HSCI-306-01 25SU

Adventures in Materials Final

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Stemmed Drinkware

Glass vs. Clay-based Ceramic

Stemmed Drinkware

Purpose :
To contain a liquid (usually alcoholic) without affecting its temperature through body heat

Ceramic

Terracotta Kylix

1300–1225 BCE, Greece

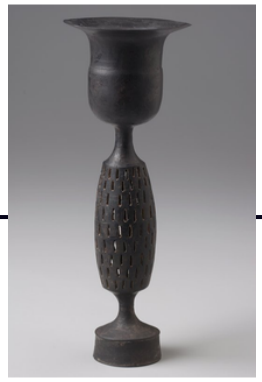
Glass

Wine Glass

2015, USA

3500 BCE, Iran

3365 BCE, Iran



2500 BCE, China

1400 BCE, Egypt

1300 BCE, Greece

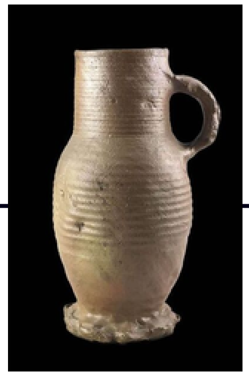
460 BCE, Greece

300 CE, Rome

4th century CE, Rome

7th century CE, China

9th century CE, Iran



14th Century, Germany

16th Century, Venice

17th Century, Japan

18th Century, England

19th Century, Austria

1954, Finland

2015, USA

Glass

Glass is classified under the material category of **ceramics**.
The types of glass are:

- Soda-lime glass
- Borosilicate glass
- Lead glass (crystal)

Soda-lime glass composition[1]:

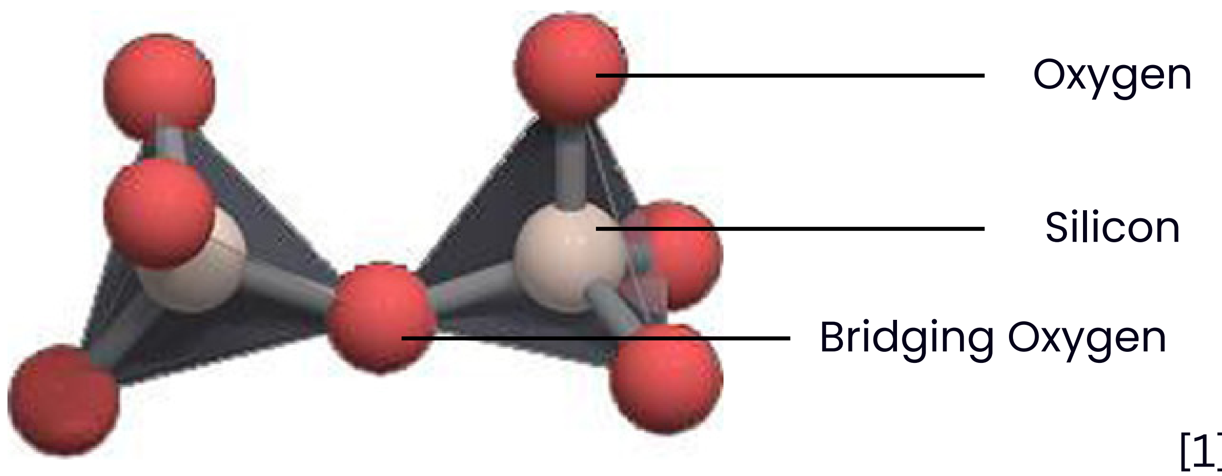
- 75 % Sand (SiO_2)
- 10% Limestone ($CaCO_3$)
- 15% Soda Ash (Na_2CO_3)

