Imperial College
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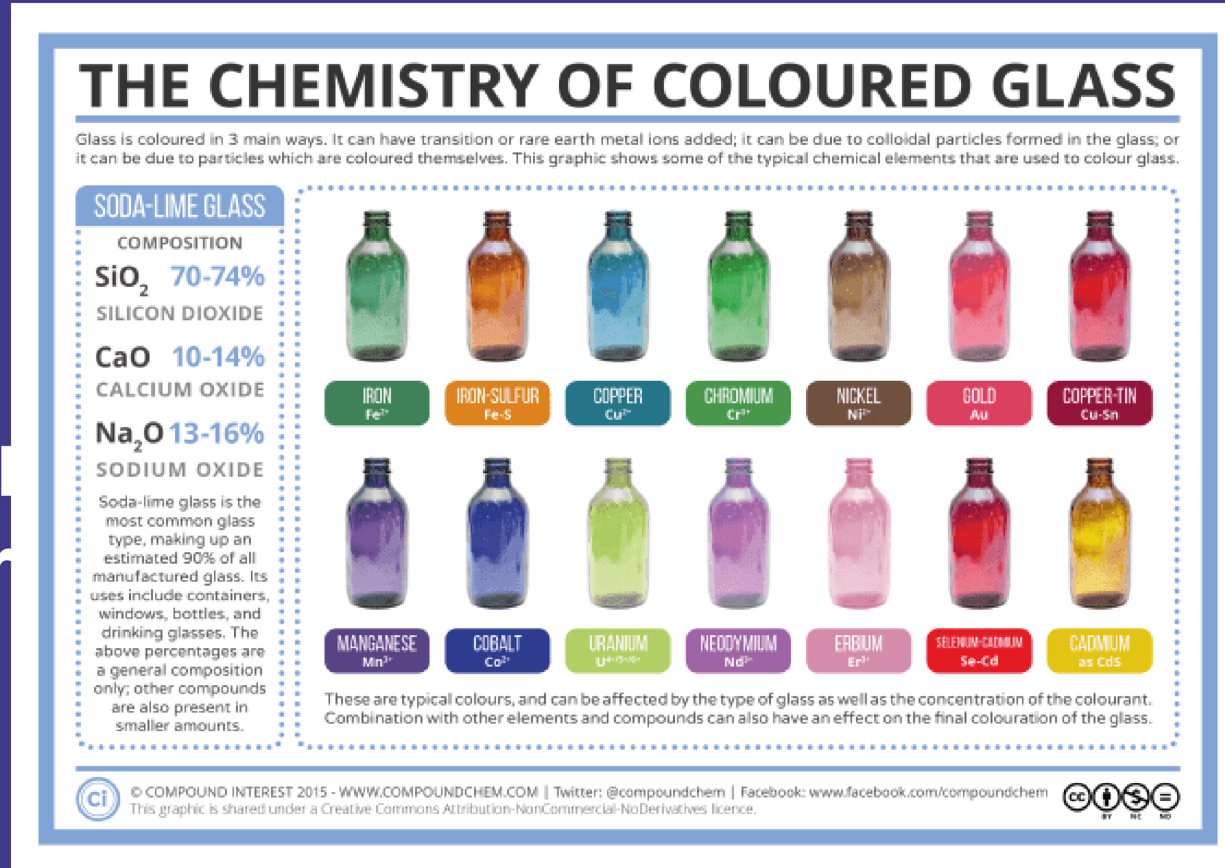
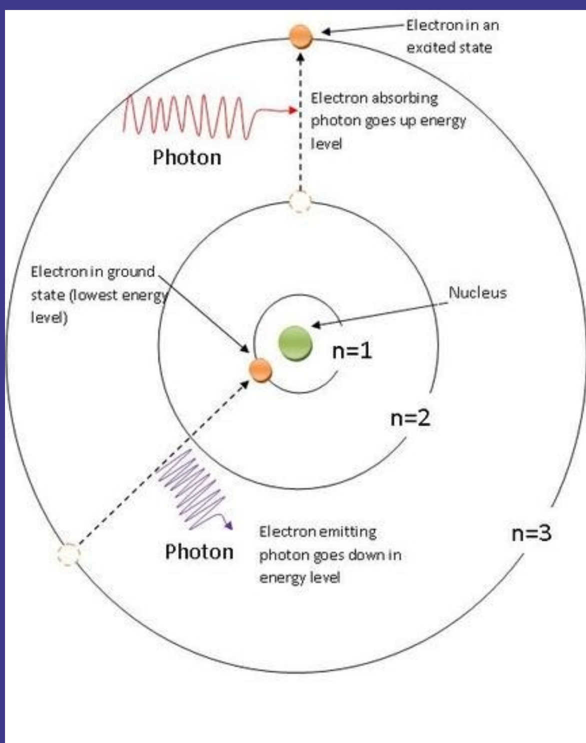
Materials a
Manufactur





