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RESEARCH PAPER

UTILIZATION OF CULLETS FOR THE PRODUCTION OF GLASS TILES THROUGH KILN CASTING

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ABSTRACT
The study explored the technique of kiln casting of glass as a means of recycling glass for aesthetic and functional purposes. Some disposed glass bottles were collected and processed through crushing, milling and sieving to particle sizes of 60, 80 and 120 mesh sizes. These particle sizes were batched and fired in an electric kiln to temperatures of 1050°C and 1180°C. The study revealed that the 60 mesh and 80 mesh specimens fired at 1180°C gave very good translucent effect with rich clear colour. It was observed that the sample that had addition of colouring oxides gave the best result when it was double-fired. The results of the study revealed that the two major parameters that were investigated in this research, (temperature and particle sizes), had an effect on each other and that they were very important for the study. The study concludes that glass recycling through kiln casting presents an avenue for producing glass tiles for functional and aesthetic applications.

Keywords: *Cullets, kiln casting, glass tiles, recycling, melting temperature*

INTRODUCTION

In Ghana, dumping waste in landfills is a common method for the disposal of solid waste. Where population density is relatively high, the amount of waste produced by industries and the consuming society presents a challenge (Puopiel, 2010). It is important that all socio-economic activities or productive engagements by members of the society are in harmony between the people, earth and profit, to reduce extensive damage to the natural environment (Merticaru *et al*., 2010). Corporate management and governmental organizations are seriously engaged in practical pollution control, waste management and recycling to reduce the devastating effects of waste on the natural environment (El-Hagger, 2007). Recycling of waste materials is a major component in providing sustainable industrial development together with the concept of creating employment. Under the quality production methods, glass recycling is considered one of the most important recycling approaches (Lee and His, 2002; Greer, 2013).

Glass is among the most abundant materials on earth obtained primarily from silica. It is combined irregularly with calcium, potassium and magnesium atoms that vitrify into a transparent and stable matter (Ozer *et al*, 2015). Glass has acquired an extensive usage due to its rust-proof, waterproof and transparent properties (Larsen *et al*, 2009). The most familiar, and historically oldest types of glass are based on the chemical compound of silica (SiO_2), the primary constituent of sand (Gaines and Mintz, 1994). Raw silica, (SiO_2), is a material with very high melting temperature of 1710°C. The term glass in popular usage is often referred to glass type that is of the material silica, which is mostly used as window glass and glass bottles. Most of the ordinary glass products that appear in containers and sheet forms are made from the type called the soda-lime glass composed of 72% silica (SiO_2), 14.2% soda (Na_2O), from sodium carbonated (Na_2CO_3), 10.0% lime (CaO), 2.5% magnesia (MgO) and 0.6% alumina (Al_2O_3) (Ojovan, 2004).

Glass products appear in varied types based on the material composition. It is an amorphous (non-crystalline) solid material which is often transparent with widespread practical, technological, and decorative applications. Examples are windowpanes, beverage containers, table wares, and optoelectronics (Babcock *et al*, 1998). Melting is by far the most energy intensive phase in the production of glass, because large quantities of the material must be heated to high temperatures (Gaines, 1981). This high melting temperature makes glass production uneconomical and capital intensive.

The high demand for energy for the production of glass, thereby, makes recycling the best option for saving energy and reducing cost of production (Babcock *et al*, 1998). The glass to be recycled is crushed into fine particles called cullet. Manufacturing glass from the raw material stage needs high energy consumption but recycling glass components results in approximately 25% less energy consumption (Willerup, 1976). The cullet is mixed with a quantity of raw ingredients to form a batch which melts at a lower temperature than the raw ingredients. Addition of various colouring oxides also helps to further lower the melting temperature of the batch and to give the batch the desired colour effect (Beveridge *et al*, 2003; Babcock *et al*, 1998).

There are different methods of producing glass including; blowing, drawing, float, casting and many others. Most of these methods are industrial and mechanical with very sophisticated machinery. Kiln casting of glass is an important, less laborious technique that involves the melting of cullet in mould for the production of functional and aesthetic objects using simple kilns. One of the most important properties of glass is its ability to be recycled infinite number of times without change in quality. Unlike paper and other products, no loss in purity is observed if only the glass is well cleaned and sorted by colour. The end products of glass has a healthy, natural and easy to clean properties (Myhre *et al*. 2011).

In Ghana, a lot of glass products in the form of clear, green or brown beverage bottles, glass jars and glass sheets are left indiscriminately in the environment (Puopiel, 2010). The waste products usually become nuisance to the environment; causing land degradation and breeding grounds for mosquitoes. Ghana's glass recycling explorations can only be seen in the area of glass bead production. Despite the opportunities available in turning these waste products into economic and artistically useful forms; not much research has been done in this respect in Ghana. This study therefore sought to experiment the possibility of turning some recyclable waste glass into useful products through the kiln casting technique.

