

## Effects of Soaking Temperature, Time and Particle Sizes on Hardness and Density of Waste Glass

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### ABSTRACT

The study investigated the effects of soaking temperature, time and particle sizes, on hardness and density of soda-lime silicates glass. The Experiment was conducted with the heat-treating temperature range between 500-1400°C and soaking time of 1hour, 2hours and 3hours. One hundred and eighty samples of amber and green glasses were employed. Sixty samples for each mesh size of 120µm, 150µm and 180µm were used in the experiment, which reveals that the optimum particle sizes, and temperature are 120µm and 1100°C respectively. Whereas the optimum soaking time of 2 hours produced the greatest yield of hardness with mesh 120µm for both amber and green glass samples. It was observed and deduced that finer particles produced greater hardness than larger particles; probably the finer particles have larger surface areas. The hardness of the melted glass was measured according to the ASTM C (1327-03, 2008). Conclusively soaking temperatures, times and particle sizes have greater effects on the property of hardness and density. Whenever heat treatment was increased there was corresponding increase in hardness with drastic increase in density.

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Soaking time, heat-treatment, temperature and particle sizes.

### INTRODUCTION

Glass has a unique combination of desirable properties for various engineering application such as hardness and density. Hardness is an important mechanical property of material that is define as a resistance of solid objects to permanent deformation under pressure (Samuel, 2009). In other words, it is a measure of a material's resistance to abrasion. While you might sometimes hear strength and hardness discussed interchangeably, they are in fact separate properties. Strength refers to the resistance of a bulk material to applied pressure, while hardness refers to the resistance of a surface to small sharp projectiles (Arun, *et al*, 2014).

Hardness has attracted much interest since it enables a tailoring of materials chemistry to yield enhanced mechanical properties; For example, the hardness of glass is a crucial issue in the development of scratch and fracture resistance, glass covers for personal electronic device. These include flat panel display glasses for TV, computer monitors, and touch screen devices, surface mechanical properties emerge as important materials properties (Souza, 2014).

These properties are evaluated using the method of micro indentation of glasses by relating hardness to scratch resistance, and relating the crack resistance (or load for crack initiation) to

fracture resistance (Chinn, 2009). A physical understanding of deformation processes is crucial for establishing accurate predictive model of indentation related properties for hardenability in glasses.

More recently, a promising approach for predicting the glass hardness from chemical decomposition has been established which is based on the temperature dependant constraint theory (Erol, *et al*, 2007, SmendsKjae, 2010). Here we extend the techniques to the glassy state at room temperature showing excellent quantitative agreement between predicted values of hardness and experimental measurement. The temperature dependence of constrain provides a natural explanation or the difference in scaling behaviour between liquid state properties at higher temperature and glassy state at a low temperature.

The effect of various particle sizes of melting temperature depends on surface area. The smaller particle size has a higher surface area than the larger particle size, hence the faster the reaction (Jekada, 2013). Density is also one the most important property of glass that provides information about the constitution or structure of glass. Density of soda-lime-silica glasses ranged from 2.40-2.45 g cm<sup>-3</sup> with an average value of 2.42 g cm<sup>3</sup> and that of borosilicate glasses ranged

from 2.02-2.33 g cm<sup>3</sup> with average value of 2.19 g cm<sup>3</sup>. Glass densities are determined by an ASTM standard method involving floatation in liquids but also the density of the glass fragments can be measured by displacement (Annual Book of Standards 2008; Vitz *et al*, 2014).

