# CHAPTER 12: mechanical properties of ceramics

#### **ISSUES TO ADDRESS...**

• Mechanical Properties:

What special provisions/tests are made for ceramic materials?

# **COORDINATION # AND IONIC RADII**

 Coordination # increases with Issue: How many anions can you arrange around a cation? r<sub>cation</sub>



Chapter 12- 4

# Measuring elastic modulus

- Room T behavior is usually elastic, with brittle failure.
- 3-Point Bend Testing often used.
  - --tensile tests are difficult for brittle materials
  - -- cannot machine or grip specimens, 0.1% fracture strain,



• Determine elastic modulus according to:



# Measuring strength

• 3-point bend test to measure room T strength.



## Geometry, load, & material

• Condition for crack propagation:



• Values of K for some standard loads & geometries:



units of K∶ MPa√m or ksi√in

Adapted from Fig. 8.8, *Callister 6e.* 



Chapter 12- 10

#### Fracture toughness of ceramics



## Fracture of ceramic materials



Considerable scatter exists in value of fracture strength  $\sigma_{ft}$ . It depends on probability of existence of a crack with favorable orientation (unstable)

Compressive strength  $\sigma_{fc}$  (more complex) is higher because no stress concentration exists. Also caused by flaws; but by linking of cracks parallel to stress axis – depends on average crack

size, a<sub>ave</sub>



### Silicate glasses



# **Glass properties**

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



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

• Crystalline materials: --crystallize at melting temp, Tm

- --have abrupt change in spec. vol. at Tm
- Glasses:
  - --do not crystallize --spec. vol. varies smoothly with T

--Glass transition temp, Tg



# Glass transition temperature, T<sub>g</sub>



T<sub>g</sub>, temperature below which disordered structure of liquid is "frozen" in place giving rise to a supercooled liquid

T<sub>g</sub> is a measure of the rigidity of the glass network

- Network modifiers decrease Tg
- Network formers
  increase Tg

#### Glass viscosity vs T and impurities

- Viscosity decreases with T
- Impurities lower Tdeform



## 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.)

## **Glass-Ceramics**



•LiO<sub>2</sub>-SiO<sub>2</sub> system (30% LiO<sub>2</sub> typical)

- Enhanced toughness
- Reduced thermal expansion coefficient

- Quartz, feldspar, dolomite, mixed with nucleating agents (TiO $_2$ , ZrO $_2$ )

- Formed using glass forming techniques
- Ceraming heated to temp high enough to form nuclei of crystals 1mm in size Devitrification
- T raised for Growth

# Improving the strength of ceramics and Glasses

Grain size reduction of ceramics

Cracks may be stopped by grain boundaries Make crack path tortuous with whiskers and fibers in ceramics Induce phase transformation (zirconia-containing ceramics) Phase transformation with volume change introduces compressive stresses ahead of advancing crack

Crystallization of glasses

presence of small crystals limit the size of flaws

Close surface defects of ceramics and glasses

- Use in compression
- Implant large atoms in the surface
- Tempering of glass or sandwich glass (Corelle)



 Flame polishing to remelt the surface and heals cracks Chapter 12-

#### **Toughened ceramics**



#### **Example of Partially Stabilized (PSZ) ceramics**

Chapter 12-

### SUMMARY

- Room T mechanical response is elastic, but fracture brittle, with negligible ductility
- Great susceptibility to flaws. Some may be toughened in many ways, including by grain size reduction, martensitic transformation
- Glass have non-crystalline structure, and are very susceptible to cracking. However, they may be toughened with appropriate thermal treatments

### ANNOUNCEMENTS

#### Reading:

#### **Core Problems:**

#### Self-help Problems: