© 2018 IJSRST | Volume 4 | Issue 10 | Print ISSN : 2395-6011 | Online ISSN : 2395-602X
Themed Section: Science and Technology
doi : https://doi.org//10.32628/IJSRST186164

Mechanical Properties of (50–x) P_2O_5–25ZnO–25Li_2O–(x) $SrCO_3$ Glass

Shivaprakash Y[1*], Ravikumar Nayaka[2], Gavisiddayya Mathod[3]
[1*]Department of Physics, Govt. First Grade College, Devanahalli, Bangalore, Karnataka, India
[2]Department of Physics, Govt. First Grade College, Ranebennur, Karnataka, India
[3]Department of Physics, Govt. First Grade College, Yelburga, Karnataka, India
[1*]Corresponding author : yshivaprakash@gmail.com

ABSTRACT

The melt-quenching method was used for synthesis of glasses with the compositional formula (50–x)P_2O_5–25ZnO–25Li_2O–(x)$SrCO_3$, where ($0.00 \leq x < 5.00$ mol%). The mechanical properties were studied using Ultrasonic testing method. The XRD analysis didn't show any Bragg peaks validating the samples' amorphous nature. It is discovered that glass densities and packing densities increase with the concentration of $SrCo_3$ dopant. This results in decreasing molar volume values, indicating the rigidity of the glasses. Because the obtained Poisson's ratio falls between 0.1 and 0.2, the ultrasonic results and other measured parameters ascribe the Sr ion increase in the cross-link density by the formation of P-O-Sr.

Keywords : Glass, Elastic Moduli, Ultrasonic Testing, Pulse Echo Technique

1. Introduction

Phosphate glasses have been investigated primarily for biomedical applications (such as bone tissue healing and fixation), These glasses also well known for its technological interest in electrochemical devices, as well as a variety of other uses, including optical and nuclear waste storage. Additionally, a wide range of ions can be doped into it with ease. phosphate glass is well known network former. The short-range order of phosphate glass network can be explained by the type and concentration of [PO_4]. Addition of any multivalent oxide to P2O5 can increase its chemical endurance and improve its physical properties. In addition to low preparation temperatures and high transmission, they typically have low glass transition temperatures, low softening temperatures, and high thermal expansion coefficients [1,2].

The glass structures can be altered by the addition of alkaline and alkaline earth metal ions by opening up a modified network and to reduce the bond strength. As a result, it will break the bridging oxygen (P–O–P) bonds and create a terminal oxygen (P–O–M) bond, disrupting the glass structure and depolymerizing the phosphate glass network. At normal temperatures and pressures, alkaline earth metals are characterized as glossy, silvery-white, and highly reactive. This family is particularly adept at forming bonds, while not being as reactive as the alkali metals. Further, a good quality of glass can be formed by adding oxide elements such as ZnO and Li_2O[3,4]. This study is to investigate special strontium doped phosphate glass with the optimum composition of P_2O_5 – ZnO – Li_2O – $SrCO_3$. Throughout this study, the nature of the glass, physical and mechanical properties were discussed to justify how they are suitable for industrial applications.

2. Experimental

2.1. Synthesis techniques

The investigated glass samples with the composition of $(50 - x)P_2O_5–25ZnO – 25Li_2O – (x)SrCO_3$ where ($0 \leq x \leq 5$ mol%) were synthesized by conventional melt quenching technique[5,6]

The required amounts of all the precursors were weighed, mixed, and heated in different types of crucibles depending on the glass composition. Then, the materials are grinded into powdered form by a ball mill to obtain more homogenous particle size in 10-15 minutes. The mixed quantities of these chemicals were placed in an electric furnace in the open atmosphere and held at 300 °C for one hour. The ground mixture is then melted in a furnace at 1000 °C. Finally, the homogeneous melt is immediately transferred to an annealing furnace and poured into specially designed molds, which held at 300 °C for three hours. This procedure was repeated for all glass samples with different mol% concentration as listed in Table 1.