#### MATERIALS AND METHOD

Amber and green waste glass samples employed for this research were obtained from Nigerian breweries PLC Kaduna and potassium carbonate CB4458651 P.A analytical grade. Facilities used were a model of three set of ISO 331011 BS 410/11 Standard sieves, 180 pieces of refractory crucibles, timer, hand-crusher, thermocouples, electrical scale balance and a milling machine

Samples of amber and green glass were obtained and beneficiated to remove contaminants such as ceramics, metals closure, wrappers, foils and debris. Then samples were crushed and milled. Three standard meshes of

different sizes were used to grade cullet sizes of 120µm, 150µm and 180µm for each colour. The three meshes are according to the BS 2975 standard grain sizes for making glass sand. The electrical balance was used to weigh 10g of the samples in 30 crucibles for each mesh size for both green and amber glasses. Each sample was mixed thoroughly with 1g of potassium carbonate which served as flux and heated to different soaking temperatures and times. Samples were cooled in the furnace down to the ambient temperature and were then removed in preparation for measurements. Scaling on the surface of the annealed samples was carried out and filed to create flat and even surface. The flat surface was then polished with emery paper to obtain very smooth surface required for hardness test which was carried out in accordance with ASTM C (1327-03, 2008). Glass densities were determined by an ASTM standard method involving floatation in liquid.

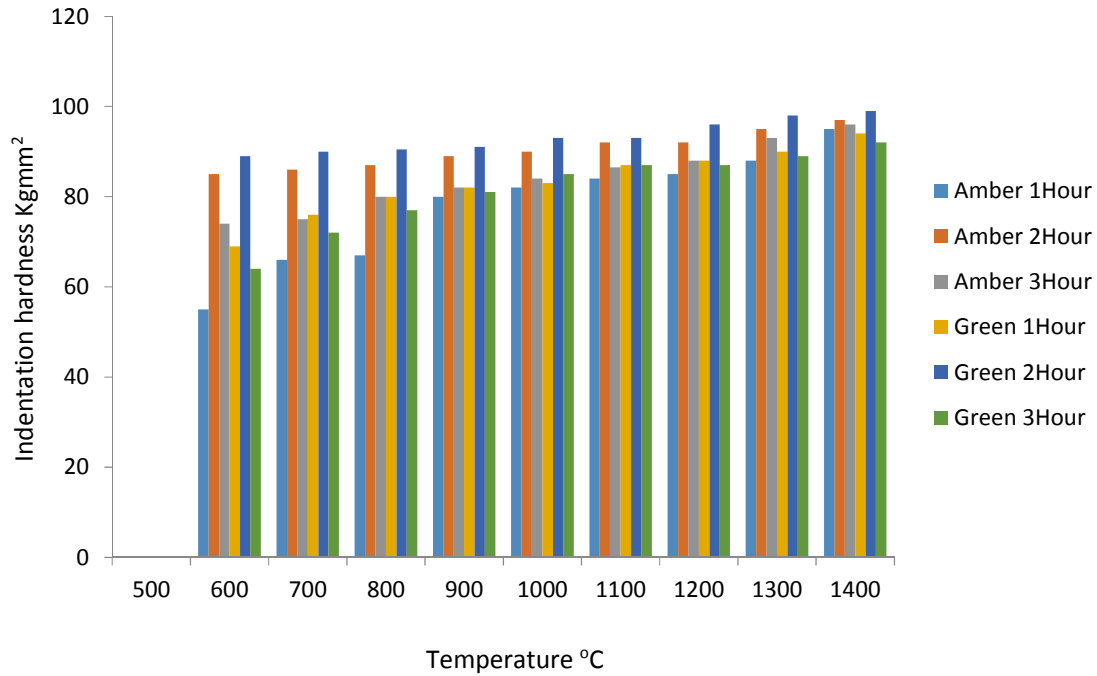
**Table 1:** Chemical Composition of Waste Glass Samples

Oxides	% CONCENTRATION	
	Amber	Green
Na <sub>2</sub> O	5.125	4.876
MgO	0.498	0.663
Al <sub>2</sub> O <sub>3</sub>	2.891	2.565
SiO <sub>2</sub>	71.242	71.227
P <sub>2</sub> O <sub>5</sub>	0.000	0.000
SO <sub>3</sub>	0.351	0.403
Cl	0.081	0.084
K <sub>2</sub> O	2.643	1.847
CaO	13.032	14.075
TiO <sub>2</sub>	0.286	0.217
Cr <sub>2</sub> O <sub>3</sub>	0.012	0.238
Mn <sub>2</sub> O <sub>3</sub>	0.032	0.038
Fe <sub>2</sub> O <sub>3</sub>	2.595	3.058
Zno	1.125	0.643
Sro	0.087	0.066

