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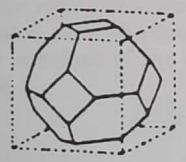

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ELASTIC MODULI OF A COMMERCIAL SODA LIME SILICA GLASS

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Abstract :

Studies have been made on the elastic moduli of a prepared commercial soda-lime-silica glass. Measurements have been made of the velocity of longitudinal ultrasonic waves propagating through the glass. The effect of annealing on the longitudinal elastic modulus been investigated. The bulk modulus, average cross-link density and Poisson's ratio have been calculated using the bond compression model according to the force constant of the cation-anion bond of each oxide in the glass.

Introduction :

From a materials science point of view, the systematics of the elastic behavior of glasses, and in particular, their anomalous behavior at high pressure, is important in the study of crack propagation and fracture strength. Some workers proposed qualitative, bond strength-related arguments. For example. Charles [1] reasoned that the weak bonds between modifier cations and nonbridging oxygens decreased the rigidity of silicate glasses. The quantitative analysis of the elastic moduli has

been started by Makishima and Mackenzie [2] to derive a formula for calculating the Young's moduli of glasses from their compositions, densities and the dissociation energy per unit volume of oxide. For the polycomponent inorganic oxide glasses the model [3] discussed all the parameters affecting the bulk modulus and Poisson's ratio.

We have measured the longitudinal elastic constants as a function of the annealing time at constant temperature. Data of the present soda lime silica glass were compared with those of SiO_2 glass from previous literature results. The bulk modulus of the investigated glass was calculated according to the bond compression model. Also, we calculated the average cross-link density and Poisson's ratio of the prepared glass.

Materials and Methods :

The specimens were prepared from the exact raw materials: quartz sand, sodium carbonate, dolomite, potash feldspar, barium carbonate, sodium nitrate, potassium carbonate, and sodium antimonate. The composition of the prepared soda lime silica glass is: 70.48 SiO_2, 0.72 AL_2O_3, 16.07 Na_2O, 0.48 K_20, 5.04 Mg 0, 5.6 CaO, 0.79 BaO, 0.08 Fe_2O_3 and 0.08 Sb_2O_3 all in Mole %. The finely powdered components were thoroughly mixed and used to prepare samples using normal quenching techniques. A quartz crucible containing the mixture was kept in an electrical furnace at 1723 K for nearly 2 hours. The melt was stirred occasionally by alumina rod to ensure homogeneity. The melt was then quickly poured onto a split mould made of mild steel. The produced glasses were annealed at 773 K for different periods. The densities of all samples were measured at room temperature by using the simple displacement method using toluene as an immersion liquid.

The velocities of the ultrasonic waves were measured by using the pulse echo method. The ultrasonic waves were generated using a commercial ultrasonic probe (ultrasonoscope 4 MHz). This is a sealed unit containing a piezo-electric crystal (with metal coating as electrodes) rigidly and permanently supported in an integral housing which contains a coaxial electric input socket with connecting wires between the socket and the crystal electrodes. The glasses were coupled to the probe using thin bonds of silica grease. The ultrasonic waves were transmitted and received by the commercial transducer (1.6 cm diameter) actuated by an ultrasonic flow detector (Kraukramer USM2 type NTL2). The commercial flow-detector actuated to the transducer to yield pulse echoes from the glasses. These echoes were displayed on one beam of a double beam oscilloscope (COS 5020, 20 MHz). The transit times were measured using the time/division scale on the oscilloscope.

Results and Discussion :

The experimental longitudinal elastic constants Le of the glass were calculated at room temperature using the measured densities ρ and the measured longitudinal ultrasonic velocity V_l . The experimental longitudial modulus is $Le = \rho V_l^2$. Since all our samples have identical geometry, errors in measurements caused by diffraction and geometrical dispersion tend to cancel out when data are compared. The maximum error in the measurements of longitudinal elastic moduli due to changes in specimen thickness (0.02%), velocity (0.05%), and density (0.001%) is therefore about 0.1%.

Table 1 depicts the relationship between annealing time (min) of the prepared glass, measured density, longitudinal ultrasonic velocity and the experimental longitudinal elastic modulus L_e (Nm^{-2}).

The density, longitudinal ultrasonic velocity and longitudinal modulus of the prepared soda-lime silica glass are higher than those of pure SiO_2 glass (longitudinal modulus has been calculated from the reference [2] for SiO_2). Annealing has a clear effect on ρ, V_1 and L_e. By increasing annealing time from 0, 1, 5, 10 to 15 min., the density has increased to 2.53 g/cm^3. Also, the longitudinal velocity has increased to 6535 m/s and the longitudinal modulus to 10.8×10^{10} Nm^{-2}.

Table (1): Annealing time, density and ultrasonic characteristic of the prepared commercial soda lime silica glasses.

