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Characterization of Vitrified Porcelain Tiles using Feldspar from Three Selected Deposits in Nigeria

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Abstract

The production of vitrified porcelain tiles has increased in recent years due to their excellent technical characteristics such as high strength, low water absorption, excellent abrasion resistance as well as good chemical resistance. The use of good fluxing agents such as feldspar to bring about the vitrification of the porcelain tiles body has initiated intensive research work to source for suitable feldspar deposits required for manufacturing this product. In this research work, feldspar samples from Ijero-Ekiti in Ekiti state, Ajaokuta in Kogi state and Okpella in Edo state, from Nigeria were used together with other raw materials to formulate vitrified porcelain tiles compositions similar to what is obtainable in industries. The porcelain tiles samples were produced under suitable industrial conditions and sintered at 1218^{0}C. Flexural strength test, fired shrinkage test, water absorption test and abrasion resistance test were used to characterize the samples. The results show that flexural strength, abrasion resistance and water absorption of all the samples are within the acceptable values specified by international standard organization (ISO). Chemical analysis was also carried out on the feldspar samples from the three deposits and the results show that the deposits contained all the constituents suitable for producing porcelain tiles. All the three feldspar deposits were found to be suitable for producing vitrified porcelain tiles.

Keywords: Vitrified porcelain tiles, feldspar, Nigeria, characterization.

Introduction

Recently, porcelain tiles have become one of the most important products of the ceramic industry mainly because of their attractive physical and mechanical properties such as high strength, high fracture toughness and density, good chemical resistance and low water absorption[1]. Among ceramic floor and wall tiles, porcelain tile is one of the most important materials, in which the quantity and the quality of the clay that the body contains play a key role in the final properties of the materials. Porcelain tiles are fully vitrified, glaze or unglazed and can be made using white or coloured ceramic bodies composed of mix of clays and feldspars. These products are manufactured by using high amount of fluxing agents such as sodium or potassium feldspar, talc, ceramics frits together with clay, kaolin and silica sand in lesser quantity. The clay, gives plasticity to the ceramic mixture; flint or quartz (SiO_2), maintains the shape of the formed article during firing; and feldspar, serves as flux. The thermal, dielectric and mechanical properties of the products can be improved by varying the proportions of the three main ingredients[2-4]. Porcelain tile bodies are normally composed of two groups of materials: plastic and non-plastic. The plastic material is predominantly based on clays and sometimes kaolin, which are essential to the development of plasticity as well as allowing for satisfactory green and dry mechanical strength. The non-plastic part is associated with inert (silica and alumina), fluxes (Soda or Potash in Feldspar) and flux-inducing materials (calcite). The correct mixture of these materials enables the products to exhibit the desired technological properties and easy processing with the lowest possible cost.

The microstructure directly affects the technical properties of the final product. Therefore, it is necessary to utilize quality raw materials of higher purity in the starting composition in order to produce porcelain tiles with the desired technical specifications and microstructural properties[5]. The products are generally shaped by pressing powdered body and then sintered at 1200^{0}C or at a slight higher temperature[3]. The microstructure of the fired product usually contain mullite ($3Al_2O_3.2SiO_2$) and undissolved quartz (SiO_2) crystals embedded in a continuous glassy phase, originating from feldspar and other low melting impurities in the raw materials[3,6]. During the process of firing porcelain, there is always competition between the formation of mullite and crystallisation of the amorphous silica present in the matrix. The proportion of un-reacted residual quartz is often influenced by the proportion and nature of the quartz used in the composition of porcelain batch during firing. The coefficient of thermal expansion of quartz is higher in comparison to that of the surrounding glassy phase, hence giving rise to thermal stresses which usually affect the strength of porcelain[6].

