Collage of Engineering
Materials Department

Third Class
Course 2 / Lecture (1)

GLASS

Asst. Lect. Shireen Hasan

Properties of Glass

1-Viscosity

The viscosity of a glass is one of its most important technological properties. It determined the melting condition, the temperature of working and annealing, fining agents (removal of bubbles from the melt), upper temperature of use. **It is a measure of the resistance of a fluid which is being deformed by either shear stress or tensile stress.** The most common viscosity unit is **the poise**. Thus there exist a number of forms of viscosity (shown in figure 1):

• **Newtonian:** fluids, such as water and most gases which have a constant viscosity.

• **Shear thickening**: viscosity increases with the rate of shear.

• **Shear thinning**: viscosity decreases with the rate of shear. Shear thinning liquids are very commonly.

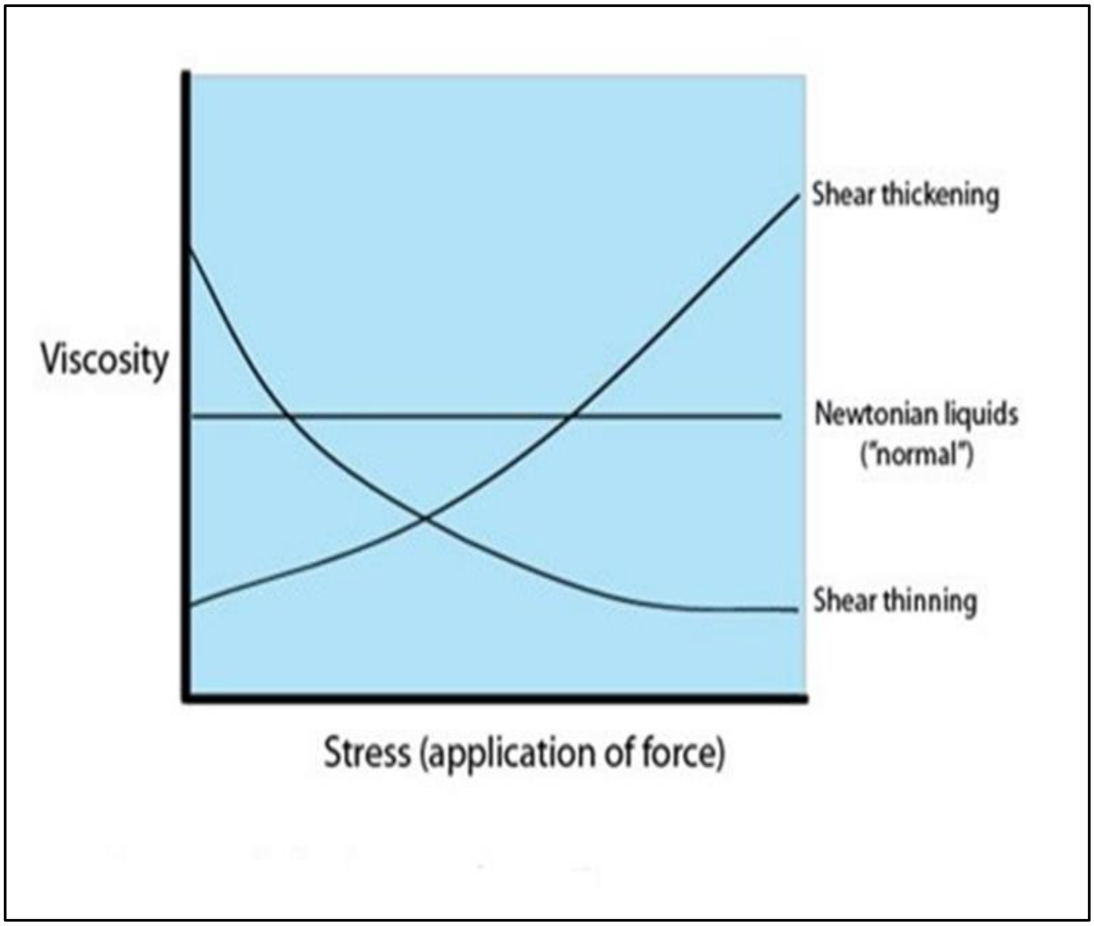

Figure 1 viscosity vs. stress for different liquid.

Viscous flow in amorphous materials (e.g. in glasses and melts) is characterized by a deviation:

$$\eta = A\, e^{Q/RT}$$

Where Q is activation energy, T is absolute temperature, R is the molar gas constant and A is approximately a constant. Q changes from a high value QH at low temperatures (in the glassy state) to a low value QL at high temperatures (in the liquid state).

