MSE200
Lecture 19 (CH. 11.6, 11.8)
Ceramics
Instructor: Yuntian Zhu

Objectives/outcomes: You will learn the following:

•Mechanical properties: Deformation mechanism, strength, toughness, Transformation toughening, Fatigue.

•Glasses: The glass transition temperature. Structure of glass. Network formers, modifiers, and intermediates. Mechanical properties of glass. Strengthening of glasses by tempering and chemical treatment

Mechanical Properties of Ceramics

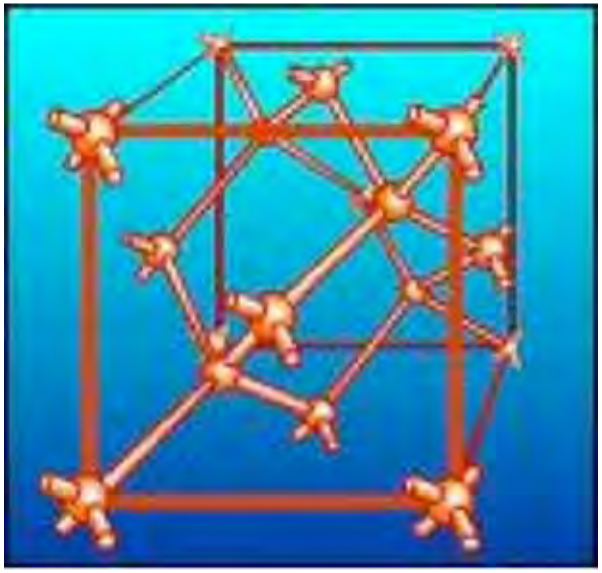
- **Ceramics are generally brittle.**
- **Tensile strength is lower than compressive strength.**
- **Toughness is the most important parameter**

Material	Density (g/cm^3)	Compressive strength		Tensile strength		Flexural strength		Fracture toughness	
		MPa	ksi	MPa	ksi	MPa	ksi	$MPa\sqrt{m}$	$ksi\sqrt{m}$
Al_2O_3 (99%)	3.85	2585	375	207	30	345	50	4	3.63
Si_3N_4 (hot-pressed)	3.19	3450	500	...	...	690	100	6.6	5.99
Si_3N_4 (reaction-bonded)	2.8	770	112	...	...	255	37	3.6	3.27
SiC (sintered)	3.1	3860	560	170	25	550	80	4	3.63
ZrO_2, 9% MgO (partially stabilized)	5.5	1860	270	...	...	690	100	8+	7.26+

Comparison: Steel usually have a strength of 500 -1000 MPa

Mechanism of deformation: Covalently bonded ceramics

- **Brittle fracture due to separation of electron-pair bonds**

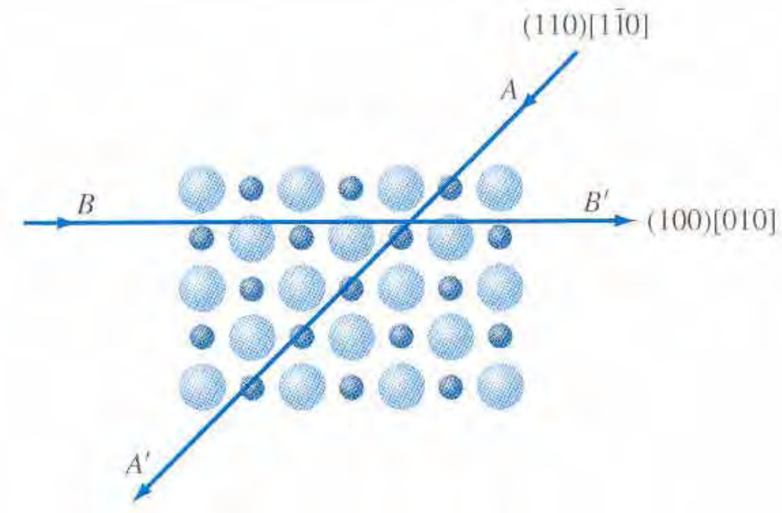


Ionically bonded ceramics

- **Single crystal show considerable plastic deformation under compression**
- **Polycrystalline ceramics are brittle**

