Effect of Tempering Temperatures on the Mechanical Performance of Soda-Lime-Silica Glass

B. Oji [1 *] and O. Aletan[1]

[1] *Department of Glass and Ceramics Technology, Federal Polytechnic P.M.B 5351, Ado-Ekiti, Nigeria.*

** Corresponding Author: Tel: +2347039582911; E-mail: ojibabatunde01@gmail.com*

ABSTRACT

This work seeks to investigate the effect of tempering temperature on the mechanical performance of soda-lime glass. The glass samples were cut into 130 x 30 x 4 mm and heated at varying temperature ranges of 570, 590, 610, 630 and 650^{o}C respectively in a muffle furnace. The samples were then tempered by rapid ooling in a bath of oil and allowed to cool to room temperature. Micro graphical examination, hardness and flexural tests were carried out on the tempered glass samples and result obtained shows that the internal structure of the tempered glass were better enhanced at temperature of 570^{o}C, while the hardness value was also found to be better at this temperature. The hardness value records it lowest when the sample was heated to a temperature of 650^{o}C while the result obtained from the flexural strength test shows that the bending strength of the tempered glass samples were reduced compared to the control sample.

Keywords: Mechanical; Micro graphical; internal structure; flexural strength. Tempered, hardness, structure.

1. INTRODUCTION

Over the year's soda-lime-silica glass have continued to find application in architectural designs, automobiles, as continuer vessels and as casement for commodity items due to their relatively lower forming temperature, lower cost, structural modification, chemical stability, hardness and easy manipulation. Although glasses are materials that are versatile and include such classes as silica glass, borosilicate glass, soda-lime glass and lead glass however of all this classes the soda-lime glass is still one of the most patronized. Although glass are generally referred to as being strong, with a relatively high compressive strength, low tensile, flexural and striking strength [1] but their qualities depends on their mechanical properties which are mostly influenced by defects inherent in the glass that arises during forming, rapid cooling or handling. This defect reduces the mechanical potency of the glass thus lowering the glass surface quality, resistance and increases brittleness during usage [2].

For optimum service applications various researchers have conducted studies on how to enhance the strength of glasses. For instance [3] reported that damaged glasses can be strengthened by coating methods. [4] also reported tempering as another strengthening method for glass and explained that this process puts the glass surface under tension stresses created by the tempering effect which makes glass to crumble to pieces rather than into sharp jagged pieces. Also [5] - [7] described tempered glass as a safety glass developed by subjecting normal glass to thermal or chemical treatment to enhance their strength and that a fully tempered glass can be 4 or 6 times stronger than an annealed glass while a heat strengthened glass is about twice stronger than an annealed glass. According to [8] glass tempering can be achieved by heating the glass material to its annealing temperature and then rapid cooling, which helps for contraction of the glass surface and increases the hardness when the internal parts is still hot and fluidly. This process deforms and permits tensile stress in the glass surface to relax. When the internal part cools and contracts

the surface will be below its strain and cannot flow, therefore glass is put in compression by the interior contractions. The surface is therefore below its strain point when the internal part cools and contract. These contraction taking place in the internal part, places a compression on the surface and in return increases the strength of the glass. The glass is not only strengthened by filling the flaws but also protected against future damage [6,7].

This research therefore seeks to examine the effect of varying tempering temperature, on mechanical performance of soda-lime-silica glass by heating the glass to different temperatures and then quenching to room temperature in a bath of oil.

2. Material and Methods

2.1. Glass Characteristics and sample preparation

The material use to carry out this research is soda-lime-silica glass (flat glass) of 4mm thickness which was acquired in the as-received state. The glass in its as-received state was first cleaned to remove dirt from the surface and thereafter 26 samples of glasses of 130x30x4mm dimensions were measured and cut out of the flat glass piece. The cut out samples were kept and used for the research. Table 1 and 2 shows the mean chemical composition of the soda-lime-silica glasses as reported by [9] and the thermal temperatures with samples designation

Table 1: The mean chemical composition and percentage mass of Soda-lime-silica glass [9]

Oxides	**SiO2**	**CaO**	**Na2O**	**MgO**	**Al2O3**	**Fe2O3**	**Others**
% Mass	71.56	7.93	13.73	4.21	1.32	0.097	1.163

Table 2: Sample designation of glass samples with tempering temperatures

Samples	Control	A	B	C	D	E
Temperatures	——	570^0C	590^0C	610^0C	630^0C	650^0C

2.2 Thermal Tempering

The thermal tempering of the glass samples were carried out above 530^{o}C which is the transition temperature of the glass. This is achieved by heating the soda-lime-silica glass samples to different temperatures in a muffle furnace at temperatures of 570^{o}C, 590^{o}C, 610^{o}C, 630^{o}C and 650^{o}C and then soaked at these temperatures for some minutes. The thermally toughed glasses were then quenched in a bath of viscous 40 SAE Oil. This process increases the strength of the glass by creating a compression stress at the glass surface through the cooling and contraction taking place at both the exterior and interior of the glass which is balanced by the internal tensile stress. The thermal temperatures were varied to determine the temperature at which thermally tempered soda-lime-silica glass can exhibit the optimum mechanical performance when subject to different tempering temperatures.