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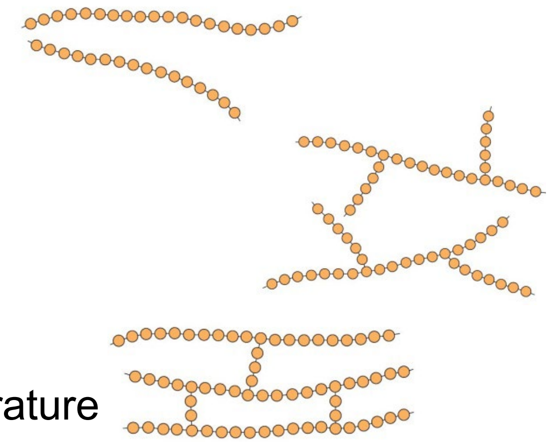
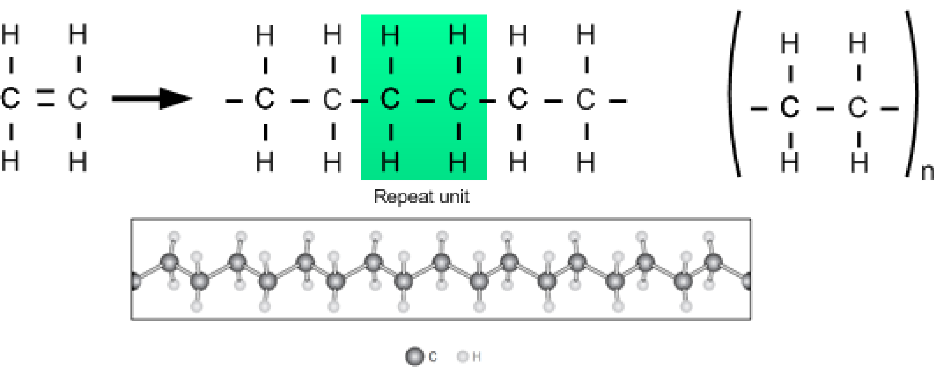
Dyson School of
Design Engineering

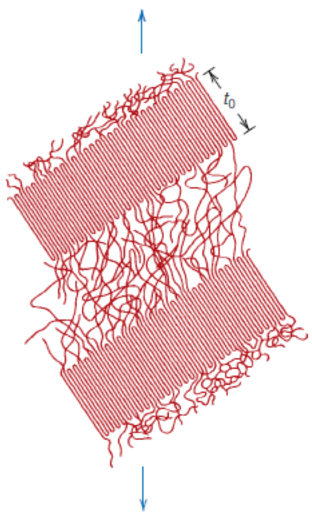
Last time on M&M…

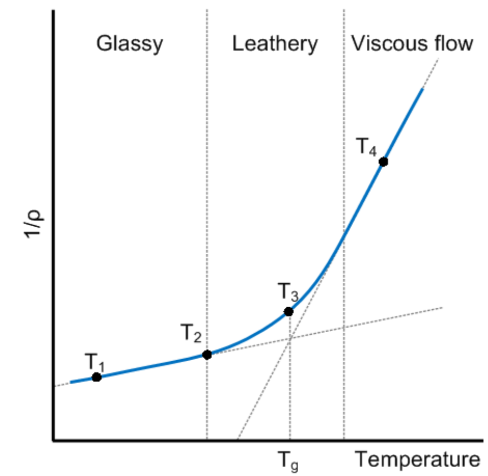
Polymers

- Types of plastics: thermoplastics, thermosets and elastomers
- Polymerisation of monomers
- Interatomic (covalent) and intermolecular (van der Waals) forces
- Chain types: linear, branched and cross linked
- Packing: crystalline, semi-crystalline and amorphous polymers
- Tensile properties of polymers – Chain entanglement
- Temperature dependent properties – The glass transition temperature
- Visco-elastic properties









Learning objectives

- Define what a ceramic is
- Describe the flexural strength, 3-point bending tests and why ceramics are tested differently to metals
- Understand the 6 main categories of ceramics: glasses, clays, refractories, abrasives, cements and advanced ceramics, giving examples of their applications

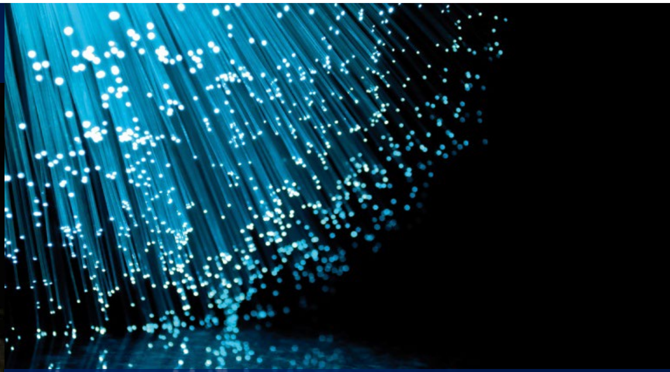
Why is it important

Ceramics and glasses are a class of material with some unique properties which, as engineers, we wish to utilize. Despite having a low toughness, ceramics have high hardness and excellent high temperature and corrosion resistance and are thermal and electrical insulators. This opens up several important applications for which ceramics are the optimum material.

With advanced understanding of these materials new applications have come about which have transformed our daily lives

Bricks and concrete

Refractories



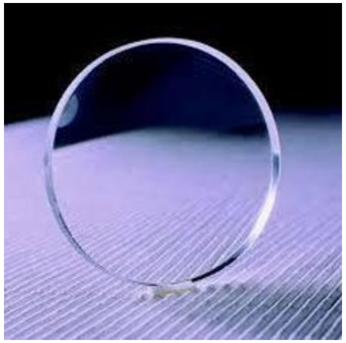
Optic fibres

What are ceramics/glasses?

