_2
- -- Backing sheets -- soft and ductile
  - — deform and absorb remaining energy
  - — aluminum, synthetic fiber laminates

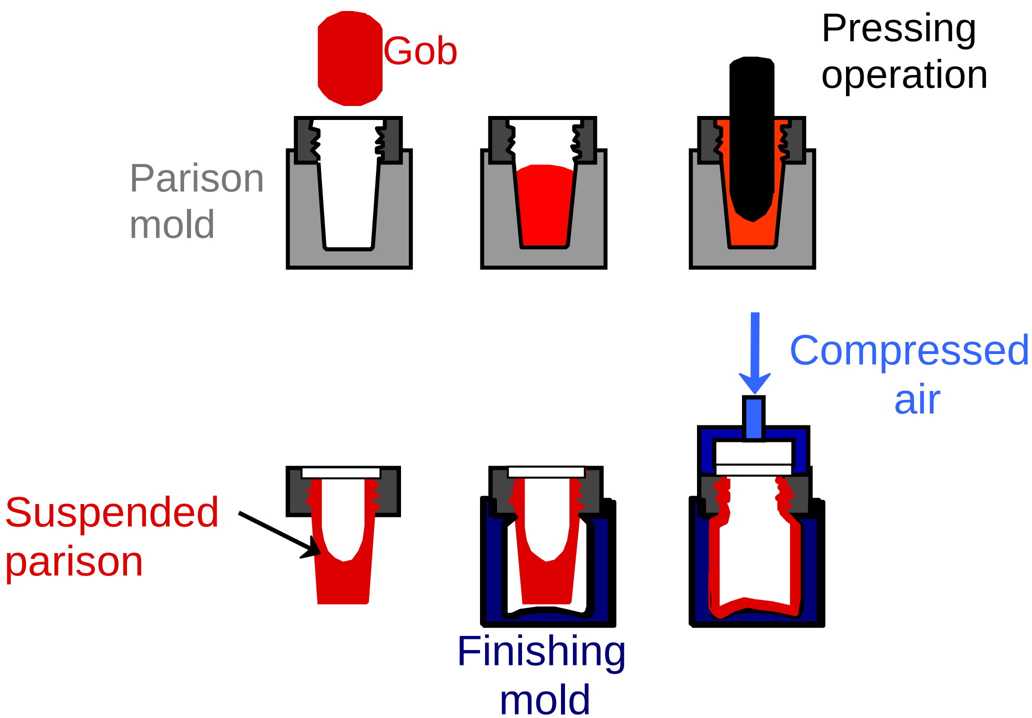
Ceramic Fabrication Methods (i)

GLASS FORMING

PARTICULATE FORMING

CEMENTATION

- Blowing of Glass Bottles:

