Introduction to Ceramics

- **Metals**
- *High density*
- *Medium to high melting point*
- *Medium to high elastic modulus*
- *Reactive*
- *Ductile*

- **Ceramics**
- *Low density*
- *High melting point*
- *Very high elastic modulus*
- *Unreactive*
- *Brittle*

- **Polymers**
- *Very low density*
- *Low melting point*
- *Low elastic modulus*
- *Very reactive*
- *Ductile and brittle types*

Types of Ceramic

- Glasses
- Traditional ceramics - clay based
- Engineering ceramics
- Cement and concrete
- Rocks and Minerals
- Ceramic Composites

- Covalent or ionic interatomic bonding
- Often compounds; usually oxides
- New “engineering ceramics” can also be carbides, nitrides and borides

Materials Data

- Hard brittle solids - no unique failure strength because it depends on crack size
- Data can vary markedly from manufacturer to manufacturer
- Strength may depend on history after manufacture (surface damage)
- Some data are invariant - *structure insensitive* e.g. Melting point, Density, Elastic Modulus
- Others are highly *structure sensitive* e.g. Tensile Strength, Fracture Toughness, Thermal conductivity, Thermal Expansion Coefficient

Typical Mechanical Properties

- Very brittle: K_{Ic} in region 1 - 12 $MPam^{1/2}$
  (*cf.* Al alloys have K_{Ic} - 25 - 50 $MPam^{1/2}$)
- This results in low, and variable, tensile strengths
  $$\sigma_F = K_{Ic} / (\pi c)^{1/2}$$
  …. controlled by size of biggest flaw.
- High elastic moduli - greater than metals
- High compressive strengths - generally much higher than tensile strength
- Very high hardness

Working definition of a ceramic - “something that the design engineer worries about fracturing rather than yielding”.

Typical Properties 2

- Good creep resistance because of high melting point
- Often have low density
  - hence high **specific** modulus, etc.
- Excellent wear resistance because of high compressive strength and hardness
- Good resistance to chemical attack
  - oxides can't oxide further !
- High melting point, chemical inertness, high hardness and low fracture strength can make it difficult to make ceramic components.

Natural Ceramic Materials

- Stone is one of the oldest construction materials
- Very durable (The Pyramids and Stonehenge!)
- Very cheap

- Limestone ($CaCO_3$)
- Sandstone (SiO_2)
- Granite (aluminosilicates)
- Behaviour similar to all brittle ceramic materials
- Use in compression only!

Cement and Concrete

- Used on an enormous scale in the construction industry
- Only brick and timber rival in volume (then steel)
- Very cheap - about one tenth the cost per volume of steel
- Mixtures of lime (CaO), silica (SiO_2) and alumina (Al_2O_3) which hydrate (react with water) to form solids.
- Can be cast to shape.
- Relatively easy to manufacture from raw materials

Glass

- Enormous tonnages used - about the same as aluminium.
  - Up to 80% of the surface area of a modern building may be glass (not load bearing)
- Load bearing applications in vehicle windows, pressure vessels, vacuum chambers
- Inert glass coatings used in chemical & food industries (glazes)

Typical Glasses and Applications

- **Soda-lime Glass**
  70% SiO_2, 10% CaO, 15%Na_2O, 5% MgO / Al_2O_3:
  Windows, bottles etc.
  Low melting/softening point, easily formed
- **Borosilicate Glass** (Pyrex)
  80% SiO_2, 13% B_2O_3, 4% Na_2O, 3% Al_2O_3:
  Cooking and chemical glassware.
  High temperature strength, low coefficient of thermal expansion (CTE), good thermal shock resistance
- **LAS Glass-Ceramic**
  60% SiO_2, 20% Al_2O_3 , 20% Li_2O, + TiO_2 (nucleating agent):
  cooker tops, ceramic composites.
  Heat treatment causes glass to crystallise to form crystal/amorphous composite with greater creep resistance and very low CTE - hence excellent thermal shock resistance

Traditional Ceramics ("whitewares")

- Pottery, porcelain, tiles, structural and refractory bricks are still made by processes very similar to those of 2000 years ago
- Made from clays which are moulded in a plastic state and then fired
- Consist of a glassy phase which melts and "glues" together a complex polycrystalline multiphase body

Trad. Ceramics: Raw Materials

- Clays: complex hydrous aluminosilicates e.g.
  - Kaolinite: $Al_2(Si_2O_5)(OH)_4$
  - Montmorrilonite $Al_5(Na,Mg)(Si_2O_5)_6(OH)_4$
- Feldspars (low melting point): $K_2O.Al_2O_3.8SiO_2$
- Quartz sand / “Flint” (cheap, high m.p.): SiO_2