1.1 Factors effect on the viscosity of Glass

a- Effect of composition on the viscosity:

This topic is related to the connectivity of the structure, i.e. changes in composition with reduce the connectivity, reduce the **viscosity**.

- The viscosity of silica varies slowly with temperature. Small addition of alkali oxide to silica causes **decrease** in the viscosity.
- Viscosities of melts containing **a mixture** of two or more alkali oxides are **lower** than those of corresponding melts containing the same total molar concentration of a single alkali oxide. The viscosities of alkaline earth silicate melts are greater than those of alkali silicate melts.
- Replacement of a modest amount of alkali oxide by an alkaline earth oxide results in small increase in viscosity due to changes in the field strength of the modifier ion.

b- Effect of temperature on the viscosity:

Between the melting point and the room temperature, glass melts pass through different points of viscosities. Figure 2 shows the main viscosity points of silica glasses.

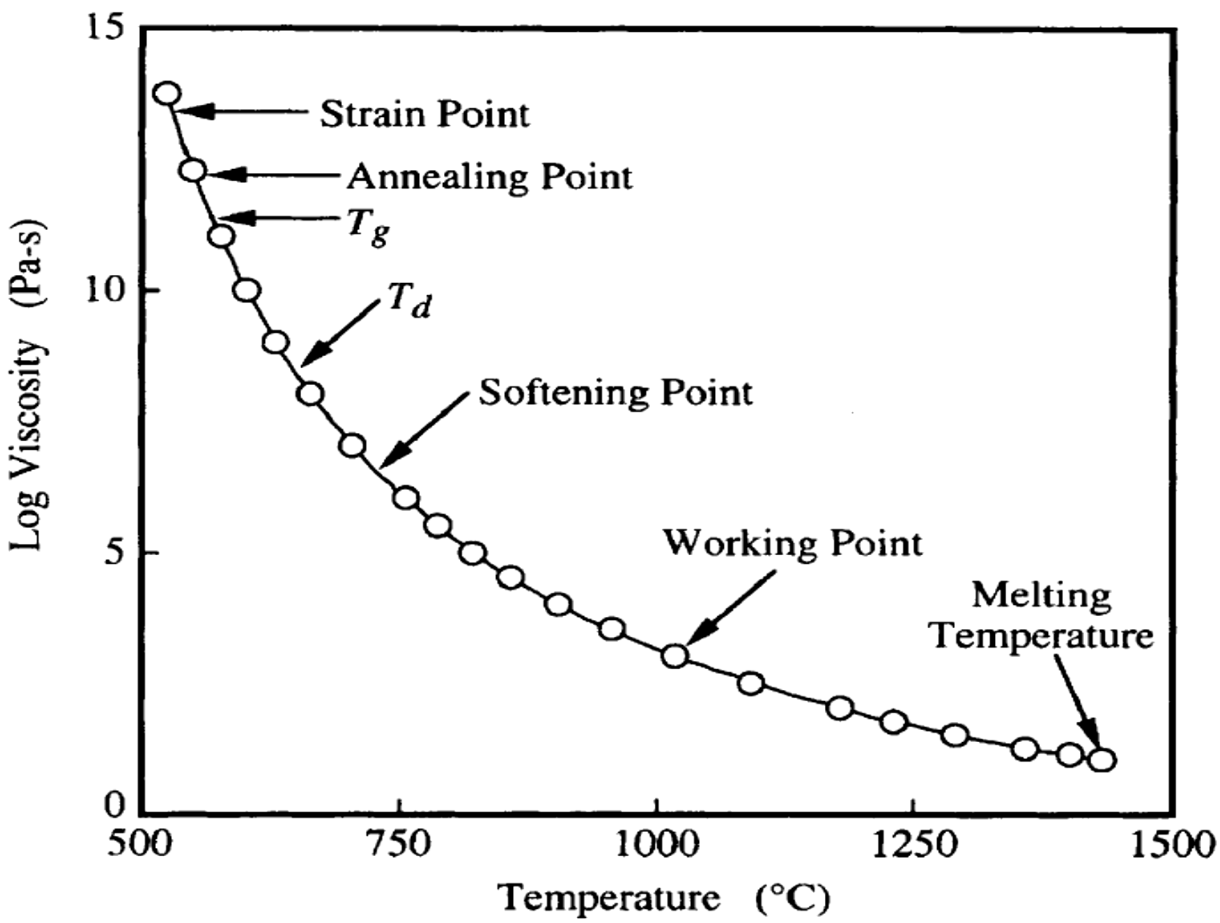

Figure (2) viscosity as a function of temperature for soda-lime-melt

1- The melting points correspond to the temperature at which the viscosity is **10 Pa.s**. The glass fluid is enough to be considered a liquid.