•**Example:** **NaCl crystal**

- **Slip in {100} family of planes is rarely observed as same charges come into contact.**
- **Cracking occurs at grain boundaries.**



Factors Affecting Strength

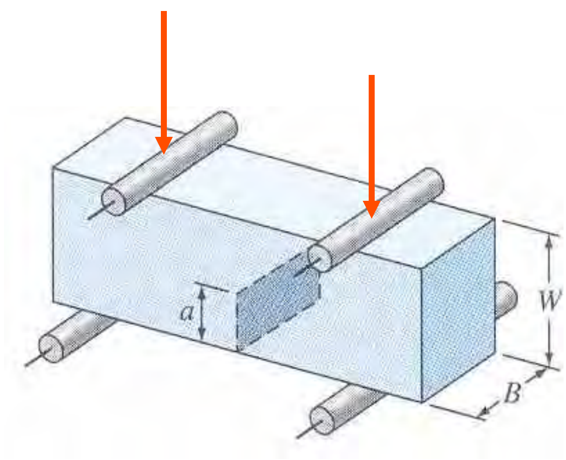
- **Failure occurs mainly from surface defects.**
- **Pores gives rise to stress concentration and cracks.**
- **Finer size ceramics have smaller flaws and hence are stronger.**
- **Composition, microstructure, surface condition, temperature and environment also determine strength.**

The strength of ceramics is usually determined by the largest flaw

Toughness of ceramic Materials

- **Ceramics have low strength**
- **Improving toughness is most important**
- **K_{IC} values (toughness) obtained by *four point bend test*.**

$$K_{IC} = Y\sigma_f \sqrt{\pi a}$$



σ_f = **fracture stress (MPa)**

a = half size of target internal flaw

Y = dimensionless constant

Size effect

$$K_{IC} = Y\sigma_f\sqrt{\pi a} \rightarrow \sigma_f = \frac{K_{Ic}}{Y\sqrt{\pi a}}$$

K_{Ic} is a material value, and can be usually regarded as a constant for the same ceramic material

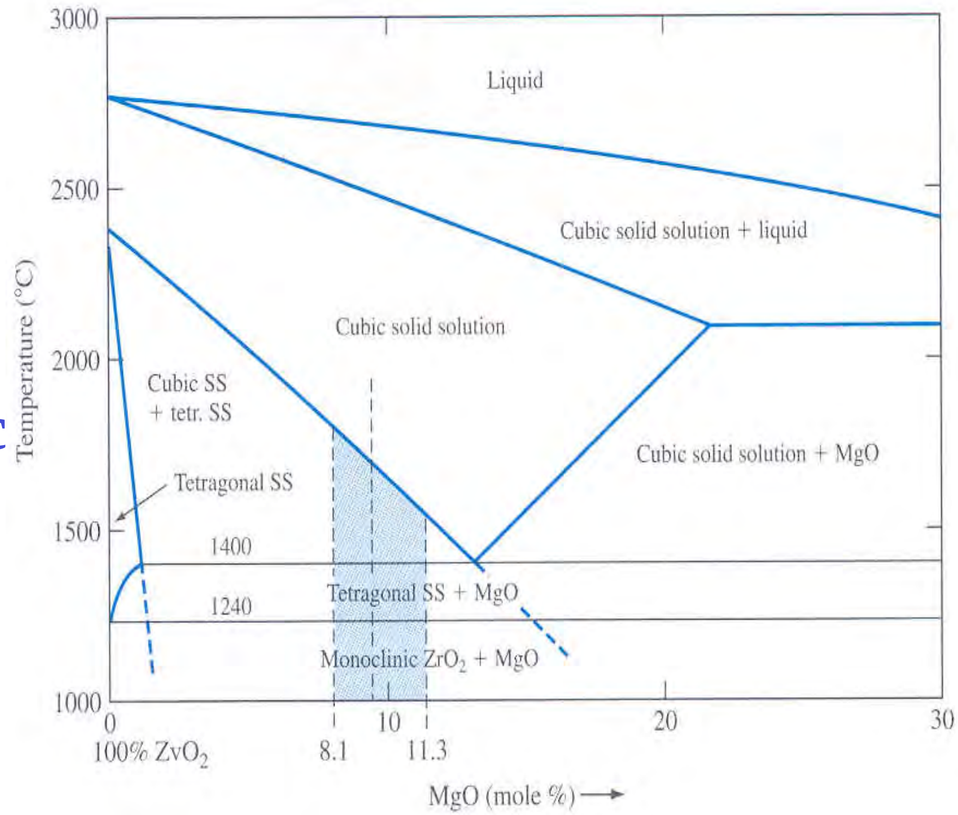
- **Larger parts has a higher probability of containing a larger flaw**
- **Larger parts are likely to have a lower strength**