Ceramics are typically non-metallic, inorganic solids. The so called traditional ceramics include clay-based bricks, tiles, porcelain, pipes and crockery.

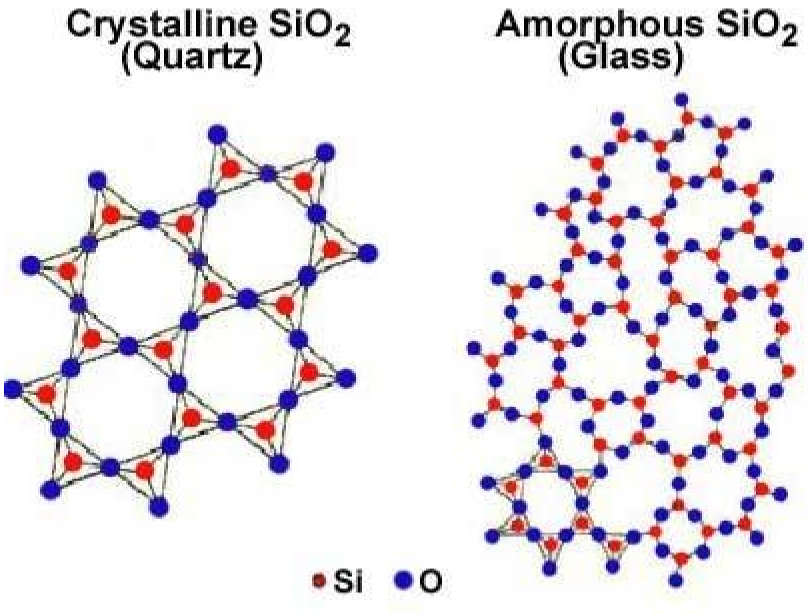
As engineers we are mainly concerned with and interested in modern, high performance ceramics.

Ceramics have crystalline, semi-crystalline and amorphous structures whereas glass is typically amorphous



Quartz vs glass

Clays

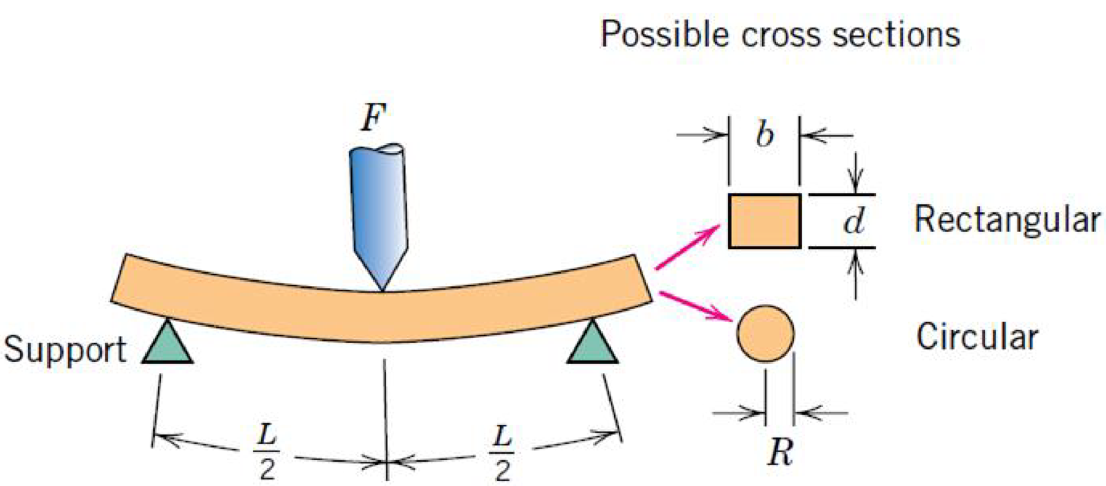


Mechanical properties of ceramics

The stress-strain behaviour of brittle ceramics is not usually ascertained by a tensile test, for three reasons:

1. It is difficult to prepare and test specimens having the required geometry
2. It is difficult to grip brittle materials without fracturing them
3. Ceramics fail after only about 0.1% strain, which necessitates that tensile specimens be perfectly aligned to avoid the presence of bending stresses, which are not easily calculated

- Transverse loading is often more suitable



$$\sigma = \text{stress} = \frac{Mc}{I}$$

where M = maximum bending moment
c = distance from center of specimen to outer fibers
I = moment of inertia of cross section
F = applied load

	M	c	I	σ
Rectangular	$\frac{FL}{4}$	$\frac{d}{2}$	$\frac{bd^3}{12}$	$\frac{3FL}{2bd^2}$
Circular	$\frac{FL}{4}$	R	$\frac{\pi R^4}{4}$	$\frac{FL}{\pi R^3}$

