International Journal of Research in Engineering, Science and Management
Volume 7, Issue 8, August 2024
https://www.ijresm.com | ISSN (Online): 2581-5792

Physio-Mechanical Properties of Earthen Whiteware Body from Selected Raw Materials in Nigeria

Floxy Imhande Jegede[1*], Olusegun Adene Fatuyi[2], Temitope Peter Ologunwa[3], Oluwafemi Samuel Adelabu[4]
[1]*Department of Glass and Ceramics, Federal Polytechnic, Ado-Ekiti, Nigeria*
[2,3,4]*Department of Industrial Design, Federal University of Technology Akure, Nigeria*

Abstract: **The properties of ceramic materials determine the characteristics of the end products. This research presents the physio-mechanical properties of ceramic whiteware produced from Ehime Mbano kaolinite clay mixed with waste glass, silica and feldspar. All samples were collected from their various sources into different bag with labels (Ehime Mbano Kaolin - EMK, waste glass- SLWG, silica-IJS and AFJ-feldspar). The samples were carefully prepared separately by breaking, crushing and milling into fine powder of about 62µm. Six batch formulations (Fv1 – Fv6) were blended with the process materials with varying addition of feldspar to waste glass ratio. The samples were uniaxially pressed followed by sintering in a kiln to a temperature of 1000°C for 2 hours. The samples were allowed to cool inside the kiln before offloading. Test such as shrinkage, porosity, water absorption, density, impact and compressive strength were examined to assess the physio-mechanical properties of the produced whiteware. The results showed that sample Fv5 exhibited better performance with the least water absorption (11.07%) while samples Fv3 and Fv5 has considerable density of 1.76 and 1.7 g/cm^3 respectively. Sample Fv5 showed better compressive strength (4.86 Ma) while samples Fv3 displayed superior impact strength (79 J/m^2). These results indicate the suitability of these materials in developing a ceramic whitewares.**

Keywords: **Whiteware, Feldspar, Kaolin, Waste glass, Sintering.**

1. Introduction

Whiteware as the name suggests in ceramics implies a clay body composition that comes with white colour. It is any ceramic product composed with white or off-white body, which may become glassy when treated under the temperature of about 1200°C and above depending on the composition of the body and area of application. Whiteware is a fired ware consisting of a glazed or unglazed ceramic body that is commonly white and of fine texture, designating such product classifications as Chinaware, porcelain, semi-vitreous ware and earthenware [1]. The appearance of whitewares depend greatly on the raw material composition. The presence of impurities such as red iron oxide (in the local raw materials), impacts a great limitation on the final appearance of the product. Whiteware is associated with some technical properties supplied from the material used in making them and these properties make them applicable in almost all fields of life.

These admirable properties are usually a function of the kaolin in the composition which varies respectively with their geological deposits and furthermore affects the mechanical and physical property of a product [2]. These materials include silica, clay, and feldspar [3], [4]. The plasticity and workability of clay varies widely so that clay which serve well for the production of other wares may not be suitable in the production of white earthenware [5]. This therefore brought the idea of material selection and combination in the production of white earthenwares for compatibility and high performance of product type since one material cannot yield optimum result in ceramic products. The objective is to take advantage of the superior properties of the materials without compromising on the weakness of the other material [6]. From study, kaolin is widely acclaimed industrial clays based on its particle size, whiteness and can also easily disperse in water due to its coarse nature [7], [8]. Kaolin from Ehime Mbano (EMK) which is pink in color served as valuable components when mixed with silica (IJS), waste glass (SLWG) and feldspar (AJF) in developing a white earthenware body. Cullet is commonly used as an additive in glass reforming due to its low softening temperature [9]. Silica is required to supply the strength. Some studies have revealed that in the manufacturing process involving high temperatures, ceramic-based products are considered suitable for the incorporation of glass cullet (GC) as a substitute of natural resources [10], [11].