Table 1: The composition of $(50 - x)P_2O_5–25ZnO – 25Li_2O – (x)SrCO_3$ where ($0 \leq x \leq 5$ mol%)

Samples	Composition (mol%)			
	P_2O_5	ZnO	**Li_2O**	**$SrCO_3$**
S1	50	25	25	0
S2	49	25	25	1
S3	48	25	25	2
S4	47	25	25	3
S5	46	25	25	4
S6	45	25	25	5

2.2 X-Ray Diffraction

The amorphous state of the sample is confirmed by X-ray diffraction (XRD) measurement with Cu-Kα radiation, operated at 40 kV.

2.3 Physical Properties

Archimedes principle is used to measure the density of prepared glass by using Mettler Toledo electronic weighing balance. The physical parameters such as the density, molar volume density and ionic packing density of the glass sample are calculated by using standard mathematical expression [3].

2.4 Ultrasonic Pulse Echo Measurements

The specially designed cylindrical samples with diameter 10 mm were used for ultrasonic pulse echo measurements. The pulse, which generated by the pulse oscillator were depends on the transmitting transducer. It transforms them into acoustic pulses. These acoustic pulses are generated through the glass sample, then converted into electrical signals, which are received by the transducer. Hence, the output signal (amplified) from the sample is displayed on the oscilloscope. Ultrasound velocities, V_l (longitudinal mode) and V_t (transverse mode) in the samples were measured using pulse echo superposition, and the round trip delay time have been calculated by McSkimin's Δt criteria[3]. The method involves injecting a train of ultrasonic pulses of 1 ms width into the sample using X-cut and Y-cut quartz transducers (10 MHz) of 10 mm diameter, coupled to one end of the parallel polished surface of a cylindrical sample using phenyl salicylate (salol) as bonding material. By measuring the thickness of the sample (d), longitudinal and transverse ultrasonic wave velocities have been calculated using the relation,

$$V = \frac{2l}{\delta} \tag{1}$$

The information displayed was taken to calculate the elastic constant measurements. Various elastic constants and microhardness were calculated using the following standard relations[12].

Longitudinal modulus:	$L = \rho V_l^2$	(2)
Shear modulus:	$G = \rho V_s^2$	(3)
Bulk modulus:	$K = L - (4/3)G$	(4)
Young's modulus:	$E = (1+\sigma)2G$	(5)
Poison's ratio:	$\sigma = (L-2G)/2(L-G)$	(6)
Microhardness:	$H= (1-2\sigma)E/[6(1+ \sigma)]$	(7)

3. Results and Discussion

3.1 XRD Analysis

The presence of a broad hump in all the samples (S1-S6) as seen in Figure 1, revealed that there is no significant Bragg's peak in XRD spectra. Therefore, it has been confirmed that the plane is glass. This is most likely because of the density is very sensitive to both the ionic size and atomic weight of the alkaline rare earth [5,6]. These results revealed that addition of alkaline earth elements leads to the formation of NBOs and expands the structure [5]. Thus, the obtained data reveals the amorphous nature of the prepared glasses and the presence of random strontium phosphate network in the samples.