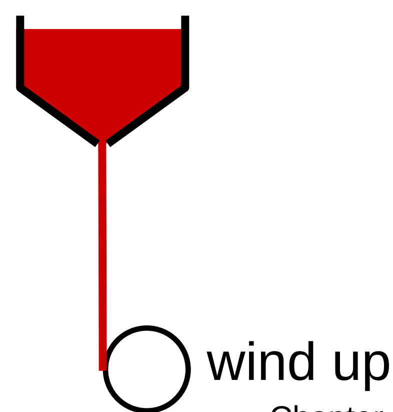


- Pressing: plates, cheap glasses

  -- glass formed by application of pressure

  -- mold is steel with graphite lining

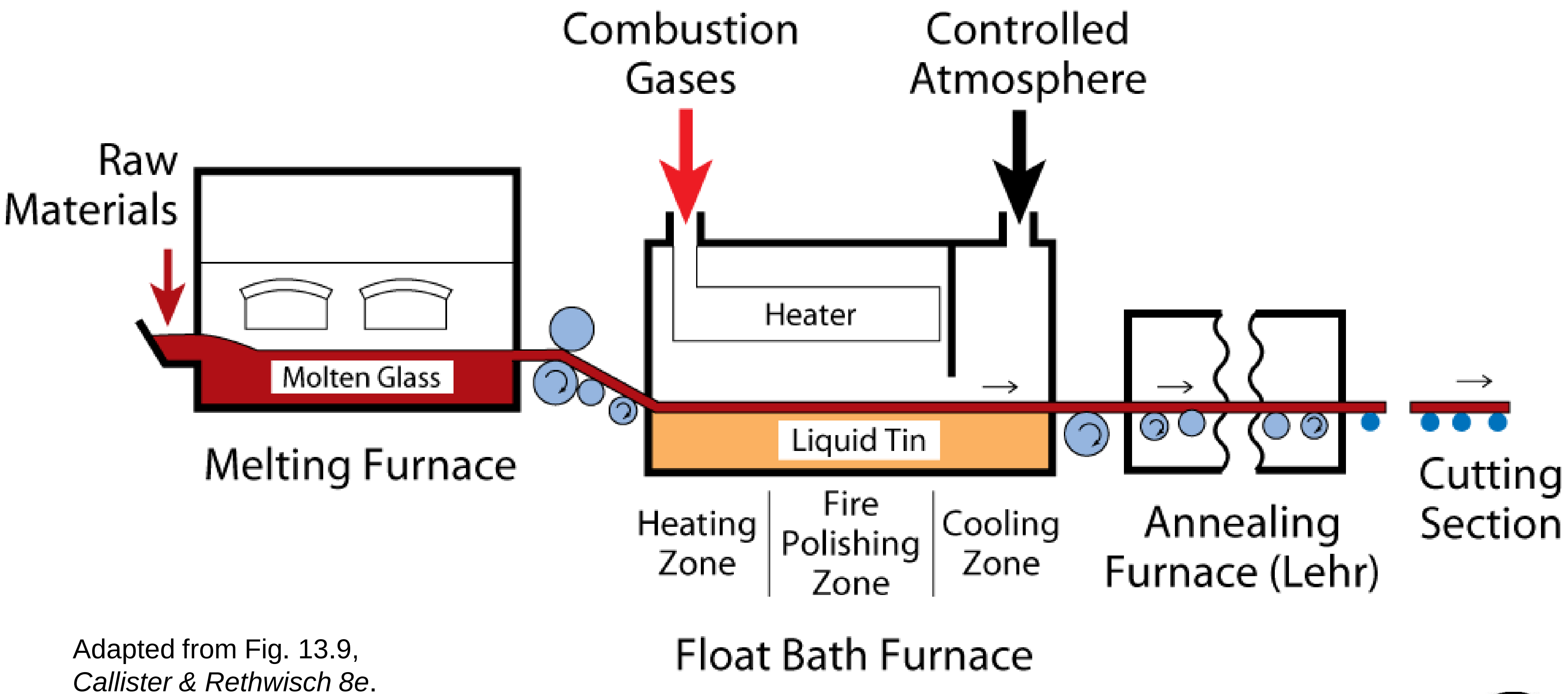
- Fiber drawing:



Adapted from Fig. 13.8, *Callister & Rethwisch 8e*. (Fig. 13.8 is adapted from C.J. Phillips, *Glass: The Miracle Maker*, Pittman Publishing Ltd., London.)