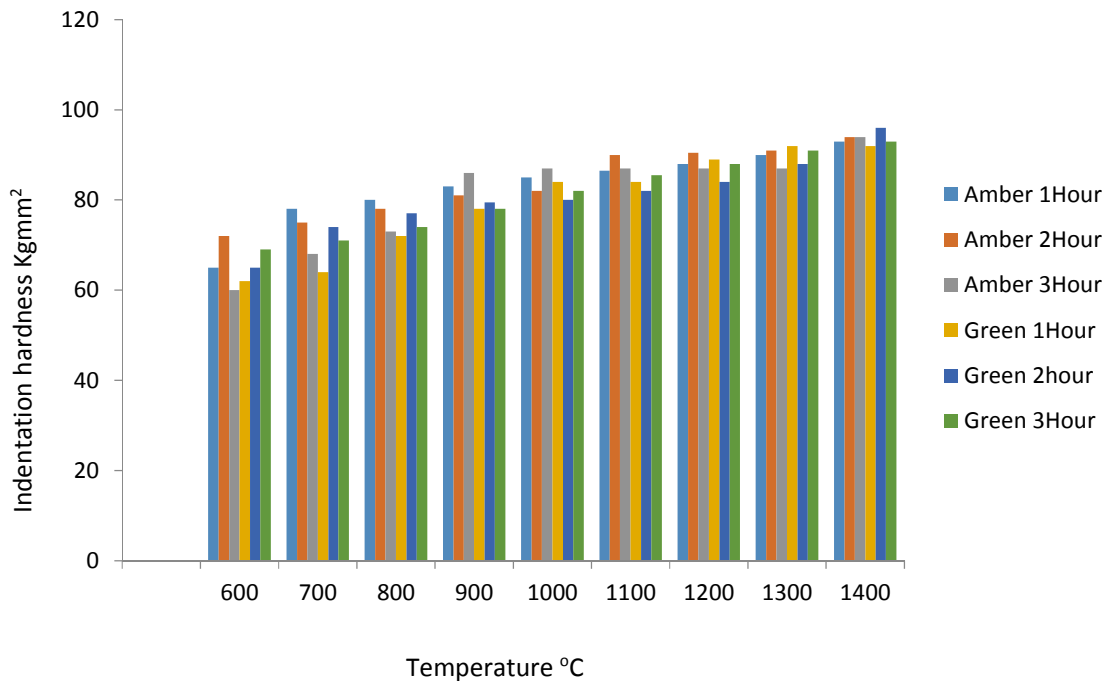
#### RESULTS AND DISCUSSION

Where by A1 = Amber soaking time of 1 hr, A2 = Amber soaking time of 2 hrs, A3 = Amber

