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INFLUENCE OF CHEMICAL COMPOSITION ON THE ELASTIC PROPERTIES OF PHOSPHATE GLASS

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ABSTRACT

This paper will report the influence of the chemical composition that affected the mechanical properties of phosphate glass. In this study lead oxide (PbO) has been used as the chemical reagent and the elastic property was evaluated by using the ultrasonic measurement technique. A series of phosphate-based glass with the percentages of lead oxide varies from 10% to 60% were prepared. An ordinary melt-quench technique of preparation produced high quality of lead phosphate glasses (PbO-P_2O_5). The ultrasonic measurement was carried out for the glass series at room temperature by using the Matec MBS 8000 Instruments. From the velocities of the ultrasonic waves namely longitudinal, V_L and shear, V_S waves the data has been used to estimate the elastic modulus such as bulk modulus, Young's modulus, Poisson ratio etc. for each composition.

INTRODUCTION

The early history of glass was started 3000 b.c. in Mesopotamia somewhere in Middle East, but tremendous progress of glass materials development was only started since the past few decades. The discovery phosphate glass and some other glass system by Stoke in 1871 was the starting point of the development glasses [1]. Recently, the uniqueness of phosphate has attracted considerable attention in the glass science and technology due to their various potential applications. Glass which containing oxide such as lead oxide as chemical constituent's shows their potential in infrared transmission and non-linear optical properties [2]. A formation of binary lead phosphate glass had used two chemical components namely the glass former, P_2O_5 and the glass modifier, PbO. In general, lead oxide has been used in a large scale in the glass industries and most of the applications were focussed on the optical properties due to the high refractive index and optical application [3]. As suggested by Weys (1867), lead is 'metallophilic' element that aid in the introduction of metal bonds into distintly ionic bonds in glass [4]. In this paper, we report on the influences of lead oxide in the phosphate glass that affected the elasticity of the glass system.

EXPERIMENTAL DETAILS

A series of lead phosphate glass varies from 10% to 60% of PbO contents were successfully prepared from an appropriate amount of lead oxide, PbO (98% purity) and phosphorus pentoxide, P_2O_5 (97% purity). The chemicals were firstly mixed thoroughly in alumina crucible. Then the mixtures were heated to about 400^{0}C for half an hour in the first furnace namely as T_1 in order to allow conditioning of the mixtures to take place. At this stage, all moisture content trapped within the mixtures would be driven out. The crucible was then transferred to the second furnace namely as T_2 , where the temperatures were progressively been set up to 1200^{0}C. At this temperatures the mixtures started to melt and reacting together. This process was held for 1 to 2 hours. Within the melting process, the mixtures were stirred gradually in order to avoid the bubble formation, thus could affected the ultrasonic measurements results.

As the mixtures were melted completely, the melt was cast into the preheated cylindrical split mould to produce a glass cylinder of 20 mm in height and 10 mm in diameter. The glass was immediately transferred to the T_1 for the annealing process and was kept for an hour as to relieve any residual stress and enhance its thermal stability. Finally, the glass samples were cut to about 4 to 5 mm in height and were polished with fine grain sandpaper to obtain two parallel and smooth surfaces. Later, the glass density was measured by Archimedes's method by using acetone as an immersion liquid.

ULTRASONIC MEASUREMENT TECHNIQUES

Ultrasonic techniques is a non-destructive testing method that been used in this works, to determine the elastic or inelastic properties of lead borate and lead phosphate glass system. Firstly, the piezoelectric transducer that attached to the samples generated the ultrasonic waves namely longitudinal and shear waves. These propagated waves velocities were measured by a fully computer interfaced measurement system MBS 8000 Matec Instrument. The velocity of an elastic wave in an isotropic solid depends on the density, ρ and the adiabatic elastic constant C_{ij}. Therefore, for isotropic solids and glasses there are two independent elastic constants C_{11} and C_{44} given by:

$$\rho V_L = C_{11} \qquad (1)$$

$$\rho V_S = C_{44} \qquad (2)$$

whereby V_L is the longitudinal wave velocity and V_S is the shear waves velocity [6,7]

The elastic constants of the glasses can be calculated from the measured velocities and densities by using the following expression [5]:

Longitudinal modulus $$C_{11} = \rho V_L^2 \qquad (3)$$

Shear modulus $$C_{44} = \rho V_S^2 \qquad (4)$$

Young's modulus $$E = \frac{\rho V_S^2 (3V_L^2 - 4V_S^2)}{(V_L^2 - V_S^2)} \qquad (5)$$

Bulk modulus $$B = \frac{\rho (3V_L^2 - 4V_S^2)}{3} \qquad (6)$$

Poisson's ratio $$\sigma = \frac{V_L^2 - V_S^2}{2(V_L^2 - V_S^2)} \qquad (7)$$

RESULT AND DISCUSSION

Experimental data are tabulated in Table 1 for lead phosphate glasses. For a series of lead phosphate glass, the densities shows a trend of increment with the mole fraction of PbO from 4036 kgm^{-3} to 5672 kgm^{-3}. The change in density of this glass could be due to the change in coordination of PbO in glass system. Some of PbO acts as a glass modifier by replacing phosphate ions and occupying the same interstice in the glass [8]. The longitudinal and shear velocities of lead phosphate decrease with a mole fraction of PbO composition. In lead phosphate glasses the velocities varying from 3606 ms^{-1} to 2937 ms^{-1} . The PbO acts as a modifier by modifying the glass structure and hence, make the glasses getting softer [9]. The wave propagation through the hard material will produce higher velocity rather than in the softer material [10]. Results of Young's modulus for lead phosphate of glasses are depicted in Figure 1. Young's modulus is a ratio of linear stress over linear strain and is related to the interatomic bond strength. This statement will let us know how much strain the material can withstand when a certain amount of stress is acted upon it. In this case, for lead phosphate glass the result varies from 26.4 GPa to 24.4 GPa but at x = 0.4 it drops to 23.5 GPa.

From the bulk modulus results of lead phosphate, it's varies with the mole fraction of PbO content. The value varying from 26.4 GPa to 24.4 GPa but at x = 0.40 the value decreases to 23.5 GPa. Meanwhile, the variation of Poisson's ratio for lead phosphate glass is plotted in Figure 3, whereby Poisson;s ratio is defined as the ratio of the lateral contraction per unit length to the longitudinal extension per unit length [11]. The results were fairly constant varying from 30 mole % to 50 mole % of PbO as a result of elastic modulus variation. The structure of lead phosphate glass that in the sheet form consists of layers of oxygen polyhedral with Van der Waal attraction between layers. The rigidity of the structure is increased by the addition of initial PbO content. Further addition of PbO, which acts as a modifier, had broken the molecular bond. The Van der Waal attraction force was ruptured by the addition of PbO into the phosphate glass system.

CONCLUSION

Lead phosphate glass series were successfully synthesized by using lead oxide as the chemical constituents. By using the ultrasonic techniques, the elastic property of binary lead oxide glasses has been estimated. In this work, we found that the elasticity is associated with a strong correlation with the PbO as a chemical composition. Through the structural changes in glass system by lead oxide which acts as glass modifier, a creation of non bridging oxygen (NBOs) is believed affected the elastic modulus, Young's modulus, bulk modulus and Poisson ratios.