Sheet Glass Forming

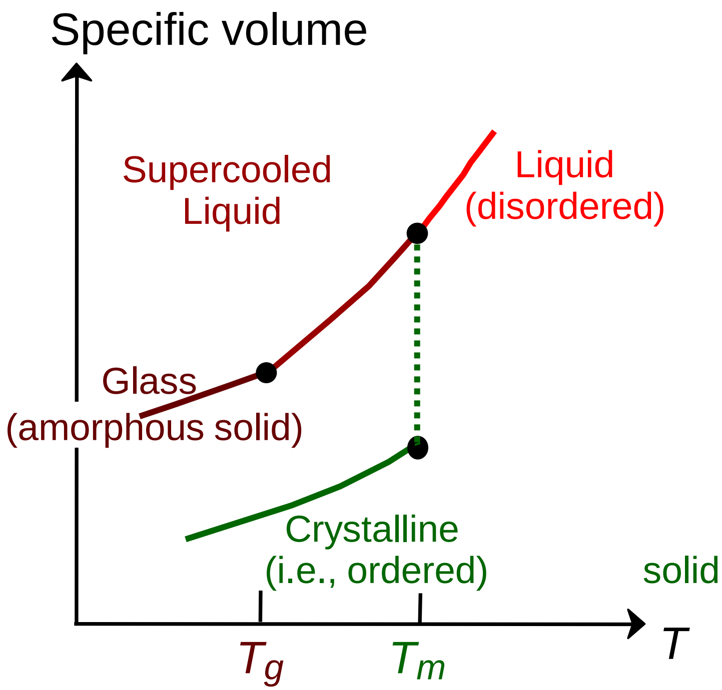
- Sheet forming – continuous casting
  - sheets are formed by floating the molten glass on a pool of molten tin



Adapted from Fig. 13.9, *Callister & Rethwisch 8e*.

Glass Properties

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



Adapted from Fig. 13.6, *Callister & Rethwisch 8e*.

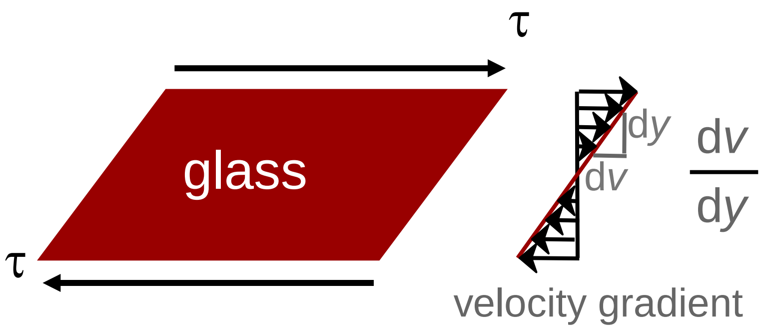
- Crystalline materials:
  -- crystallize at melting temp, T_m
  -- have abrupt change in spec. vol. (or density) at T_m

- Glasses:
  -- do not crystallize with relatively fast cooling
  -- change in slope in spec. vol. curve at glass transition temperature, T_g
  -- transparent - no grain boundaries and few pores to scatter light

Glass Properties: Viscosity

- Viscosity, η:

  -- relates shear stress (τ) and velocity gradient *(dv/dy) or shear strain rate:*



