DEVELOPMENT OF PORCELAIN BALUSTERS FROM LOCAL CERAMIC RAW MATERIALS IN SOUTH EASTERN NIGERIA

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Abstract: The Nigerian economy continues to reel from the effects of excessive importation of finished goods, including ceramic products. This is in spite of the abundance of high grade ceramic raw materials across the country. Three casting slip batches were produced from Nsu clay and Otammiri river sand, both sourced from Imo state in south eastern Nigeria, as well as sodium feldspar, also sourced locally. Batch A contained 45% of nsu clay, 40% of sodium feldspar and 15% of river sand. Batch B contained 50% of clay, 45% of sodium feldspar and 5% of river sand. Batch C contained 50% of clay, 40% of sodium feldspar and 10% of river sand. The three slip batches were used to cast balusters as well as test pieces in a plaster of paris mold. The balusters and test pieces were dried and bisque fired up to 1280°C in an electric kiln. The balusters produced from batch B developed some cracks, especially at the base, after firing. The test pieces were subjected to cold compressive strength test. Sample A had a compressive strength of 140.9MPa, sample B had a compressive strength of 180Mpa, while sample C had a compressive strength of 169.7MPa. It is recommended to incorporate grog additives in slip samples produced from these raw materials to improve shrinkage behavior.

Keywords: *Baluster, ceramic, porcelain, grog, slip, mold, silica, clay, feldspar.*

INTRODUCTION

A baluster is a short pillar or column, typically decorative in design, mounted in a series, supporting a rail, coping or parapet, (MMC Fencing and Railing 2005). Balusters serve several purposes within the overall structure. First they support the copping or hand rail. They also serve as a safety feature by closing the gaps between posts, thereby eliminating excess space through which someone could fall. The application of balusters to building architecture dates back to fifteenth century, (Davis and Hemsoll 1983). Modern cast ceramic balusters are made of either glazed stoneware or porcelain bodies. They have the advantage of a scratch resistant and easy to clean surface, mold resistant as well as never requiring painting throughout its lifespan. The composition of the clays used, types of additives, firing temperature and duration, determine the quality and hardness of a ceramic product, (Bertollisi 2014). However these variables can be widely adjusted, resulting in many different types of ceramic bodies, such as earthenware, terracotta, stoneware, or porcelain. Stoneware is composed of fire clay, ball clay, feldspar and silica. They are fired up to vitrification point, typically 1150-1320°C, and are inherently non porous, (Bertollisi 2014). Porcelain is a white clay body used in making functional and non functional items. It is basically composed of kaolin and other plastic clays, in combination with feldspar, silica and quartz, although other materials may be added. It is traditionally fired at a high temperature, usually above 1260°C, at which the body vitrifies and thus the surface is non adsorbent.

Porcelain surfaces are very smooth even when unglazed and quite translucent. This is the most significant distinguishing factor of porcelain, as all other ceramics are opaque and do not transmit light, (Bertollissi 2014). Another identifying factor of porcelain is the sound. If a porcelain object is struck lightly, it will ring with a clear bell-like sound.

The superior aesthetic advantages of porcelain balusters come in addition to meeting mechanical strength requirements of balusters used for hand railings. Loferski and Woeste (2005) stated that International Residential Code (IRC) for one and two family dwellings, prescribes that balusters must resist a concentrated horizontal load of 50 pounds applied to a square foot area. Also the IRC(2000), require that a guardrail or a hand rail be able to resist a 200 pound concentrated load, applied along the top in any direction. Omar et al (2014) reported that porcelain bodies have a typical compressive strength of 125-250 MPa and a bending strength > 35MPa.

DESCRIPTION OF STUDY AREA

This research study was carried out in the ceramic main workshop of Akanu Ibiam Federal Polytechnic Unwana Afikpo in Ebonyi state of Nigeria. The raw materials, Nsu clay, feldspar and Otammiri river sand, were all sourced within south eastern Nigeria. Beneficiation processing, including crushing, grinding and sieving were done using laboratory jaw crusher, ball mill and mechanical sieve equipment. Firing was done using a J.W RATCLIFFE electric kiln.

MATERIALS AND METHODOLOGY

The clay raw material, as well as feldspar and river sand, were separately milled for several hours, in a laboratory ball mill. Afterwards they were sieved using a mesh 200 sieve and the oversize particles were discarded.

MOLD PREPARATION

A concrete pattern was used to prepare the mold. The parting line was carefully marked around the pattern with an ink. A mold box of appropriate dimensions was prepared from old metal sheets. The mold box was half filled with a plastic clay material. The pattern was then pressed into the plastic clay, up to the parting line. A paint brush was used to generously apply mixed liquid soap on the exposed surface of the pattern, as well as the mold box. The end of the paint brush was used to make six indentions on the clay, three on either side, to act as alignment guard for the two mold pieces.

A good quantity of the plaster of paris was measured out and put in a plastic bucket. Clean tap water was then put in the mixing bucket and the plaster powder was gradually sprinkled on top of the water, until a good consistency was achieved, which roughly corresponds to two parts of powder to one part of water. The mixing bucket was occasionally tapped on the table to drive air bubbles to the surface. The mixed plaster was then slowly poured in from one corner of the mould box, allowing the plaster to glide slowly over the pattern, until the box was filled. After the plaster has set properly, the overspill guard was removed and the box turned upside down. The plastic clay material was carefully removed to expose the opposite side of the pattern. The mold release soap was then generally applied on the pattern as well as on the plaster surface that has been poured previously. Afterwards, newly mixed plaster was carefully poured into the box from one corner, until all the space over the pattern was filled. After the plaster was set, the two halves of the mold were carefully separated and the pattern removed. The mold was now ready for use. Two other molds were also prepared using the same method described above. In a similar manner, three cubic molds measuring 150mmx150mmx150mm were prepared for casting test pieces from the three slip batches.