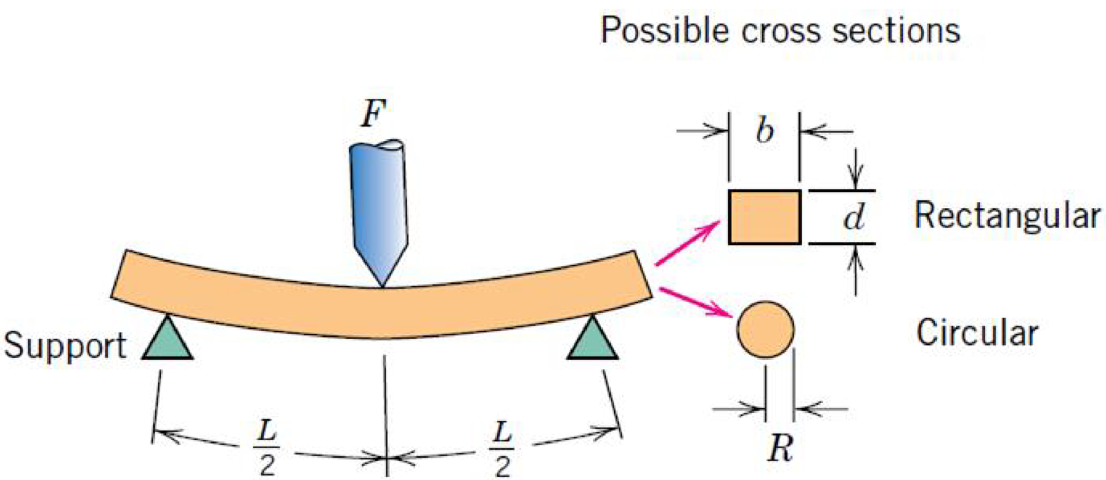
Mechanical properties of ceramics

- The stress at fracture using this flexure test is known as the **flexural strength**, **modulus of rupture**, **fracture strength**, or the **bend strength**, an important mechanical parameter for brittle ceramics

$$\sigma_{fs} = \frac{3F_f L}{2bd^2}$$ **Rectangular**

$$\sigma_{fs} = \frac{F_f L}{\pi R^3}$$ **Cylindrical**

- σ_{fs} will depend on the thickness of the sample
- With increasing specimen volume (that is, specimen volume exposed to a tensile stress) there is an increase in the probability of the existence of a crack-producing flaw and consequently, a decrease in flexural strength



