Collage of Engineering
Materials Department

Third Class
Lecture (11)

GLASS

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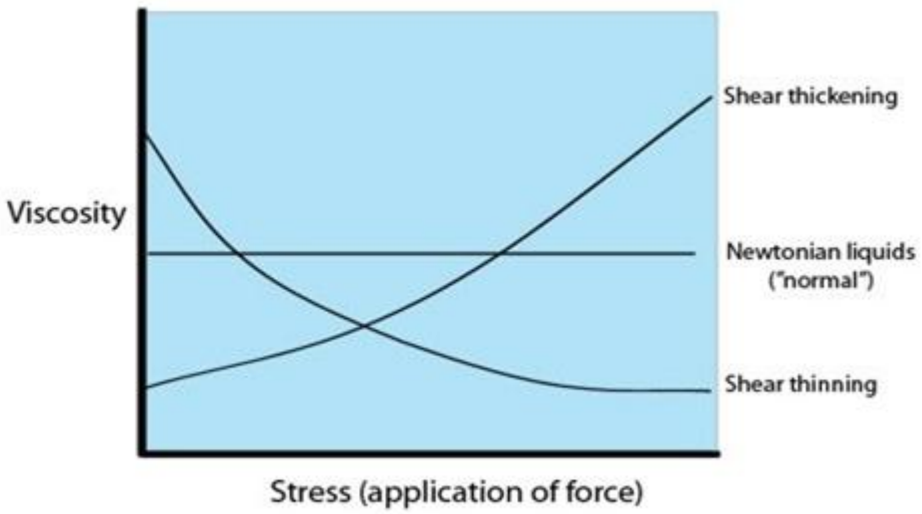
6- Properties of glass

6-1 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, and devitrification rate. The viscosities of different glasses vary enormously with composition and are strong functions of temperature. 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 fig 14):

- 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 (14) viscosity vs. stress for different liquid

Viscous flow in amorphous materials (e.g. in glasses and melts) is characterized by a deviation from the Arrhenius-type behavior

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

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).

6-1-1 The factors effect on the viscosity

- 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 and vice versa. Vitreous silica is the most viscous of all common glass forming melts. The glass transformation temperature of vitreous silica lies in the range of 1060°C to 1200°C. The viscosity of silica varies slowly with temperature. Small addition of alkali oxide to silica causes decrease in the viscosity. The effect of further alkali oxide additions decreases with alkali oxide concentration, and eventually becomes small for concentration exceeding 10-20%mol R_2O.The differences among the alkali oxides have small effect on the viscosity as compared to the effect of alkali oxide concentration. 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. Although a direct replacement of Na_2O for example, by an equi-molar concentration of CaO does not alter the non-bridging oxygen concentration. In fact, the greater field strength of the divalent calcium ion strengthens bond of the neighboring oxygen. This increases slightly strength the glass network. Replacement of an alkali or alkaline earth oxide by alumina or Gallia reduces the concentration of non-bridging oxygen and increases the connectivity of the network. The effect of the intermediate oxide is very small for small concentrations; however, it increases rapidly until the concentration of intermediate oxides equals that of the modifier oxides.

- Effect of temperature on the viscosity:

Between the melting point and the room temperature, glass melts pass through different points of viscosities. Figure 15 shows the main viscosity points of silica glasses.

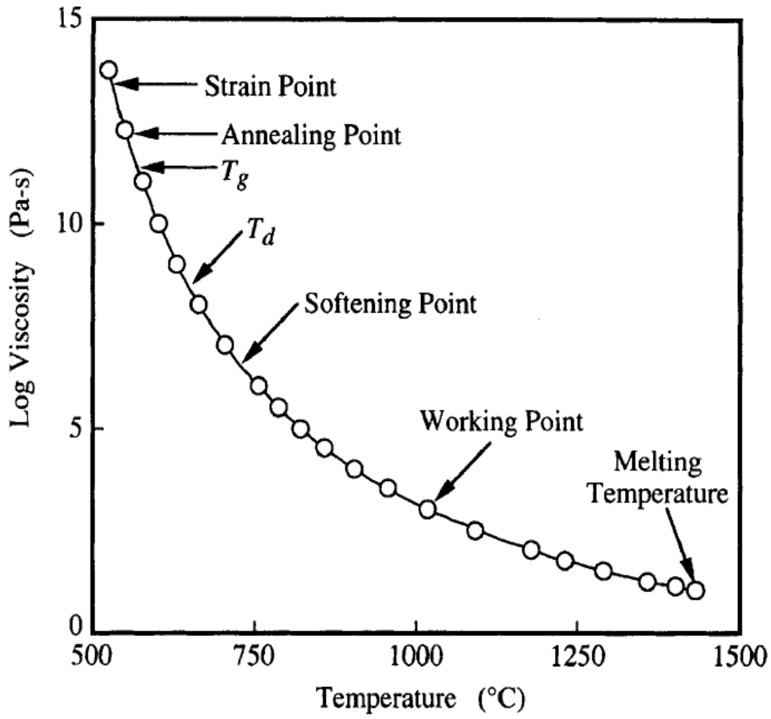


Figure (15) viscosity as a function of temperature for soda-lime-melt

1- The **melting points** correspond to the temperature at which the viscosity is 10 Pa.s. The glass fluid 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}poises. At this temperature, atomic diffusion is sufficiently rapid that any residual stress may be removed within about 15 min.

