Introduction

Glass and ceramics are essential materials that play a crucial role in various industries and daily life. Glass is known for its unique properties, such as transparency, while ceramics are prized for their durability and resistance to harsh conditions, such as high temperatures.

1. Glass

Glass is a solid, non-crystalline, and transparent material primarily composed of silica (SiO_2) with the addition of other oxides. It is manufactured by melting raw materials such as sand, sodium carbonate, and lime at high temperatures, followed by rapid cooling to prevent crystallization. Glass is widely used in fields such as construction, packaging, optics, and electronics due to its properties, including transparency and chemical resistance. Additionally, glass is 100% recyclable, making it an environmentally friendly choice in various industries.

1.1 Raw Materials

Glass is primarily composed of :

- **Silica (SiO_2) :** Extracted from sand and serves as the main component.
- **Sodium carbonate (Na_2CO_3) :** Lowers the melting temperature.
- **Lime (CaO) :** Enhances chemical and mechanical resistance.
- **Other additives :** Metallic oxides for coloring, alumina (Al_2O_3) for improved durability.

1.2 Glass Production Process

Glass is produced by heating a mixture of sand, sodium carbonate, and limestone to **1500°C**. At this high temperature, the crystalline silica (SiO_2) in the sand melts and transitions into a liquid phase, losing its crystalline structure in favor of an amorphous form. During the cooling process, glass formation begins around **700°C**, when it enters a viscous state. If cooled rapidly, its amorphous structure is preserved upon solidification. This phenomenon is known as the glass transition, a direct transformation from liquid to solid without a change in the material's nature or crystallization. The color of glass can be modified by adding metallic oxides, which act as coloring agents.

- **Manganese oxide** gives a **purple** color.
- **Nickel oxide** produces a **gray** color.
- **Chromium and iron oxides** contribute to a **green** hue.
- **Cobalt oxide** creates a **blue** shade.

Additionally, other additives can be introduced into the glass composition to enhance its physical and chemical properties, making it suitable for specialized applications.

1.3 Types of Glass

Glass exists in various forms, each with unique properties that make it suitable for different industrial, scientific, and artistic applications. Below are the most common types of glass :

1.3.1. Soda-Lime Glass (Ordinary Glass)

Soda-lime glass is the most widely used type of glass, accounting for approximately **90%** of global glass production due to its low cost and ease of manufacture. It is primarily composed of :

- **Silica (SiO_2) (70-75%)** : Provides hardness and transparency.
- **Sodium oxide (Na_2O) (12-15%)** : Lowers the melting point of silica, facilitating shaping.
- **Calcium oxide (CaO) (10-15%)** : Enhances durability and chemical resistance against water and acids.
- **Alumina (Al_2O_3) (1-3%)** : Increases scratch and heat resistance.
- **Small amounts of magnesium oxide (MgO) and potassium oxide (K_2O)** to improve specific properties.

Applications Ordinary Glass

- **Construction and decoration :** Windows, glass doors, mirrors, architectural glass.
- **Household items :** Drinking glasses, bottles, and containers for water and soft drinks.
- **General industries :** Television and smartphone screens, fiberglass, lighting fixtures.

1.3.2. Borosilicate Glass (Pyrex Glass)

Borosilicate glass is known for its high heat resistance, able to withstand temperatures up to **500°C** without cracking, and its thermal shock resistance, which minimizes expansion during heating and reduces the risk of breakage. It also offers excellent chemical resistance. Additionally, borosilicate glass has high transparency. It is primarily composed of :

- **Silica (SiO_2) (~80%)** : Provides hardness and strength.
- **Boron oxide (B_2O_3) (~12%)** : Reduces thermal expansion, making it heat-resistant.
- **Sodium oxide (Na_2O) (~4%)** : Lowers the melting point during manufacturing.
- **Alumina (Al_2O_3) (~2%)** : Enhances chemical and mechanical resistance.
- **Other trace oxides**, such as calcium and potassium oxides, to improve physical properties.

Borosilicate glass is widely used in laboratory equipment**,** for kitchenware (**h**eat-resistant cookware like Pyrex), in the medical and optical industries (medical vials**,** surgical instruments**,** telescopes, and high-precision lenses).

1.3.3. Crystal Glass

Although called "crystal," this glass remains amorphous (non-crystalline). It contains about **50%** silica (SiO_2), **30%** lead oxide (PbO), and **10%** potassium oxide (K_2O), along with other additives. Its exceptional shine makes it highly sought after for decorative and premium applications.

Crystal glass is a luxurious type of glass known for its high transparency and brilliance, making it ideal for fine glassware, decorative pieces, and chandeliers.

- The higher the lead oxide (PbO) content, the greater the brilliance and luster of the glass.
- In modern variations, lead is replaced with boron or barium to maintain transparency without health risks.

