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Experimental Study of the Mechanical Properties of Silicate Glasses Using Various ratios of Alkaline Earth Oxides

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Abstract

Projects in engineering that requires the use of glasses demand specific mechanical properties so as to guarantee the reliability, availability and the system effectiveness. Therefore, depending on the peculiarity of the system, the type of glasses required largely depends on the ratios of alkaline earth oxide used in the making of the glass. This work therefore, is aimed at establishing the effects of varying the composition of some alkaline earth oxides (calcium + barium +silicate content) in the mechanical properties of silicate glasses. To this end, glass specimens produced in a related work were cut to the desired sizes, washed and dry cleaned to avoid unwanted impurities that may alter our results. The dry cleaned glass specimens were then suspended in an electrically heated tank with steel pipes. The tank was made up of molten sodium chloride salt (NaCl) and the solution was heated for eighteen hours (18 hrs.) at a temperature of 420^{o}C. During the heating, exchange of ions took place in the heating chamber. The compression layer was set at 180µm, at a pressure of – 850 MPa. Our findings showed that in addition to the alkaline earth oxide ratio to magnesia components, the kinetic of alkali ion exchange was largely responsible for strengthening the mechanical properties of glasses. On the application of Vickers hardness indenter, there was a significant increase in the hardness, strength and Young modulus of the glass series A. These findings were further subjected to a confirmatory test using the Ball drop test. The confirmatory test showed a superior remarkable departure in terms of hardness, strength and Young Modulus of the glass series B.

Keywords: Glass, vicker hardness, ion exchange, ball drop, test.

1.0 Introduction

Glasses are naturally endowed with both static and dynamic properties. The dynamic properties which include, connectivity, diffusion and viscosity can as well be referred to as transport properties. The static properties on the other hand include, the density, the refractive index and the molar volume. The choice of glasses for industrial applications depends largely on these inherent properties. As a result of the wide application of glasses in various fields of endeavor, different composition of glass materials and special manufacturing technologies are needed. Some glasses are manufactured to take the form of tubes, rods, spheres, hollow vessels and a plethora of other shapes, glasses made in this form are referred to as technical glasses. They can also be flat shapes or in powdery form, the distinguishing factor is the manufacturing processes, manufacturing methods and the range of compositional earth oxides used. It is therefor, our view to investigate the effects of substituting and varying various rare earth oxides on the static properties of glass formed in this experiment.

This area of research is replete with works both at the local and the international levels most especially research works that has to do with the dynamic properties of alkaline earth oxides. Some of these works include Kjeldsen et al. (2013) who studied the mixed alkaline earth effect in a series of MgO/CaO. The study showed a maximum T-O-T bond and a minimum in the Vickers, micro hardness and glass transition temperature. Similarly, Ashiedu and Akpan (2015) studied the effects of mixed alkaline earth oxides in potash silicate glass and observed that the dynamic properties of silicate oxide glasses can be altered to suit the desired industrial application of such glasses. In a related study, Aleksander, (2016) pointed out that in the formation of glasses using appropriate materials, the scientific application and the technological procedures involved usually affects the mechanical and the optical properties depending on the desired area of application of the glass. The paper added that other areas affected by the use of these procedures includes the hardness, the refractive index, thermal properties, chemical properties and the refractive index of the glasses. Similarly, Quintas et al. (2008) and Zheng et al. (2012) applied different methods to study the impact of the nature of R^+ and R^{2+}cations on two glass structure and melt crystallization tendency during cooling. In doing this, two glass series were prepared by substituting Na^+ and Ca^+ with K^+, Rb^+ Cs^+ or Mg^{2+}, Sr^{2+}, Ba^{2+}.respectively. Their findings showed that the melt crystallization tendency strongly varies with the nature of the alkaline earth during cooling. Also, a decrease in glass stability at critical concentration when heated to a standard temperature of 20 K/min was observed. Klinic and Hand (2015) studied the effects of varying alkaline earth oxide contents of three soda lime silicate glasses. The result of their findings showed an increase in network depolarization when MgO – SiO_2 and CaO - SiO_2 alkaline content is increased at the expense of the silicate content. However, for the MgO – CaO series, network depolarization decreased when MgO dominates the mixtures. Also, Hong et al. (2012) studied Batch - to - Melt conversion process using x – ray diffraction (XRD) and high temperature differential scanning calorimeter (DSC) to ascertain some mechanical properties relevant to industrial applications. Their findings revealed that a 10% higher Modulus and a 20% higher strength were achieved for high Modulus fibre using MgO, CaO and Li2O.in a related development, Hauwa (2008) considered the need for a more coordinated recycling of all or most of the waste associated with glass making. According to the paper, the recycling of these materials will lead to a clean environment, create employment opportunities, and create room for the production of less expensive glasses and other products. Conversely, Henderson et al. studied the compositional differences among glasses made in different parts of the globe with emphasis in glasses made in the Mediterranean region. The paper added that there exists a remarkable distinctive compositional difference for glasses made in different regions using major minor oxides and radiogenic isotopes. Other works that corroborate this finding include but not limited to Freestone et al. (200), Jackson (2005) and Sayre and Smith (1961).