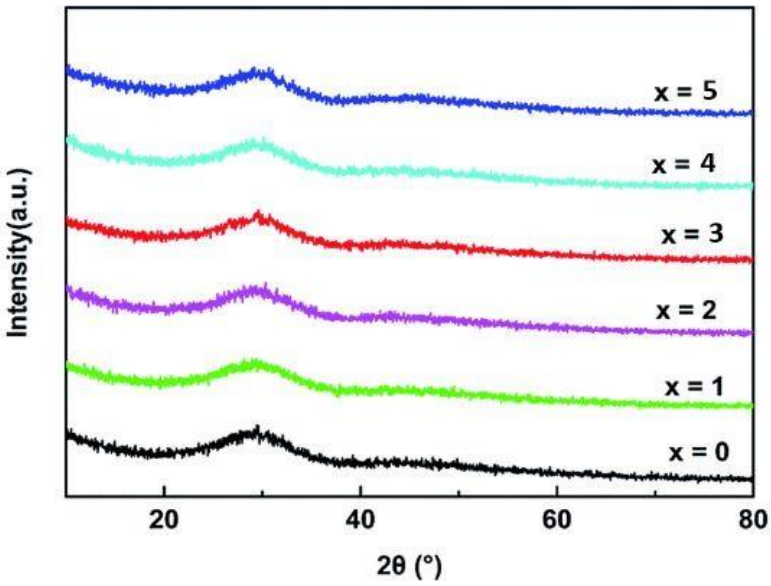


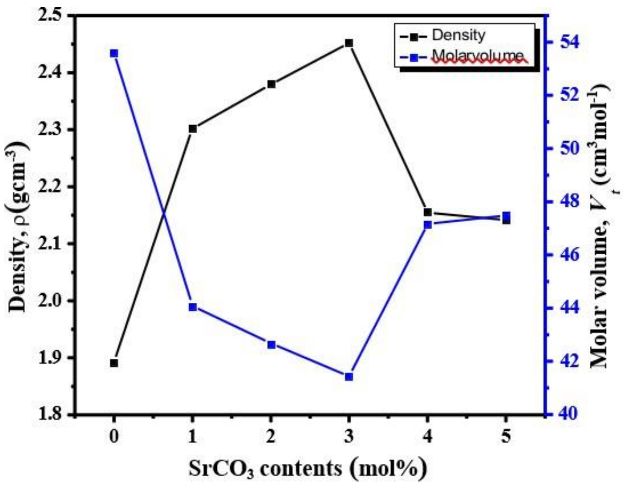
Figure 1: XRD pattern of samples S1-S6 (with x=0 to 5 mol%)

3.2 Physical properties Analysis

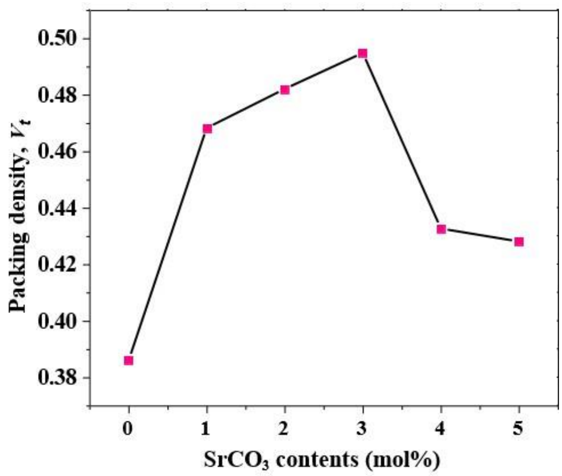
The calculated physical parameters are tabulated in Table 2. Figure 2(a) and 2(b) present the change in density, molar volume and packing density that occurred with the addition of $SrCO_3$. The increase in Sr content directly correlated with an increase in glass density [6-8].

Table 2: Density, molar volume and packing density of the glass.

Mol% of $SrCO_3$	Density, ρ (gcm^{-3})	Molar Volume, V_m (cm^3mol^{-1})	Packing Density, V_t
0	1.8910	53.6044	0.3861
1	2.3020	44.0588	0.4681
2	2.3796	42.6457	0.4818
3	2.4524	41.4031	0.4946
4	2.1548	47.1473	0.4325
5	2.1415	47.4672	0.4280



(a)



(b)

Figure 2: Density and molar volume (a) while (b) is packing density of (50–x)P_2O_5 – 30ZnO – 20Li_2O – (x)$SrCO_3$ glass system.