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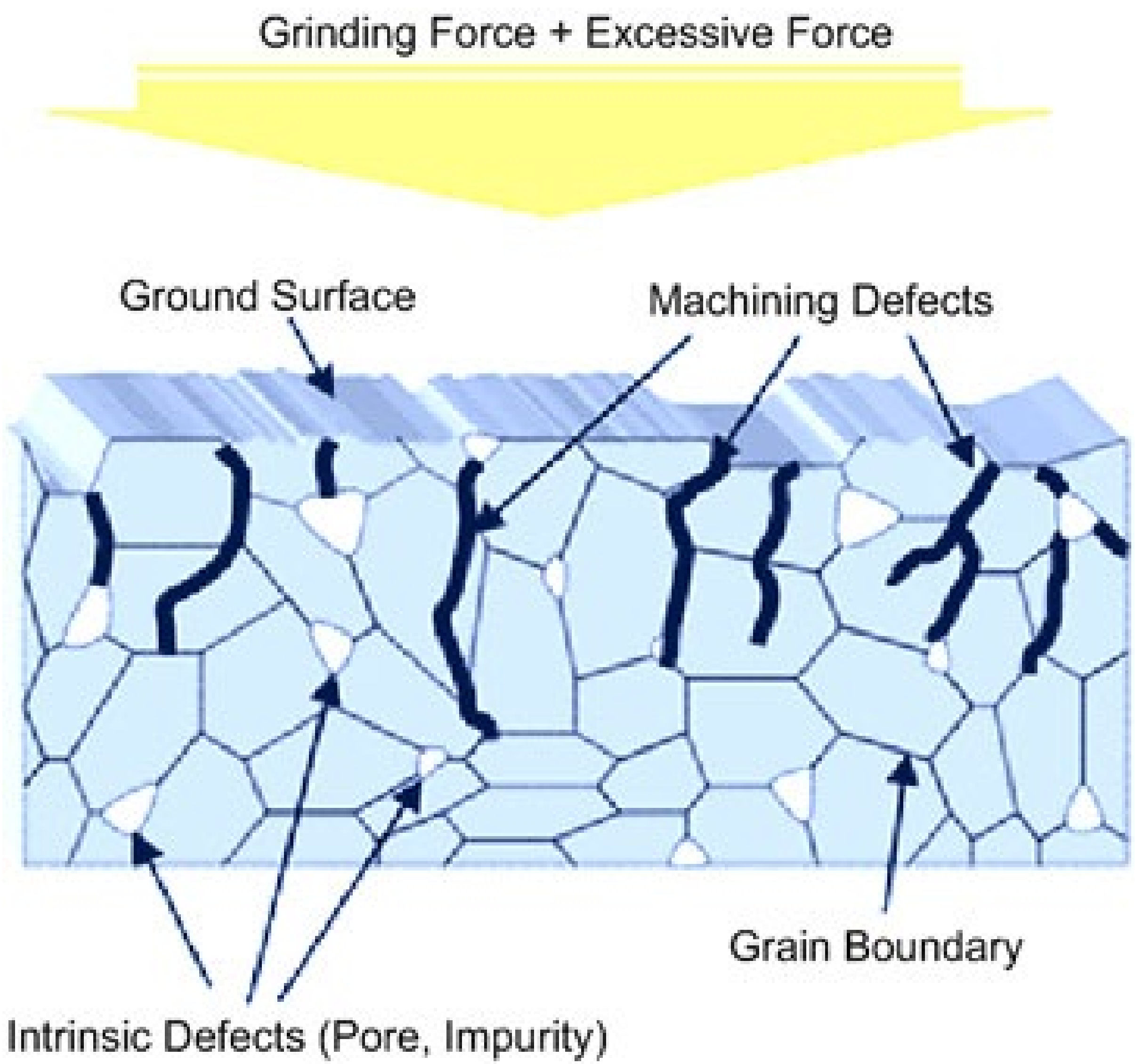
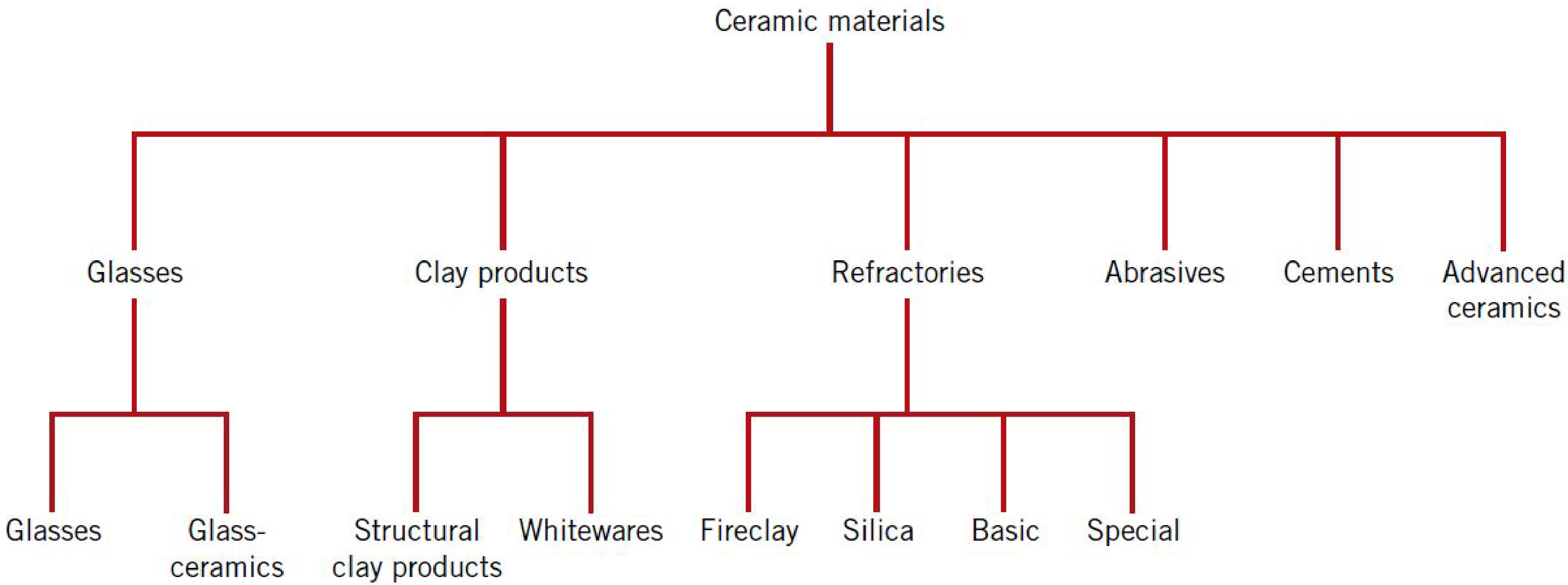
Stress concentrators



Types of ceramics



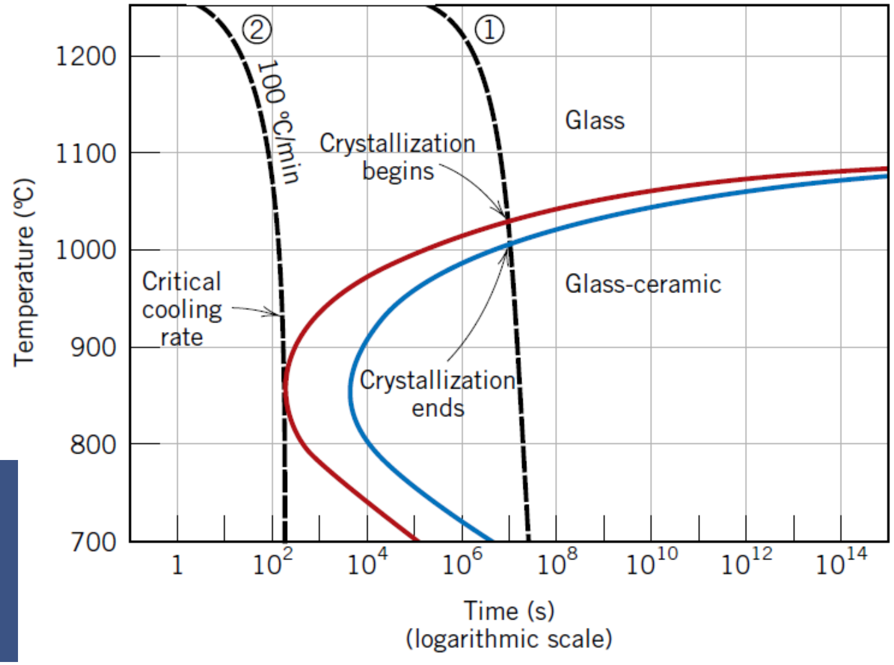
Glasses

- The glasses are a familiar group of ceramics; containers, lenses, and fiberglass represent typica applications
- They are non-crystalline materials containing othe oxides, notably CaO, Na_2O, K_2O, and Al_2O_3
- A typical soda-lime glass consists of approximatel 70 wt% SiO_2, the balance being mainly Na_2O (soda) and CaO (lime)
- Optically transparent and easy to make