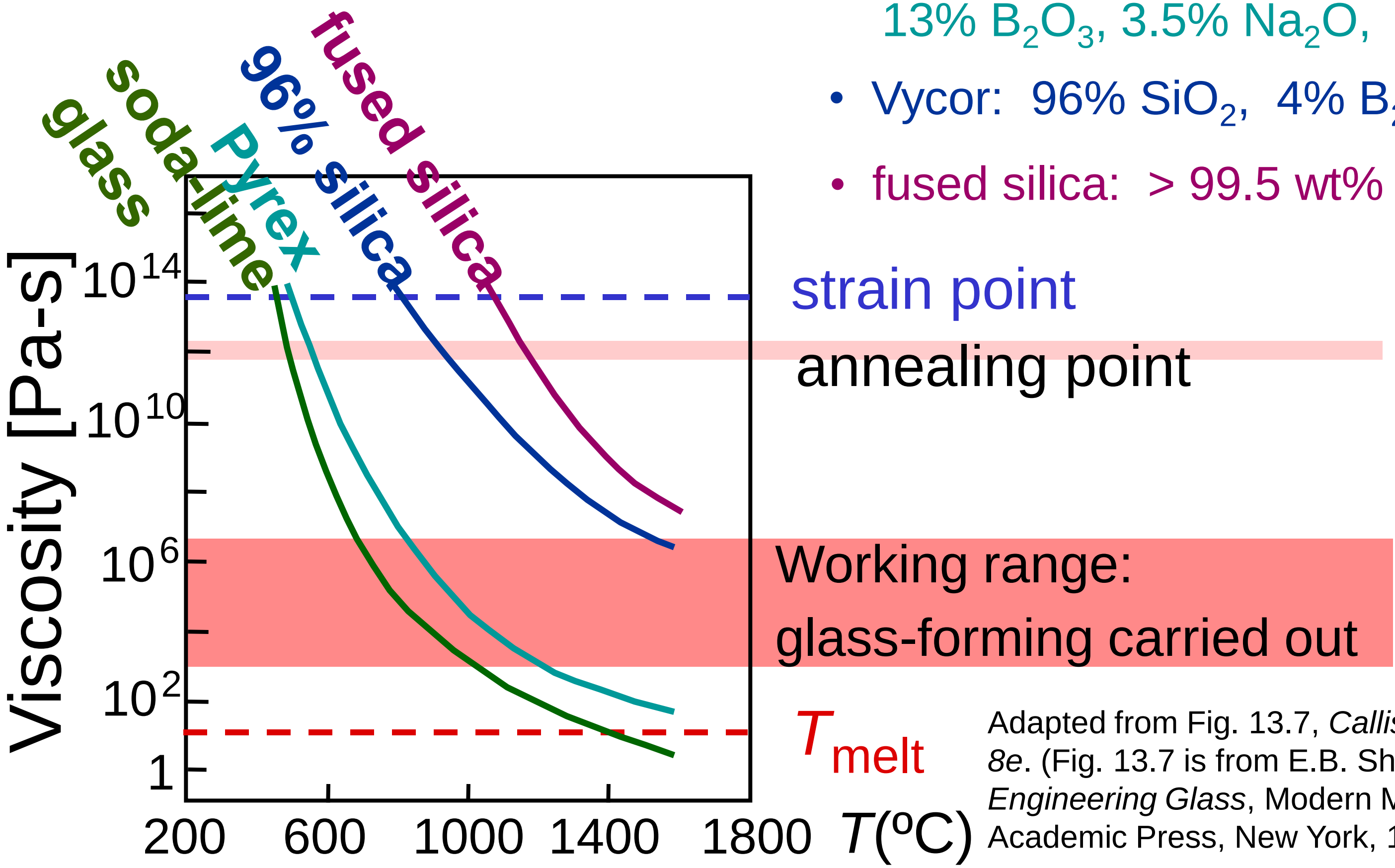
$$\eta = \frac{\tau}{dv / dy}$$

η has units of (Pa-s)

Glass Viscosity vs. Temperature

- Viscosity decreases with T

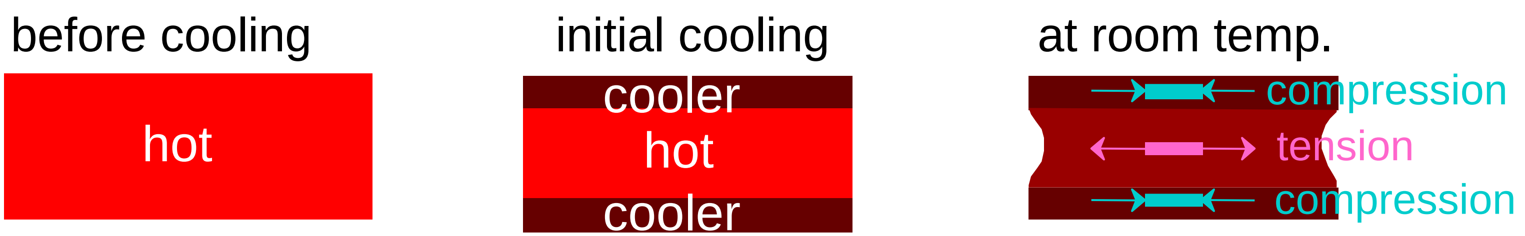
- soda-lime glass: 70% SiO_2 balance Na_2O (soda) & CaO (lime)
- borosilicate (Pyrex): 80% SiO_2 13% B_2O_3, 3.5% Na_2O, 2.5% Al_2O_3
- Vycor: 96% SiO_2, 4% B_2O_3
- fused silica: > 99.5 wt% SiO_2