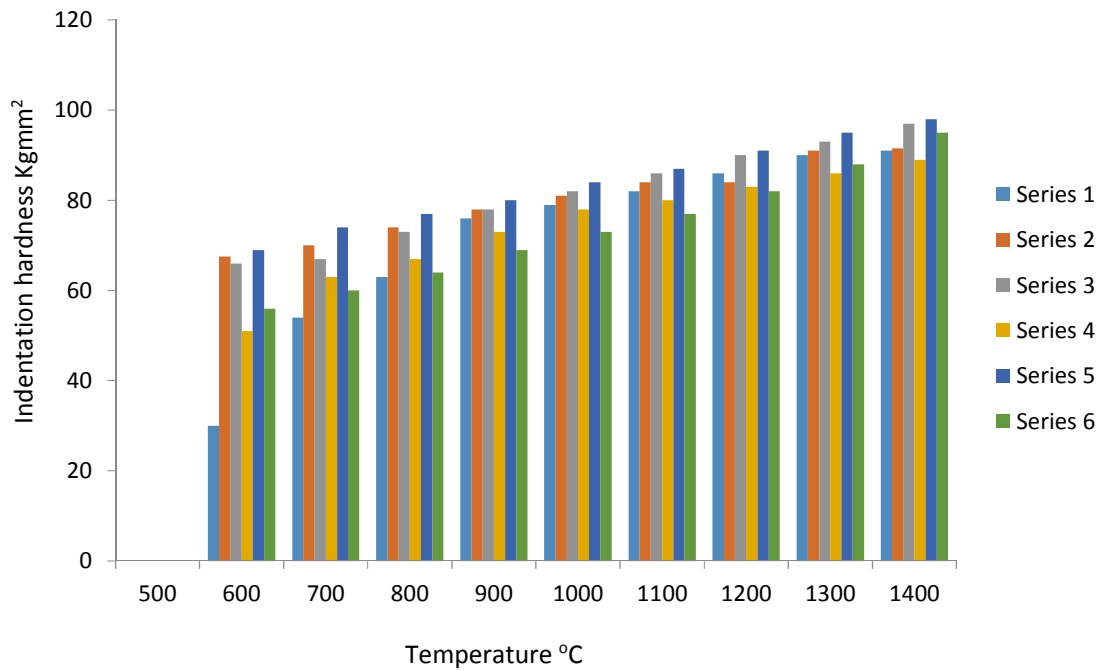
soaking time of 3 hrs, G1= Green soaking time of 1 hr, G2 = Green soaking time of 2hrs, G3 = Green soaking time of 3 hrs



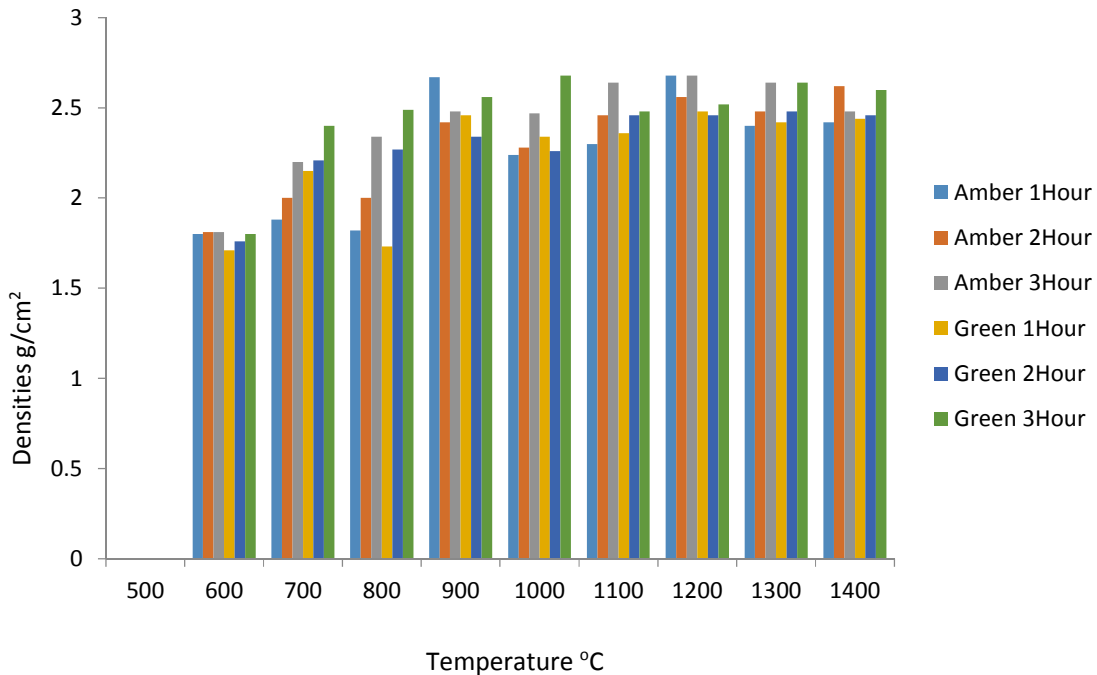
**Figure 1:** Results of Hardness for Mesh Size 120µm for Temperatures Ranging from 500°C to 1400°C for 1 Hour, 2 Hour and 3 Hours