The process of mullitisation is also affected by the grade of feldspar which particularly influences the formation of secondary mullite. The main differences between primary and secondary types of mullite are the size, shape and degree of aggregation of the mullite crystals[7,8]. The quality of feldspar is determined by the amount of albite and orthoclase, respectively

in the sodium and potassium feldspar, the most commonly used fluxes in porcelain composition. Recently, several authors have reported that feldspars with high alkaline contents are suitable fluxing agents for porcelain manufacture since they promote the formation of very viscous liquid phase that embeds the new forming crystals and part of the residual crystals present in the microstructure, thereby enhancing the process of densification[9,10].

Despite the fact that feldspar is one of the most important raw materials for manufacturing porcelain tiles, very few researchers have worked on the suitability of numerous feldspar deposits around the world for producing porcelain tiles. This work is part of current efforts being initiated to determine the suitability of feldspar deposits in Nigeria for producing high quality porcelain tiles. In this investigation, samples from three feldspar deposits in Nigeria together with other raw materials were used to produce porcelain tiles in order to ascertain the effect of each feldspar deposit on properties of the tiles produced. The psycho-chemical and mechanical properties of the porcelain tiles obtained were studied.

Material and Methods

Location of the three feldspars: Feldspar samples from three different selected locations in Nigeria were utilized for this research work. The locations are Ijero-Ekiti in Ekiti state, Okpella in Edo State and Ajaokuta from Kogi State. Ijero-Ekiti is a town located in Ijero local government area of Ekiti state which is few kilometers away from Ado-Ekiti (Capital city of Ekiti-State). Okpella is a border town between Edo State and Kogi State in Etsako East local government area of Edo State while Ajaokuta is located in Ajaokuta local government area of Kogi State. Chemical analysis was carried out on feldspar samples from these three locations using X-ray fluorescence spectroscopy. The result of the chemical composition is as presented in table 2.

Body Composition: The body composition for this research work was formulated using feldspar samples from the three selected locations and other raw materials. For the purpose of this research work, feldspar samples from Ajaokuta, Ijero-Ekiti and Okpella were used to prepare sample A, B and C respectively. Other raw materials employed for formulating the vitrified porcelain specimens include; Abia white clay from Abia State, Yankari kaolin, Silica sand from Igbokoda Ondo state and white talc supplied by West African Ceramics Limited Ajaokuta, Kogi State. The vitrified porcelain body formulation is as shown in table 1.

Experimental Methods: The processed raw materials were weighed according to the composition in table 1 using accurate electronic weighing balance. The weighed raw materials were charged into pot mill containing porcelain grinding media (pebbles) and 35% water of the total charge was added together with sodium tripoliphosphate as deflocculant.

Table-1
Body Composition of Samples

Samples	Abia clay	Feldspar	Kaolin	Silica sand	White talc
A_1	20	50	15	10	5
A_2	20	40	15	20	5
B_1	20	50	15	10	5
B_2	20	40	15	20	5
C_1	20	50	15	10	5
C_2	20	40	15	20	5

The pot mill was allowed to run for thirty minutes before its content was discharged into a dry pan. The pan and its content were dried in electric oven at the temperature of 105^0C for two hours. The dried material was then crushed and 6% weight of water was added before passing through a 100 mesh (150µm) to obtain suitable powders for pressing. Each composition were used to produce thirty samples of tiles of size 100mm x 100mm x 10mm by using uniaxial hydraulic pressing machine at the pressure of 50bars. The samples were dried and fried in an electric laboratory kiln at 1218^0C (standard temperature for firing porcelain tiles at West African Ceramics Limited) with a thermal cycle of 4 hours cold-to-cold.

Characterization of the samples: In order to characterize the fired samples, different tests were carried out using standard procedures. Some of the test used for characterizing the samples include: Flexural strength, water absorption test, shrinkage test and abrasion resistance test.

The flexural strength was determined using a universal testing machine (MTS 810.23M), in three-point bending fixture, 70 mm support span and with a crosshead speed of 0.5 mm min^{-1}. Water absorption test was performed on the specimens using the acceptable standard method in accordance with ASTM C20-00. The shrinkage test was carried out on the samples by determining the size before and after firing using digital venier caliper. Abrasion resistance was performed as described in the standard ISO 10545-6. Six specimens per sample were used for each test and the values obtained were averaged.

