Chapter 13: Applications and Processing of Ceramics

ISSUES TO ADDRESS...

- How do we classify ceramics?
- What are some _____ of ceramics?
- How is processing of _____ different than for metals?

Classification of Ceramics

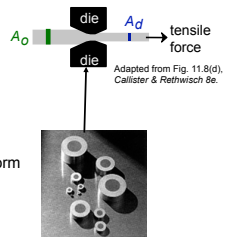
Ceramic Materials

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

Adapted from Fig. 13.1 and discussion in Section 13.2-8, *Callister & Rethwisch 8e.*

Ceramics Application: Die Blanks

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

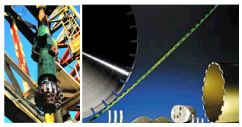


Adapted from Fig. 11.8(d), *Callister & Rethwisch 8e.*

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

Ceramics Application: Cutting Tools

- Tools:
  - -- for grinding glass, _____, carbide, ceramics
  - -- for cutting Si wafers
  - -- for oil drilling
- Materials:
  - -- manufactured single crystal or _____ diamonds in a metal or resin matrix.
  - -- polycrystalline diamonds _____ by microfracturing along cleavage planes.



oil drill bits blades

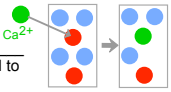
Single crystal diamonds

polycrystalline diamonds in a resin matrix.

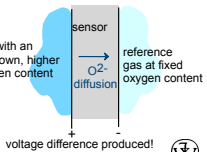
Photos courtesy Martin Deakins, GE Superabrasives, Worthington, OH. Used with permission.

Ceramics Application: Sensors

- Example: ZrO_2 as an _____ sensor
- Principle: Increase diffusion rate of _____ to produce rapid response of sensor signal to change in _____ concentration
- Approach:
  Add _____:
  - -- increases O^{2-} vacancies
  - -- increases O^{2-} diffusion rate
- Operation:
  - -- voltage _____ produced when O^{2-} ions diffuse from the external surface through the sensor to the reference gas surface.
  - -- magnitude of _____ difference ∝ partial pressure of oxygen at the external surface



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



Refractories

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

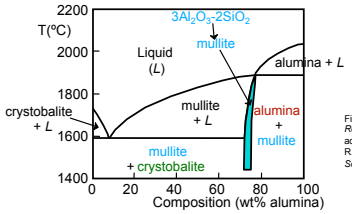


Fig. 12.27, *Callister & Rethwisch 8e.* (Fig. 12.27 adapted from F.J. Klug and R.H. Doremus, *J. Am. Cer. Soc.* **70**(10), p. 758, 1987.)

Advanced Ceramics: Materials for Automobile Engines

- Advantages:
  - Operate at _____ temperatures – high efficiencies
  - _____
  - Operate without a cooling system
  - Lower weights than current engines
- Disadvantages:
  - Ceramic materials are _____
  - Difficult to remove internal voids (that weaken structures)
  - _____ parts are difficult to form and machine
- Potential candidate materials: _____
- Possible engine parts: engine block & piston coatings

Advanced Ceramics: Materials for Ceramic Armor

Components:

-- _____

-- Backing sheet

Properties/Materials:

-- Facing plates -- _____

— fracture high-velocity projectile

— Al_2O_3, B_4C, SiC, TiB_2

-- Backing sheets -- _____

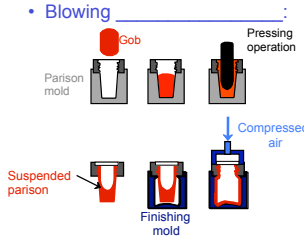
— deform and absorb remaining energy

— aluminum, synthetic fiber laminates

Ceramic Fabrication Methods (i)

GLASS FORMING | PARTICULATE FORMING | CEMENTATION

- Blowing _____:

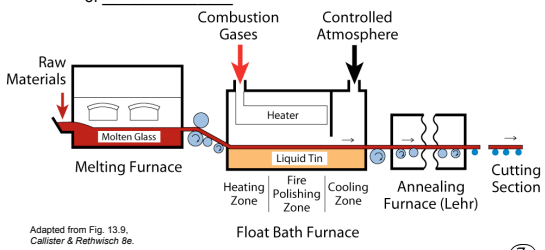


- _____: plates, cheap glasses
  - -- glass formed by _____ of pressure
  - -- mold is steel with _____ lining
- _____ drawing:

