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 typically transparent material. It is an inorganic product of fusion that has cooled to a rigid state without crystallization, and is therefore classified as an amorphous solid. Unlike crystalline materials, glass lacks long-range atomic order and exhibits only short-range structural organization.

Glass is primarily composed of silica SiO_2, which constitutes its main component, together with additional oxides that modify its properties. It is manufactured by melting raw materials such as silica sand, sodium carbonate, and calcium oxide at high temperatures, followed by controlled cooling that prevents crystallization and preserves the amorphous structure.

Due to its transparency, chemical resistance, mechanical stability, and versatility, glass is widely used in construction, packaging, optics, and electronics. Furthermore, glass is fully recyclable without loss of quality, making it a sustainable material for various industrial applications.

1.1 Raw materials of Glass

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 General properties of Glass

- Hard but brittle
- Chemically inert
- Non permeable to gas and liquid (fluid).
- Non-conductive for electricity or heat.
- Transparent.

1.3 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.

1.4 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:

1.4.1. 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.

Ordinary glass is widely used across various sectors due to its transparency, durability, and versatility. In the field of construction and decoration (windows, glass doors, mirrors, and architectural glazing systems), in domestic applications (drinking glasses, bottles, and containers for water and soft drinks). Furthermore, in general industries, glass plays an essential role in the production of television and smartphone screens, fiberglass, and lighting fixtures.

1.4.2. Borosilicate Glass

Borosilicate glass is a high-performance glass known for its excellent resistance to heat, thermal shock, and chemical corrosion. It also offers excellent chemical resistance. Additionally, borosilicate glass has high transparency, it is primarily composed of:

- **Silica (SiO_2) (~80%)**: Provides mechanical strength and hardness.
- **Boron oxide (B_2O_3) (~12%)**: Reduces thermal expansion, making it heat-resistant.
- **Sodium oxide (Na_2O) (~4%)**: Lowers the melting temperature during manufacturing.
- **Alumina (Al_2O_3) (~2%)**: Enhances mechanical strength and chemical durability.
- **Minor oxides**, such as small quantities of calcium and potassium oxides, may be added to improve physical and chemical properties.

Borosilicate glass is commonly used for laboratory glassware such as beakers and test tubes, heat-resistant cookware including Pyrex products, and in medical, pharmaceutical, and optical devices such as vials, lenses, and precision instruments.

1.4.3. Crystal Glass

Despite its designation, “crystal” is not a crystalline material in the scientific sense but remains an amorphous solid, similar to other types of glass. It is distinguished by its high transparency, brilliance, and elevated refractive index, which give it exceptional sparkle and clarity. Its typical composition includes approximately:

- **Silica (SiO_2) (~50%)**.
- **Lead oxide (PbO) (30 %),** whose presence increases density and refractive index, thereby enhancing luminosity and optical brilliance.
- **Potassium oxide (K_2O) (10 %).**
- Other additives intended to adjust its physical and optical properties.

Owing to its aesthetic qualities, crystal glass is widely used in luxury glassware, including fine drinking glasses and decorative vases, in high-end lighting fixtures such as chandeliers, and in the production of trophies and commemorative awards.

In general, the higher the lead oxide content, the greater the brilliance of the glass. However, in modern formulations, lead oxide is often partially or completely replaced by barium oxide or boron oxide in order to reduce health and environmental risks while maintaining comparable optical properties.

1.4.4. 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 inter layer**

- **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.

1.4.5. Low Emissivity (Low-E) Glass

Low emissivity glass, commonly referred to as Low E glass, is a technologically advanced glazing material designed to improve thermal performance while maintaining high visible light transmission. It consists of a conventional float glass substrate, typically soda lime silica glass, coated with an extremely thin, transparent multilayer system composed of metallic and metal oxide films.

The glass substrate is primarily composed of silica SiO_2, together with sodium oxide Na_2O and calcium oxide CaO, which form the structural network of the material. The functional coating generally includes a thin silver layer that acts as the principal infrared reflective component. This metallic layer is sandwiched between protective and dielectric layers made of metal oxides such as tin oxide SnO_2, zinc oxide ZnO, titanium oxide TiO_2, or silicon dioxide SiO_2. These additional layers enhance adhesion, durability, chemical stability, and optical performance.

The primary function of the Low E coating is to reduce the emissivity of the glass, thereby limiting radiative heat transfer. It reflects long wave infrared radiation while allowing most visible light to pass through. As a result, Low E glass significantly reduces heat loss in winter and minimizes solar heat gain in summer, contributing to improved energy efficiency in buildings. For this reason, it is widely used in energy efficient architectural glazing, automotive windows, and high performance optical applications.

1.4.6. Fluoride Glass

Fluoride glass is a specialized type of glass in which silicon oxides are replaced by metal fluorides, resulting in distinctive optical properties. Unlike conventional silicate glasses, fluoride glasses exhibit excellent transmission in the infrared region and high transparency at longer wavelengths.