MATERIALS AND METHODS

Material and processing

The primary materials employed in the study were glass bottles and colouring oxides. Other auxiliary materials employed include kaolin and ball clay. Plain glass bottles of the soda lime glass type were collected; all labels and stickers were removed, and bottles were washed with clean room temperature water and dried in the sun for eight hours. The bottles were broken with hammer to sizes that could be fed through the jaw crusher. The broken bottles were further crushed with the fine jaw crusher (jaw crusher type that produces finer particles of about 40 mesh size). The crushed glass particles were pulverized into finer particles sizes using the disc pulverizer. The 25kg glass particles were milled in the disc pulverizer for one hour in order to obtain the required fineness (Fig. 1). The resultant glass particles were sieved through the 120, 80 and 60 mesh sizes for batching.

Making of the mould for the glass tiles

Clay moulds were formed for melting the glass particles. The clay was pug-milled and kneaded after which slabs of 6cm thickness were rolled out. The slabs were cut and joined to form rectangular shaped moulds with the inner perimeter measuring 10 cm x 8 cm x 4 cm. A different mould measuring 9 cm x 7 cm x 2.5cm on the inside was also formed (Fig 2). The moulds were allowed to dry for one week to bone dried state and were fired at the temperature of 1180℃ to stabilize the mould. Kaolin was mixed with water and the slip was used to coat the inside of the mould after which they were allowed to dry in the sun for 20 minutes (Fig. 3). The kaolin served as a releasing agent for the glass tiles after firing them in the kiln.

Experimental procedure

Three different specimens (batches) of cullet were filled into the moulds and fired to two different temperatures to determine their outcome. Two types of firing were carried out in this study, which were the single and double firings. The single firing involved the firing of the cullets together with the powdered oxides once in the kiln (Fig. 4). The second was done twice, first by firing to 1050ºC after which colouring oxides were added for the second firing

Fig. 1: Glass particles

Fig. 2: Clay moulds

which matured at 1180ºC. These two temperatures were chosen because the available kiln was set to these fixed temperatures.

Experiment 1: Single firing

In this experiment three different specimens; 60 mesh size, 80 mesh size and 120 mesh sizes of the cullets (batches) were filled into the clay mould and fired at 1180ºC. The percentage of the colouring oxide that was added to the cullet was 0.1%. The glass particles were first mixed together manually in a bowl with spoon by starring for two minutes before they were filled into the moulds in designed patterns. Three different types of oxides that were used included, cobalt for blue, copper for green and iron for red. The glass particles in the moulds were fired in an electric kiln once at two different temperatures, one at 1050ºC and the other, at 1180ºC for 10 and 12 hours respectively. The fired glass tiles were then carefully removed from the moulds after they were cooled to room temperature in the kiln. The edges of the glass tiles were polished with grinding stone to remove the sharp edges.

Experiment 2: Double firing

In this process the specimens (batches) without the colouring oxides were filled into the moulds and fired to 1050ºC. At this temperature the glass particles were partially melted after the specimens were cooled down to room temperature. The partially melted glass were painted over with the paste obtained from the mixture of water and the colouring oxides. The second firing was carried out at temperature of 1180ºC, after which the specimens were cooled to room temperature. This option of double firing was considered because the single firing produced the unanticipated results. The edges of the glass tiles were again polished with grinding stones to remove all the sharpness.

RESULTS AND DISCUSSION

Experiment 1: Single firing

In experiment 1, three different specimens

Fig. 3: Fire clay moulds coated with kaolin slips

Fig. 4: Unfired glass particles with colouring oxides

(batches) 60 mesh, 80 mesh and 120 mesh sizes were fired at temperatures of 1050ºC and 1180ºC. The results show that tests conducted on specimens 60 mesh did not melt at all at 1050ºC, while 80 and 120 mesh sizes at the same temperature came out partially melted and appeared matte. The colouring oxides melted and fused together with the glass without any definite design (Figs. 5 and 6). These results showed that the specimens 80 and 120 mesh sizes did not melt properly and showed visible rough texture at the edge of the tiles; especially the 80 mesh specimen (Fig.5).

Secondly, the experiment conducted on specimen 60 mesh size at 1180°C showed that the cullets melted to a glossy and translucent state with tiny patches of colouring oxides showing visible bright effect (Fig. 7). The experiment conducted on the specimen 80 mesh size at a temperature of 1180ºC show that the tiles came out glossy, completely melted but almost all the colouring oxides had burnt off (Figs. 8 and 9). The last experiment was conducted on specimen 120 mesh size at a temperature of 1180°C. The specimen in this experiment came out deformed and shrunk, while the colouring oxides almost disappeared. Also the melted glass got stuck and could not be removed from the moulds (Figs. 10 and 11).