Glass type	Characterstics and applications
Fused silica	High melting temperature, very low coefficient of expansion (thermally shock resistant)
96% Silica (Vycor^{TM})	Thermally shock and chemically resistance - laboratory ware
Borosilicate (Pyrex^{TM})	Thermally shock and chemically resistant-ovenware
Container (soda-lime)	Low melting temperature, easily worked, also durable
Fiberglass	Easily drawn into fibers-glass resin composites
Optical flint	High density and high index of refraction-optical lenses
Glass-ceramic (Pyroceram^{TM})	Easily fabricated; strong; resists thermal shock-ovenware

Glass-ceramics

- Most inorganic glasses can be made to transform from a non-crystalline state to one that is crystalline by the proper high-temperature heat treatment
- This process is called **crystallization**, and the product is a fine-grained polycrystalline material which is often called a **glass-ceramic**
- High mechanical strength, low thermal expansion, high temperature operation, good dielectric properties and good biological compatibility
- Relatively easy to make



Continuous cooling transformation diagram for the crystallization of lunar glass

Clays

- One of the most widely used ceramic raw materials is clay
- This inexpensive ingredient, found naturally in great abundance, often is used as mined without any upgrading of quality
- Easy to form when mixed with water
- Fired at elevated temperatures to improve mechanical properties

Structural clays
Bricks, tiles sewer pipes

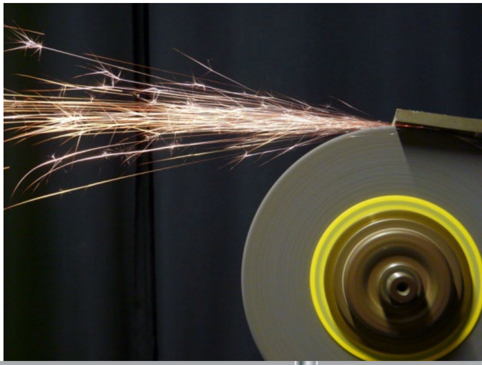
Whitewares
Porcelain, pottery, china

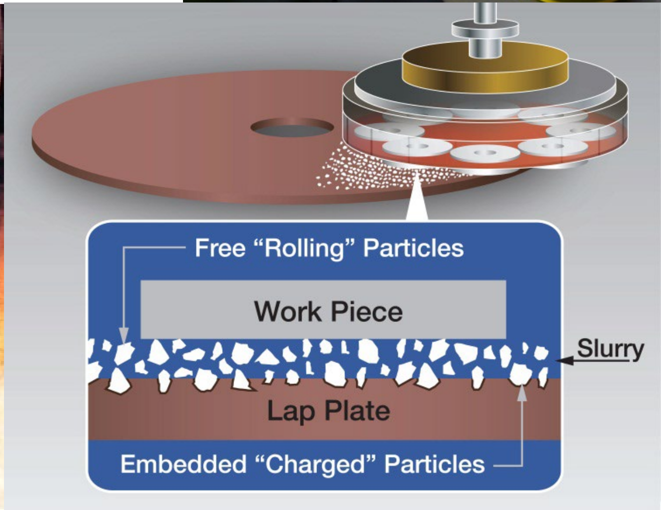
Refractories

- Refractory ceramics are able to withstand high temperature without melting or decomposing as well as remaining inert
- Often used to provide thermal insulation
- Applications include: furnace linings, glass manufacturing, metallurgical heat treatment and power generation
- Types include: fire-clay, silica, basic and special refractories

Abrasives

- Abrasive ceramics are used to wear, grind, or cut away other material
- Prime requisite for this group of materials is hardness or wear resistance; in addition, a high degree of toughness is essential to ensure that the abrasive particles do not easily fracture
- High temperatures may be produced from abrasive frictional forces, so some refractoriness is also desirable
- Common abrasives include: diamonds, silicon carbide, tungsten carbide, silica sand etc
- Abrasives are used in 3 main forms
- **Bonded to grinding wheels**
    - Abrasive particles are bonded to a wheel by means of a glassy ceramic or an organic resin
- **Coated**
    - Abrasives are bonded to some sort of paper or cloth
- **Loose grains**
    - Abrasives delivered in a carrier fluid (water or oil)
    - Grinding, lapping and polishing