Therefore, this research aimed to develop a whiteware body made from Ehime Mbano kaolin, Igbokoda silica while substituting Ajaokuta feldspar for waste glass using 40×40mm iron mould to cast the samples. The physio-mechanical properties of the developed samples are then evaluated.

2. Materials and Method

A. Preparation of Materials

The materials that were utilized for this research are window waste glass, kaolin from Ehime Mbano in Imo State, silica from Igbokoda, in Ondo State, and feldspar from Kogi State all in Nigeria. The waste glasses were washed in water, cleaned, dried, packed into a sack and crushed into smaller pieces using

*Corresponding author: floxyjegede.fj@gmail.com

wooden pestle before reducing to fine powder with a pulverizer. The same procedure was repeated for other materials (kaolin, silica and feldspar). The chemical composition of the materials was examined by the X-Ray fluorescence spectroscope (XRF) techniques while their mineralogical constituents (phase analysis) was examined by X-ray diffractometry (XRD) technique. Figure 1 shows the pictorial representation of each processed materials used.

IJS SWLG

EMK AFJ

Fig. 1. Representative diagram of the processed materials used

B. *Sample Preparation*

Table 1
Material composition (wt. %)

Materials	F_{V1}	F_{V2}	F_{V3}	F_{V4}	F_{V5}	F_{V6}
EMK-Kaolin (%)	50	50	50	50	50	50
IJS-Silica (%)	25	25	25	25	25	25
AFJ-Feldspar (%)	25	20	15	10	5	0
SLWG- Glass (%)	0	5	10	15	20	25

The batch formulation was done in six batches as shown in Table 1. The powder materials were weighed, mixed with 200ml of water and pressed in a 40 × 40mm iron mould. Three (3) samples were made from each batch (A- F) making a total of 18 samples. The cast forms were allowed to dry at room temperature for two weeks after which the forms were subjected to heat treatment at 1000ºC after soaking for 2 hours. The samples were removed from the kiln after cooling to a room temperature and physio-mechanical properties were investigated. Tests such bulk density, apparent porosity, water absorption, and shrinkage were conducted to assess the physical properties of the samples while compressive strength, impact strength and strength index were used to analyze their mechanical properties. These tests were carried out following standard procedures. The phase analysis of the samples was analyzed X-ray diffractometry (XRD).

3. Results and Discussion

A. *Shrinkage*

Figure 2 shows the shrinkage values of six samples labeled as Fv1 to Fv6. Fv1 has a shrinkage value of 5.60%, a low level of dimensional change after processing. Fv2 has a slightly higher shrinkage value of 5.70% compared to Fv1, indicating slightly more dimensional change. Fv3 a shrinkage value of 6.30%, which is higher than Fv1 and Fv2, indicating a moderate level of dimensional change. Fv4 has a shrinkage value of 5.88%, falling between the values of Fv2 and Fv3. Fv5 has a shrinkage value of 6.39%, indicating a moderate level of dimensional change, higher than Fv3 and Fv4. Fv6 has the highest shrinkage value of 7.01%, indicating the highest level of dimensional change among the samples. Based on the data, sample Fv1 (soda-lime glass 0%, Feldspar 25%) has the lowest shrinkage, while Fv6 (soda-lime glass 25%, Feldspar 0%) has the highest. In this batch, it can be inferred that Feldspar has the lowest shrinkage compare to soda-lime glass.