2- **The working point** represent the temperature at which the viscosity is **10^3 poises** and the glass is easily deformed at this viscosity i.e at this temperature glass fabrication operation can be carried out.

3- **The softening points** the temperature at which the viscosity is **10^7poises**. It is the temperature at which a glass piece may be handled without causing significant dimensional alterations. This point cannot be defined by a precise viscosity because it depends on the density and surface tension of the glass.

4- **The annealing point** is the temperature at which the viscosity is **10^{12} - 10^{13}poises**. At this temperature, atomic diffusion is sufficiently rapid that any residual stress may be removed within about 15 min.

2. Density and Molar volume

The density **ρ** is the mass per unit volume (**g/cm3**). If sample is free of bubbles, voids, or other defects, the calculated density is **the true density** of the material. If sample contains bubbles, which is occasionally the case for glasses, the calculated density will be less than that of the true density and is termed **the apparent density**.

- The molar volume is defined as **the volume occupied by one mole of a material** and is obtained by dividing the molecular weight of a material by its density:

$$V_m = \frac{MWt}{\rho}$$

Where $\mathbf{V_m}$ is the molar volume, **MWt** is the molecular weight of substance, and **ρ** is the true density of that substance.

- If the networks formed by the primary glass forming oxides contain a large number of **empty interstices**, it must be possible to stuff a correspondingly large number of modifier ions into these interstices. Such a process would **increase the mass** of a substance without increasing its bulk volume, resulting in an increase in **density**.

- The addition of alkali ions to any of the common glass forming oxides results in an increase in density .even Li2O, which has only half the molecular weight of silica, increases the density of silicate, borate, or germanate glasses when substituted for the basic glass forming oxide. Shown in figure 3.

➢ Glasses containing lithium are often more dense than those containing sodium or potassium. If potassium ion weights about 6 times as much as a lithium ion and both simply occupy interstices in an existing network.