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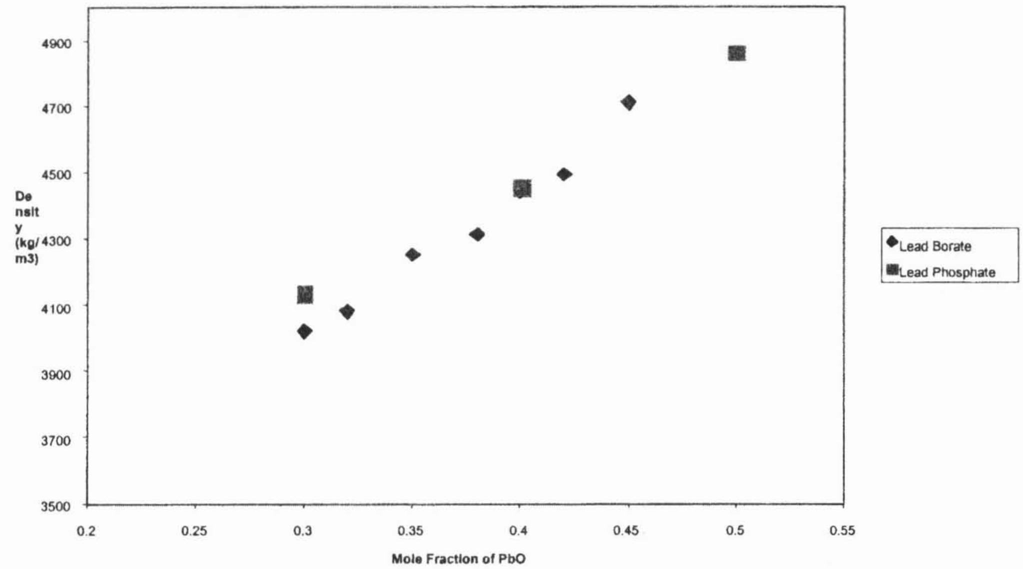
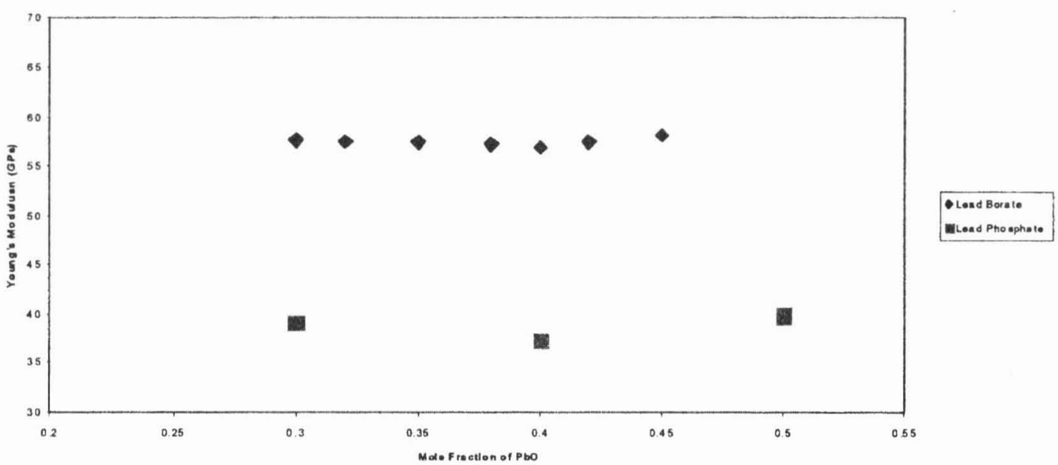
Table 1: Physical and Elastic Properties of Lead Phosphate Glasses.

	$(PbO)_X (P_2O_5)_{1-X}$						
Composition (x)	0.30	0.32	0.35	0.38	0.40	0.42	0.45
Density (kg/m^3)	4019	4081	4251	4312	4441	4493	4709
Velocity (m/s)							
V_L	4215	4205	4190	4106	4038	4017	3939
V_S	2380	2302	2292	2278	2264	2240	2202
Elastic Modulus							
(Gpa)							
C_{11}							
C_{44}	71.4	72.2	74.6	72.7	72.4	72.5	73.1
C_{12}	22.8	21.6	22.3	22.4	22.8	22.5	22.8
B^S	25.9	28.9	30.0	27.9	26.9	27.4	27.4
E^S	41.0	43.3	43.1	42.9	42.1	42.4	42.6
	57.6	55.6	57.4	57.2	56.9	57.4	58.1
Poisson Ratio	0.265	0.286	0.287	0.277	0.270	0.275	0.273
Compliance							
(m^2/N)	1.734	1.797	1.740	1.748	1.728	1.740	3.072
S_{11}	4.392	4.624	4.477	4.469	4.393	4.435	1.368
S_{44}	-4.614	-5.142	-4.986	-4.856	-4.680	-4.774	-3.770
S_{12}							
Debye Temp. (Kelvin)	348	334	331	324	320	314	307

Density of Lead Phosphate compare to Lead Borate



Young's Modulus of Lead Borate and Lead Phosphate Glass



Bulk Modulus of Lead Borate and Lead Phosphate Glass