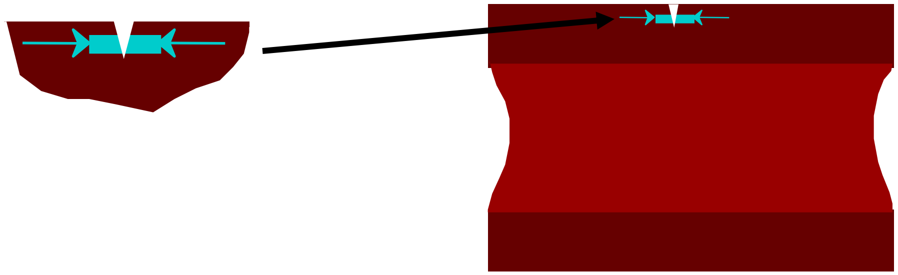
Adapted from Fig. 13.7, *Callister & Rethwisch 8e*. (Fig. 13.7 is from E.B. Shand, *Engineering Glass*, Modern Materials, Vol. 6, Academic Press, New York, 1968, p. 262.)

Heat Treating Glass

- Annealing:
  -- removes internal stresses caused by uneven cooling.
- Tempering:
  -- puts surface of glass part into compression
  -- suppresses growth of cracks from surface scratches.
  -- sequence:



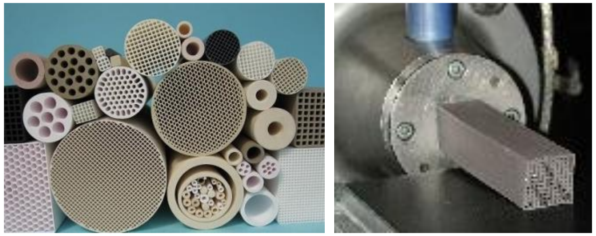
-- Result: surface crack growth is suppressed.



Ceramic Fabrication Methods (ii)

GLASS FORMING | **PARTICULATE FORMING** | CEMENTATION

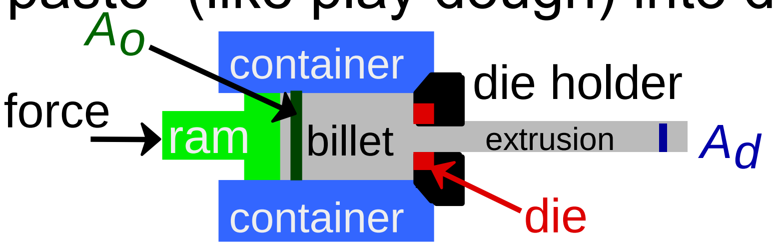
Typical ceramics have relatively high melting point and are brittle → They are NOT processed via casting or forming (via machining or working) techniques as metals. Instead, they go through "particulate forming" to obtain "green bodies", which are then heat treated (sintered) to obtain final products



http://www.ikts.fraunhofer.de/en/research_fields/processes_and_components/Shaping/Extrusion.html

Particulate forming #1: Extrusion:

- Extrude thick "paste" (like play dough) into desired, simple shape



Adapted from Fig. 12.8(c), *Callister & Rethwisch 8e*.