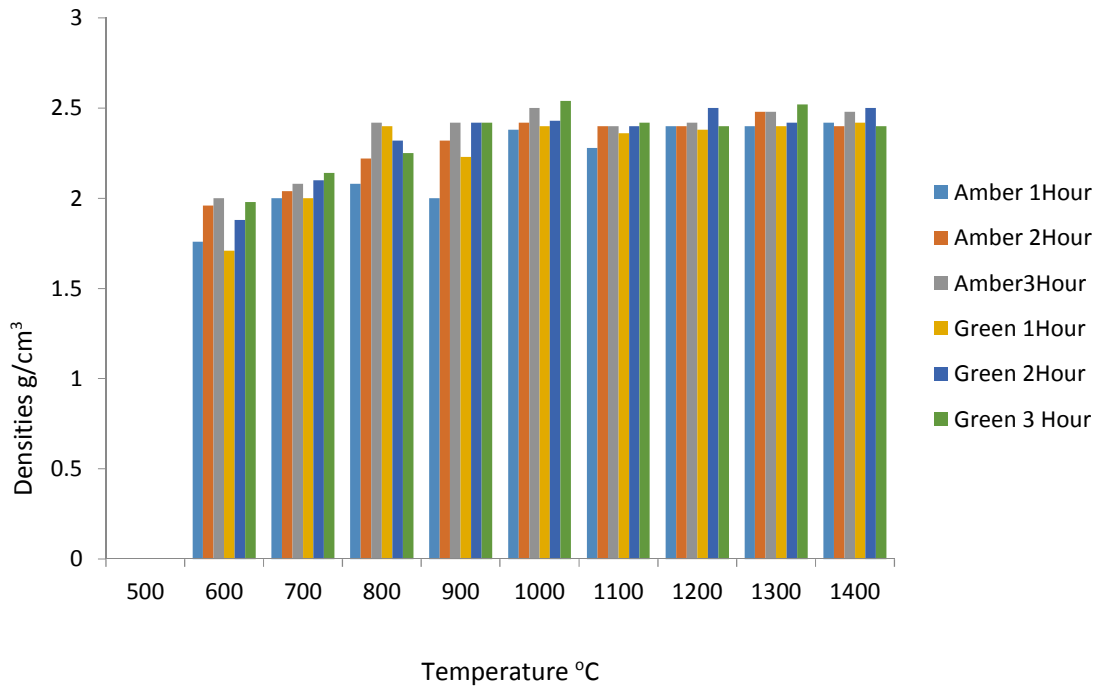
**Figure 2:** Results of Hardness for Mesh Size 150µm for Temperatures Ranging from 500°C to 1400°C for 1 Hour, 2 Hour and 3 Hours