Glass Structure

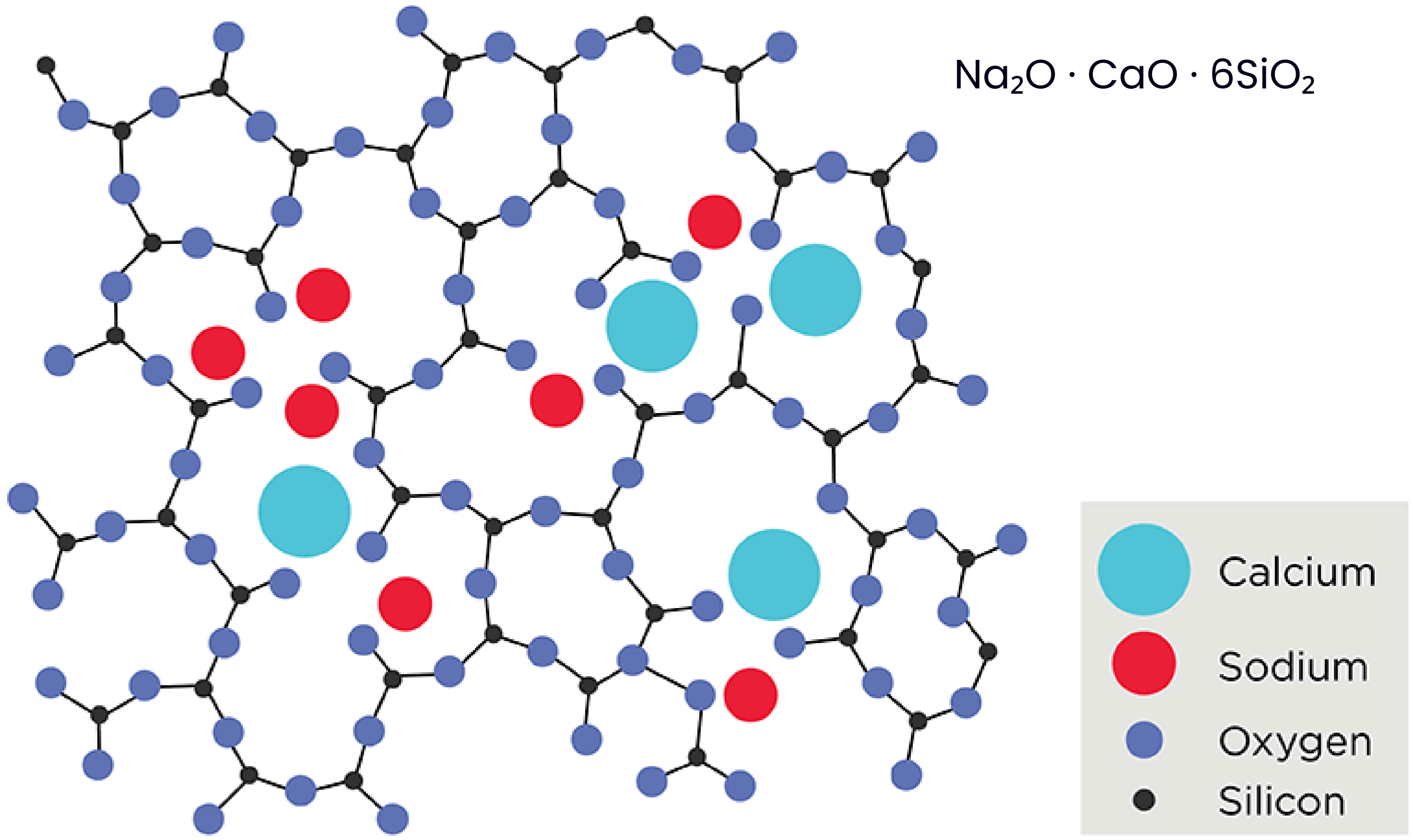
The molecular structure of glass is formed by **polar covalent bonds** between silicon and oxygen. Silicon and oxygen share valence electrons but since oxygen is significantly more electronegative, the electrons pull closer towards the oxygen atoms. This unequal sharing gives silicon a partial positive charge and oxygen a partial negative charge, making the bond polar.

While the tetrahedral construction of the molecule has a bond angle of 109.5, the angle of the oxygen that bonds multiple molecules (bridging oxygen) is greater/lesser than 109.5. The amorphous structure of glass is due to the **differences in bond angle and length**. [1]

Soda-lime-silica (SiO_4) molecules



[1]



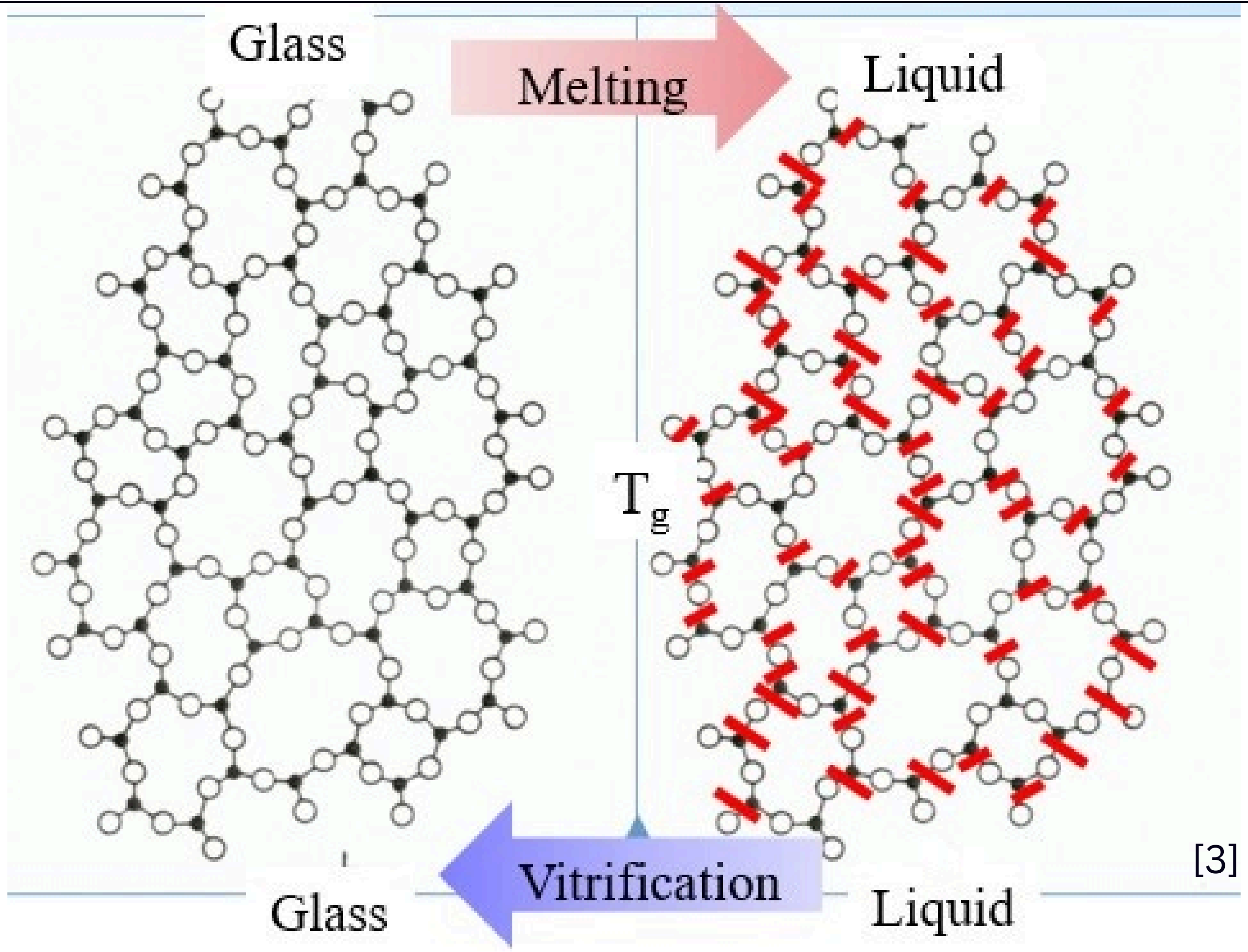
[2]