Wang et al. (2016) investigated the effects of adding rare oxides to natural minerals such as wollastone, talc and quartz sand as raw material in the production of fibre glass. The paper reported the result of their findings to include an increase in the crystallization temperature by strengthening the network structure of the fibre. However, the solubility of the fibre is reduced. Also, Palvic et al. (2014) tried to establish the relationship that exist between the insulating properties of glasses and their structural characteristics, by conducting a study on the dielectric properties of glasses over a wide range of frequency and temperatures. Such properties include the dielectric permittivity and conductivity. More so, studies have shown that variables that can affect the fracture toughness of glasses which remained a critical item in the mechanical property of glasses includes, the indentation time of loading, the time lapse in the interval of making the indentation and measuring the crack growth length. Finally, the load of indentation.

2.0 Research Methodology

The glass series A and B produced were cut into the desired sizes washed and dry cleaned using fresh water. The freshly prepared specimen was suspended using steel pipes in an electrically heated steel tank containing molten sodium chloride salt for eighteen hours (18 hrs.) at about four hundred and twenty (420^{o}C) degrees Celsius. Table 1 show the batch composition by mole for the formation of glass A and B series.

Table I; shows the batch composition by mole for the formation of glass

Series	**Glass System**	**Composition**
A	I	$60SiO_220K_2O.20CaO$
	Ii	$60SiO_220K_2O.4MgO.16CaO$
	Iii	$60SiO_220K_2O.8MgO.12CaO$
	Iv	$60SiO_220K_2O.12MgO.8CaO$
	V	$60SiO_220K_2O.16MgO.4CaO$
	Vi	$60SiO_220K_2O.20MgO$
B	I	$60SiO_220K_2O.20BaO$
	Ii	$60SiO_220K_2O.4MgO.16BaO$
	Iii	$60SiO_220K_2O.8MgO.12BaO$
	Iv	$60SiO_220K_2O.12MgO.8BaO$
	V	$60SiO_220K_2O.16MgO.4BaO$
	Vi	$60SiO_220K_2O.20MgO$

Similarly, table 2 shows the respective weight of raw materials used for 100 g of both series A and B glasses. Since the kinetic of alkali ion exchange in glass during heating is a critical variable in the determination of the mechanical properties of glasses, we then use the expression as shown in equation 1.

$$D_i = \frac{D_{Na} D_K}{D_{Na} N_{Na} + D_K N_K} \quad (1)$$

Where D_i = self-diffusion coefficient of i

N_i = fractional molar concentration of i

In the surface, when $N_{Na} = 0,\ \overline{D} = D_{Na}$

In the deep when $N_K = 0,\ \overline{D} = D_k$

However,

Table 2: Weight of the Raw Material used for 100g of Glass

Series	Glass system	Weight of raw material for 100g glass				
		SiO_2	**K_2CO_2**	**$4MgCO_3.Mg(OH)2.5H_2O$**	**$CaCO_3$**	**$BaCO_3$**
A	1	54.54	41.78	--	30.28	--
	2	55.06	42.18	5.93	24.46	--
	3	56.60	42.59	11.98	18.52	--
	4	54.47	43.01	18.15	12.47	--
	5	56.70	43.43	24.44	6.29	--
	6	57.26	43.87	30.86	--	--
B	1	42.10	32.28	--	--	46.12
	2	44.48	34.08	4.79	--	38.96
	3	47.11	36.09	10.15	--	30.94
	4	50.07	38.36	16.19	--	21.92
	5	53.43	40.93	23.03	--	11.70
	6	57.26	43.87	30.86	--	--

3.0 Results and Discussion

The results of our findings showed that the density of both series decreases with increases in the alkaline earth oxide content used for the experiment as seen in figure 1. The glass series B (MgO-BaO) indicated the highest density as against glass series B whose value was lower. From the graph, there was a significant decrease in the density of glass series B with the decreasing BaO addition. Similarly, the density of series A decreases slightly with decreasing CaO addition as seen in figure 1.