Results and Discussion

Chemical analysis of Ijero-Ekiti, Ajaokuta and Okpella feldspar: The results of chemical analysis carried out on the feldspar samples are as presented in table 2. From the result of the chemical analysis, all the three feldspar samples being investigated can be classified as potash feldspar since the percentages of K_2O in the three samples are higher than that of Na_2O and CaO. The result showed that the three feldspar deposits have constituents in the ranges comparable to many deposits cited elsewhere[11] which have been reported to be suitable for porcelain body.

Table-2
Chemical analysis of Ijero-Ekiti, Ajaokuta and okpella Feldspar

Constituents (wt.%)	Ijero-Ekiti	Ajaokuta	Okpella
SiO_2	66.52	65.70	65.66
Al_2O_3	18.12	13.82	15.48
Fe_2O_3	0.29	0.85	0.74
MgO	0.21	0.18	0.28
K_2O_3	9.86	11.00	9.04
Na_2O	2.61	2.01	3.12
CaO	0.71	0.24	0.87

Shrinkage: Figure 1 shows the contraction pattern for the samples after they were fired at the temperature of 1218^0C. The result shows that samples A_1, B_1 and C_1 exhibited higher shrinkage values in comparison to their respective counterpart (A_2, B_2, C_2). This trend can be attributed to the fact that samples A_1, B_1 and C_1 contain 50% of feldspar and 10% of quartz while samples A_2, B_2, C_2 contain 40% feldspar and 20% quartz. Several authors have reported that feldspar plays the role of fluxing agent in porcelain body thereby help to increase vitrification and shrinkage[3,4]. Also from figure 1, it was observed that sample A formulated with Ajaokuta feldspar exhibited the highest shrinkage value. This trend can be attributed to the higher percentage of k_2O (11.00%) in Ajaokuta feldspar sample which has been reported to promote vitrification[12]. Martin-Marquez *et al.*[13] have also reported that optimum vitrification is achieved in porcelain tiles when there is maximum linear shrinkage.

Water Absorption: It is essential to carry out water absorption test on ceramic tiles so as to define the class to which the product belongs. The result of water absorption test carried out on the samples is as presented in figure-2. From the result in figure-2, it was observed that all the samples exhibited low water absorption values. The water absorption results showed that all the samples have water absorption values of less than 0.4%. This result is in agreement with water absorption value of not greater than 0.5% recommended by ISO 13006 for porcelain tiles. All the samples can be classified in the range used for porcelain tiles as far as water absorption is concerned.

Flexural Strength: Flexural strength depends on the material composition and dimension and morphology of the flaws. Figure 3 shows the results of flexural strength test conducted on the samples. From figure-3, it was observed that sample A_1 exhibited the maximum flexural strength value of 87N/mm^2 while sample B_2 exhibited the lowest flexural strength value of 73N/mm^2. According to ISO standard, the minimum flexural strength value recommended for porcelain tiles is 35N/mm^2. This implies that all the samples being investigated have flexural strength values that exceed the international standard.