Glass Structure

Glass is a solid that has the atomic structure of a liquid. It is called an **amorphous solid** as its molecules do not form a crystalline lattice structure, which solids usually form.

When glass is heated its structure relaxes and changes into a liquid state. When cooled below its **glass transition temperature**, the atoms harden until they eventually freeze into a random arrangement (like in liquid state) to avoid forming a crystalline phase.

Understanding and controlling this property of glass **viscosity** helps manufacturers create glass products with desirable qualities. [1]



[3]

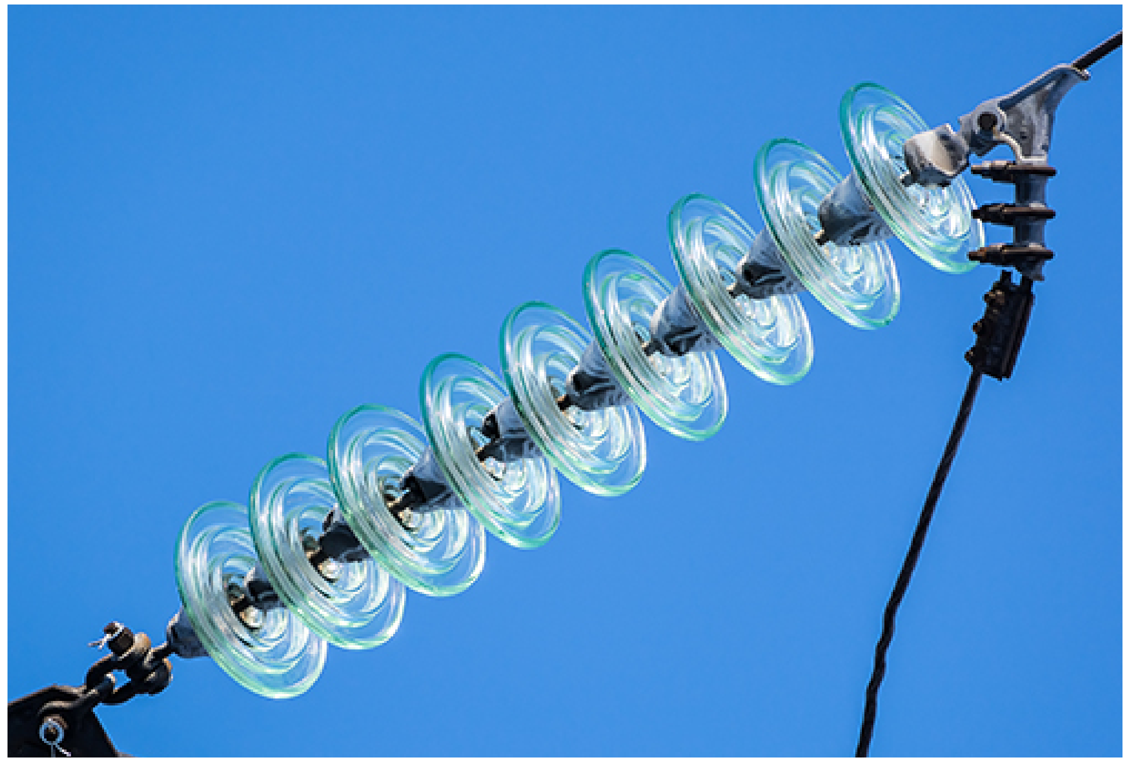
Glass Properties

Bonding Network

Mechanical

- The tighly linked, rigid network created by the bonds strongly **resists deformation** and surface scratches.

- The rigid network lacks slip planes (like in layered structures of crystalline material) so when stress is applied it can't deform to absorb energy. This causes the bonds to **shatter**, leading to fracture.



Insulative

- Unlike the delocalized electrons (sea of electrons) in metals that move freely to carry charge and heat, the electrons between silicon and oxygen atoms are held tightly by the covalent bonds. This **lack of free moving electrons** makes glass a **good insulator of heat and electricity.**

[2][3]

Glass Properties

Amorphous Structure

Thermal

- Glass doesn't have a specific melting point. It **softens gradually** over a temperature range (working range) which allows for it to be blown, pressed and shaped.

- Glass is **isotropic** in nature, which means that its material properties are uniform in all directions. With no repeating atomic lattice structure (no long-range order), there is no reference plane or axis for variation in properties like strength, hardness, thermal expansion, etc.