Transformation Toughening of Partially Stabilized ZrO_2

- **Transformation of Zirconia combined with some other refractory oxides (MgO) can produce very high toughness ceramics.**
- **ZrO_2 exists in 3 structures.**
  - **Monoclinic → Up to 1170^0C**
  - **Tetragonal → $1170 – 2370^0C$**
  - **Cubic → above 2370^0C**
- **Adding 10% mol of MgO stabilizes cubic form so that it can exist in metastable state in room condition.**

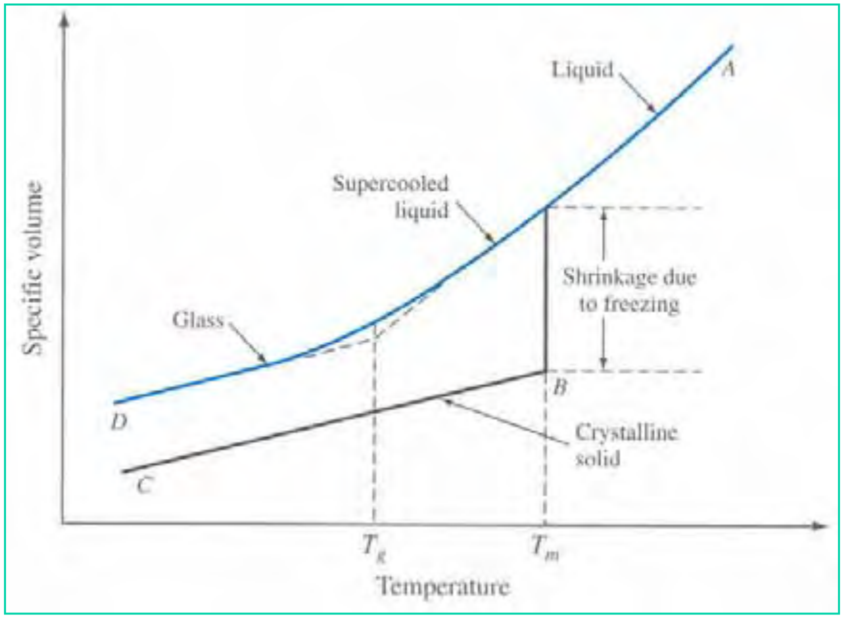
Toughness of Zirconia (Cont..)

- If a mixture of ZrO_2 – 9 mol% MgO is sintered at about 1800^0C and rapidly cooled, it will be in metastable state.
- If reheated to 1400^0C and held for sufficient time tetragonal structure precipitates.
- Under action of stress, this tetragonal structure transforms to monoclinic increasing volume and hence retarding crack growth.