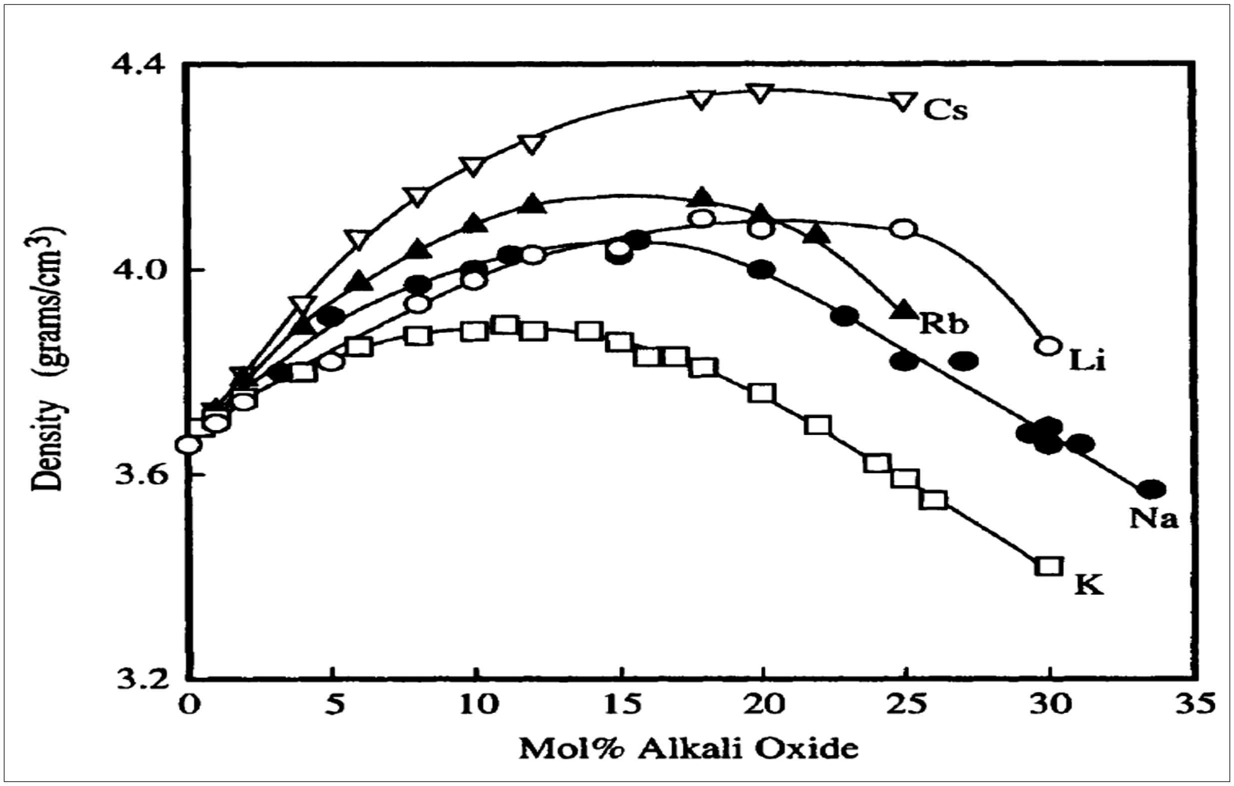

Figure (3) Effect of composition on the density of alkali germanate glass.

➢ The molar volumes in every case increase in order Li < Na < K < Rb< Cs. Additions of lithium or sodium to the network reduce the molar volume, implying that they cause shrinkage of the network. Potassium, rubidium, and cesium, on the other hand, increase the molar volume of glasses, implying that they force an increase in the volume of the structure. See in figure (4).

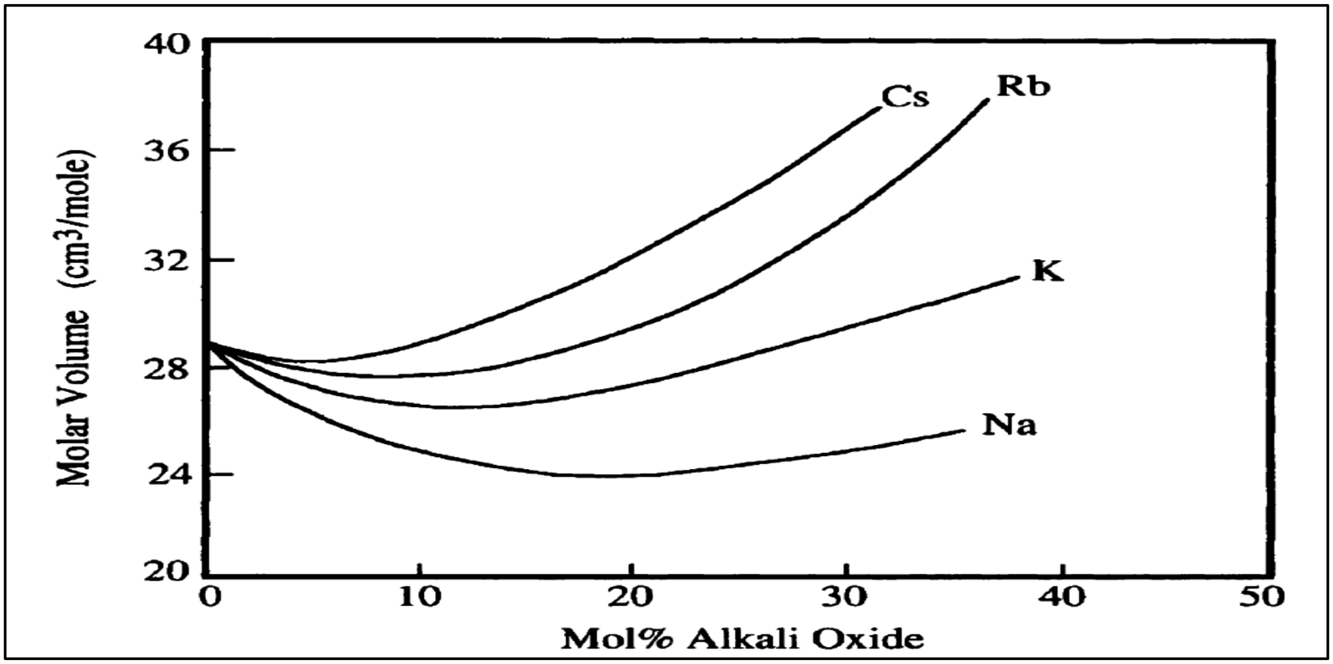

Figure 4 Effect of composition on the molar volume of alkali gremanate glass.

3. Strength

The high theoretical structural strength of glasses (ranges from 1 to 100 GPa), which depends on **glass composition**, is an attractive property. However, this high strength of glasses cannot be utilized in practical applications due to presence of **flaws/defects** on its surface which reduce the actual fracture strength by many orders of magnitude.