Glasses are usually melted at a temperature that corresponds to a viscosity of about 10 Pa.s. During forming the viscosities of glasses are compared qualitatively. A hard glass has a high softening point, whereas a soft glass has lower softening point. Most glass-forming operations are carried out within the working rang between the working and soften temperature. The temperature at which each of the above points occurs depends on glass composition. For example, the softening points for soda-lime and high silica glass (96% silica glasses), from figure (16) are about (700 and 1550) $^{\circ}$C respective. That is, forming operations may be carried out at significantly lower temperature for the soda-lime glass.

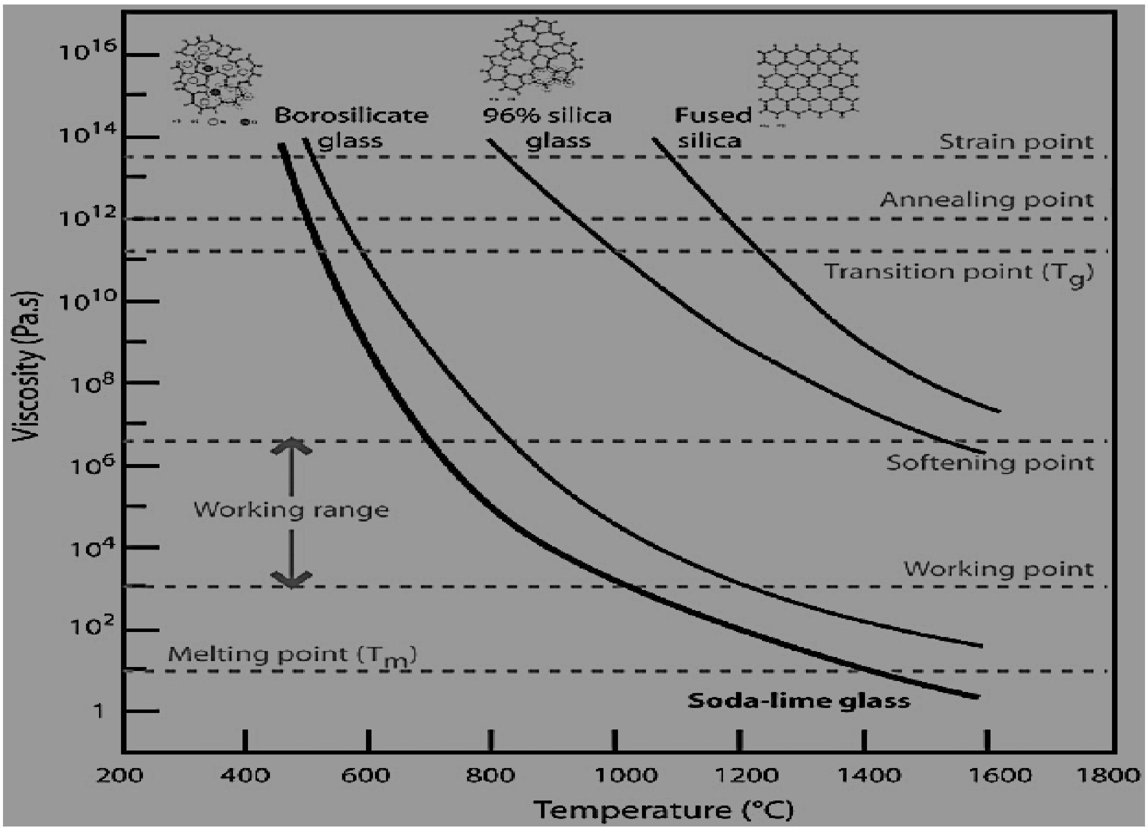


Figure (16) Logarithm of viscosity versus temperature for fused silica and three silica glasses.

EX: A 96% silica glass has a viscosity of 10^{12} Pa.s at its annealing point of 940°C and a viscosity of 10^{7} Pa.s at its softening point of 1470°C. Calculate the activation energy in kilojoules per mole for the viscous flow of this glass in this temperature range.