Introduction

The word glass is derived from the Latin term *glaesum*. *Glaesum* is used to refer to a transparent material. The first glass object used by man originated from obsidian, a natural volcanic glass. First man-made glass was found in Egypt around 3500 years ago. Generally, glass can be defined as an inorganic product of fusion that has been cooled to a rigid condition without crystallization. Glass is therefore, by definition, an amorphous or non-crystalline solid. The behavior of glass is similar to amorphous polymers because glass has no distinct melting and freezing point. Today, there are around 750 different types of commercial glasses available. The commercial glass that is majorly manufactured around the world is soda-lime glass (sand 63-74%, soda ash 12-16% and limestone 7-14%). The different uses of glass ranges from windows (flat glass), containers and cookware to glass with special mechanical, electrical and optical characteristics. Depending upon the manufacturing process and end use of the product, different constituents can be used. For example, boron oxide (B$_2$O$_3$) is added to improve heat durability in glass which is used for cookware, automobile headlamps and laboratory glassware. Similarly silver (Ag) is added in sunglasses and strontium is added in television screens to absorb radiation.

The commercial glasses mainly used are categorized by following types:

a) *Soda-lime glass* (high density, low strength, low cost, e.g. beverage containers, window glass).

b) *Lead-alkali glass* (low strength, high electrical resistivity, e.g. microelectronics).

c) *Borosilicate glass* (good chemical and impact resistance, e.g. laboratory glassware, automobile headlamps, utensils).

d) *96% silica glass* (good thermal and chemical resistance).

e) *Fused silica* (high impact resistance).

f) *Aluminosilicate glass* (e.g. high-efficacy lamps).

Handling of glass is a critical issue. Glass breakage may take place due to stress concentration, scratches, impurities present in glass, thermal stresses etc. Depending upon the application, glass is manufactured using different processes. For example, toughened glass is manufactured by rapid cooling, which is used in making bullet proof windows. Similarly, wired glass is
manufactured by meshing steel wire into molten glass by rolling process. It is used for making low cost fire resistant glass which automatically breaks at high temperatures.

**Glass structure**

Glass is an amorphous or non-crystalline solid that is brittle in nature and the structure is obtained by melt-quenching process. The glass structure (Figure 1(b)) is also obtained by using *sol-gel* and *vapor deposition technique*. Glass is weak in tension because of its non-crystalline molecular structure. When load is applied beyond the strength limit, glass breaks without any prior warning, unlike steel and aluminium where plastic deformation occurs. Therefore, the atomic structure of the glass is different from the structure of the crystalline materials (Figure 1(a)).

![Figure 1](image)

Figure 1. Two-dimensional demonstration of: (a) crystalline structure of silica; (b) amorphous structure of silica glass; (c) soda silica glass.

The main constituent of glass is silica sand. Almost, all glass contains at least 50% silica. The structure of the glass is formed by bonding silicon and oxygen ions. *Network modifiers (or intermediates)* and *network formers* such as sodium (Figure 1(c)), may interrupt the continuity or contribute to the network structure of glass.

There are two main differences between crystalline and amorphous solids; crystalline solids are formed by repeating geometric arrangement of atoms whereas; amorphous solids have random atomic arrangement. The second difference is their phase transformation behavior (Figure 2) when they are heated. For example, the transformation phases of crystalline and amorphous
solids can be understood by examining silica (SiO$_2$) which can exist in either state. When silica is in crystal form and is heated at a temperature $T_m$ (freezing or melting point), it becomes liquid. It is observed that at melting point the specific volume of crystalline solids changes abruptly which causes sharp changes in physical properties. Whereas the amorphous structure of silica softens gradually (start softening at temperature $T_g$) when those are heated because there is a wide temperature range between the solid and liquid state. The temperature $T_g$ is the glass transition temperature of the solids.

**Figure 2. Phase transformation of crystalline and amorphous solids on heating.**

**Glass properties**

The behavior of glass is linearly elastic and brittle. The stress-strain curve for the glass is shown in Figure 3. In compression, the glass is very strong and its compressive strength can reach up to 10,000 MPa. But in tension, when stress level exceeds 100 MPa, glass fails easily. The failure of glass is due to the stress concentration at surface flaws as no plastic flow is possible in glass. For the most commercial glasses, Young’s modulus of elasticity (E) ranges from 55-90 GPa and the Poisson's ratio ($\mu$) ranges from 0.16-0.28. The fiberglass which is drawn from the molten glass has tensile strength ranges from 0.2-7 GPa. The glass fiber is stronger than the steel and most of the time used as a reinforcing material to form reinforced plastics. The other important properties
of glass are low thermal conductivity, high dielectric strength, resistance to corrosion on attack by water and acid.

Figure 3. Stress versus strain diagram of steel and glass.