2.3 Measurements

Material properties such as hardness, flexural behavior and microstructure analysis were tested and studied to evaluate the influence of varying the thermal tempering temperatures on the mechanical performance of the glass samples.

2.4 Microstructure Examination

The morphological (structure) examinations of the developed samples were determined using a light reflection microscope. The micrograph image were shown using a 100 magnification size

and then snapped at a computer screen joined to the microscope. These morphological evaluations were carried out on all the developed samples, that were thermally tempered and the control.

2.5 Hardness Test

The hardness values of the thermally tempered glass samples were measured using ASTM E384 laid down procedure on a Vicker micro hardness testing machine of LM 700 AT model. The control sample and thermally tempered glasses were loaded on the hardness machine one after the other with a load of 980.7 mN applied on them at a dwelling time of 10secs. The micro hardness of the samples was thereafter detected via microscope through a light beam incident on the glass samples.

2.6 Flexural Strength Test

The flexural strength of the samples was determined using Instron universal testing machine in accordance with ASTM 8M-91 laid down procedure at a room temperature of 25ºC. The developed samples were mounted on the two support rods of the machine operating at a strain/load rate of 5mm/min and are positioned strategically so that the projecting ribs of the samples are at equal distance from the two supporting rods. A load was thereafter applied on the sample to get an increased stress rate of 0.2 N/mm per sec. The fracture forces of the glasses were recorded as the samples fractured under the influence of the applied load. The machine being automated produces the flexural strength readings of the samples automatically.

$$\text{Flexural strength} = \frac{3\,FL}{2\,bd^2}$$

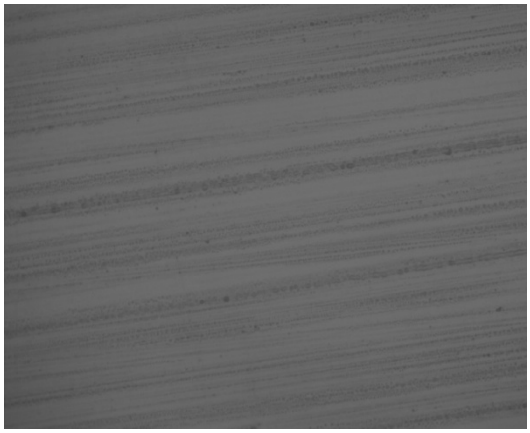
Where F represents the breaking force (N), L distance (mm), b is breath of samples (mm), and

d is sample thickness (mm)

3. Results and Discussion

3.1 *Microstructure Evaluation*

Figure 1 – 6 shows the micrograph images of the thermally treated samples and the control samples. Figure 1 show a plate of untreated soda-lime-glass with non-uniform wavy lines while figures 2 – 6 displays the optical images of the thermally tempered glasses representing samples A – E. From the result it can be observed that samples A and B, glasses tempered at 570^{o}C and 590^{o}C shows a fine grain like structural dispersion within the glass. Samples C and D which are glasses tempered at 610^{o}C and 630^{o}C also display some sort of coarse grain structure, with a homogenous structural arrangement of the grains structures after tempering. However sample E, glasses tempered at 650^{o}C also shows a structural consistency that is similar to samples B and D but the uniformity of grain dispersion is not as higher in samples E like we have in B and D



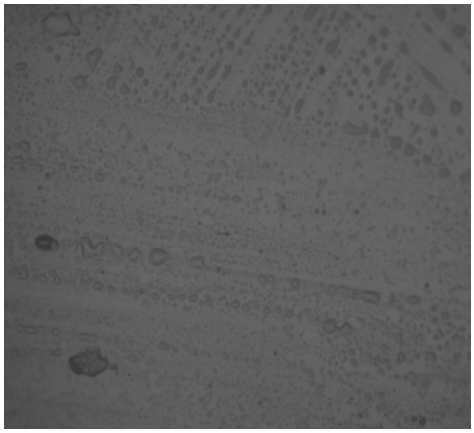


Fig 1: Micrograph Control sample

Fig 2: Micrograph of thermallly treated at 570^{o}C

Fig 3: Micrograph of thermallly treated at 590^{o}C

Fig 4: Micrograph of thermallly treated at 610^{o}C

Fig 5: Micrograph of thermallly treated at 630^{o}C

Fig 6: Micrograph of thermallly treated at 650^{o}C

3.2 *Hardness Evaluation*

Table 3 represents the Vickers hardness results of the control sample and thermally tampered glasses. From the result it was observed that the control sample has a hardness value of 400.6 HV which represents the basis of comparing the hardness performance of the thermally treated samples. It was observed from the result that samples A and B treated at 570^{o}C and 590^{o}C had the highest hardness results of 496.6 and 444.8 HV as compared to the control sample while

samples C, D and E treated at temperatures of 610^{o}C, 630^{o}C and 650^{o}C showed a hardness value of 410.9, 395.8 and 395.7 HV representing a reduction in hardness value as compared to the control sample. This therefore shows that their hardness values were lower than the control. The increase in hardness observed in samples A and B may be attributed to the presence of fine grains structures developed within the material during the tempering process.