Optical

- Glass' structure has a **large band gap** (energy difference between valence and conduction band) that's energy is greater than visible light's photon energy. Since the photons don't have enough energy to move electrons across this gap, they aren't absorbed and **pass through**, making glass **transparent** in visible light.

[2][3]

Why glass stemmed drinkware?

- Visual aesthetic of **optical transparency** which helps see the liquid contained
- **Resistance to surface scratches** and chipping helps during frequent use
- **Thermal insulation** keeps drinks colder for longer periods of time

Clay-based Ceramic

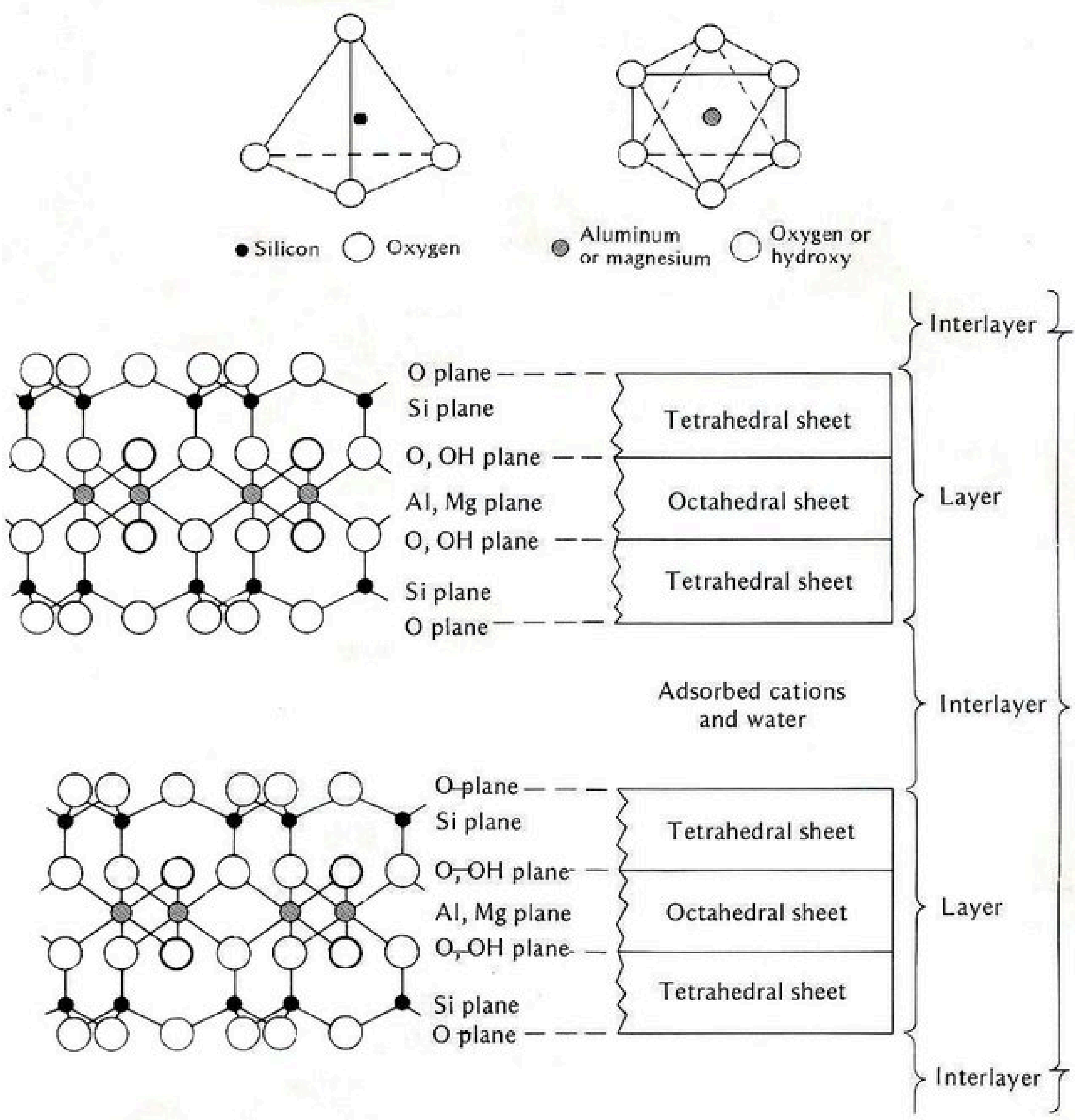
Clay-based ceramics falls under the **ceramics** category in material classification. It is a composite material, made using varying ratios of [4] :

- Clay - the plasticizer
  eg. silica, alumina
- Flux - the melter
  eg. calcium, potassium, sodium
- Filler - the structure
  eg. boron, lithium, phosphorus

Clay-based Ceramic Structure

Clay provides the necessary plasticity for the clay body to form and hold shape. They contain **hydrous aluminum silicates** that dictate color, plasticity and texture based on their origin.[5]