- Dry and "fire" ("burn" organics and then "sinter") to obtain ceramics

Ceramic Fabrication Methods (ii)

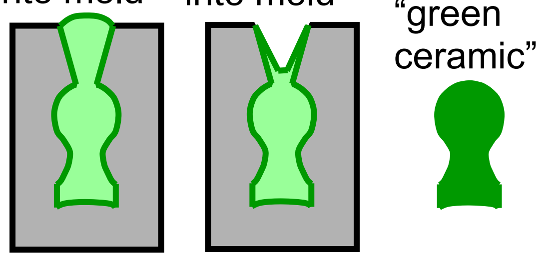
GLASS FORMING | **PARTICULATE FORMING** | CEMENTATION

Particulate forming #2: Slip casting:

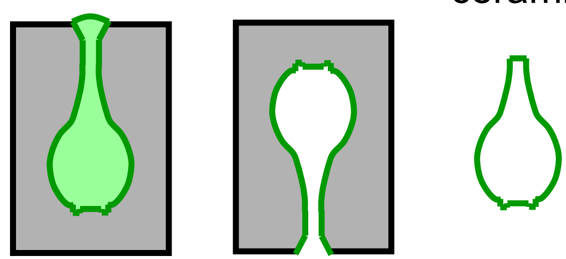
Slip-casting green ceramic ware

http://www.veniceclayartists.com/african-pottery-arts-traditional-contemporary/

- Mix ceramic particles with solvent (e.g., water) and other constituents to form slip (concentrated suspension)
- Slip casting operation



solid component



hollow component

Adapted from Fig. 13.12, *Callister & Rethwisch 8e*. (Fig. 13.12 is from W.D. Kingery, *Introduction to Ceramics*, John Wiley and Sons, Inc., 1960.)

- Dry (in controlled fashion) and "fire" the cast piece

Ceramic Fabrication Methods (ii)

Particulate forming #3: Tape casting:

- Thin sheets of green ceramic cast as flexible tape from “slip”
- Used for integrated circuits and capacitors and other flat components
- Slip = suspended ceramic particles + liquid carrier (contains binders, plasticizers)