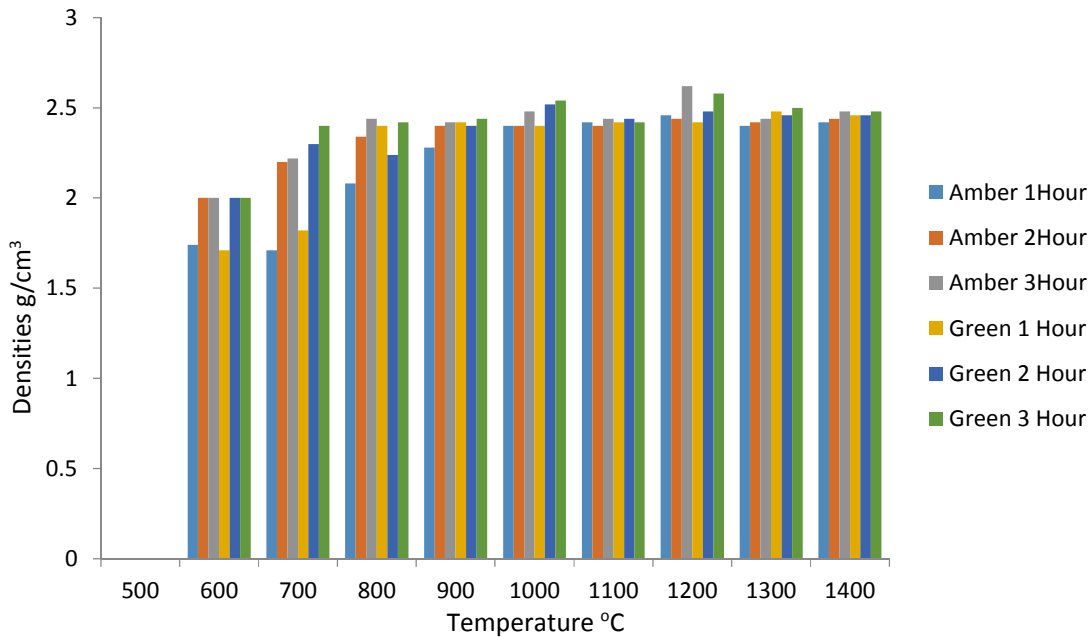
**Figure 3:** Results of Hardness for Mesh Size 180 $\mu$ m for Temperatures Ranging from 500°C to 1400°C for 1 Hour, 2 Hour and 3 Hours



**Figure 4:** Densities of Melted Glass Samples of Particle Mesh size of 120 $\mu$ m



**Figure 5:** Densities of Melted Glass Samples of Particle Mesh size of 150 $\mu$ m



**Figure 6:** Densities of Melted Glass Samples of Particle Mesh size of 180 $\mu$ m

## DISCUSSION

Table 1 present the chemical compositions of waste glass samples which are similar to that of soda lime silicate glass and the results of hardness and densities test of the samples are presented in Figures 1, 2, 3, 4, 5 and 6. Figure 1, 2 and 3 shows the effects of various particle sizes of 120  $\mu\text{m}$ , 150  $\mu\text{m}$  and 180  $\mu\text{m}$  with soaking times of 1 hour 2 hours and 3 hours and also temperatures range from 500 - 1400  $^{\circ}\text{C}$  on hardness.

Hardness increases gradually with increases temperature, from 800 $^{\circ}\text{C}$ -900 $^{\circ}\text{C}$  there was significant increase in hardness from 67kg/mm<sup>2</sup>-80kg/mm<sup>2</sup>, then thereafter it maintained a steady increase in hardness as the temperatures increases. A2 followed the same tread with a steady increase in hardness with the corresponding increase in temperature between 600 $^{\circ}\text{C}$ -1100 $^{\circ}\text{C}$ . The hardness of about 92kg/mm<sup>2</sup> was maintained between 1100 $^{\circ}\text{C}$ -1200 $^{\circ}\text{C}$  thereafter hardness increased gradually with increase in temperature to 97kg/mm<sup>2</sup>1300 $^{\circ}\text{C}$ -1400 $^{\circ}\text{C}$ . A3 indicated that 1200 $^{\circ}\text{C}$  there was steady increase in hardness as temperature increases to 1400 $^{\circ}\text{C}$  hardness achieved was 95kg/mm<sup>2</sup>. The same general trend was observed with sample of G1, however, 13kg/mm<sup>2</sup> of hardness was obtained higher than that of A1 at corresponding temperature. At temperatures 900 $^{\circ}\text{C}$  – 1000 $^{\circ}\text{C}$  the hardness was maintained at 83kg/mm<sup>2</sup>. Consequently, as the temperature increase above 1000 $^{\circ}\text{C}$  to 1400 $^{\circ}\text{C}$  the hardness increases to 95kg/mm<sup>2</sup>. As shown in G2 having a slightly higher value than what was obtained in A2, the hardness in G2 increase steadily to 93kg/mm<sup>2</sup>for temperature of 900 $^{\circ}\text{C}$  -1000 $^{\circ}\text{C}$  and from 1100 $^{\circ}\text{C}$  - 1400  $^{\circ}\text{C}$  the hardness increases gradually to about 98kg/mm<sup>2</sup>.