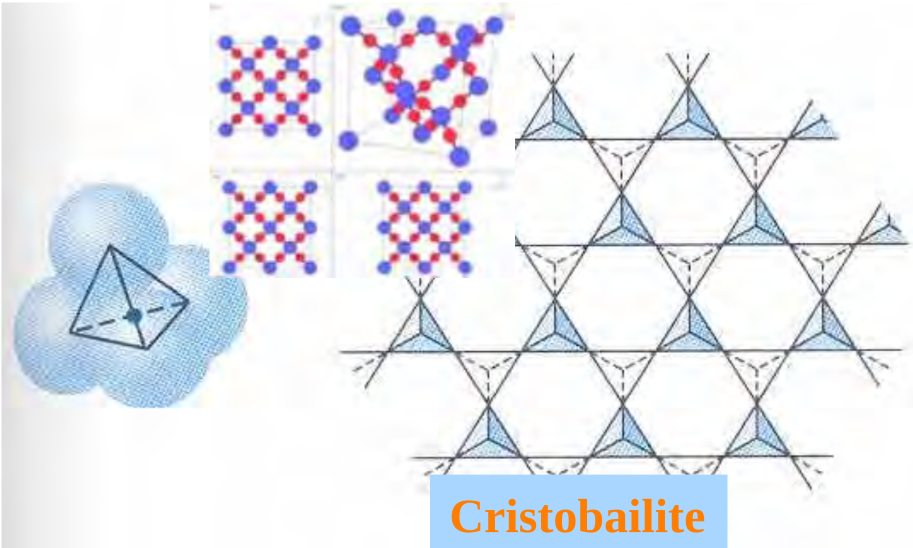
Glasses

- **Combination of transparency, strength, hardness and corrosion resistance.**
- **Glass is an amorphous ceramic material**
- **Up on cooling, it transforms from rubbery material to rigid glass.**

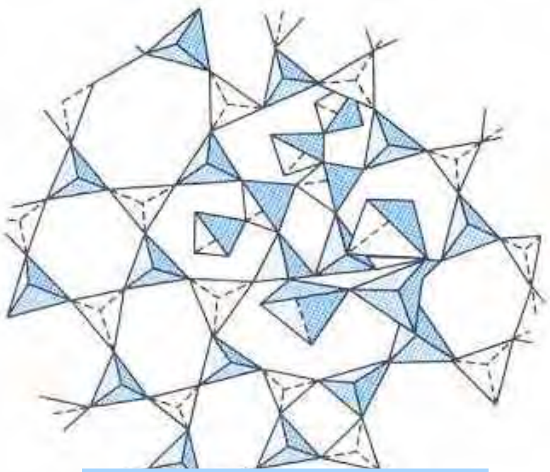


Structure of Glasses

- **Fundamental subunit of glass is SiO_4^{4-} tetrahedron.**
- **Si^{4+} ion is covalently ionically bonded to four oxygen atoms.**
- **In cristobalite, Si-O tetrahedra are joined corner to corner to form long range order.**
- **In simple silica glass, tetrahedra are joined corner to corner to form loose network.**



Cristobailite



Simple silica glass

Glass Modifying Oxides and Intermediate Oxides

- **Network modifiers: Oxides that breakup the glass network.**
  - **Added to glass to increase workability.**
  - **Examples:- Na_2O, K_2O, CaO, MgO.**
  - **Oxygen atom enters network and other ion stay in interstices.**
- **Intermediate oxides: Cannot form glass network by themselves but can join into an existing network.**
  - **Added to obtain special properties.**
  - **Examples: Al2O3, Lead oxide.**

Composition of Glasses

- **Soda lime glass: Very common glass (90%).**
  - **71-73% SiO_2, 12-14% Na_2O, 10-12% CaO.**
  - **Easier to form and used in flat glass and containers.**

Borosilicate glass

Alkali oxides are replaced by boric oxide (B_2O_3) in silica glass network.

- **Known as Pyrex glass and is used for lab equipments and piping.**








Lead glass

Lead oxide acts as network modifier and network former.

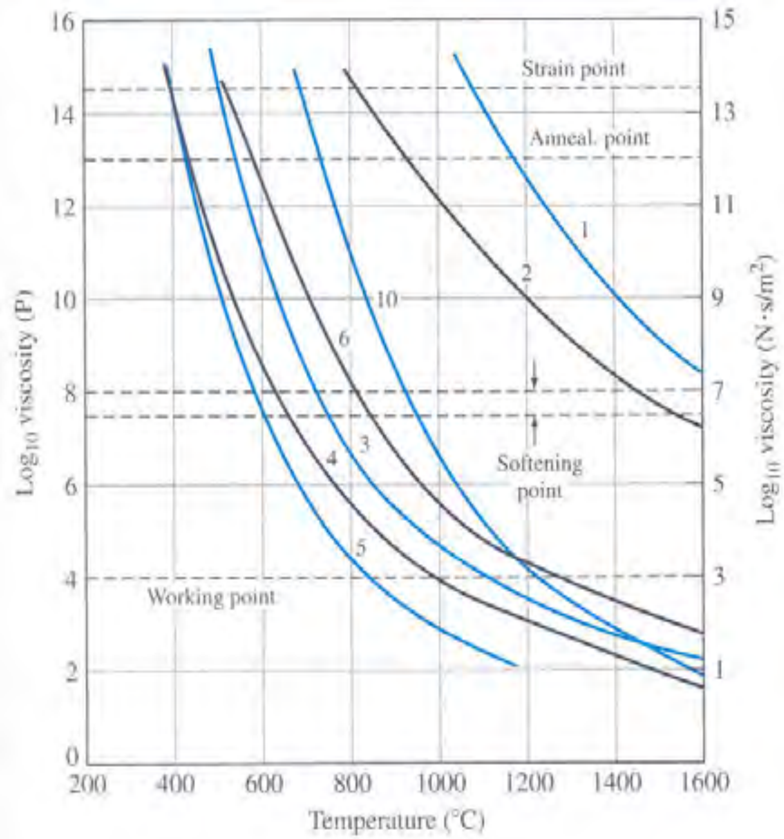
- **Low melting point – used for solder sealing.**
- **Used in radiation shields, optical glass and TV bulbs.**