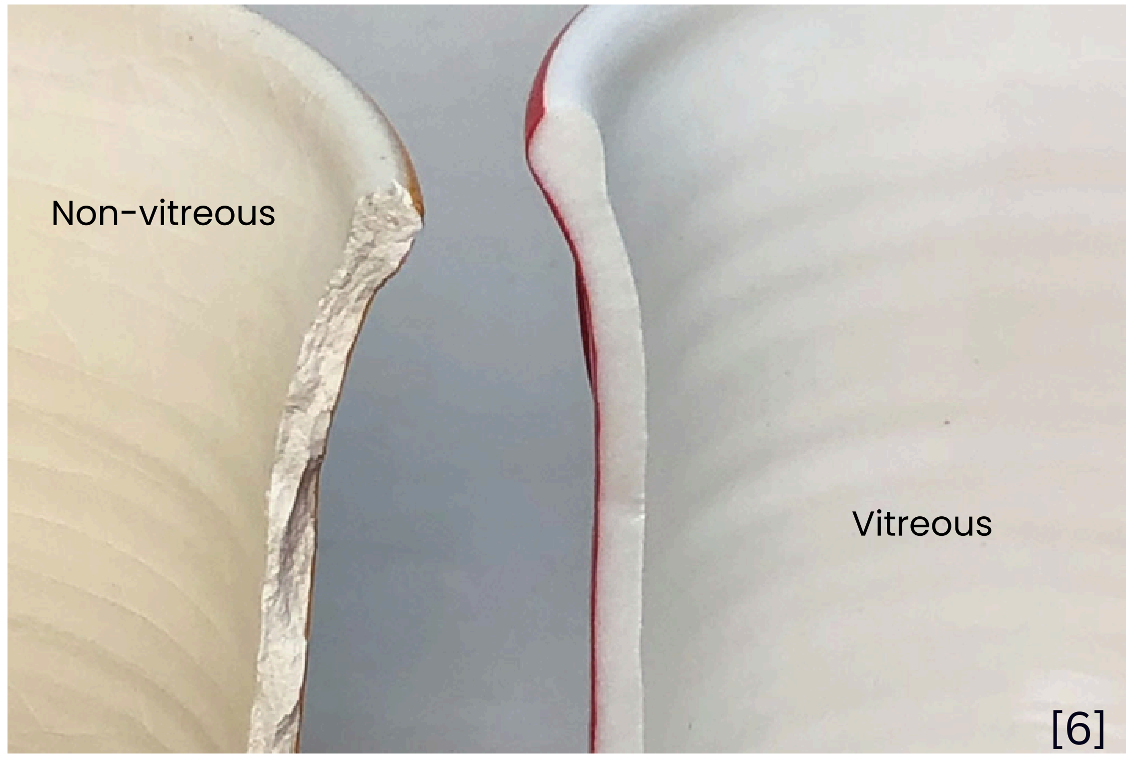
Features	Primary Clay	Secondary Clay
Origin	Residual	Sedimentary
Particle	Large, irregular	Fine, flat, uniform
Purity	High (low contamination)	Low (high contamination)
Plasticity	Low	High
Refractory	Melts at high temp	Melts at low temp
Example	Kaolin	Ball clay, stoneware



Structure of silicate clay [4]

Clay-based Ceramic Structure

Fluxes lower the melting point of the clay body to promote **vitrification** during firing. Vitrification is the process where the clay body becomes dense and non-porous as the components melt and fuse together. [6]
eg. feldspar that naturally contains fluxing oxides like potassium oxide (K_2O) or sodium oxide (Na_2O)



Fillers are non-plastic materials that are added to the clay body to **control shrinkage** which reduces the risk of cracking and warping during drying and firing. They provide a **structural skeleton** for the clay and also add texture. [6]
eg. Silicon dioxide (SiO_2), grog (fired clay that is ground up)

Clay-based Ceramic Structural Changes

During Forming
In the wet stage, clay minerals are formed of very fine, flat, hexagonal platelets that **electrostatically attract water** to the platelets' surface. The water layer acts like a lubricant which allows the platelets to slide past each other, giving the material its plasticity.

As the water evaporates when drying, the **capillary action** pulls the platelets together causing physical **shrinkage**.

During Firing

1. Dehydration and Decomposition

- Kaolin transforms into metakaolin as the **hydroxyl groups** (OH) are driven out of the clay's crystal lattice
- Fluxes begin to decompose, releasing alkali oxides.