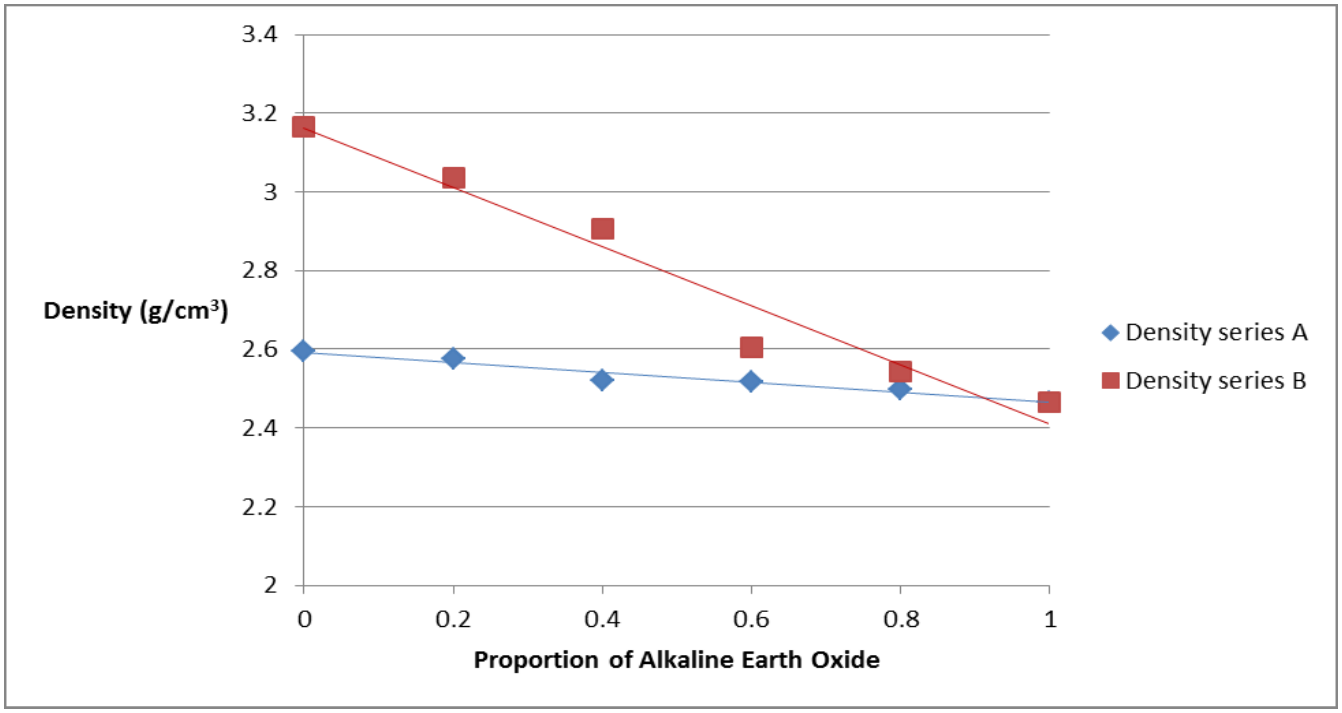

figure 1: Average density value for Series A and B Glass

For the glass transition temperature of series A glass as against the alkaline earth oxide proportion, it was observed that the curve was fairly stable until at 0.4 gm of a mixture of magnessiun and calcium oxide were added, at this point, a sharp drop in temperature of the mixture was observed. Again,When the content was increased to 1.0 gm, the transition temperature increased rapidly as seen in figure 2.