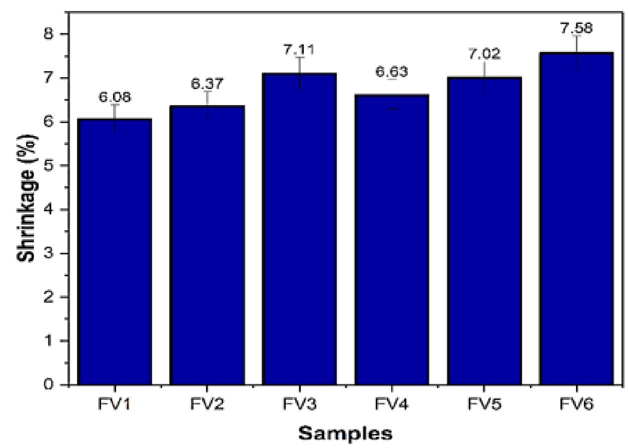

Fig. 2. Percentage shrinkage

B. *Water Absorption*

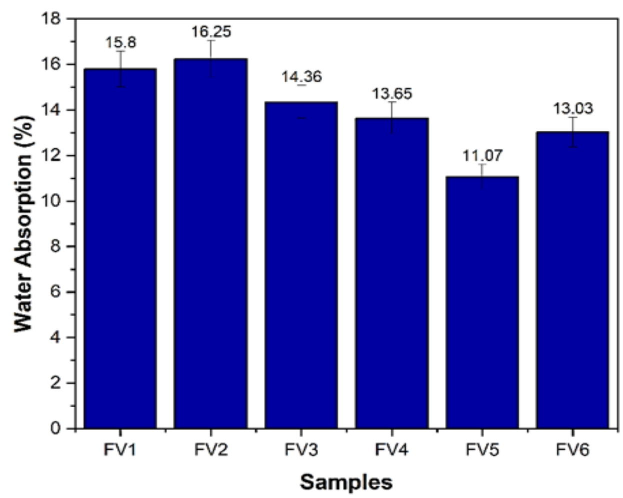

Fig. 3. Percentage water absorption

Figure 3 depicts the result of the water absorption of the sintered whiteware samples. Sample Fv1 has an absorption value of 15.80%, Fv2 has a slightly higher absorption value of

16.25% compared to Fv3, Sample Fv3 has a lower absorption value of 14.36% compared to Fv1 and Fv2 Sample Fv4 (13.65%) has an absorption value close to Fv3, indicating moderate water absorption. Sample Fv4 has the lowest water absorption (11.07%), indicating the least amount of water absorption. Sample Fv6 has 13.03% as an absorption value between Fv3 and Fv4. Based on the data, Sample Fv5 (soda-lime glass 20%, Feldspar 5%) has the lowest water absorption, while Fv2 (soda-lime glass 5%, Feldspar 20%) has the highest. In this batch, it can be inferred that soda-lime glass has the lowest water absorption compare feldspar. The effect of water absorption on clay ceramics is essential to validate their durability [12].

C. Apparent Porosity (%)

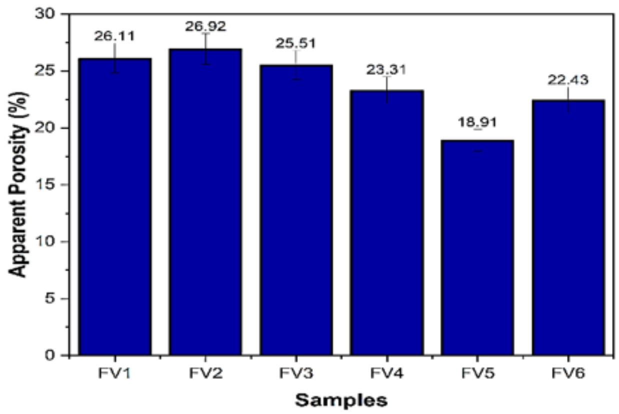

Fig. 4. Percentage apparent porosity

Figure 4 displays the porosity values of the developed whiteware samples. Sample Fv1 has porosity of 26.11% indicating a moderate percentage of void spaces. Sample Fv2 has 26.92% indicating a slightly higher percentage of void spaces. Sample Fv3 25.51% porosity similar to FV1, indicating a similar percentage of void spaces. Sample Fv4 has 23.31%, a lower porosity compared to Fv1, Fv2, and Fv3, indicating a lower percentage of void spaces. Sample Fv5 has 18.91% among the samples, indicating the lowest percentage of void spaces and sample Fv6 has 22.43% higher than Fv4, indicating a higher percentage of void. Based on the data, sample Fv5 (Soda-lime glass 20%, Feldspar 5%) has the lowest porosity, while Fv2 (Soda-lime glass 5%, Feldspar 20%) has the highest Porosity value. In this batch, it can be inferred that soda-lime glass has the lowest apparent porosity compare to feldspar.