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

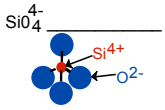
- Sheet forming – _____ casting
  - sheets are formed by floating the _____ glass on a pool of _____



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

Glass Structure

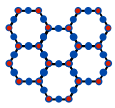
- Basic Unit:

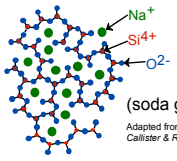


Glass is _____(amorphous)

- Fused _____ is SiO_2 to which no impurities have been added
- Other common _____ contain impurity ions such as Na^+, Ca^{2+}, Al^{3+}, and B^{3+}

- Quartz is _____ SiO_2:



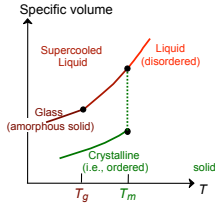


(soda glass)

Adapted from Fig. 12.11, *Callister & Rethwisch 8e.*

Glass Properties

- _____ (1/ρ) vs Temperature (*T*):



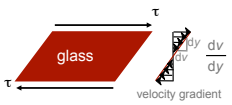
Adapted from Fig. 13.6, *Callister & Rethwisch 8e.*

- _____ materials:
  -- crystallize at melting temp, T_m
  -- have _____ in spec. vol. at T_m

- _____:
  -- do not crystallize
  -- change in ____ in spec. vol. curve at glass transition temperature, T_g
  -- transparent - no grain boundaries to scatter light

Glass Properties: Viscosity

- Viscosity, η:
  -- relates _____ (τ) and _____ *(dv/dy):*



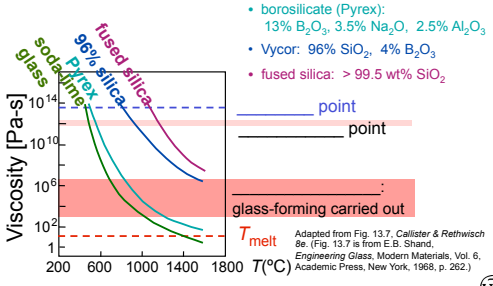
$$\eta = \frac{\tau}{dv/dy}$$

η has units of (Pa-s)

Log Glass Viscosity vs. Temperature

- _____ decreases with T

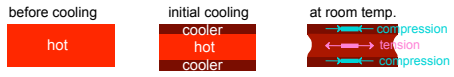
- soda-lime glass: 70% SiO_2 balance Na_2O (soda) & CaO (lime)
- borosilicate (Pyrex): 13% B_2O_3, 3.5% Na_2O, 2.5% Al_2O_3
- Vycor: 96% SiO_2, 4% B_2O_3
- fused silica: > 99.5 wt% SiO_2



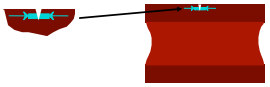
Adapted from Fig. 13.7, *Callister & Rethwisch 8e.* (Fig. 13.7 is from E.B. Shand, *Engineering Glass*, Modern Materials, Vol. 6, Academic Press, New York, 1968, p. 262.)

Heat Treating Glass

- _____:
  -- removes _____ stresses caused by uneven cooling.
- _____:
  -- puts surface of glass part into _____
  -- suppresses _____ from surface scratches.
  -- sequence:



-- Result: surface crack growth is _____.

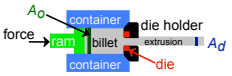


Ceramic Fabrication Methods (iia)

GLASS FORMING | PARTICULATE FORMING | CEMENTATION

_____ forming:

- Mill (grind) and screen constituents: _____
- Extrude this mass (e.g., into a brick)



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

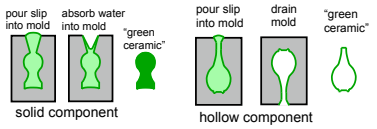
- _____ the formed piece

Ceramic Fabrication Methods (iia)

GLASS FORMING | PARTICULATE FORMING | CEMENTATION

_____:

- Mill (grind) and screen _____: desired particle size
- Mix with _____ and other constituents to form slip
- _____ operation



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.)