Crystal glass is commonly used in luxury glassware, including fine glasses and decorative vases (brilliance and clarity). It is also favored in elegant lighting (Swarovski chandeliers). Additionally, crystal glass is often used in the creation of awards and trophies (crystal shields and commemorative awards).

1.3.4. Laminated Glass

Laminated glass consists of two or more glass layers bonded with a plastic interlayer, providing enhanced durability and safety. It is composed of :

- **Glass layers :** Primarily composed of **silica (SiO_2) (70-75%)** with added oxides:

- **Sodium oxide (Na_2O) (10-15%)** – Lowers melting point for easier shaping.
- **Calcium oxide (CaO) (5-10%)** – Enhances hardness and durability.
- **Alumina (Al_2O_3) (1-3%)** – Improves scratch resistance.

- **Plastic interlayer**

- **Polyvinyl butyral (PVB) :** The most common interlayer, providing transparency, flexibility, and impact resistance.
- **Ethylene vinyl acetate (EVA) :** Resistant to moisture and UV rays, ideal for outdoor applications.
- **Ionoplast (SentryGlas) :** Stronger than PVB, used for bulletproof and explosion-resistant applications.

Laminated glass is widely used in construction and architecture , in the automotive industry, in security applications**,** in explosion and bulletproof structures, providing protection in **embassies** and government buildings.

1.3.5. Borosilicate Glass

Borosilicate glass is an advanced material known for high thermal and chemical resistance, making it ideal for laboratory, medical, and kitchenware applications. Its composed of Silica **(SiO_2)** and Boron oxide **(B_2O_3)** provide unique properties. Borosilicate glass is extensively used in laboratory applications (test tubes, beakers, Petri dishes)**.** In kitchenware (Pyrex glassware and heat-resistant oven dishes)**.** The medical and pharmaceutical industries **(** medical vials, lenses, microscopes), and in the optical and scientific fields (space telescopes (Hubble), and precision lenses).

1.3.6. Low Emissivity (Low-E) Glass

Low-E glass is coated with a thin layer of metallic oxides, reducing heat loss and controlling infrared and UV radiation transmission. Low-emissivity (Low-E) glass is commonly used in architectural applications for smart, energy-efficient windows in modern buildings and skyscrapers. In the automotive industry, it is applied in windshields and side windows to minimize heat buildup inside vehicles. Additionally, Low-E glass plays a crucial role in advanced industries, where it is used in high-performance optical screens, reducing reflections and improving thermal efficiency.

1.3.7. Fluoride Glass

Fluoride glass replaces silicon oxides with metal fluorides**,** offering unique optical properties such as infrared transmission and high transparency at longer wavelengths. It is widely used in fiber optics and telecommunications for high-speed data transmission cables**,** as well as in astronomical and space applications for precision telescopes and infrared imaging systems**.** Additionally, fluoride glass is essential in laser and optical devices, including infrared lasers for medical and industrial applications and high-end camera lenses. It also plays a crucial role in medical diagnostics**,** particularly in infrared-based eye scanning and thermal imaging for disease detection**.**

1.3.8. Foam Glass

Foam glass is a lightweight, porous material that offers excellent thermal and sound insulation. It is widely used in building insulation **(** walls, roofs, and floors to maintain temperature stability, as well as in industrial insulation for chemical and oil pipelines to prevent heat loss. Foam glass is also used in the automotive and aerospace industries (lightweight material to improve fuel efficiency). Additionally, it is utilized in fire-resistant walls.

1.3.9. Metallic Glass (Amorphous Metal)

Metallic glass is a non-crystalline (amorphous) solid made primarily of metallic alloys, combining the properties of glass with high mechanical strength**,** flexibility, and unique electrical/magnetic properties. It is widely used in electronics and magnetic applications, as well as in high-performance engineering materials for aerospace and medicine, where its strength and versatility are highly valued. Some examples are :

- **Copper-beryllium glass (Cu-Be):** Lightweight and highly durable.
- **Iron-silicon-boron glass (Fe-Si-B):** Excellent magnetic properties.
- **Zirconium-titanium glass (Zr-Ti-Ni-Cu-Be):** Used in aerospace and medical applications.

2. Ceramics

Ceramics, derived from the Greek word ***keramos*** meaning "**pottery maker**" or "burnt earth," are non-metallic, inorganic solid materials produced by firing natural substances at high temperatures. This broad category includes pottery, porcelain, glass, diamond, and more, known for their hardness, durability, high-temperature resistance, and corrosion resistance, making them essential in various industrial, scientific, and everyday applications.