These glasses are typically composed of heavy metal fluorides such as zirconium fluoride ZrF_4, barium fluoride BaF_2, lanthanum fluoride LaF_3, aluminum fluoride AlF_3, and sodium fluoride NaF. This composition enables low optical attenuation in the infrared range and makes fluoride glass particularly suitable for advanced photonic applications.

Fluoride glass is widely used in fiber optics and telecommunications, especially for high-speed data transmission in infrared optical fibers. It also plays an important role in astronomical and space technologies, where it is employed in precision telescopes and infrared imaging systems. Furthermore, fluoride glass is essential in laser and optical devices, including infrared lasers for medical and industrial applications, as well as in high-performance optical components. In the medical field, it is utilized in infrared diagnostic systems, including thermal imaging and specialized ophthalmic instruments.

1.4.7. Foam Glass

Foam glass is a lightweight, rigid, and highly porous material characterized by its closed-cell structure, which provides excellent thermal and acoustic insulation. It is produced by heating finely ground glass with a foaming agent, resulting in a stable cellular structure with low density and high mechanical stability.

Foam glass is widely used in building construction for thermal insulation of walls, roofs, and floors, where it contributes to temperature stability and energy efficiency. It is also employed in industrial insulation systems, particularly for chemical installations and oil and gas pipelines, in order to minimize heat loss and provide moisture resistance. In addition, foam glass is utilized in the automotive and aerospace industries as a lightweight material that contributes to weight reduction and improved fuel efficiency. Owing to its non-combustible nature and high fire resistance, it is further applied in fire-resistant walls and protective structural systems.

1.4.8. Metallic Glass (Amorphous Metal)

Metallic glass, also known as amorphous metal, is a non crystalline solid produced from metallic alloys that are rapidly cooled to prevent the formation of a crystalline structure. As a result, the material exhibits a disordered atomic arrangement similar to that of conventional glass, while retaining the characteristic bonding of metals. Metallic glasses combine high mechanical strength, elasticity, corrosion resistance, and distinctive electrical and magnetic properties.

Due to these characteristics, metallic glasses are widely used in electronic components and magnetic applications, particularly in transformer cores, sensors, and inductive devices because of their low magnetic losses. They are also employed in high performance engineering applications in aerospace, biomedical, and precision industries, where their high strength to weight ratio and wear resistance are advantageous. Common examples include:

- **Copper beryllium glass (Cu-Be):** valued for their strength and durability.
- **Iron silicon boron glass (Fe-Si-B):** Excellent soft magnetic properties.
- **Zirconium-titanium glass (Zr-Ti-Ni-Cu-Be):** frequently used in aerospace structures and medical devices due to their high strength and corrosion resistance.

2. Ceramics

Ceramics, derived from the Greek word ***keramos*** meaning "**pottery maker**" or "burnt earth". Ceramic is a non-metallic material generally made from clay, whose main component is aluminum silicate. After shaping and firing at high temperatures, it develops remarkable properties such as high hardness and strong resistance to elevated temperatures and pressure. However, despite its hardness, ceramic remains brittle and can fracture easily under impact. It is also chemically inert, meaning it does not readily react with its environment and does not rust. In addition, ceramic is an excellent thermal and electrical insulator, which explains its wide use in applications such as tableware, construction materials, and insulating components.

2.1 Raw materials of Ceramics

The raw materials of ceramics are primarily natural minerals that provide plasticity, structural stability, and functional properties after firing. The principal raw materials include clay minerals, silica, and fluxing agents.

Clay is the fundamental component of most traditional ceramics. It consists mainly of hydrated aluminum silicates and provides plasticity, allowing the material to be shaped before firing. Common clay minerals include kaolinite, illite, and montmorillonite.

Silica SiO_2 is added to improve mechanical strength and control shrinkage during drying and firing. It also contributes to the formation of the glassy phase at high temperatures.

Fluxes, such as feldspar, sodium compounds, or potassium compounds, lower the melting temperature during firing and promote vitrification, enhancing the density and strength of the final product.

In advanced ceramics, additional materials such as alumina Al_2O_3, zirconia ZrO_2, silicon carbide SiC, and silicon nitride Si_3N_4 may be used to achieve specific mechanical, thermal, or electrical properties.

2.2 General properties of Ceramics

- Mechanical properties: Hard, wear resistant, friction, Getas easily broken, cracked, high temperature resistance.
- Thermal properties: High temperature resistance, electrical properties (isolator, except superconducting ceramics
- Magnetic Properties: Not magnetic, except ceramics based on ferrite with spinel structure.
- Optical properties: Instrinsically transparent.

2.3 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 Advanced

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 Traditional Vs Advanced Ceramic

Traditional Ceramics	Advanced Ceramics
Clay/Silicate based	Non Clay/Silicate based
Low Purity	High Purity
Simple manufacturing process (Simple, unhomogen microstructure, high porosity, multiphase)	Complex manufacturing process (complex, homogen, low porosity, single phase)
Example : Brick, sanitary ware	Resistor, coating technology, superconductor

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.