Tape-casting green ceramic tape

http://www.cgcri.res.in/page.php?id=43

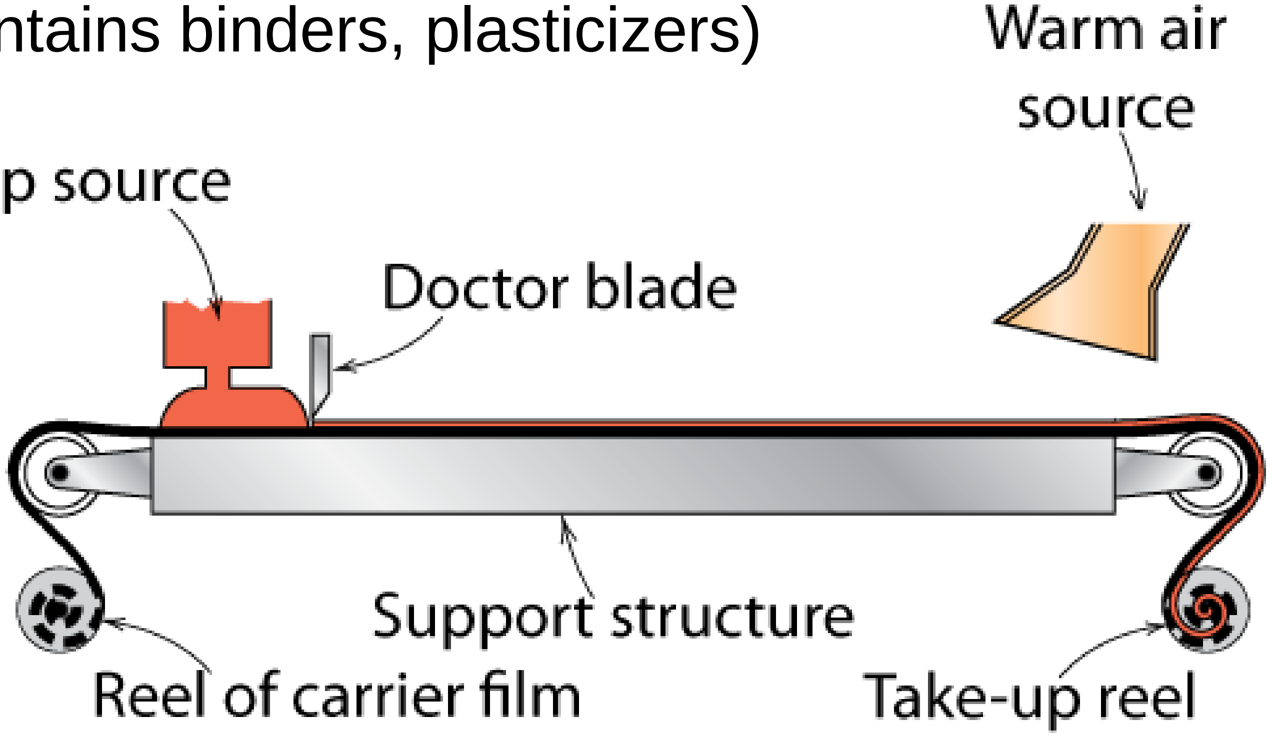
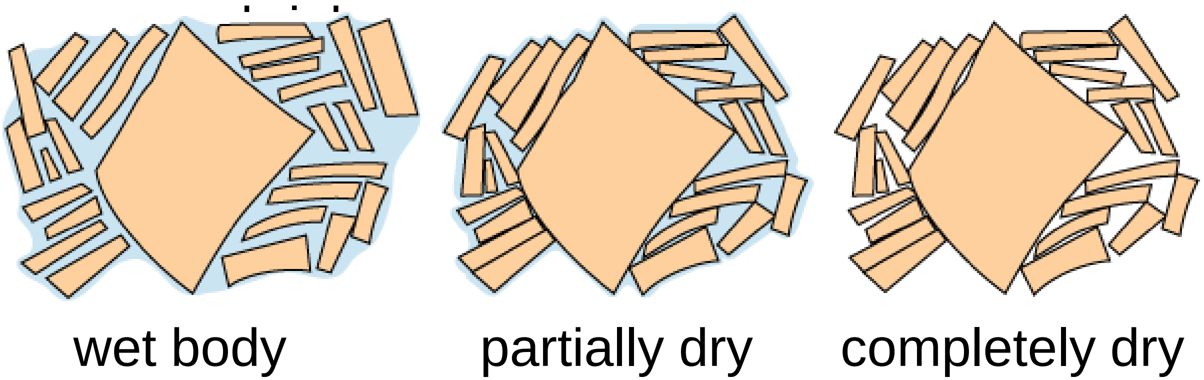


Fig. 13.18, *Callister & Rethwisch 8e*.

Drying

After ceramic green body formation via extrusion, slip casting or tape casting, the products need to go through "drying" to remove solvents (e.g., water)

- Drying: as solvent (e.g., water) is removed - interparticle spacings decrease



Adapted from Fig. 13.13, *Callister & Rethwisch 8e*. (Fig. 13.13 is from W.D. Kingery, *Introduction to Ceramics*, John Wiley and Sons, Inc., 1960.)

Drying too fast causes sample to warp or crack due to non-uniform shrinkage, like mud cracks

Ceramic Fabrication Methods (ii)

GLASS FORMING | **PARTICULATE FORMING** | CEMENTATION

Particulate forming #4: Dry Powder Pressing:

Used for both clay and non-clay compositions.