D. Bulk Density

Figure 5 shows the result of the percent apparent porosity of the developed whiteware samples. Sample Fv1 has a density of 1.61 g/cm³, indicating a moderate density level. Sample Fv2 has 1.65 g/cm³, a slightly higher density compared to Fv1, indicating a slightly higher mass per unit volume. Sample Fv3 has the highest density of 1.76 g/cm³ among the samples, indicating the highest mass per unit volume. Sample Fv4 (1.67 g/cm³), has a density between Fv1 and Fv2, indicating a moderate mass per unit volume. Sample Fv5 has a density of 1.70 g/cm³) which is higher than Fv4, indicating a higher mass per unit volume. Fv6 (1.67 g/cm³), has a density similar to Fv4, indicating a similar mass per unit volume. Based on the data, sample Fv3 (Soda-lime glass 10%, Feldspar 15%) has the highest density, while Fv1 (Soda-lime glass 0%, Feldspar 25%) has the lowest density. it can be inferred that Soda-lime glass has the highest density compare to feldspar.

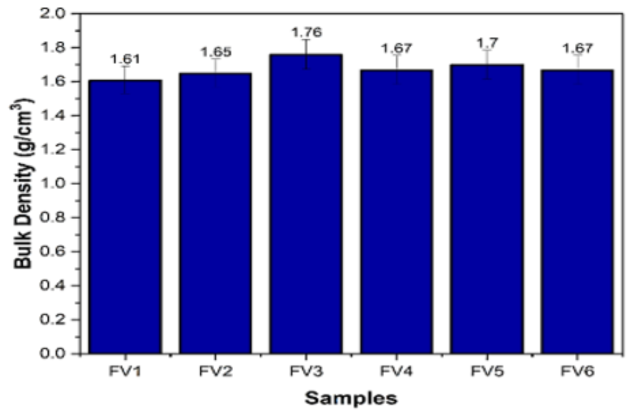

Fig. 5. Bulk density

E. Compressive Strength

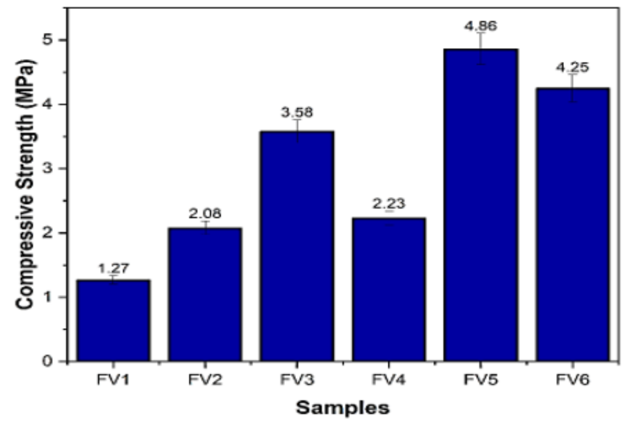

Fig. 6. Compressive strength

Figure 6 displays the compression strength (com/s) values of the six samples labeled Fv1 to Fv6. Sample Fv1 has a com/s of 3.92, indicating a moderate ability to withstand compressive forces, sample Fv2 has com/s of 4.08 similar to Fv1, indicating a similar ability to withstand compressive forces. Sample Fv3 has com/s of 14.46 a significantly higher compared to Fv1 and Fv2, indicating a much higher ability to withstand compressive forces, sample Fv4 has com/s of 13.36, compression strength similar to Fv3, indicating a similar ability to withstand compressive forces. Sample Fv5 has com/s of 14.13, similar to Fv3 and Fv4, indicating a similar ability to withstand compressive forces and sample Fv6 (22.86) indicates the highest ability to withstand compressive forces. Based on the data, sample Fv6 (Soda-lime glass 25%, Feldspar 0%) has the highest compression strength, while Fv1 (Soda-lime glass 0%, Feldspar 25%) and Fv2 (soda-lime glass 5%, Feldspar 20%) have the lowest com/s. In this batch, it can be inferred that soda-lime glass has the lowest compressive strength.