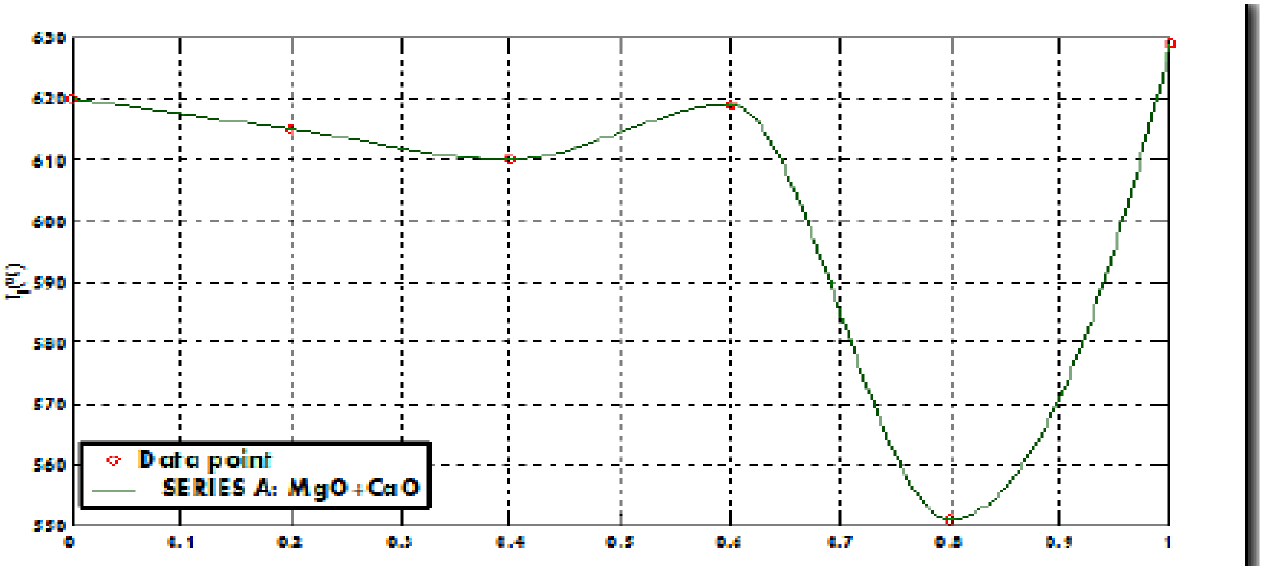

Figure 2:Glass transition temperature of series A against varied alkaline earth oxide

For the series B glass, the transition temperature inceases uniformly as the mixture strenght increases as shown in figure 3.

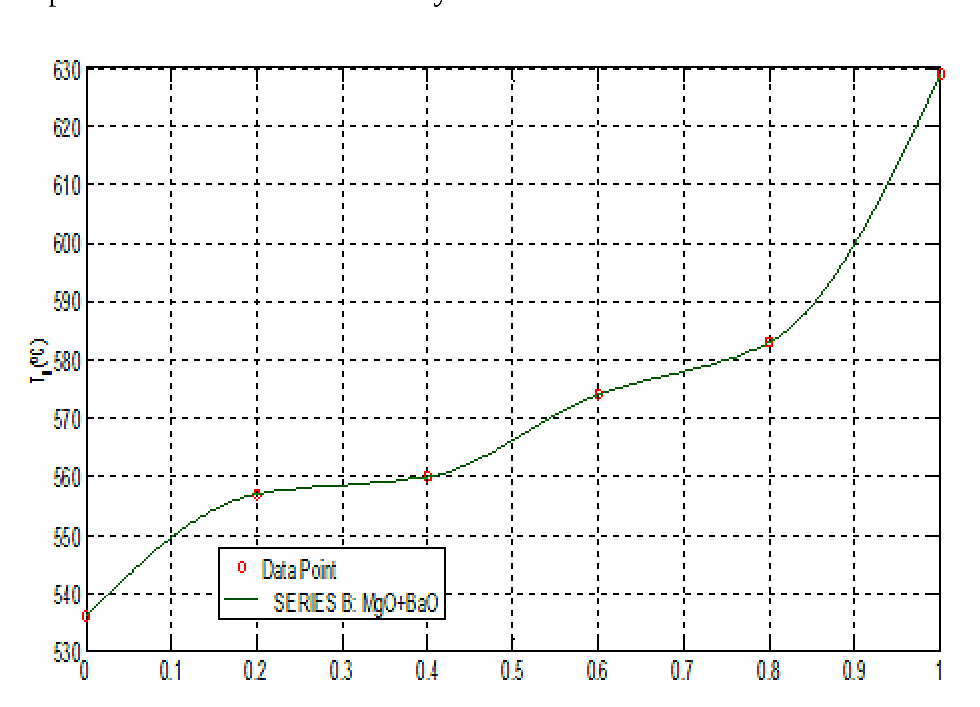

Figure 3: Glass transition temperature of series B against varied alkaline earth oxide

As seen from figure 4 through to figure 8, it was observed that there exist a paternistic correlation in the nature of decrease in the hardness, brittleness, young modulus, shear modulus and the poison ration when there exists an increase in the ratio of the magnesia content of the total alkaline earth oxide.