3.3 Ultrasonic Measurement (Pulse echo Technique)

The ultrasonic wave velocities obtained for the prepared samples are presented in Table 3 and Table 4. It is observed as $SrCO_3$ content increases, both V_l and V_S also increase. The decreasing trend of σ in Figure 4, indicates the glass network weakens. It is well reported that as Poisson's ratio decreases, the rigidity increases in glasses [8]. The de-polymerization of phosphate group increases the mechanical strength. The rigidity is generally dependent upon the bond strength and cross-link density [9]. Modi et al. [10] and Manupriya et al. [11] have also reported that a low cross-link density contained glass has higher σ i.e. (0.2 to 0.5) whilst the high cross-link density has σ between 0.1 and 0.2. Thus, it certainly shows that the present glass samples contain high-cross link density with addition of $SrCO_3$ to the glass system attributed to the compactness in the packing structure of the glass due to the reduction of NBO's. Elastic moduli are particularly helpful in correlating structural changes in glasses which are expected to occur as a function of composition [12]. The ultrasonic wave velocities obtained from existing samples are found to be sensitive to the glass system as shown in Table 3. It is observed from Table 3 as $SrCO_3$ content increases, both longitudinal and shear velocity also increase. Figure 3 with aid of Table 3 displays the divergence of elastic moduli with addition of $SrCO_3$ content. Longitudinal modulus, L obtained increases from 35.372 to 82.273 GPa with the increasing concentration of $SrCO_3$ up to 2 mol%. The increase in velocities has been attributed to the increase of rigidness of glass network. The presence of $SrCO_3$ in zinc-lithium phosphate increased the formation of bridging oxygens (BO), resulting in high rigidity. However, the addition of $SrCO_3$ up to 5 mol%, decreases the value of L from 82.273 to 21.697 GPa. It can be seen, from Table 3, all the elastic moduli values decreased with increasing of $SrCO_3$. This nonlinear variation also happens to shear, bulk as well as Young's modulus, which follow the same trend of variation as density.

Table 3: The velocities and elastic moduli of the glass system.

Mol % of $SrCO_3$	Longitudinal Velocity, v_l (ms^{-1})	Shear Velocity, v_S (ms^{-1})	Longitudinal Modulus, L (GPa)	Shear Modulus, G (GPa)	Bulk Modulus, K (GPa)	Young's Modulus, E (GPa)
0	4320	3193	35.373	19.256	9. 698	3.7590
1	5192	3335	62.005	25.618	27.846	58.8213
2	5883	3374	82.274	27.072	46.175	67.9425
3	4828	2692	57.142	17.798	33.407	45.3446
4	4090	2652	36.064	15.142	15.873	34.4681
5	3182	2572	21.698	14.178	2.792	15.8049

Table 4: The Poisson's ratio and microhardness of the glass system.

Mol % of $SrCO_3$	Poisson's Ratio, σ	Microhardness, H (GPa)
0	-0.0972	0.8294
1	0.149	6.0110
2	0.2549	4.4253
3	0.2739	2.6840
4	0.1382	3.6533
5	-0.4425	8.9089

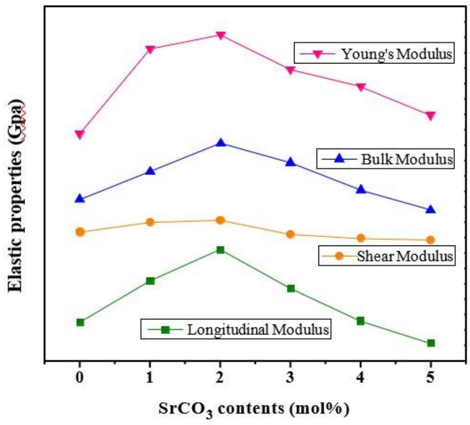


Figure 3: The variation of elastic moduli with different mol% of $SrCO_3$.

