The Effect of Raw Materials and Production Conditions on Glass Quality

Ayo S. Afolabi, *Member, IAENG*, Olugbenga T. Johnson and Ambali S. Abdulkareem

Abstract— **The deviations of glass quality from specifications, which are caused by batch losses during transportation and variations in the starting raw materials, have been investigated. In this study, 20 samples were collected from the production line and characterized in terms of XRF analysis, density and cord measurement. The results from the XRF analysis showed considerable deviations in raw materials components from set points and also confirmed changes in the time for the glass to set in the forming stage. Considerably low density shifts were noted and the cord rating remained unchanged due to the undersized quantities of raw materials lost per batch through the system. The varied compositions of raw materials resulted in exaggerated shifts in density, suggesting alterations in the properties of glass. The shift in glass properties results in difficulties during the melting and bottle formation processes, and is potentially dangerous as the containers formed from this glass could shutter under pressure when filled with product.**

Keywords— **batch, glass, cord measurement, raw materials, XRF.**

I. Introduction

Glass is a super cooled liquid and a product of fusion which has been cooled to a rigid state without crystallization [1]. Glass has a structure of a liquid but behaves like a solid. It was referred to as a 'congealed liquid', in which the process of congealing refers to no change in structure, the molecules are not rearranged but that the liquid has stiffened to the point the viscosity is so high that the body behaves like a solid [2].

The raw materials used for the production of glass have constant chemical composition, optimal granulation, minimal humidity percentage, and minimal content of harmful additives. The raw materials are silica sand, soda, calcite, dolomite (raw material of calcium carbonate and magnesium carbonate), and feldspars (raw materials in the form of fine sand). Aluminium trihydrate, sodium sulphate, chromite, coal, etc. are used as auxiliary raw materials which are used as dyes and clarifiers of the melt [3].

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The raw materials are offloaded into storage silos from which they are weighed automatically according to the batch recipe programmed in the EME scada. The weighed material is then transported to the mixer via buckets elevators and conveyor belts (Fig. 1). The homogeneous batch then meets with cullet along the transportation route to furnace holding bins. The batch is charged into the furnace where it is melted and refined. Forming then draws the molten glass into the bottle making machine. The newly formed bottles are lead into the annealing lehr. The lehr cools the bottles from 600^{o}C - 100^{o}C in a controlled manner to remove the stresses caused by uneven cooling. This ensures safe handling. The bottle containers are conveyed pass inspection equipment that ensure quality specifications are adhered to and for individual coding with production data. Good quality containers are then loaded for bulk palletizing and shrink wrapping before being dispatched to the customer.

Raw Materials

Storage, weighing, mixing

↓

Melting

Refining, homogenising

↓

Forming

Shaping

↓

Annealing

Controlled Cooling

↓

Inspection and Packaging

Warehouse

Fig. 1: Flow sheet for the glass manufacturing process

This paper aims at investigating the effect of the batch plant conditions and variations of raw materials compositions on the quality of glass produced.

II. Experimental

In order to assess the composition and homogeneity in the batch being conveyed from the batch plant, 20 bottle samples were collected from the flint furnace W4 on production line W4/1 during normal operation on a daily basis. These samples were collected after the annealing lehr, and were free of defects, gas and solid inclusions.

Before the density measurement, the glass bottle is checked for seeds and blisters and then cut to the required dimension. The density of the samples was determined using the Density Comparator (DC) [a laboratory device that provides a fast, reliable measurement of glass density]. The method used for density analysis is the sinking method. The principle involves when the solution is heated, the sample that is denser will sink to the bottom of the test tube first before the less dense sample. The temperature of the solution at the time the sample reaches the drawn reference line will be recorded. Density is then calculated for net increase or decrease (using equation *i*) and the temperature recorded at which the sample crossed the reference line will be compared to that of the previous sample (usually the one for the previous day if density is conducted on a daily basis).

$$\Delta\rho = \Delta T \times 0.0018 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots i$$

For XRF analysis, gob samples are required or the base of bottles can be shaped and sized into a suitable sample for analysis. The gob is a drop of molten glass formed by the cutting of the stream of glass as it flows from the furnace Forehearth. Gobs are the molten glass fed into the forming machines to be moulded into ware (bottles, drinking glasses, etc). Additionally, a cord analysis was done on the samples using a Polariscope. The sample was immersed in mono-chlorobenzene solution which was in a Petri-dish. The dish was carefully rotated and viewed through the eye piece of the Polariscope. Cords are then identified, which are usually represented by blue and yellow colouration. The blue colour signifies tension in the glass, while the yellow colour signifies compression. These cords would then be rated using the compensator.