Table 3: Result for Hardness Test of Un-tempered Glass (Control Sample) and Thermally tempered Soda-Lime Glass Samples

S/N	LABEL	READING 1		READING 2		READING 3		AVERAGE	
		HV	HRC	HV	HRC	HV	HRC	HV	HRC
1	A	491.7	48.5	495.8	48.8	502.5	49.3	496.6	48.8
2	B	410.0	41.8	434.0	44.0	489.0	48.3	444.8	44.7
3	C	402.0	41.0	413.2	42.1	417.5	42.5	410.9	41.9
4	D	420.3	42.7	345.4	35.0	421.9	42.9	395.8	40.2
5	E	412.2	42.0	371.2	37.9	403.8	41.1	395.7	40.3
6	CTR	400.6	40.8	438.3	44.3	428.2	43.4	420.7	40.9

3.3 Flexural Evaluation

Figures 7 – 8 shows the flexural strength and maximum flexural strain of the thermally treated glasses. From the result in figure 7 it was observed that sample A tempered at 570^{0}C had the

highest flexural strength of 34.87 Mpa while samples B, C, D, E tempered at 590^0C, 610^0C, 630^0C and 650^0C showed a considerably low flexural strength when compared to the value recorded in sample A. It was however observed that the flexural strength of all the produced samples were low.

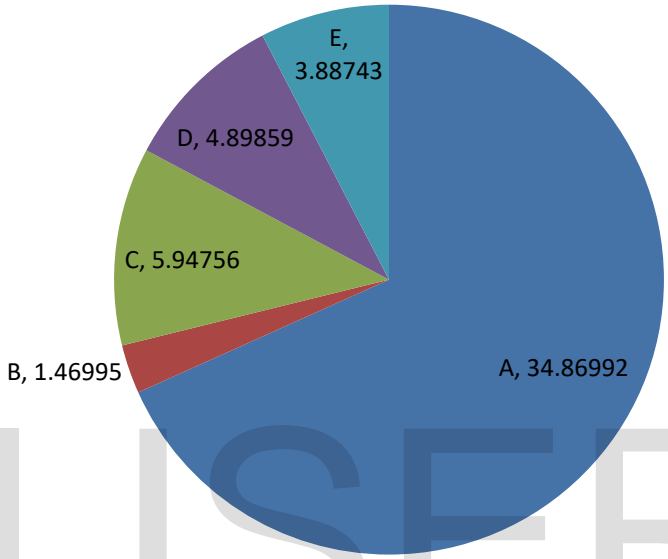


Fig. 7: Flexural strength Pie-chart of thermally tempered glasses

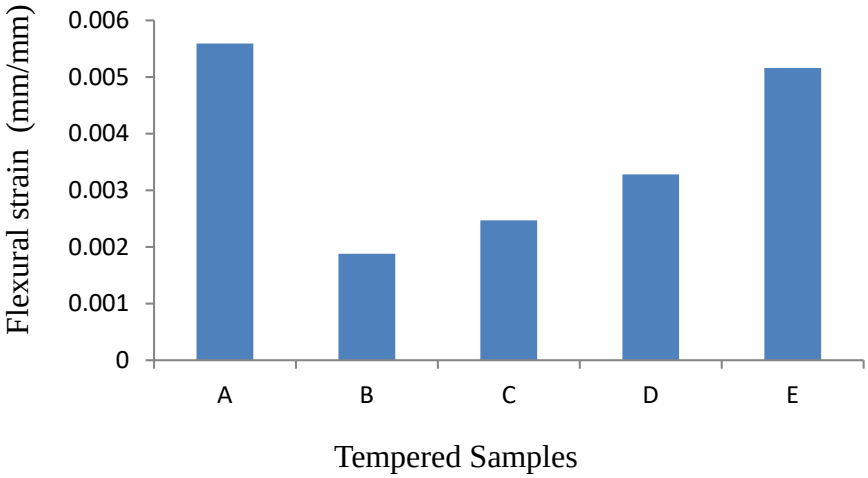


Fig.8: Flexural strain of thermally tempered glass samples

Figure 8 also represents the maximum flexural strain of the produced samples. The result shows that samples A displayed the highest strain value, while from samples B to E the strain values tend to increase in an ascending order. However their strain values were observed to be lower than the strain value of sample A. The strain chart shows that the rigidity of the glass material affected its flexural behaviour and this may have accounted for the reduction in flexural property observed in the result.

4.0 Conclusion

The following conclusions can be drawn from this research:

i. Soda-lime-silica glass tempered at a temperature of 570^0C had the highest hardness values.
ii. Microstructures of the samples were enhanced with sample A showing a better grain structure.
iii. Thermal tempering of the soda-lime-silica glass helped enhanced the hardness values of the glasses tempered at 570^0C and 590^0C
iv. Flexural strength of the tempered glasses were observed to decrease with increased temperature with samples tempered at 570^oC having the highest flexural strength of 34.87Mpa

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