2.2 Classification of Ceramics : Ceramics can be classified into two main types :

2.2.1. Traditional Ceramics

Traditional ceramics refer to ceramic products that contain clay, typically ranging from 20% to 100% in composition. This category is sometimes referred to by various terms, including:

- **Earthenware :** Includes glazed and unglazed ceramic items, mainly made from porous clay. Common applications are Kitchenware (Cooking utensils), Artware (Decorative ceramics).
- **Stoneware :** Includes vitrified or semi-vitrified ceramics, made from non-refractory fire clay mixed with silica and fluxing agents. Applications (Art pieces and chemical vessels, Drainpipes and cookware).
- **Chinaware :** It includes fully vitrified ceramics with zero or very low liquid absorption after firing. Not used in technical ceramics but commonly found in Art pieces and Sanitaryware (bathroom fixtures).
- **Porcelain :** A glazed ceramic made from China clay (Kaolin), quartz sand, and feldspar. It used in technical applications such as ball mill containers, grinding media, electrical insulators, and chemical-resistant components, as well as in traditional ceramic applications.
- **Technical Ceramics :** Includes all vitrified ceramics with a clay base, used in Electrical insulation, Chemical and mechanical applications and High-temperature environments.

2.2.2. Engineering Ceramics

Engineering ceramics are a specialized type of ceramics with exceptional properties, making them ideal for high-performance industrial and engineering applications. They are widely used in aerospace, automotive, electronics, chemical engineering, medical equipment, and industrial tools. Common examples include alumina ($\mathbf{Al_2O_3}$), zirconia ($\mathbf{ZrO_2}$), and silicon nitride ($\mathbf{Si_3N_4}$), which are used to manufacture heat-resistant components and insulating materials. The properties of engineering Ceramics

- High-temperature resistance (making it suitable for industries requiring heat-resistant materials).
- Corrosion resistance (Chemically stable and does not easily react with liquids or chemicals).

- Durability and hardness (Highly resistant to mechanical stress, ensuring longevity in demanding environments).
- Electrical insulation (Due to the absence of free electrons, engineering ceramics serve as excellent electrical insulators).

2.2.3 Classification of Ceramic Materials

a. Raw Ceramic Materials

These are the natural minerals used as the primary raw materials for ceramic production. Examples include :

- Dolomite ($CaMg(CO_3)_2$): A carbonate mineral composed of calcium magnesium carbonate
- Andalusite (Al_2SiO_5) : Aluminum Nesosilicate

b. Simple Oxides

These ceramics are based on single oxide compounds with unique chemical and thermal properties. Examples include :

- Alumina (Al_2O_3) : Aluminum Oxide.
- Beryllium Oxide (BeO).

c. Complex Oxides and Silicates

These include ceramic materials with complex oxide compositions and silicate structures. Examples include :

- Forsterite (Mg_2SiO_4) : Magnesium Orthosilicate
- Magnesium Phosphate ($Mg_3(PO_4)_2$) *:* Magnesium Orthophosphate

d. Non-Oxide Ceramics

These ceramics are composed of non-oxide compounds, often providing exceptional hardness and thermal resistance. Examples include:

- Boron Carbide (B_4C) : Tetraboron Carbide
- Chromium Carbide (Cr_3C_2, Cr_7C_3, $Cr_{23}C_6$)

e. Additives

These are substances added to ceramics to modify their properties during manufacturing, including fluxing agents, stabilizers, and lubricants. Examples include:

- Cerium Oxide (CeO_2): Cerium(IV) Oxide or Ceric Oxide

- Polyethylene Glycol (PEG) $H(OCH_2CH_2)nOH$: Poly(ethylene glycol) or Poly(oxyethylene)

f. Other Ceramic Materials

This category includes miscellaneous ceramic materials used in specialized applications. Examples include :

- **Flux** is generally a mixture that facilitates melting**,** such as sodium carbonate (Na_2CO_3), borax ($Na_2B_4O_7 \cdot 10H_2O$) or calcium fluoride **(CaF_2, etc.)**

3. White Clay (Kaolin)

White paste is a processed clay primarily composed of kaolin ($Al_2Si_2O_5(OH)_4$)**,** known for its high plasticity, white color, and fine texture**.** It is widely used in porcelain and fine ceramics due to its thermal stability, low shrinkage, non-porous surface, and high mechanical strength after firing. Its chemical resistance and smooth finish make it ideal for tableware, sanitary ceramics, and decorative pieces**.**

3.1 Properties of White Clay

- Thermal Stability (1200–1400°C) : Making it suitable for durable ceramics.
- Low Shrinkage.
- Non-Porous Surface : After vitrification, it becomes dense, glassy, and water-resistant**.**
- High Mechanical Strength : Forms a hard, durable structure after firing.
- Chemical Resistance : Resists acids and alkalis, making it suitable for sanitary ceramics**.**

4. Glazing (Adding a Coating)

Glazing is the process of applying a layer of glaze (coating) to a ceramic piece before it is fired for the second time. Glazing enhances the appearance of ceramics and increases their durability by adding properties such as water resistance and stain resistance.