Experiment 2: Double firing

Experiment 2 was carried out on specimen 60 mesh, 80 mesh and 120 mesh sizes. As mentioned in the experiment 2, under the experimental procedure section, all the specimens were fired twice at 1050ºC first and 1180ºC. The specimens for 60 mesh and 80 mesh sizes came out with high glossy, clear and transparent appearance with marbled effect (Figs. 12, 13 and14). The effects achieved with the 60 mesh and 80 mesh specimens, as in Figs (12, 13 and 14), showed that for good results the above specimen should be fired at 1180°C. The 120 mesh specimen appeared matt and the designs made by the colouring oxides had changed into specks and bubbles of white, blue and yellow. It changed to greenish colour with

Fig 5: Single firing of 80 mesh at 1050ºC

Fig 6: Single firing of 120 mesh at 1050ºC

Fig. 7: Single firing of 60 mesh at 1180°C

Fig. 9: Single firing of 80 mesh at 1180°C

Fig. 8: Single firing of 80 mesh at 1180°C

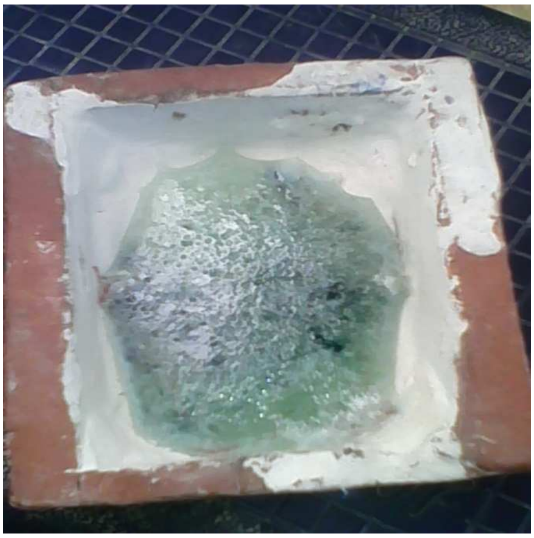

Fig. 10: Shrunk and deformed tile (120 mesh fired at 1180°C)

irregular tile shape showing signs of over firing. The result was due to the effect of the high temperature on the fine particles of the glass which caused the burning of the specimen (Fig.15). The two parameters which were considered in this research (temperature and parti-

Fig. 11: Shrunk tile (120 Mesh fired at 1180ºC)

Fig. 13: Double firing of 80 mesh at 1180°C

Fig. 12: Double firing of 60 mesh at 1180°C

cle size) have effect on each other and that fine particle cullets demanded relatively lower temperature than coarse ones and therefore the 120 mesh particles could give good results at a lower temperature. Figs. 16 and 17 show final compositions created from the various tiles.

The study anticipated vitreous, gloss and finely coloured glass tiles. The results showed that the double firing of 60 mesh and the 80 mesh gave the best results with translucent, clear, bright colour effect (Figs. 12-15). The single firing did not produce the anticipated results, because the cullets and the oxides were mixed together in the powdered state before firing. As a result they melted together and did not produce the

Fig.14: Double firing of 80 mesh at 1180°C

Fig.16: Glass tiles used for table decoration

Fig. 15: Double firing of 120 mesh at 1180°C

Fig. 17: Glass tiles for wall decoration

qualities of translucent, vitreous, glossy effect.

Although the single firing did not give the anticipated results obtained by the double firing, and could be considered failure in scientific experimentations, the result is positive when considered aesthetically within and against artistic practices and prevailing indigenous glass bead technologies.

The results of the study show aesthetic qualities that could be adapted for numerous applications in furniture (Fig.16), architecture (Fig.17), jewelry and fashion industries.

Aesthetically, all of the results whether fused, vitreous, gloss, fine grained, coloured, clear, rough, translucent or opaque, they all present glass trajectories worthy of scholarly pursuits. Artistically, it is plausible to pursue glass in the first category of the single firing, for effects that contradict or provoke modern sense of glass with its own historical facts and conditions. Within such pursuits, the aesthetics will not be visual but contextual. Equally, all the results can be employed in architecture, fashion, souvenir and the trophy industries.

CONCLUSION

This study explored glass recycling through the technique of kiln casting. Some disposed glass bottles were collected and processed through crushing and milling to particle sizes of 60, 80 and 120 mesh sizes, and fired to temperatures of 1050°C and 1180°C. The study revealed that particle size and temperature are the major determinant factors for the melting of glass. The finer particles melted at a lower temperature than the coarse ones.

The study also showed that the best specimens to be adopted for application are the 60 and 80 mesh sizes fired at a temperature of 1180°C. It revealed that the double firing method was the most appropriate method for getting the right melting effect if the process involves the addition of colouring oxides. The study revealed again that, glass kiln casting innovation can augment the other indigenous recycling processes in the glass industry, particularly in Ghana. It has the potential for turning most waste glass into scholarly, industrial, economic and artistically viable products. In the absence of highly industrialized and advanced glass recycling technology and culture, and pending the introduction of such, the study and its results present avenues of thinking about glass cycling.

With the introduction of various colouring oxides, the results of the study have the potential for practical and aesthetic applications in industries such as architecture; for flooring components, glass wall decorations, and furniture ornamentations as well as fashion accessories, gift items, and trophy industry. Finally the results of the project revealed that recycling of waste glass products through kiln casting can be a good source of employment for the youth because the technology is simple and easy to adopt.

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