Quiz 6 Ceramics and Glass

You should Be Able to:

- *name two to three of the most important andvantages of common structural ceramics such as Si_3N_4, SiC, ZrO_2, and Al_2O_3.*
- State the type of bonding present in ceramics and what effect the bonding has on such properties as strength, ductility, stiffness, electrical and thermal conductivity, melting temperature, coefficient of expansion, and toughness.
- State the importance of fracture mechanics (the combination of stress and flaw size) for ceramics, and relate flaws affect mechanical properties.
- Describe what microstructural changes can be made to improve toughness, esp. transformation toughening.
- Define thermal stress in a material or in the combination of two materials; state why thermal stresses are of particular concern for ceramics; and how the problems can be mitigated (including the joining of metals and ceramics).
- Describe the common method of manufacturing ceramics. (Powder - Form -Sinter), and some of the common forming methods (press, isostatic press, slip cast, extrusion, injection molding.
- Name and/or recognize circumstances in which ceramics would be a good choice over metals and polymers and when they are contraindicated.
- State the microstructure of a glass (e.g. name the difference between SiO_2 in glassy and nonglassy forms.
- Describe the steps in the glass tempering process, and explain how tempering allows the material to withstand more stress.

Vocabulary

Be able to match the following terms with their definition

Chap 13-14

Devitrification
Firing
Glass-ceramic
Glass transition temperature
Green ceramic body
Modulus of Rupture
Sintering
Thermal shock
Tempered glass
Vitrification
Weibull Modulus

Ceramics and Glass

What are ceramics?

Ionically and/or covalently bonded solids, often a combination of a metal and a non-metal (e.g. Alumina, Aluminum Oxide, Al_2O_3)

How is Glass different?

Glass is the term used for an amorphous structure (no microstructural) repitition while crystalline structures are referred to as ceramics.

What Structural Ceramics are common?

Silicon Nitride Si_3N_4	**Silicon Carbide** SiC	**Zirconia** ZRO_2	**Alumina** Al_2O_3
• High temp strength • Highest thermal shock resistance • Low SpGr • Bearings, turbo-charger rotors, cutting tools	• High temperature strength • High thermal conductivity • High corrosion resistance • Water pump seals, combuster liners	• Thermal expansion is close to steel • Can have transformation toughening, TTZ, and highest toughness • Cutting blades and tools, wire drawing dies	• Lowest cost • Excellent strength at room temp • Chemical inertness • Body armor, hip implants, thread guides

What are the big advantages and disadvantages of ceramics?

Ceramic Design Advantages	**Ceramic Design Challenges**

• Lower specific gravity than metals
• Higher Stiffness (Young's Modulus)
• High Temperature Resistance
• High Compressive Strength
• Wear Resistance
• Corrosion Resistance
	• Brittle
	    o Poorer tensile properties
	    o Significant scatter in strength (statistical design)
	• Difficult to fabricate (can't easily cast, forge, weld, or machine)
	• Thermal stress
	• Cost

How do we measure Strength in such a brittle material?

Because of significant scatter, using small specimens to predict behavior of large parts is problematic. As stated in Richerson's article, 4 point bend tests are preferred to 3 point bend since more material sees the high tension load. Tensile tests are better, but are much more difficult to perform (specimen fabrication and alignment).

Strength in bending is reported as Modulus of Rupture, MOR.

How do we deal with Brittleness in design?

Flaw Sensitivity

- Apply Fracture Mechanics $K_I = Y\sigma\sqrt{(\pi a)}$
- Use finer grained ceramics (smaller flaw sizes)
- Reduce internal porosity

Statistical Design

- Use Weibull distribution (Like the Normal distribution, there are two parameters, but the are not the Mean and Standard Deviation. Rather, they are the Shape parameter (Weibull Modulus) and the Scale parameter)
- Weibull Modulus is a measure of relative data scatter; a larger Weibull modulus is good because the distribution is tighter (like having a small ratio of standard deviation to mean)
- Richerson reports typical Weibull moduli of 5-10 in the 70's to greater than 20 for structural ceramics today.
- Computer software like CARES/LIFE

How do we Toughen ceramics when planer slip is so difficult?

- Microcrack formation – energy in many new surfaces
- Crack deflection – split the energy of one crack into branches
- Transformation Toughening – scattered grains of one phase change to a less efficiently packed phase (grain gets bigger in volume) in response to stress, thereby causing compressive residual stress in the surrounding grains. This tends to impede a crack driven by tension.

If we can't easily forge, cast, weld, machine ceramics, how do we make them?

Manufacturing ceramics is usually much like Powder Metallurgy (or similar to making sand castles)

1. **Make Powder** – finer powders are better (smaller flaw sizes)

2. **Press Powder** into a Mold (green body) - Die pressing, isostatic pressing, slip casting, extrusion molding, injection molding
3. **Sinter** the green body to form a solid part – heating below the melting temperature, allows diffusion of the particles to form a single solid piece. Part shrinks as pores between particles go away.

Alternatives: Combined forming and sintering – Hot pressing, Hot Isostatic Pressing (HIP). Reaction sintering.

How do we get Thermal Stress?

There are two main issues Mismatched materials and Thermal transients:

1) If two bonded materials with different thermal coefficients of expansion change temperature, one will try to expand more than the other and stress at the interface will result. This can be minimized by trying to match coefficients or by putting in an intermediate material or a flexible material.

2) Transient thermal stress is seen when we take a glass pan from the freezer to the oven. The difference in temperature across the thickness of the pan can lead to significant stress due to differential expansion. To deal with this you can use a material with minimal thermal expansion (Pyrex) or you use a material with a high R value.
   $R = (\sigma_{fract}(1-\nu)/(\alpha E)$
   Therefore we want High Strength, Low Stiffness, Low Coef of Exp.
   Also, a high thermal conductivity reduces the gradient.

How do we make Tempered Glass

Step 1 - Heat above T_g (glass transition temperature so easy plastic flow occurs)

Step 2 - Cool outside surfaces (surface layers are rigid and glassy, core is hot and viscous)

Step 3 - Cool entirely to room temp (as core cools and shrinks it pulls the rigid surfaces into compression (core is left in tension))