SLIP PREPARATION

Three batches of slip were prepared from the sieved clay, feldspar and river sand samples. The composition of the batches is as shown table 1 below.

Table 1: The composition of the three slip batches.

Material	Batch A (%)	Batch B (%)	Batch C (%)
Nsu clay	45	50	50
Otammiri river sand	15	5	10
Feldspar	40	45	40

An electric motor driven slip mixer was used to mix the raw materials and water in a 5 gallon slip bucket. About 3 gallons of water was used to mix 20 kg of dry raw materials. Half ounce of soda ash, (approximately 14.2 grams) and

1.5 ounces, (approximately 533.2 grams) of sodium silicate were used to deflocculate the slip. Also a quarter of an ounce of barium carbonate, (approximately 7.4 grams), was added to neutralize any sulphates present in the clay body or water. The slip was allowed to mix for up to two hours. Afterwards a hydrometer was used to check the specific gravity of the slip. A reading of 1.78 was obtained on dipping the hydrometer, which is within the normal range for a good casting slip. The slip batches were then left overnight. The specific gravities of the slip batches were again checked the next morning and they remained within normal range.

The molds were then prepared for casting by applying liquid soap over the internal surfaces of the moulds and coupling them. The two parts of the molds were fastened firmly with rubber bands, before the slip was carefully poured in. Both the balusters and the test pieces were cast from the three slip samples. The mold walls absorbed water from the slip by capillary action, as the slip solidified. A thickness of 15 mm was reached after 20 minutes and the excess slip was carefully poured out from the mould. The cast test pieces were however allowed to solidify completely in the mould, and additional slip was added as needed until the entire volume of the test piece mold was filled with solidified slip.

The cast balusters were then allowed to dry in the mold for one hour, before being carefully detached from the mold. The balusters and test pieces were then allowed to dry in open air for five days and afterwards dried in an electric oven at

110°C for eight hours. They were then placed in an electric kiln and bisque fired at a heating rate of 50°c per minute, up to 1280°c. After cooling overnight, the balusters and test pieces were brought out for physical inspection and cold compressive strength test. The test pieces were then successively mounted on a hydraulic compressive strength test machine and a uniaxial hydraulic load was applied to each specimen until failure occurred. Cold compressive strength was determined from the relation:-

$$CCS = \frac{maximum\ load\ at\ failure\ (KN)}{average\ area\ of\ breaking\ face\ (mm2)}$$

………………..equation 1 (Osaremwinda et al 2014).

RESULTS AND DISCUSSION

Table 2 below shows the oxide compositions of Nsu clay used to produce the slip, while table 3 shows the results of the cold compressive strength tests of the test pieces produced from the three slip batches.

Table 2. Oxide composition of Nsu clay determined by x-ray fluorescence spectroscopy, as reported by Osonwa et al (2017).

Oxides	Percentages
SiO_2	56.03
Al_2O_3	33.96
Fe_2O_3	0.73
CaO	0.03
MgO	0.23
K_2O	0.24
TiO	0.34
Na_2O	0.18
LOI	7.80

Table 3. Cold compressive strength results of the test pieces.

Specimen	Length of breaking face (mm)	Width of breaking face (mm)	Area of breaking face (mm^2)	Maximum load at failure (KN)	Cold compressive strength KN/mm^2 (MPa)
A	150	150	22500	3170	0.14, (140.9 MPa)
B	150	150	22500	3980	0.18, (180MPa)
C	150	150	22500	3820	0.169, (169.7 MPa)

The three baluster samples had a fairly good translucent appearance. Also when struck lightly with the hand, they produced a clear bell-like sound, that of the batch B baluster being the clearest. It was observed on inspection, that the balusters produced from slip sample B had some minute cracks along its body, and especially at the base. This could be attributed, possibly to the very low silica content of the batch. Silica opens up a clay body, thereby improving drying and firing shrinkage characteristics, although too much of silica could introduce other risks associated with quartz inversion. Thus there has to be an optimum silica content for any combination of raw materials. Batch B also produced the best mechanical properties as indicated by the cold compressive strength of 180MPa. Thus the shrinkage behavior of the baluster could possibly be improved by incorporating some grog into the slip batch. This could improve both the physical and mechanical behavior of the baluster produced from such batch composition. Batches A and C also showed cold compressive strengths of 140MPa and 169.7MPa respectively, which are quite within the expected range for a porcelain body as reported by Omar et al (2014).

CONCLUSIONS AND RECOMMENDATIONS

From the results of this research work, it can be concluded that local ceramic raw materials in south eastern Nigeria can be successively employed for the production of high quality structural ceramic products such as balusters. It can also be deduced from this work that the high silica content of nsu clay used to produce the slip could pose possible shrinkage challenges if batch compositions are not properly managed. It is recommended to use incremental additions of processed grog, with these batch materials, to determine their effect on the shrinkage behavior and mechanical properties. It is also recommended to further test the flexural strength of products from these batch raw materials as given by their modulus of rupture values.

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