Cements

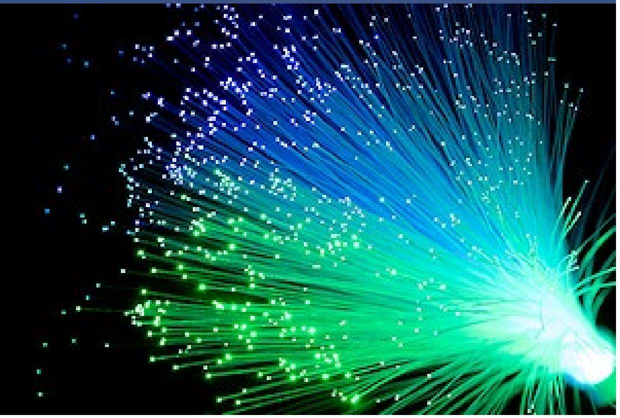
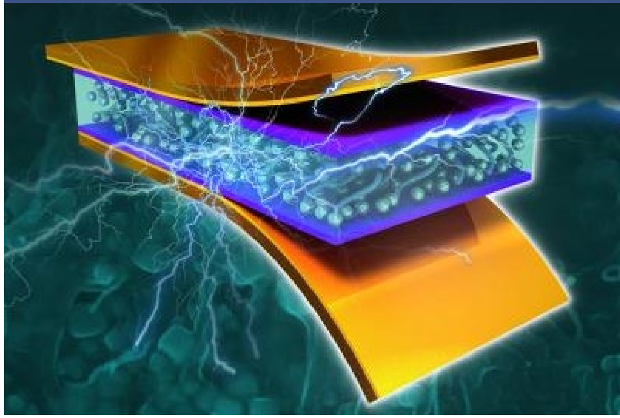
- Several familiar ceramic materials are classified as inorganic cements: cement, plaster of paris, and lime
- When mixed with water, they form a paste that subsequently sets and hardens
- Portland cement is probably the most used of the cements
- Produced by mixing clay and lime-bearing materials and heating (**calcination**)
- Resulting **clinker** is then ground and a gypsum ($CaSO_4$-$2H_2O$) is added to set (**retard**)
- **Hydraulic cement** develops its hardness with reaction with water
- **Non-hydraulic cement** involve other compounds to harden the material (i.e. CO_2)

Advanced ceramics

Although the traditional ceramics discussed previously account for the bulk of the production, the development of new and what are termed advanced ceramics has begun and will continue to establish a prominent niche in our advanced technologies.

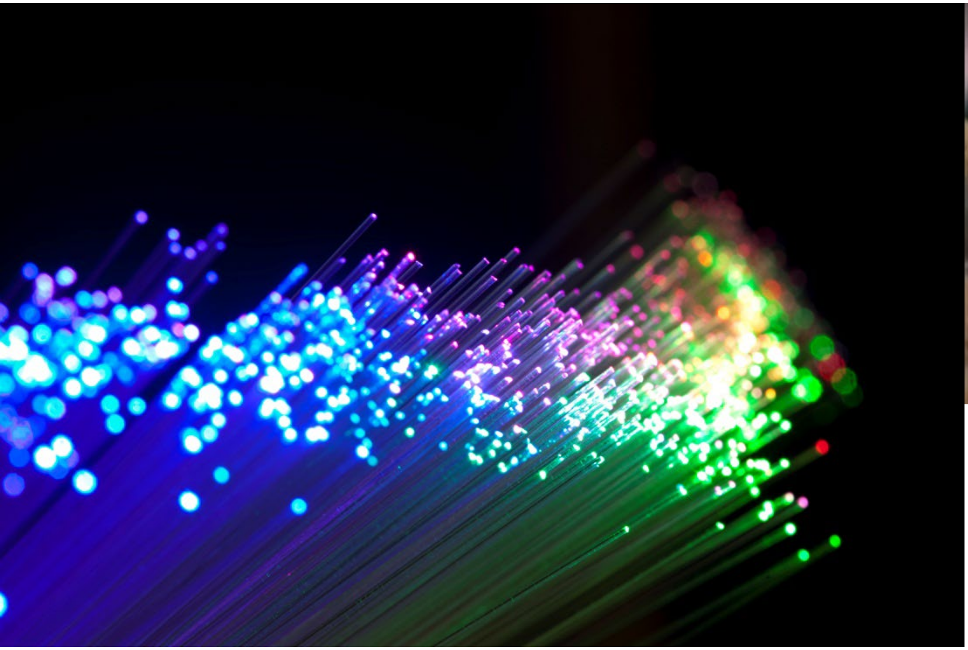
In particular, electrical, magnetic, and optical properties and property combinations unique to ceramics have been exploited in a host of new products

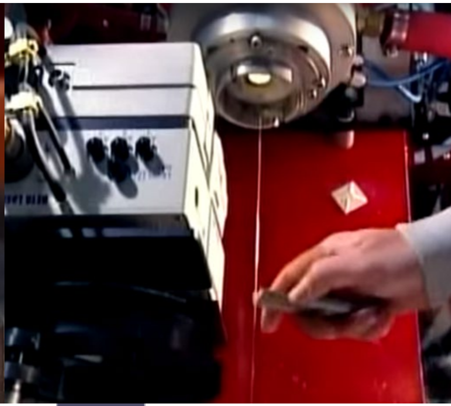
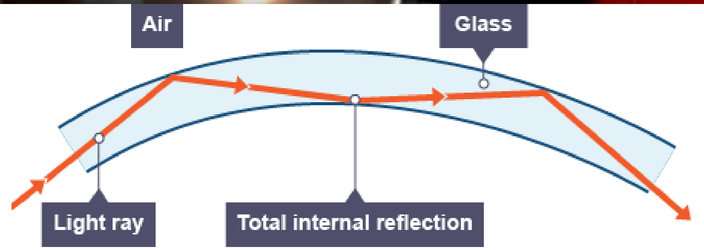
Examples