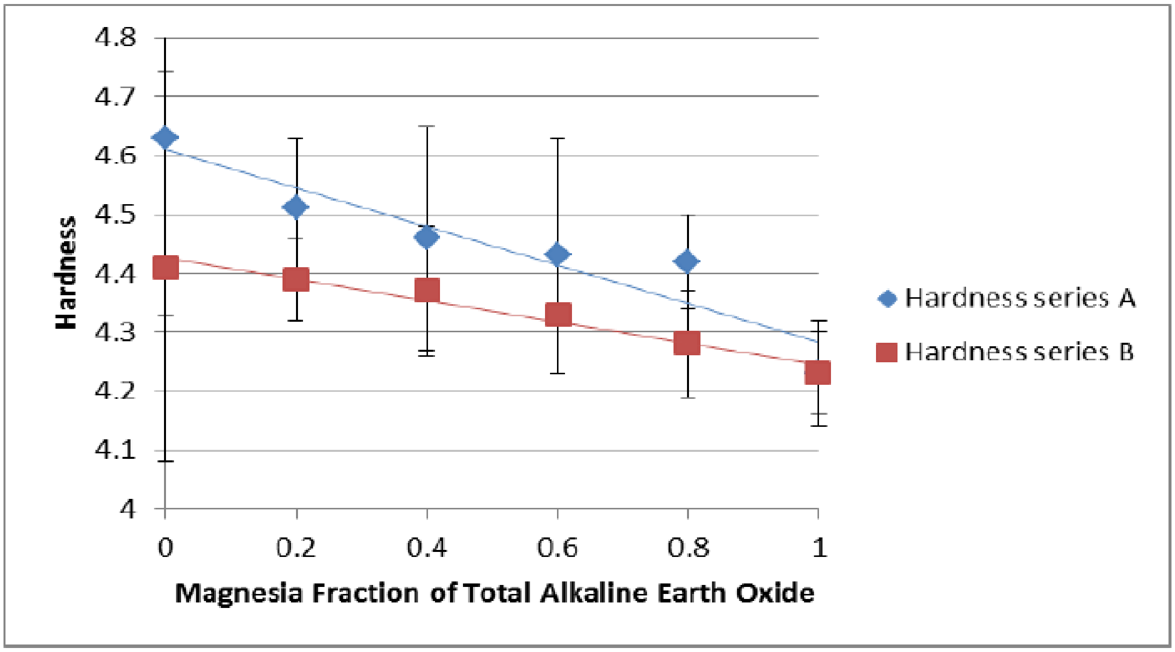

Figure 4: plot of hardness against magnesia fraction of total alkalie earth oxide