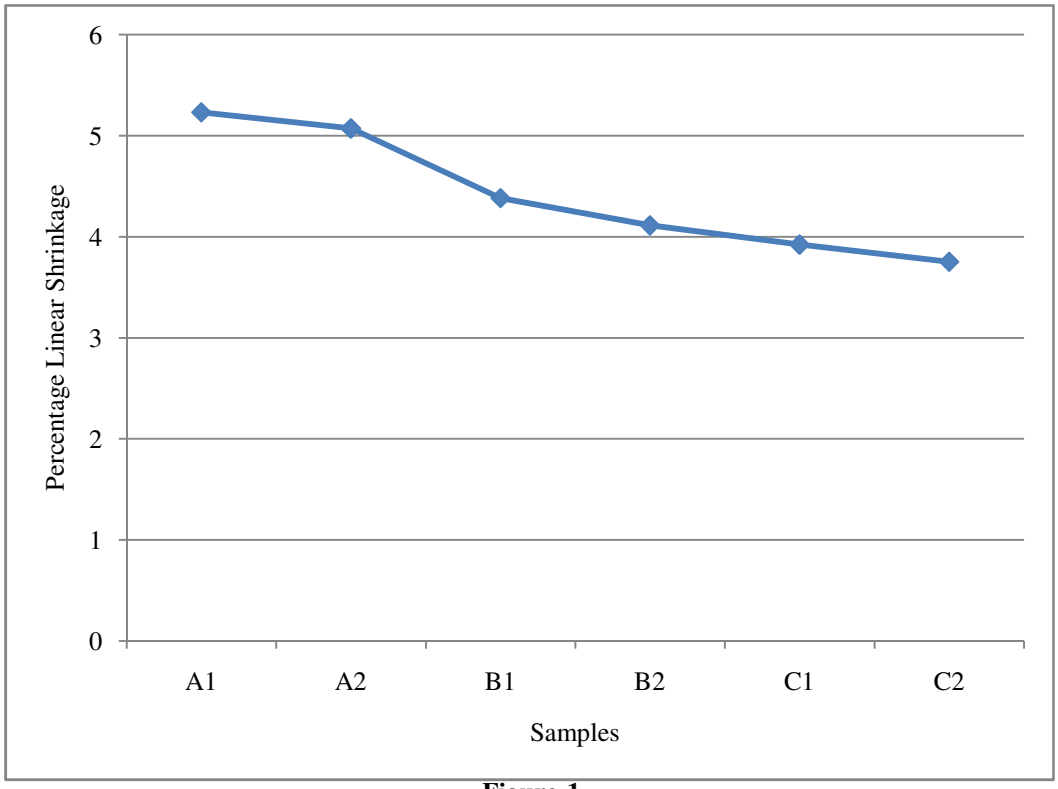

Figure-1
Fired Shrinkage Test Result

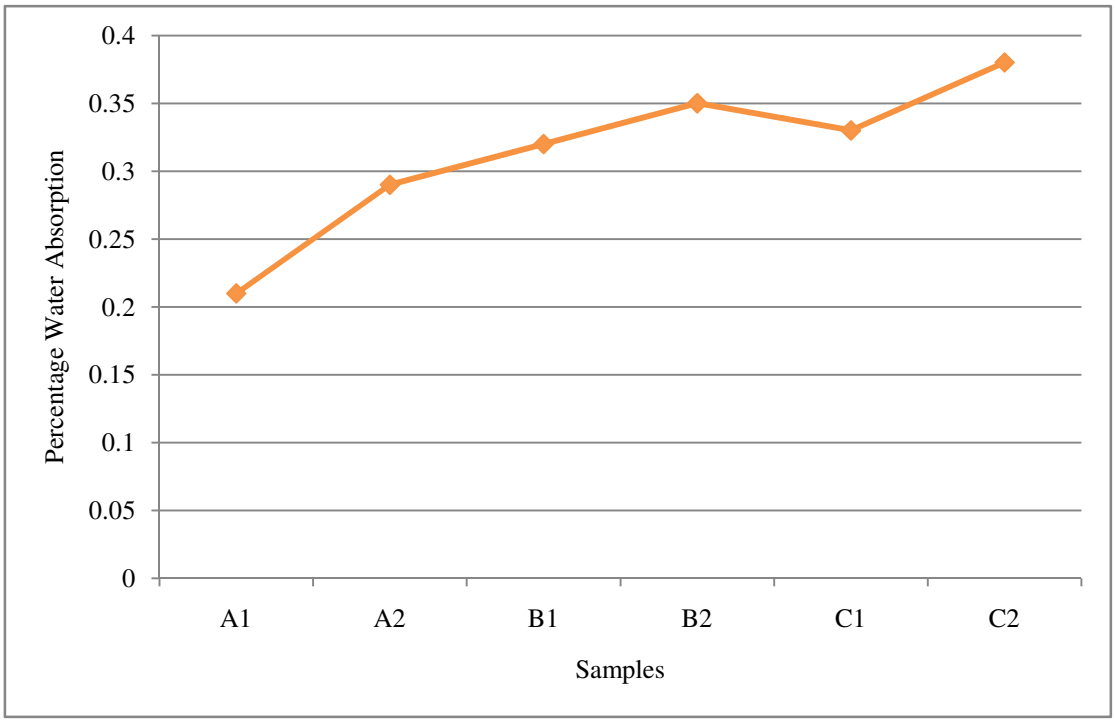

Figure-2
Percentage Water Absorption Test Result

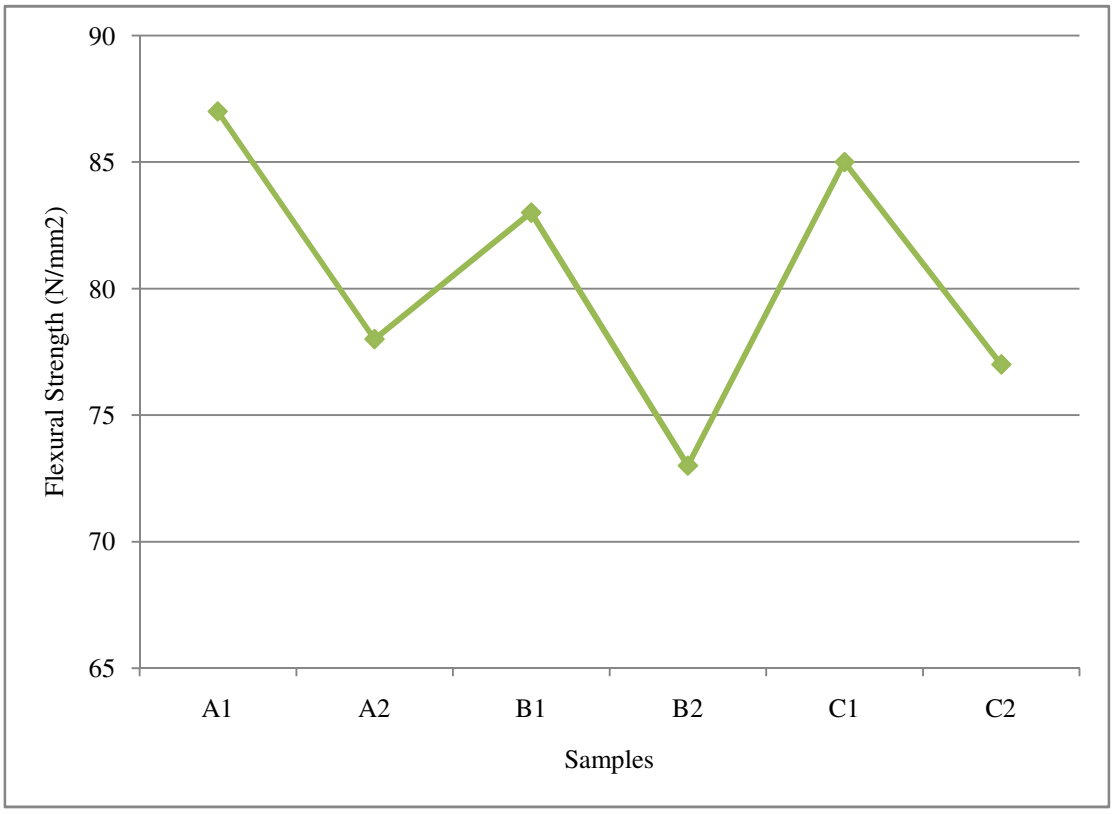

Figure-3
Result of Flexural Strength Test

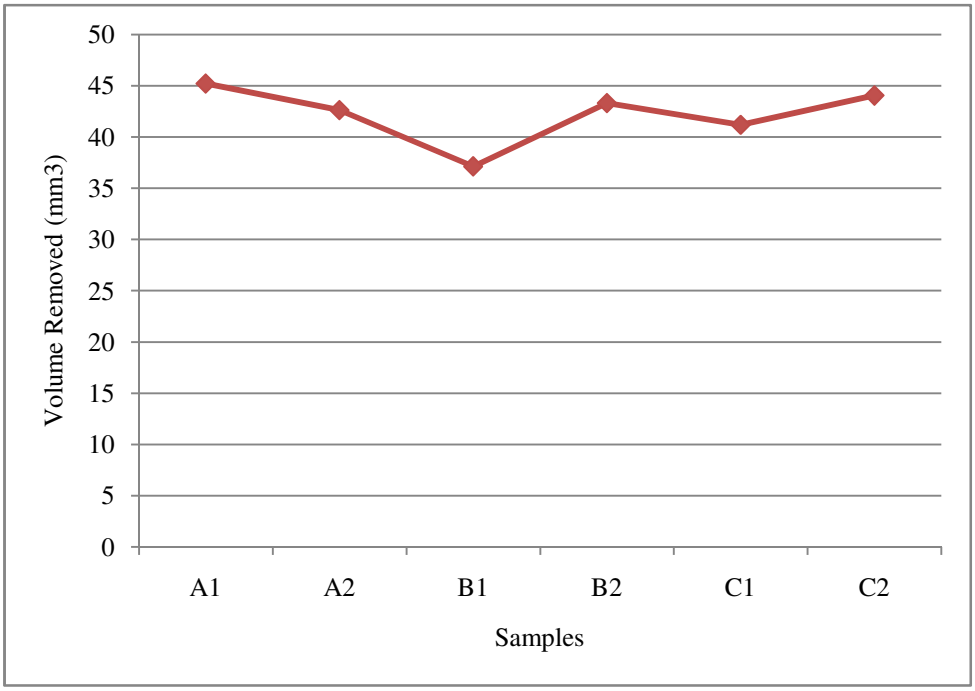

Figure-4
Result of Abrasion Resistance test

Abrasion Resistance: Abrasion resistance test was carried out on the fired specimens in accordance with ISO 10545-6 and measured in terms of removed sample volume (figure-4). The result shows that the abrasion resistance values of the samples ranges between 45.21-37.14mm^3. Sample B_1 exhibited the lowest abrasion resistance value while the highest abrasion resistance value was observed in sample A_1. According to previous research works reported by other authors[14,15], porcelain stoneware must present abraded volume values lower than 175mm^3.

Conclusion

In this research work, the use of feldspar from three selected deposits for the production of vitrified porcelain tiles was investigated. After detailed chemical analysis using XRF, it was found that feldspar samples from the three selected deposits have constituents in the right proportions that meet up with the requirements for feldspar to be used in porcelain tiles production. It can be concluded that the three feldspars from Nigeria are suitable as feldspar for porcelain bodies. The properties of the final products show that: i. Sample with 50% of Ajaokuta Feldspar has the highest shrinkage value of 5.07% while sample with 40% of Okpella feldspar recorded the lowest shrinkage value of 3.75%, ii. All the samples formulated with the feldspars from deposits under investigation have water absorption values (0.21-0.38%) less than 0.5% which has been reported to be maximum water absorption value for porcelain tiles according to ISO standard. iii. The flexural strength of all the samples is within the range of 87-77N/mm^2. These results show that all the samples meet up with ISO standard which recommended flexural strength of not less than 35N/mm^2 for porcelain tiles. iv. All the samples have abrasion resistance values within the range of 45.21-37.14mm^3. These results are also within the range of abrasion resistance values recommended for porcelain tiles.

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