Viscous Deformation of glasses.

- **Viscous above Tg and viscosity decreases with increase in temperature.**

$\eta^* = \eta_0 e^{+Q/RT}$ **η^* = Viscocity of glass (PaS)**

Q = Activation energy **η_0 = preexponential constant (PaS)**

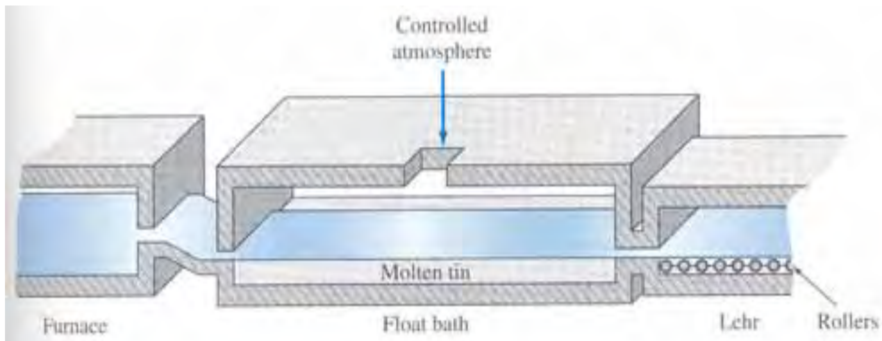


1. **Working point: 10^3 PaS – glass fabrication can be carried out**
2. **Softening point: 10^7 PaS – glass flows under its own weight.**
3. **Annealing point: 10^{12} PaS – Internal stresses can be relieved..**
4. **Strain point: $10^{13.5}$ PaS – glass is rigid below this point.**

Forming Methods

- **Forming sheet and plate glass:**

  Ribbon of glass moves out of furnace and floats on a bath of molten tin.
- **Glass is cooled by molten tin.**
- **After it is hard, it is removed and passed through a long annealing furnace.**