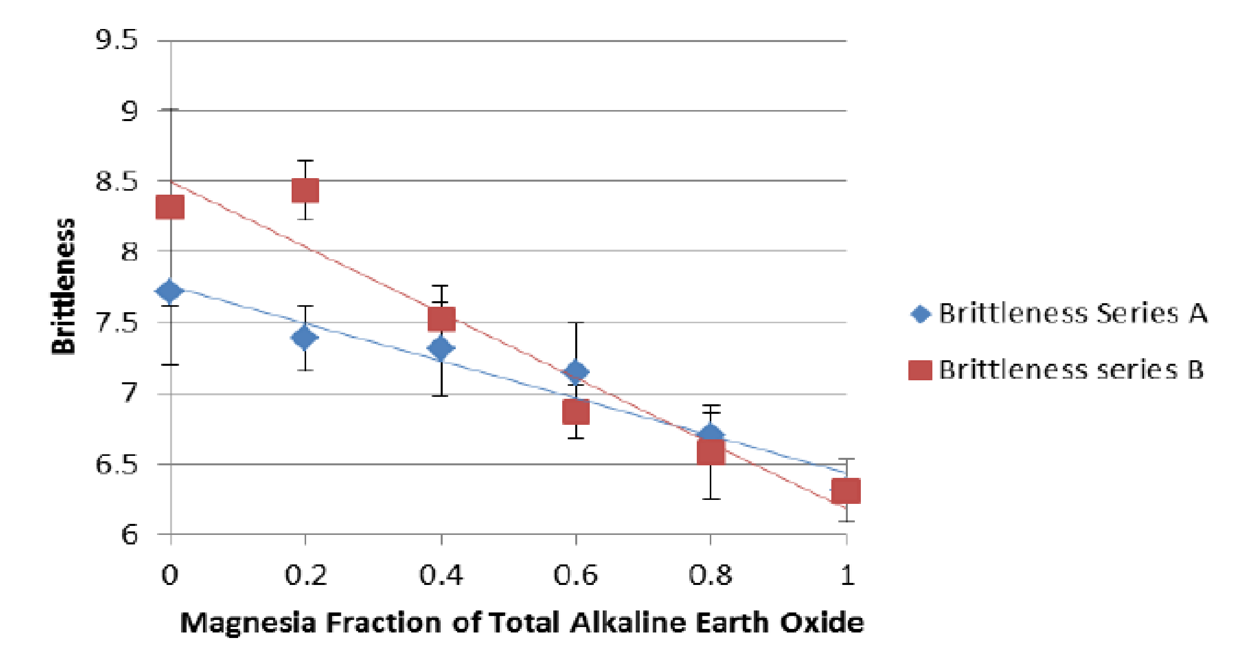

Figure 5: plot of britleness against magnesia fraction of total alkalie earth oxide

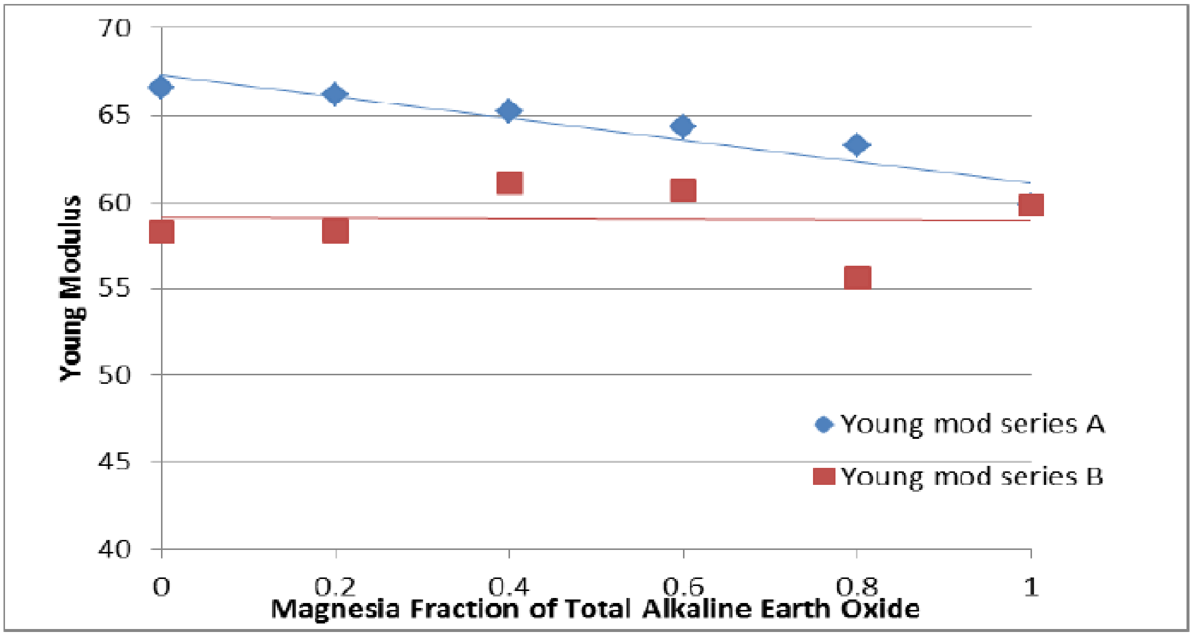

Figure 6: plot of young modulus against magnesia fraction of total alkaline earth oxide