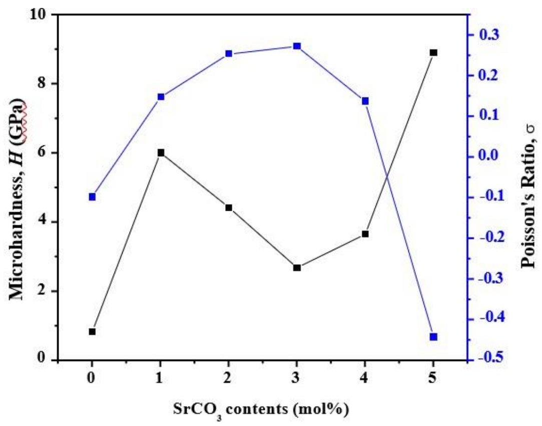


Figure 4: Microhardness (H) and Poisson's ratio (σ) varied with different mol% of $SrCO_3$

Conclusion

The mechanical and physical characteristics of phosphate-zinc-lithium glasses were examined when P2O5 was substituted with SrCO3. The presence of a broad hump in XRD indicates that the glass spectra lack a substantial or Bragg's peak. The Sr ion increase in the cross-link density due to P-O-Sr production is responsible for the ultrasonic results and other measured parameters. The Poisson's ratio, which ranges from 0.1 to 0.2, indicates that the current glass samples have a high cross link density when SrCO3 is added to the glass system. This is because the glass's packing structure is more compacted because of the decrease in NBOs. Decreasing molar volume values, indicating the rigidity of the glasses. Hence the prepared glasses are tested in terms of all mechanical properties required to use in various potential applications in the respective fields.

References

[1] R.K. Brow. Review: the structure of simple phosphate glasses. J. Non-Cryst. Solids.263–264, 1–28 (2000).

[2] J.E. Shelby. Introduction to Glass Science and Technology 2nd edn. The Royal Society of Chemistry Cambridge. (2005)

[3] F. Torres; K. Narita et al. Elastic and mechanical properties of transparent $KNbGeO_5$ nanocrystallized glass. J. Appl. Phys. 94, 5265–5272 (2003).

[4] Jone N. Watson J.D. 1990 Digital Signal Processing: Principles, Devices and Applications; IEE Control Engineering Series. 42, 424p (1990).

[5] M. Farouk A. Samir et al. Effect of alkaline earth modifier on the optical and structural properties of Cu^{2+} doped phosphate glasses as a bandpass filter Physica B: Physics of Condensed Matter. 530, 43-48 (2018).

[6] Al Qaysi, M. Walters F et al.2015 Strontium- and calcium-containing, titanium- stabilised phosphate-based glasses with prolonged degradation for orthopaedic tissue engineering Journal of Biomaterials Applications. 30 (3), 300-310 (2015).

[7] Ensanya A. Abou Neel Wojciech C 2009 Structure and properties of strontium-doped phosphate-based glasses J. R. Soc. Interface. 6, 435–446 (2009).

[8] S. Marzouk, A. Hammad et al. The correlation between the structural, optical, and electrical properties in mixed alkali fluoroborate glasses containing vanadium ions Journal of Non-crystalline Solids. 476, 30-35 (2017).

[9] P.K. Jha, O.P. Pandey K. et al FTIR spectral analysis and mechanical properties of sodium phosphate glass-ceramics Journal of Molecular Structure. 1083, 278-285 (2015).

[10] Modi K. B, Shah S. J. et al. Infrared spectral evolution, elastic, optical and thermodynamic properties study on mechanically milled (0.5)NiO – (0.5)Zn0 – $5Fe_2O_4$ spinel ferrite. J. Mol. Str. 1049, 250–262 (2013).

[11] Manupriya K.S. Thind G. et al. Aravindan 2006 Structural and acoustic investigations of calcium borate glasses. Phys. Stat. Sol. 203(10), 2356-2364 (2006).

[12] Y. Shivaprakash, Rajan V. Anavekar. Investigations of lithium-chloro-borate glass-ceramic and its elastic properties. Can. J. of Phy. 88(8),569-574 (2010).