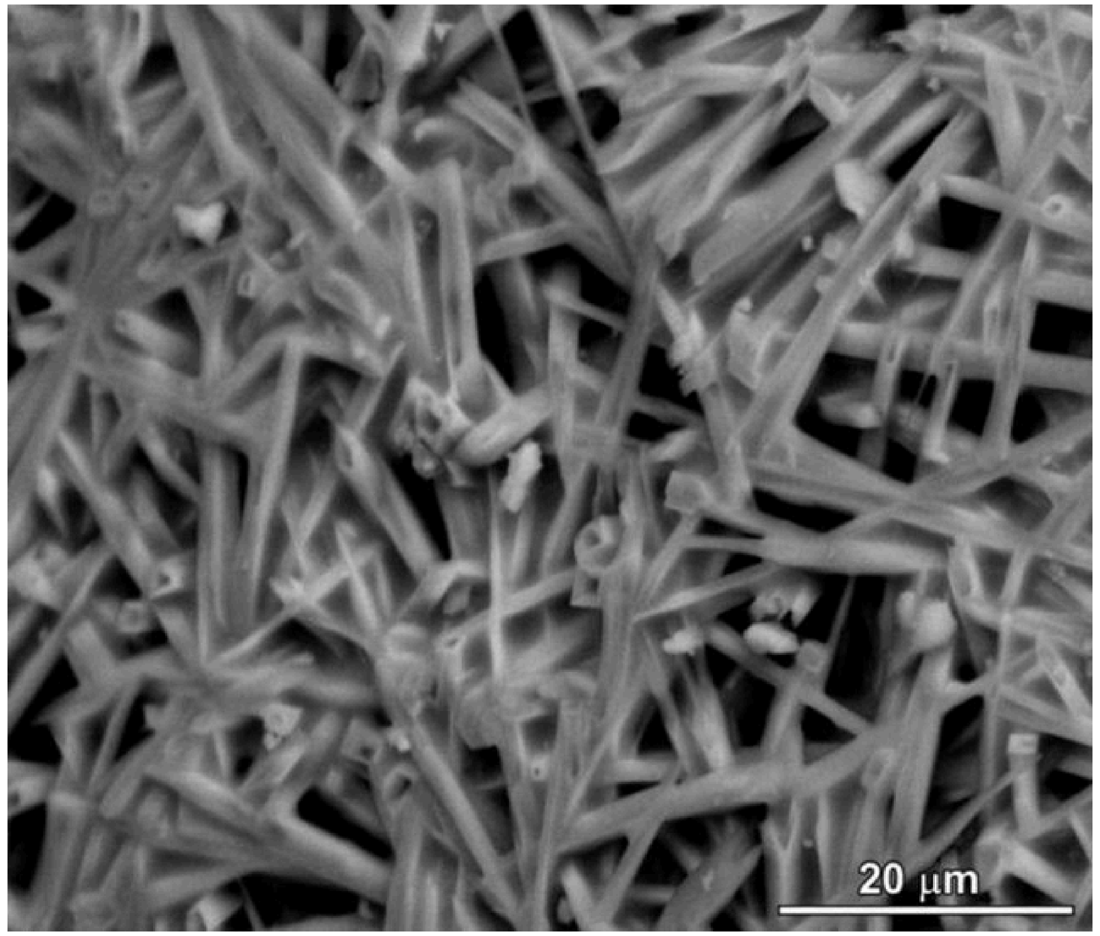
[7]

Clay-based Ceramic Structural Changes

2. Vitrification
   - The alkali oxides react to the silica in the filler and metakaolin, creating a **eutectic system** - where the combination of oxides melt at a significantly lower temperature than any individual component would by itself.
   - The molten material begins to flow into the pores of the remaining solid particles. This liquid phase sintering pulls the particles together causing more shrinkage, leading to the **increase of density** and **vitrification** of the body.

3. Crystalline Skeleton
   - The crystalline structure of the silica filler changes causing a slight and abrupt **volume change**. This creates internal stresses that are manages by slow heating and cooling.
   - The unstable metakaolin begins to recrystallize, forming a silica-rich spinal structure that transforms into **mullite** ($Al_6Si_2O_{13}$). This forms interlocking, needle-like crystals.

[7]



Mullite Crystals [7]

Clay-based Ceramic Properties

Properties of ceramics are dependent on the ratio and interaction between its crystalline and glassy phases.

Crystalline Skeleton

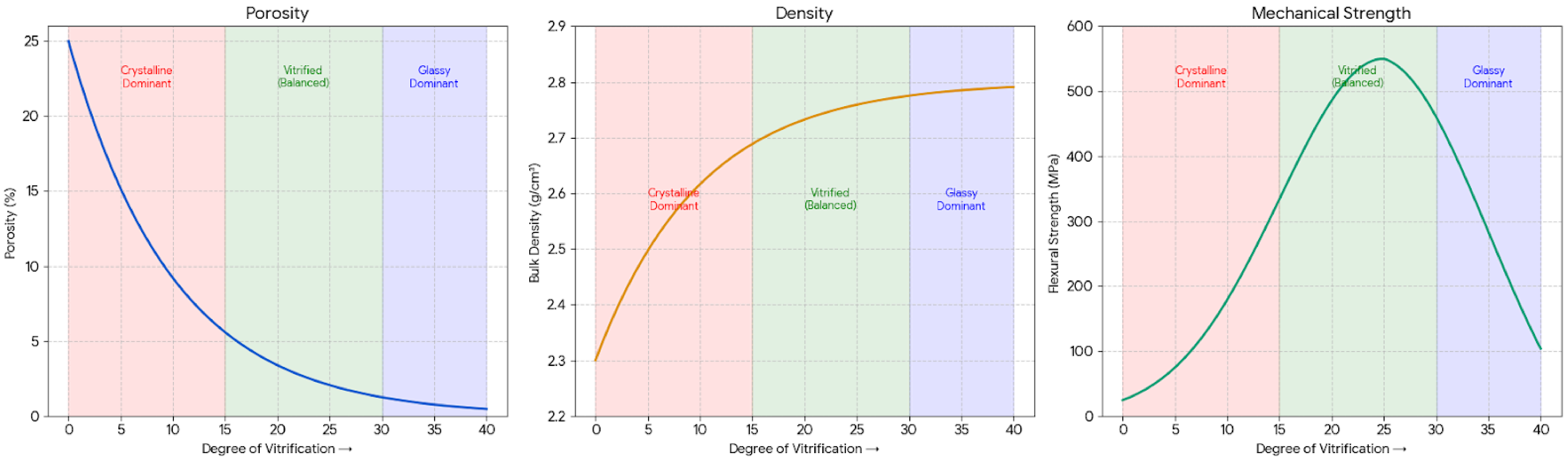
- The crystalline structures provide **strength** and **rigidity** due to the interlocking atomic lattices. They have **high melting points** and give ceramics its characteristic **hardness** and **thermal stability**.
- The interlocking mullite crystals are effective at **resisting cracks**, like rebar reinforcing concrete.

Glassy Binder Glue

- The glassy phase fills the voids between the crystalline particles binding them together. This is what makes ceramics **dense**, **impermeable to liquids** and gives it a **smooth surface**.