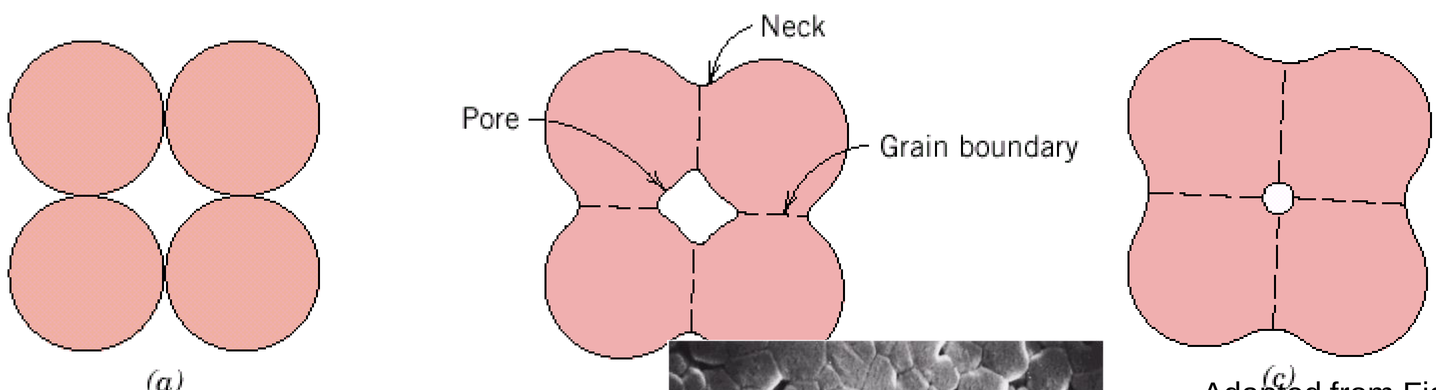
- Powder (plus binder) compacted by pressure in a mold/die
  - -- Uniaxial compression - compacted in single direction
  - -- Isostatic (hydrostatic) compression - pressure applied by fluid - powder in rubber envelope

http://www.ebay.co.uk/itm/20mm-Diameter-ID-Pellet-Press-Steel-Dry-Pressing-Die-Set-Mold-/200438956668

Firing/Sintering

After drying, heat treatment or sintering of green ceramic bodies at high temperature (e.g., >1000 ºC) have to be carried out to remove organic additives (used in particulate forming) and also bonds the powders together while reducing the pores in-between so that mechanical strength and other properties are obtained for the ceramics.

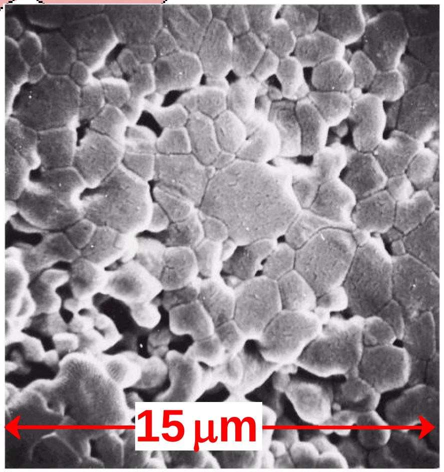
-- powder particles coalesce and reduction of pore size and total surface area



Adapted from Fig. 13.16, *Callister & Rethwisch 8e*.

Aluminum oxide powder:

-- sintered at 1700ºC for 6 minutes.



Adapted from Fig. 13.17, *Callister & Rethwisch 8e*. (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.)

Ceramic Fabrication Methods (iii)

GLASS FORMING | PARTICULATE FORMING | CEMENTATION

- Hardening of a paste – paste formed by mixing cement material with water
- Formation of rigid structures having varied and complex shapes
- Hardening process – hydration (complex chemical reactions involving water and cement particles)

Summary

- Ceramic Fabrication techniques:
  - -- glass forming (pressing, blowing, fiber drawing).
  - -- particulate forming (hydroplastic forming, slip casting, powder pressing, tape casting)
  - -- cementation
- Heat treating procedures
  - -- glasses—annealing, tempering
  - -- particulate formed pieces—drying, firing (sintering)

Homework

- **Read textbook chapter 12 and 13 for ceramics**