III. RESULTS AND DISCUSSION

A. Density Measurement

The density measured ranged from 2.4977 to 2.4986 g/cm^3 during the experiment period. For the period between the 16th to the 19th, an increase in 0.0008 g/cm3 was noted. This increase is acceptable as it presented a shift of less than 10 units per day. It was noted that the concentration of lime during that period increased from 11.19 to 11.27%. Lime tends to increase density as its component is CaO, the molecular mass of Ca is 40, therefore the more in the glass the more dense it would be.

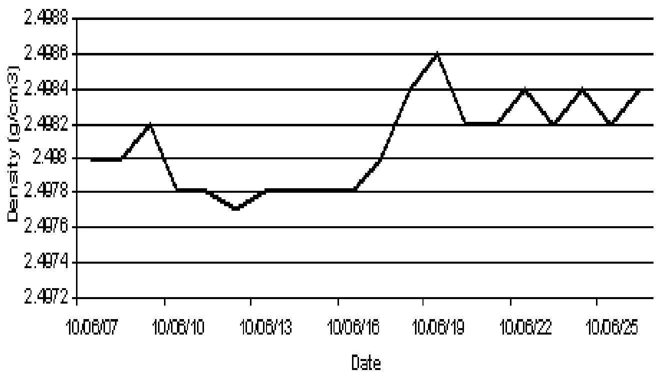

Fig. 2. Variation of glass density with time.

B. XRF Analysis

The three main raw materials that affect the chemical and physical properties of glass are silica sand, Limestone and Soda ash. From the XRF data obtained from graph of SiO_2, Al_2O_3 and Na_2O were drawn to enable an extensive look at variations that occur with regards to the 3 mentioned. No compositional changes were done on the flint glass recipe but noticeable changes daily are observed.

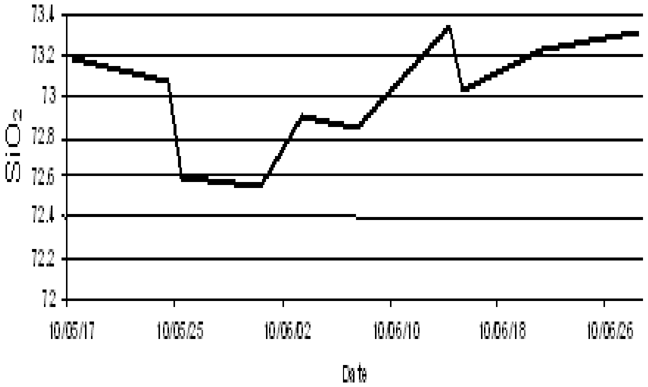

Fig. 3. XRF analysis results of SiO_2 concentration in glass.

The ideal compositional concentration of SiO_2 in glass is specific at 72% - 73%. From the figure 3 it is noted that the concentration is within the specified range, and does spike on occasion about the 73% mark. This is still acceptable provided it does not go over the 74% limit. Few losses if any can be attributed for sand. Note that sand has large particle size and will not be easily segregated from the batch.

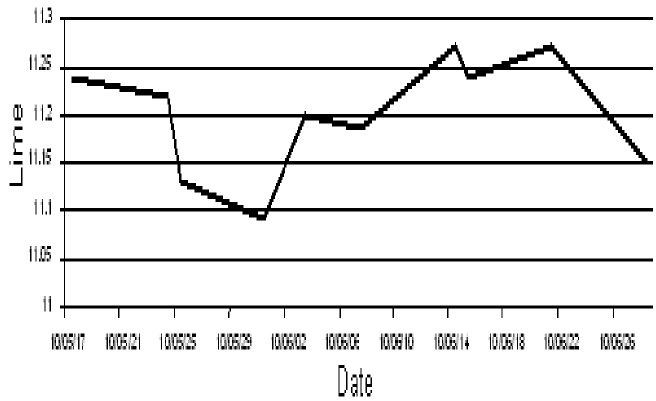

Fig. 4. XRF analysis results of CaO concentration in glass.

The aim of lime concentration in glass is 11.6%. In the graph presented in Fig. 4, the lime concentration is between 11.3% and 11.05%. Less lime than aim is evident in the glass, although still in tolerance. Lime has finer particles and could be the major material lost during batch transportation due to batch segregation.