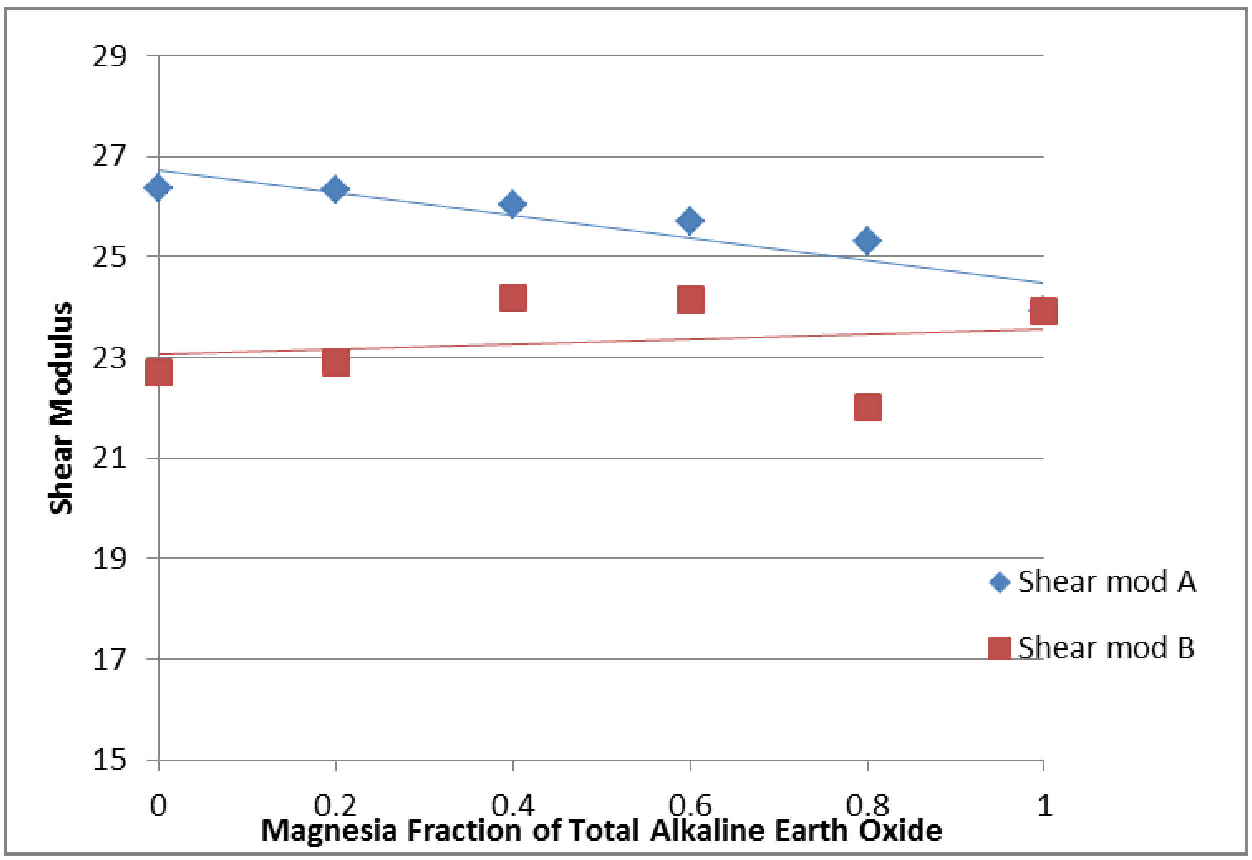

Figure 7: Plot of Shear Modulus against Magnesia Fraction of Total Akaline Eeath Oxide