- These flaws, in the form of **tiny chips** or **cracks**, act as **stress concentrators**. At the tips of these flaws, stress concentration may be introduced by a load which exceeds the theoretical strength and cause fracture/breakage of the glass. Contact with other hard objects often cause flaws on glass surface.
- **Chemical attacks** and **thermal stresses** introduced during rapid cooling may also generate flaws on glass surface. Annealing can also be a reason for the reduction of strength as it may introduce small crystals to the glass surface.
- **The thermal expansion** mismatch between the matrix glass and these crystals during cooling lead to flaws. In general, it is very challenging to keep glass surfaces free from flaw formation during production process or during annealing.
- **Lubrication** or **coatings** are often applied to the fresh glass surfaces to help prevent the formation of flaws. Reducing the flaw length below the Griffith critical crack length for crack growth, by **etching** or **polishing** is another way to improve the glass strength.

*As discussed earlier **the strength** of glasses can **be improved** by:*

1. **Preventing or removing** the flaws from the surface which causes the reduction of glass strength. The other way is to prevent the crack growth.
2. **Compressive strength** of glass which is very high can be exploited for strengthening. Internal stresses can be introduced to the glass by **thermal tempering** (quenching of softened glass) or **ion exchange.** By **air-quenching** glass, compressive stresses can be formed on the surface while the interior is held in tension. In this way, the strength of glass can be increased typically 4–6 times. Such glass is commonly used in bus stops and automobile applications.
3. **Ion-exchange** or **'chemical toughening'** works by replacing sodium ions, for example, with potassium ions (which are 30% larger), by immersion of the glass into a bath of molten potassium nitrate. **Chemical toughening** can be applied to glass objects of complex shapes. Oftentimes, polymeric materials (polycarbonates) are used in combination with glass to form layered composite materials with enhanced properties.

4. Optical Properties

The optical properties of glasses are of utmost importance and can be subdivided into three categories –

- **a- refraction**
- **b- absorption**
- c- **Transmission of light.**

Glass is among only few other solids that transmits light in the visible region of the spectrum. Therefore, the development of optical glasses with appropriate refractive index and dispersion characteristics plays an important role in modern scientific evolution, especially in nano-science, medical science, astronomy, and biology.

a. Refraction of Light

The refractive index of a material is defined as **the ratio of velocity of light in a vacuum to that in a defined material**. The refractive index of a glass is not a constant, but depends on the wavelength of the incident light, known as **dispersion**.

Dispersion causes the separation of white or compound light into its constituent colors in prisms.

Effect of composition of glasses on refractive index

- ✓ Increasing electron density or polarizability increases the refractive index of a glass. Glasses containing low atomic number ions, which have low electron density and low polarizabilities, also have low refractive indices.
- ✓ Non-bridging oxygens are more polarizable than bridging oxygens. As a result, formation of non-bridging oxygens in a glass system due the compositional change increases the refractive index of that glass. For commonly used alkali silicate glasses, refractive indices increases with increasing alkali oxide concentration.
- ✓ Density and refractive index are directly correlated, such that increasing the density of glass also increases its refractive index.

b. Absorption

Ultraviolet (UV) light with wavelength **(100–400 nm)** cannot transmit through glass even if it is transparent. The electrons attached to molecules in typical glasses can absorb radiation at UV wavelengths which are beyond their ultraviolet edge.

A very intense absorption band can be achieved in glasses by adding small concentration of impurities (i.e., iron) which result in a very intense absorption band due to transfer of electron from cations to neighboring anions. This absorption band is called **charge transfer band**. Absorption of light in the visible region of spectrum is known as color.

5. Electrical Properties

Glasses are well known for their excellent **insulating properties**. Most oxide glasses are ionic conductor, but very poor electrical conductor due to low numbers of free monovalent ions. Due to its high insulating properties, glasses are used in the area of electrical and electronics engineering for the production of seals, high-voltage insulators, microelectronic packaging, high-vacuum tubes, lamps, etc.

5.1 Resistivity and conductivity of glass

- ❖ Electrical conductivity in glasses depends on **mobility of ions – especially alkali ions**. Therefore, the conductivity of the alkali silicate glasses increases with the increasing alkali oxide content.

- However, for **the glasses containing two or more alkali oxides**, the mixed-alkali effect occurs where the conductivity decreases. Addition of alkaline earth oxide to any alkali containing glass also decreases the electrical conductivity. The immobile divalent alkali earth ions block and occupy the interstitial sites and thus reduce the mobility of the alkali ions in a glass.
- The conductivity of a glass also very much **depend on temperature**. At room temperature, the mobility of ions is so small that volume resistivity almost always lies beyond the range of measurement. The ionic mobility increases with increasing temperature and as a result resistivity also decreases.
- **Crystallization** also influences the conductivity. If the formed crystal removes alkali ions from the residual glass, the conductivity usually decreases. However, conductivity of theglass-ceramic increases if the crystal phase is free of alkali ions.