Glass	Annealing time (min)	Density ($kg\ m^{-3}$)	Longitudinal	
			Velocity (m/s)	modulus ($10^{10} N\ m^{-2}$)
A	0	2519	5820	8.53
B	1	2520	5874	8.70
C	5	2526	6070	9.30
D	10	2529	6350	10.20
E	15	2530	6535	10.80

The present data confirm earlier observations that differences in thermal history affect the density and elastic constants of glass [4]. The observed increase in longitudinal modulus associated with a small increase in density, suggests that annealing causes structural compaction in the glass which in turn leads to increased moduli. Such structural rearrangement involves the formation of new bonds, resulting in altered linkages between silicon-oxygen tetrahedra. Changes in moduli would be caused by increased polymerization and stiffening of the structure.

The bulk modulus of the present soda lime silica glass was calculated according to the bond compression model for the polycomponent oxide glass [3].

$$K_{cal} = \sum_{i=1}^{n} (K_{cal}) = \sum_{i=1}^{n} \frac{(n_b)_i \; r_i \; f_i}{9}$$

With n different types of network bonds labeled by subscripts i = 1, 2, ..., n where n is the number of network bonds per unit volume, f is the first order stretching force constant and r is the cation-anion bond length. The bond length has been adopted from the crystal structure and f has been calculated according to the relation $f = 17 / r^3$ [3]. The number of network bonds per unit volume has been calculated according to the percentage of each oxide in the glass.

The last column in Table 2 gives the calculated bulk modulus of each oxide according to its mole % in the prepared soda-lime silica glass (70.48% SiO_2, 16.07% Nas_2O, 5.04% MgO and 5.9% CaO gave 8.804, 1.549, 0.818 and 0.922 x 10^{10} Nm^{-2} respectively, while $A1_2O_3$, K_2O, BaO, F_2O_3 and Sb_2O_3 all together gave us 0.312 x 10^{10} Nm^{-2}.

Table (2): Structural calculations of the bulk modulus of soda lime silica glass

Oxide	Mol %	r (A°)	f(Nm-1)	nf	nc	nb $10^{28}(m^{-3})$	Nc	Kcal $(10^{10}\overline{N m^{-2}})$
SiO_2	70.48	1.61(7-a)	432	4	2	7.0762	0.7048	8.8040
Al_2O_3	0.72	1.92(7-b)	240	6	4	0.1048	0.0144	0.1066
Na_2O	16.07	1.96(7-c)	225	4	2	1.6134	0.3214	1.5494
K_2O	0.84	2.18(7-c(	164	4	2	0.0843	0.0168	0.0730
MgO	5.04	1.75(7-d)	317	6	4	0.7589	0.0504	0.8186
CaO	5.90	1.82(7-d)	282	6	4	0.8885	0.0590	0.9221
BaO	0.79	1.94(7-e)	232	6	4	0.1189	0.0079	0.1154
Fe_2O_3	0.08	2.03(7-b)	203	6	4	0.0121	0.0016	0.0112
Sb_2O_2	0.08	2.00(7-f)	213	3	1	0.0060	0.0016	0.0057

Compression mol%, cation-anion bond length r(A°), stretching force const. f, coordination No. nf, average number of cross-links per cation nc, number of network bonds/unit volume nb, number of cations/glass formula unit Nc, calculated bulk modulus of each oxide in soda lime silica glass Kcal (Nm^{-2}).

Consequently SiO_2, Na_2O, MgO and CaO are responsible for bulk modulus of this glass. The total value of the calculated bulk modulus would be 12.4×10^{10} Nm^{-2} which is higher than $11 \times 10^{10} N m^{-2}$ calculated value of pure SiO_2 [5]. This can be explained as the increase in the number of network bonds per unit volume from 8.83×10^{28} m^{-3} [6] to 10.67×10^{28} m^{-3} while the average stretching force constant reduces from 432 [5] to 348.1 N/m for the silica and present soda lime glasses respectively.

Similarly, the structural sensitive parameter which is the average cross-link density of each oxide in the soda lime glass was considered. The average cross-link density of the soda lime glass according tot he model of the polycomponent oxide glass [3] was calculated form column 6 in table 2 and gave us the value of 2.2263 which is higher than 2 [6] of pure SiO_2 glass. So, the estimated Poission's ratio according to the equation:

$$\sigma_{cal} = \text{const.} (n_c)^{-1/4}$$

will be equal to 0.1577 for the investigated glass. This value is less than that of pure SiO_2 glass [6] which is 0.162.

Conclusion :

1. The effect of annealing on soda lime silica glass is to increase the density and the longitudinal elastic modulus.
2. The bulk modulus of the investigated glass calculated according to the bond compression model is higher than that of pure silica glass.

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