Trad. Ceramics: Applications

- Earthenware, Stoneware, China, Porcelain, are all distinguished by their firing temperature and glass forming temperature
- Tiles are made from similar composition material
- Structural bricks are made from cheaper mixtures - often a single clay (“Fletton Brick”)
- Refractory bricks have special compositions to withstand high temperatures or corrosive environments

Engineering Ceramics

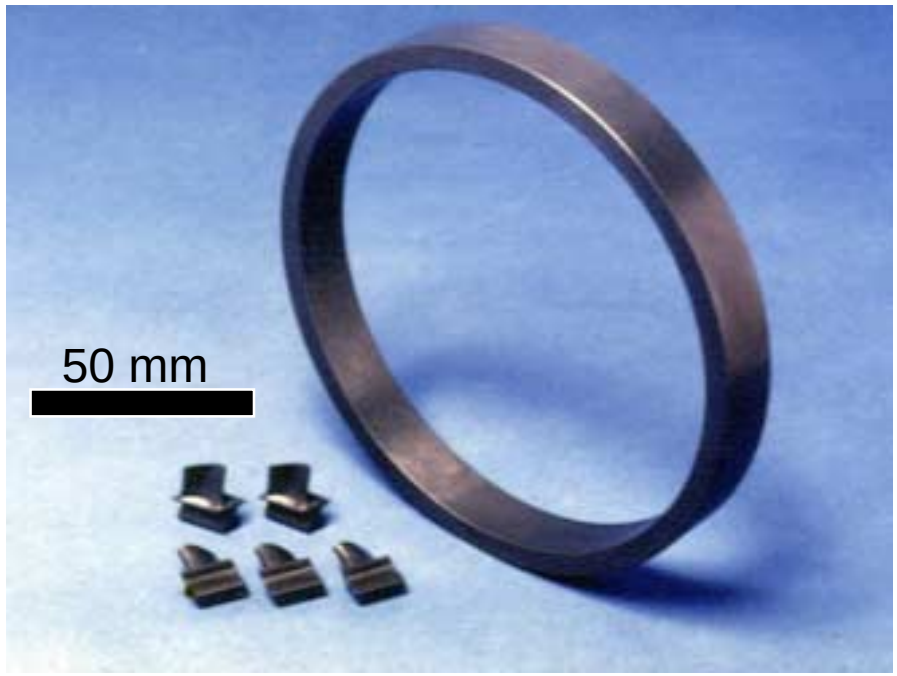
- Traditional ceramics are weak because they contain many pores and cracks. Their elastic moduli are low because of the glassy phases present.
- “Engineering ceramics” have been developed: these are pure fully dense ceramics with many fewer cracks and higher intrinsic elastic modulus.

Engineering Ceramics

Ceramic		Applications
Alumina	Al_2O_3	Cutting tools, dies, wear resistant parts and coatings, oxidation barriers, bearing surfaces, high temperature components, turbine parts, hip implants, body armour, radiation shielding.
Silicon Carbide	SiC	
Silicon Nitride	Si_3N_4	
Zirconia	ZrO_2	
Boron Nitride	BN	

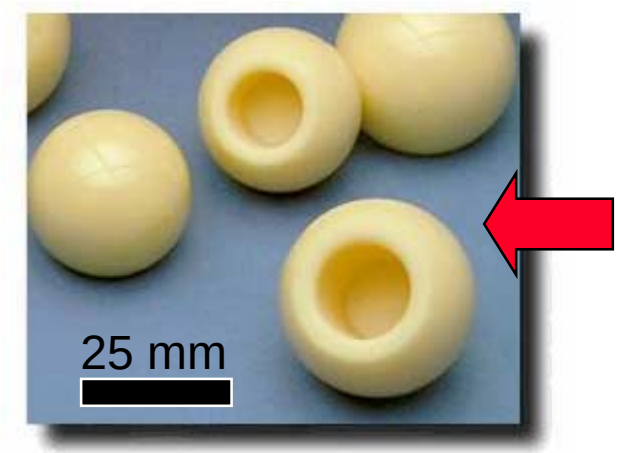
Gas Turbine Components

Shroud ring and turbine blades for a small helicopter engine fabricated from sintered silicon nitride



Wear Resisting Components

Pump face seals, polishing supports and sealing rings made from sintered silicon carbide



Hip joint balls from zirconium oxide

Ceramic Composites

- Often we would like the stiffness and hardness of a ceramic without brittleness -
- Combine with polymers, metals or other ceramics to form “composites”
- Not cheap! - except steel / concrete & maybe GFRP

- Glass or carbon fibre reinforced plastic
- Ceramic – ceramic particulate or fibre composites
- Cermets - particles of hard ceramic bonded by a thin metal film
- Reinforced concrete - steel rods or glass fibres
- Bone - natural ceramic composites, hydroxy-apatite bonded by collagen