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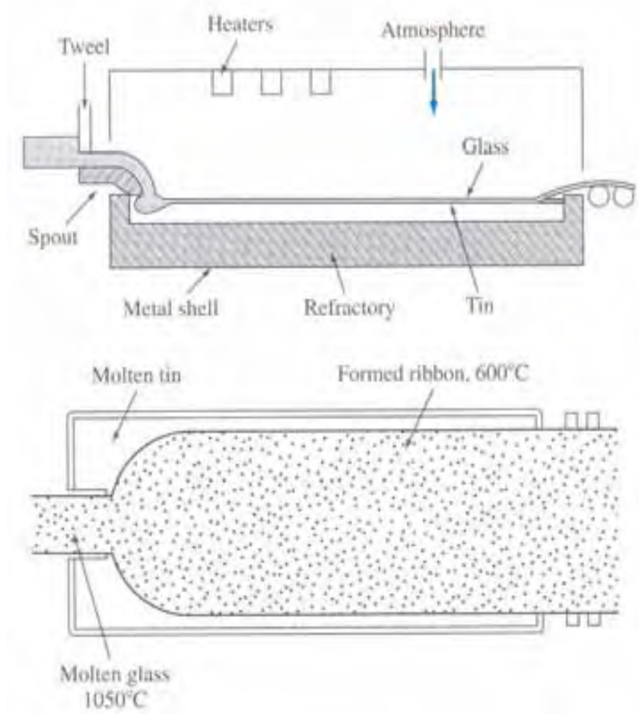
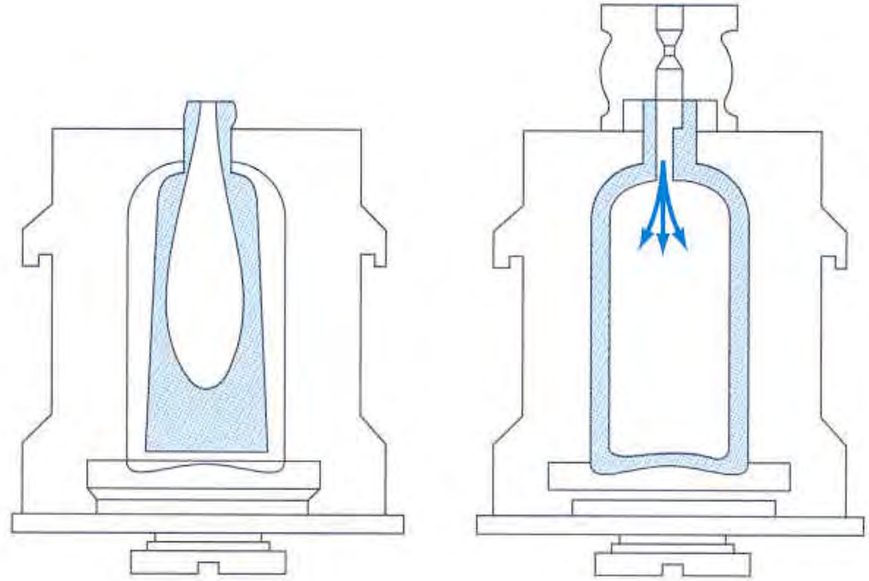


http://video.google.com/videosearch?q=glass+blowing&hl=en&sitesearch=

Blowing, Pressing and Casting

- **Blowing: Air blown to force molten glass into molds.**
- **Pressing: Optical and sealed beam lenses are pressed by a plunger into a mold containing molten glass.**
- **Casting: Molten glass is cast in open mold.**



- **Centrifugal casting: Glass globs are dropped into spinning mold.**

Tempered Glass

- **Glass is heated into near softening point and rapidly cooled.**
- **Surface cools first and contracts.**
- **Interior cools lastand contracts causing tensile stresses in the interior and compressive stress on the surface.**

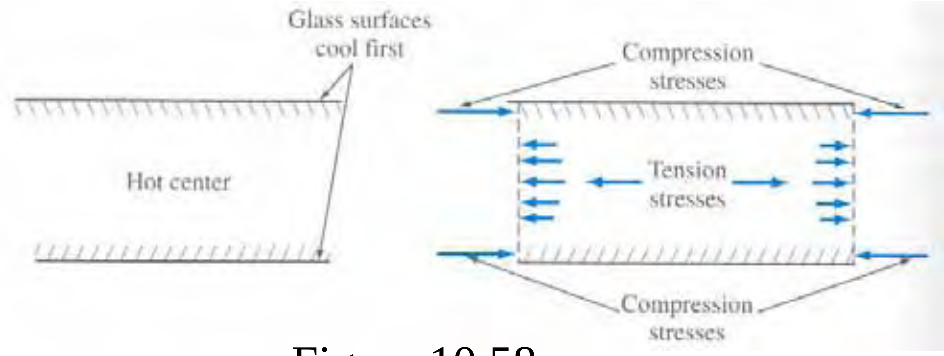


Figure 10.58

- **Tempering strengthens the glass.**
- **Examples: Auto side windows and safety glasses.**

Chemically Strengthened Glass

- **Special treatment increases chemical resistance of glasses.**
- **Example:- Sodium aluminosilicate glasses are immersed in a bath of potassium nitrate at 50^{0}C for 6 to 10 hours**
  - **Large potassium ions are induced into surface causing compressive stress.**
  - **Compressive layer is much thinner than that in thermal tempering.**
  - **Used for supersonic aircraft glazing and ophthalmic lenses.**

HW

- **Reading assignment: 12.1-12.3**
- **HW: download from web**
- **Example problems: 11.9, 11.10**