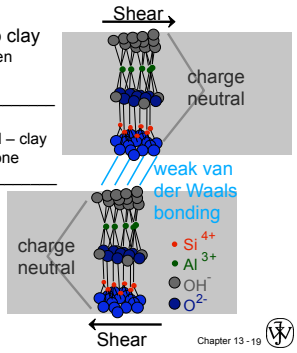
- Dry and fire the _____

Typical Porcelain Composition

(50%) 1. Clay
(25%) 2. _____ – e.g. quartz (finely ground)
(25%) 3. _____ (Feldspar)
-- _____ plus K^+, Na^+, Ca^+
-- upon firing - forms low-melting-temp. glass

Hydroplasticity of Clay

- Clay is inexpensive
- When _____ is added to clay
  - -- water molecules fit in between layered sheets
  - -- reduces degree of _____ bonding
  - -- when external forces applied – clay particles free to move past one another – becomes _____

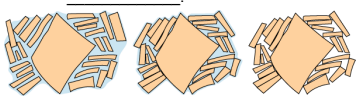


- Structure of Kaolinite Clay:

Adapted from Fig. 12.14, *Callister & Rethwisch 8e.* (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

- _____: as water is removed - interparticle spacings decrease – _____.

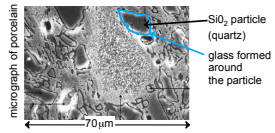


Adapted from Fig. 13.13, *Callister & Rethwisch 8e.* (Fig. 13.13 is from W.D. Kingery, *Introduction to Ceramics*, John Wiley and Sons, Inc., 1960.)

wet body partially dry _____ dry

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

- Firing:
  - -- heat treatment between 900-1400°C
  - -- _____: liquid glass forms from clay and flux – flows between SiO_2 particles. (Flux lowers melting temperature).



Adapted from Fig. 13.14, *Callister & Rethwisch 8e.* (Fig. 13.14 is courtesy H.G. Brinkies, Swinburne University of Technology, Hawthorn Campus, Hawthorn, Victoria, Australia.)

Ceramic Fabrication Methods (iib)

GLASS FORMING | PARTICULATE FORMING | CEMENTATION

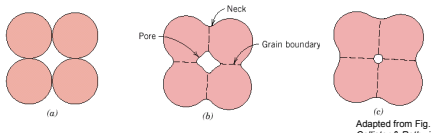
_____: used for both clay and non-clay compositions.

- _____ (plus binder) compacted by pressure in a mold
  - -- _____ compression - compacted in single direction
  - -- _____ (hydrostatic) compression - _____ fluid - powder in rubber envelope
  - -- Hot pressing - pressure + heat

Sintering

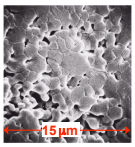
Sintering occurs during _____ of a piece that has been _____

-- powder particles coalesce and reduction of pore size



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

Aluminum oxide powder:
-- _____ 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.)

Tape Casting

- Thin sheets of _____ cast as flexible tape
- Used for integrated circuits and _____
- Slip = suspended ceramic particles + organic liquid (contains binders, _____)

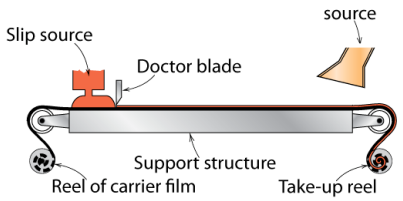


Fig. 13.18, *Callister & Rethwisch 8e.*

Ceramic Fabrication Methods (iii)

GLASS FORMING | PARTICULATE FORMING | CEMENTATION

- Hardening of a _____ – paste formed by mixing cement material with water
- Formation of _____ structures having varied and complex shapes
- Hardening process – _____ (complex chemical reactions involving _____)
- Portland cement – production of:
  -- mix clay and _____
  -- calcine (heat to 1400ºC)
  -- grind into fine powder

Summary

- Categories of ceramics:
  - -- glasses
  - -- clay products
  - -- refractories
  - -- cements
  - -- advanced ceramics
- 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)