Clay-based Ceramic Properties

By changing the ratio of the clay and filler to flux, we can determine the final ratio of **glass** to **crystal**, which dictates the ceramic's behavior.



Why clay-based ceramic stemmed drinkware?

- **Opacity** of drinkware can protect from light and radiating heat.
- High potential for **aesthetic surfacing** (glazing, textures, surfacing)**Plasticity** of clay can help shape a variety of forms
- Good **thermal insulator** that keeps drinks cold
- Fully vitrified ceramics are **non-porous** and **chemically inert**.


[8]

Comparing Glass and Ceramic stemmed drinkware

Context - Drinking alcohol

Formal occasions

Casual occasions

[9]

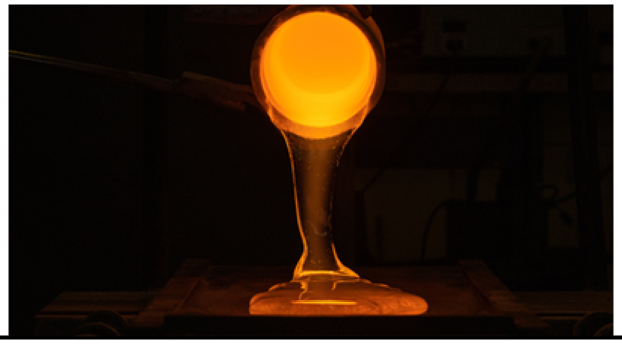
Comparision

Factors	Property	Glass	Clay-based Ceramic
Functionality	Thermal Insulation	Good thermal insulation, but insulates less due to thin walls 	High thermal insulation due to thicker walls and higher heat capacity despite similar conductivity 
Personality	Surface finishing & Forming Method	Uniform and Precise • smooth surface, perfect clarity • communicates elegance and tradition 	Variable and Unique • can be glazed any color or texture • communicates craft and substance 

Comparision

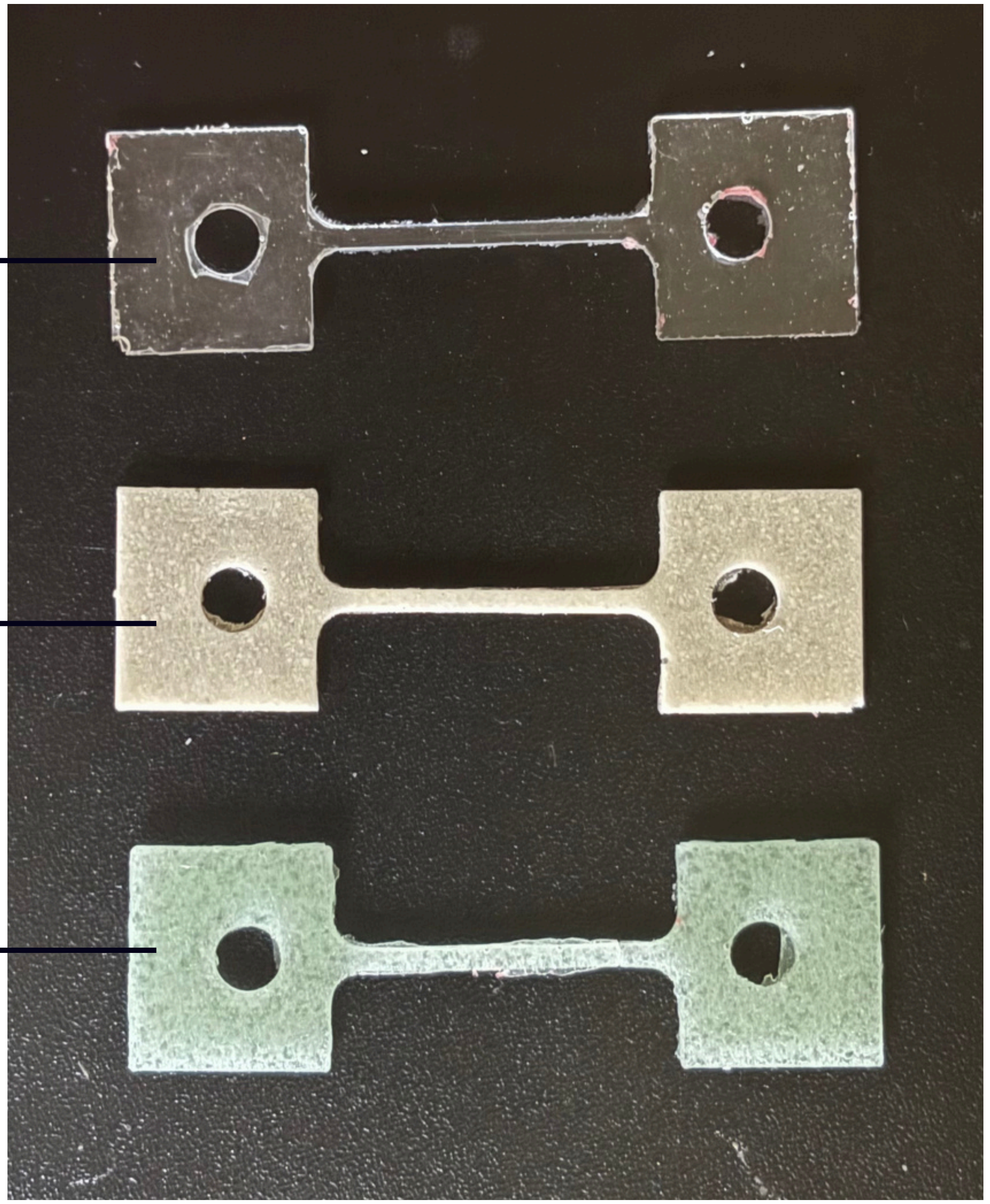
Factors	Property	Glass	Clay-based Ceramic
Cost & Value	Forming process & Energy input	• Lower cost due to automated production • Value is in precision and brand 	• Higher cost from multi-stage hand work and firing • Value is in craft and uniqueness 
Usability	Fracture toughness & Optical transparency	• Low fracture toughness makes it brittle and easy to shatter • Transparent in visible light, can see liquid 	• Higher fracture toughness makes it more durable against chipping • Opaque in visible light, can't see liquid 