Optical fibres	Ceramic bearings	Piezoelectrics
		

Optic fibres

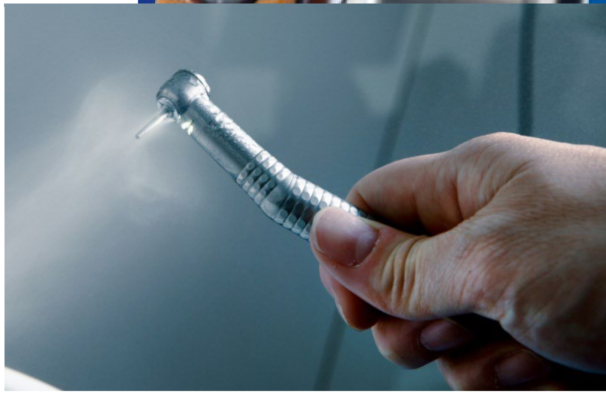
- Critical component in our modern optical communications systems is the optical fibre
- The optical fiber is made of extremely high-purity silica, which must be free of even minute levels of contaminants and other defects that absorb, scatter, and attenuate a light beam



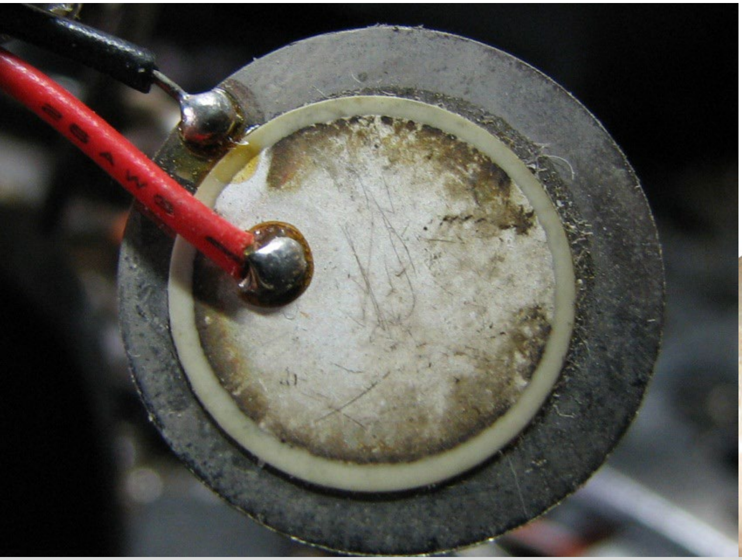
Ceramic bearings

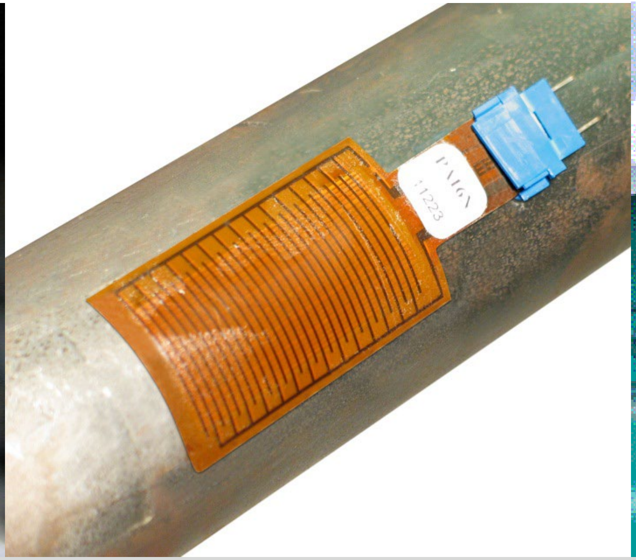
- A bearing consists of balls and races that are in contact with and rub against one another when in use
- In the past, both ball and race components traditionally have been made of bearing steels that are very hard
- Recently silicon nitride (Si_3N_4) balls have begun replacing steel balls
- Lighter weight
  - Density of Si_3N_4 is much less than steel (3.2 versus 7.8 g/cm^3)
- Higher speed
  - Lower centrifugal loads (20-40% faster)
- Reduced noise and vibrations
  - Higher Young's modulus (320 GPa vs ~200 GPa) so less deformation and vibrations
- Higher lifetime
  - Better wear resistance (~3-5x better)
- Used in bikes, skates, electric motors, chemical equipment, dental drills



Piezoelectrics

- A few ceramic materials (as well as some polymers) exhibit the unusual phenomenon of piezoelectricity - electric polarisation (i.e. an electric field or voltage) is induced in the ceramic crystal when a mechanical strain (dimensional change) is imposed on it
- Can be used as transducers between mechanical and electrical energies
- Early uses include sonar
- Modern applications include: microactuators for hard disks, ink-jet printing heads, strain gauges, ultrasonic welders, energy harvesting etc





Summary

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