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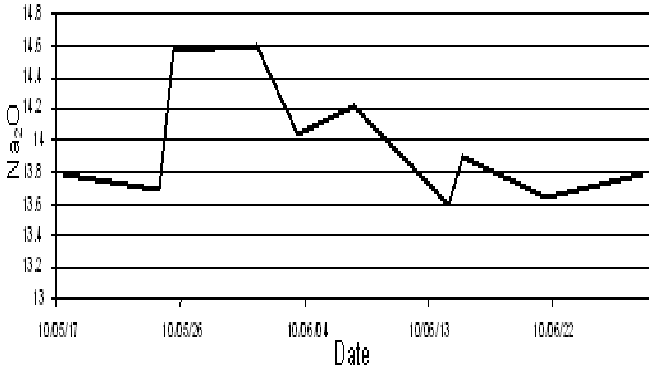

Fig. 5. XRF analysis results of Na_2O concentration in glass.

The aim of Soda concentration in glass is 14%. A range of soda concentration in the results obtained and also represented in Figure 5, is from 13.8% to 14.6%. Not much loss during transportation can be concluded here. Variations in soda increase the workability of the glass. Meaning that a slight increase in the soda, the less viscous the glass becomes and the more time in seconds the forming process has to form the bottle before the glass stiffens. Generally the forming department prefers the cooling time of 100 – 101 seconds.

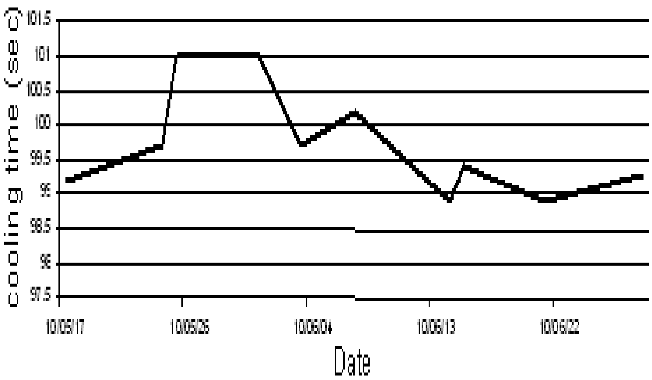

Fig. 6. XRF analysis results of forming cooling time.

Note the similarity of the soda (Fig. 6) and cooling time (Fig. 7) graph. The illustration is a good confirmation that variations in the soda ash composition in glass are directly proportional to the changes experienced in the forming cooling time.

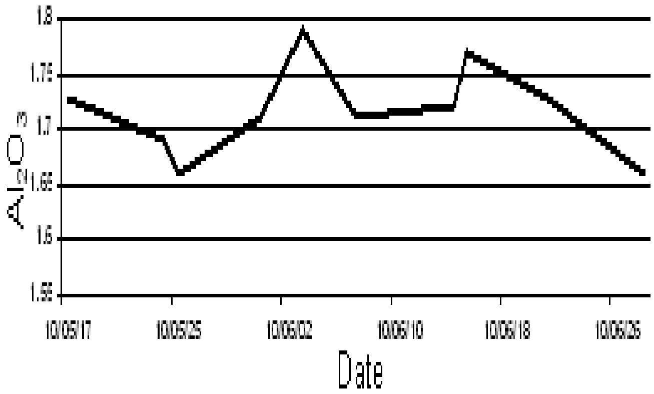

Fig. 7. XRF analysis results of the Alumina concentration in glass.

The aim of 1.76% is stipulated for alumina concentrations. It is noted that alumina only reached aim on 2 separate occasions of the experiment period. The lowest result recorded is that of 1.66% on the 25th May. Feldspar is a source of alumina in the glass making process and has fine particles. Feldspar is possibly the other material lost in large quantities during the transportation of batch.

C. Cord Rating

The cord ratings for all samples were ‘A-‘, meaning that there was no cord and the sample passed. Therefore all bottle produced from the glass will not fail when pressurized.

IV. CONCLUSION

Although the batch losses that result from spillages in the batch plant are significant, the raw materials lost per batch do not alter the batch composition immensely to affect chemical and physical properties of the glass. The investigation conducted highlighted the XRF analysis variation from aim, and also verified that the variations were within specifications. The density shifts were all within the tolerance of 10 units shift per day, which is recommended. The cord ratings were all the favourable A- rating, meaning that the glass is good to be dispatched to the customer.

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