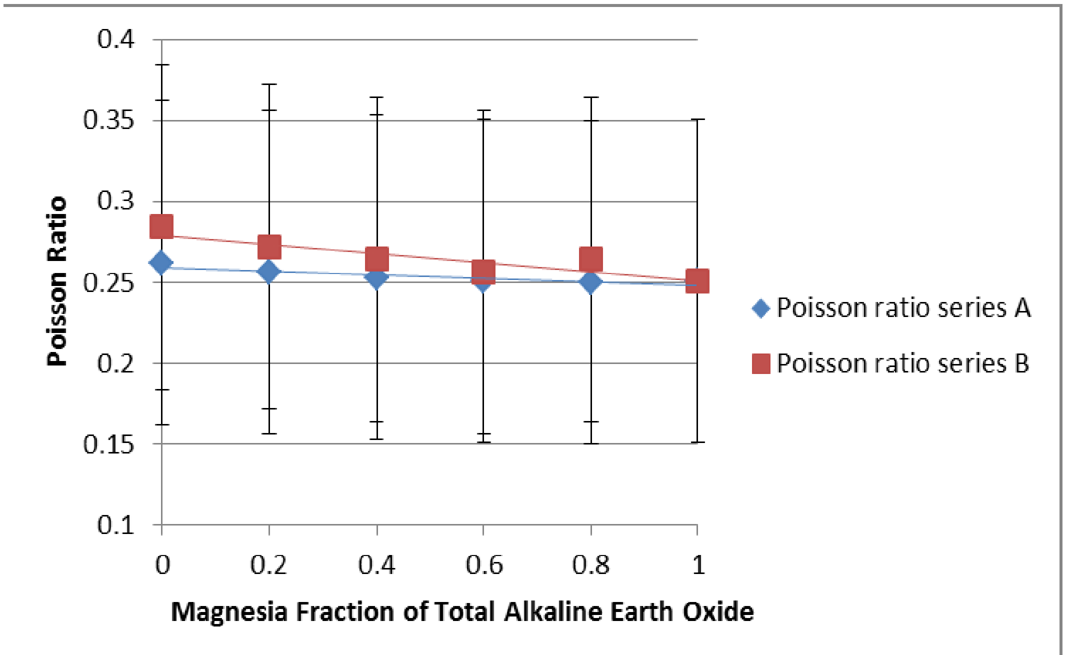

Figure 8**:** plot of poisson ratio against magnesia fraction of total alkalie earth oxide

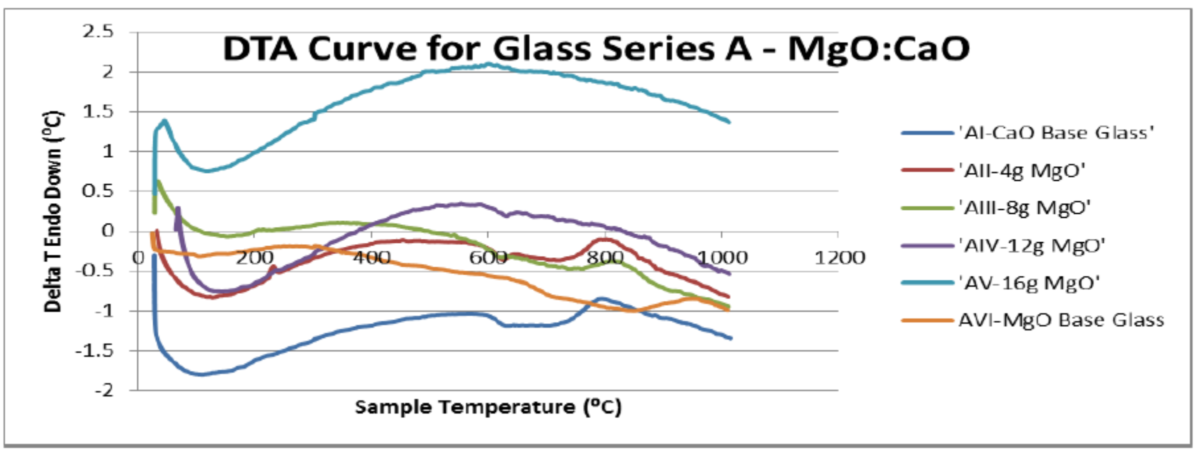

Figure 9: DTA curve for glass series A

During the formation of glass in the series, exchange of ions dominates all other processes; the interstitial spaces created are filled by these ions, most often the larger ions. The filled spaces become densified, thus increasing the density of the glass. Hence, the larger the ions formed, the denser the glass obtained from the series. Similarly, the yield strength was affected by the indentation process. The glass sharing that took place during indentation causes the smaller ions to occupy more spaces in the interstitial region making the glass denser in nature. This quality thus creates room for increased yield strength of glass formed in the process. Experimentally, the brittleness of the series A glass increased as the molar ratio of CaO+BaO to that of SiO_2 increased.

Hardness of both series A and B glasses increases with an increase in the calcium+barium +silicate content. Toughness of glass series A decreases with increasing calcium+barium +silicate content. Other mechanical properties that increased with increasing calcium+barium +silicate content, are the Young Modulus, the Poissonratio and the Shear Modulus. However, glass series B displayed irregular pattern on addition of calcium+barium +silicate content.

Conclusion

The findings of this study revealed that mechanical characteristics necessary for scientific, domestic and industrial applications are directly affected by the ratio of the alkaline earth oxides to the magnesia component as depicted in figures 1 to 8. The mechanical properties affected include the hardness of the glass, the brittleness, young modulus, shear modulus and the Poisson ratio. Generally, the result of the study, showed an inverse relationship between the mechanical properties of glasses and the ratio of the magnesia component in the alkaline oxide mixture. Therefore, depending on the choice of glass application, ranging from aircraft wind shield, hard disk used for external drives, Hurricane and earthquake resist architectural windows to laboratory glasses among others, the ratio of the alkaline earth oxides to that of magnesia oxide can be varied to adequately accommodate the desired domestic, scientific and industrial applications of glasses.

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