Comparision

Factors	Property	Glass	Clay-based Ceramic
Sustainability	End of Life Path	Recyclable - can be melted and reformed into new glass infinitely 	Durable - not recyclable; sustainability is based on extreme longevity; ends up in landfill if broken 
Fire Resistance	Coefficient of Thermal Expansion, Flammability, Ignition & Toxic Fume Production	• High CTE - prone to thermal shock • Starts to soften at 700C • Does not support fire spreading • Non-combustible mateiral • Does not produce toxic fumes 	• Low CTE - excellent thermal shock resistance due to pre-fired, composite • Composition changes at 1200C and above • Zero flame spread • Non-combustible, no toxic fumes 

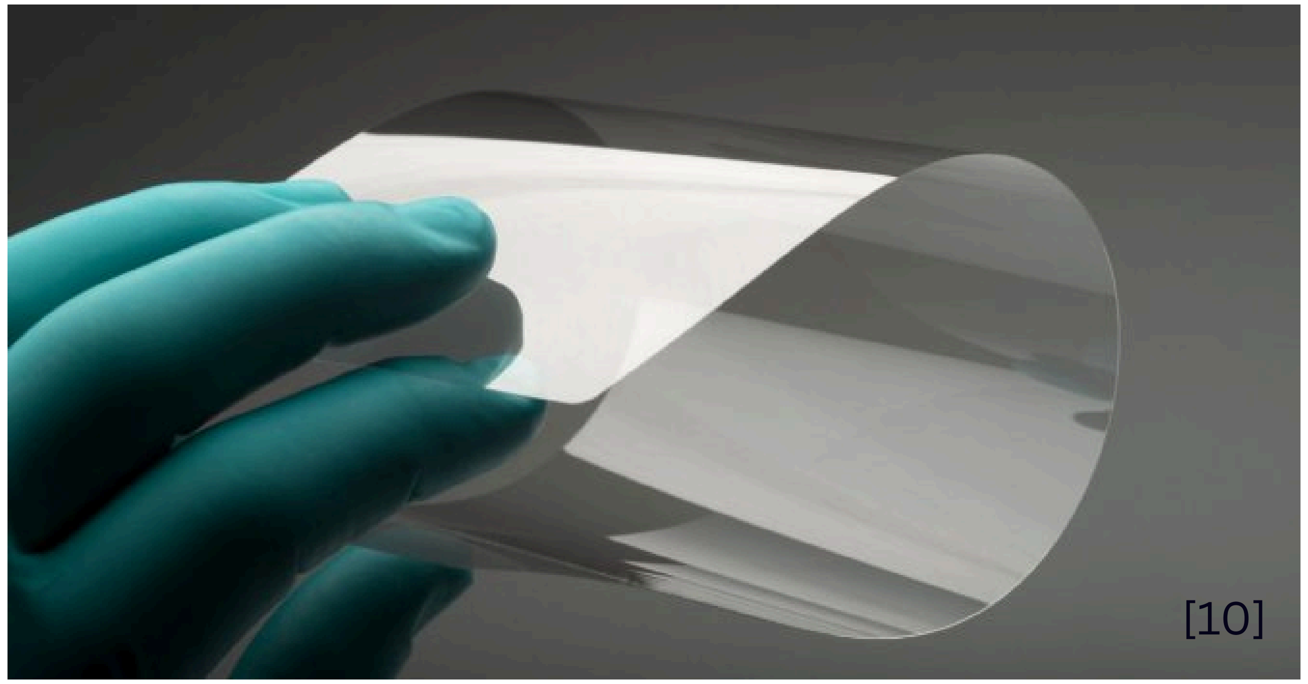
Material Testing

Tensile testing glass and ceramics



Impossible Materials

Flexible Glass (Willow Glass by Corning) [8]
Glass is usually prone to shattering due to its brittle nature. Corning has created flexible glass by letting glass' rigid atomic network behave elastically by producing ultra thin sheets of it. With the addition of an **alkali free composition** that ensures structural stability, the **extreme thinness** allows for elastic deformation. They also use manufacturing techniques (**fusion draw**) to produce continuous, defect-free sheets that withstand ebending while preserving hardness and optical tansparency.



Translucent Ceramics [9]
Ceramics are normally opaque in visible light due to its composition and atomic structure. Translucent porcelain works because it has a **higher flux content**, which promotes melting during firing and creates a high glass content that fills pores and lets light pass more easily. It is made from very pure, low-iron clay, which keeps the body white and **free from discoloration**. Its dense, fine-grained mullite structures **reduce** the number of **surfaces** that can **scatter light**. The **refractive indices** of the glassy phase and the crystals are **closely matched**, so light can travel through with minimal distortion.

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