A hardness of about 63.5kg/mm<sup>2</sup>was recorded in G3 at 600 $^{\circ}\text{C}$  which has less value as compared what was obtained in A3 at the same temperature. Between 600 $^{\circ}\text{C}$  - 1100 $^{\circ}\text{C}$  there was a steady increase in hardness to 87kg/mm<sup>2</sup>. Also between 1100 $^{\circ}\text{C}$  and 1200 $^{\circ}\text{C}$  the hardness was maintained at about 87kg/mm<sup>2</sup> and thereafter there was increase in hardness to 92kg/mm<sup>2</sup> as the temperature increases from 1200 $^{\circ}\text{C}$  - 1400  $^{\circ}\text{C}$  as shown in G3 of figure 1.

Figure 2, A1 shows that hardness was observed to be directly proportional to increases temperature which maintain a steady increase in value of hardness to 94kg/mm<sup>2</sup> at a temperature between 800 $^{\circ}\text{C}$  - 1400 $^{\circ}\text{C}$ . It indicated in A2 value of hardness 91kg/mm<sup>2</sup> was obtained which is lower compared to hardness value obtained in A1 at the

same temperature. Figure 3 follows the same trend as obtained in figures 1and 2 indicating increase in temperature is directly proportional to increase in hardness. However, particle sizes play a vital role since the particle size is dependent on the surface areas. The small particle size has a higher surface area than larger particle sizes, so the reaction of the melting occurs faster.

As shown in Figure: 4, 5 and 6 the average density value of A1, A2, A3, G1, G2 and G3 were in the range 1.7g/cm<sup>3</sup> to 2.62 g/cm<sup>3</sup> with a temperature range from 600 $^{\circ}\text{C}$  to 1400 $^{\circ}\text{C}$ , and effects of particles mesh size of 120 $\mu\text{m}$ , 150  $\mu\text{m}$  and 180 $\mu\text{m}$  on their densities. The increase in density was observed to be directly proportional to the increase in temperature. The variation in densities values in some instances were as results of temperature fluctuation. Densities values of the glass samples were measured in accordance to the ASTM C (20-00, 2005) at a range of 1.72g/cm<sup>3</sup> – 2.68g/cm<sup>3</sup> however, an average density of typical soda lime silicate glass is being put at 2.37g/cm<sup>3</sup> these values are in line with the values obtained by Boyd et al (1986).

## CONCLUSIONS

The optimum temperature and particles size were found to be at 1100 $^{\circ}\text{C}$  and 120 $\mu\text{m}$  and the optimum soaking time of 2 hours produce a greater hardness with mesh sizes of 120 $\mu\text{m}$  for both amber and green glass melted samples. It is evident from the foreseen that increase in temperature resulted in increase in hardness and densities of the samples. The parameters reported meet the desire result which stated that hardness must ultimately be governed by the resistance to the individual deformation processes occurring during indentation and densities of the glasses has meet all qualities requirements for ordinary soda-lime glasses.

## RECOMMENDATIONS

1. Use of the hardness samples sintered between the range 700 $^{\circ}\text{C}$  - 1000 $^{\circ}\text{C}$  for the constructions of tiles, drainages glass blocks and also those samples that melted in the range 1000 $^{\circ}\text{C}$  - 1400 $^{\circ}\text{C}$  could be used for light bulbs, bottles, fibre glass and window panels.
2. Consider the possibilities of using the optimum mesh size of the hardness result obtained in this research work to produce glass ceramic products with lower power consumption to reduce greenhouse effects.



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