F. Impact Strength

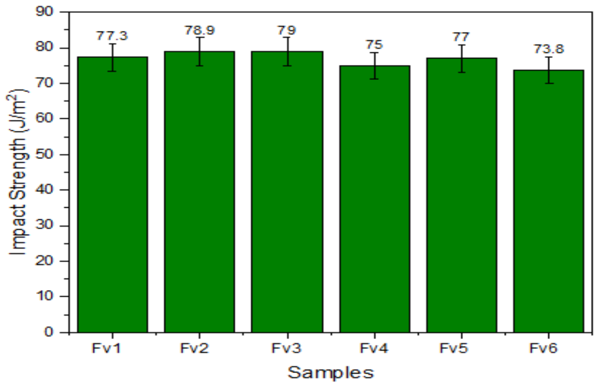

Fig. 7. Impact strength

Figure 7 illustrates the impact strength values of the developed whiteware samples. The impact strength values ranging from 73.8 (Fv6) to 79.0 (Fv3) indicate a relatively narrow variation in the impact resistance of the samples, with Fv3 having the highest impact resistance with a value of 79.0 and Fv6 having the lowest impact resistance with a value of 73.8. Most of the samples have impact resistance values close to the average (around 76.83), except for Fv6, which is slightly lower. The values for Fv1, Fv2, Fv3, Fv4, and Fv5 are quite consistent, all falling within a narrow range (75.0 to 79.0). Fv3 standing out as the sample with the highest impact resistance, indicates slightly better material quality or more favorable processing conditions for this particular sample. Fv6's slightly lower impact resistance suggests minor defects, variations in material composition, or differences in the manufacturing process. The overall consistency among the other samples (Fv1, Fv2, Fv3, Fv4, and Fv5) suggests that the material and processing techniques are generally reliable, with Fv6 being the lowest.

G. Strength Index

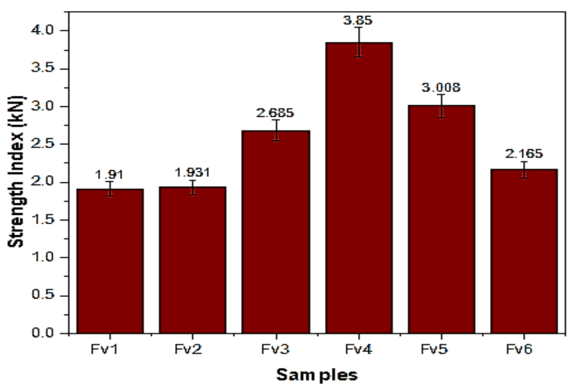

Fig. 8. Strength index

The strength index values of the developed samples are depicted in Figure 8. Sample Fv4 (3.850) is significantly higher than the other values, indicating a substantial difference in the strength of the white earthenware sample in this index. This could be due to a variation in the sample composition, manufacturing process, or testing conditions. **S**ample Fv1 (1.910) indicates the weakest sample or conditions that resulted in lower strength measurements. The difference between the highest and lowest values Fv4 (3.850) − Fv1 (1.910) =1.940. Fv4 (3.850) – Fv1 (1.910) = 1.940. The strength test indices Fv1 to Fv6, with their respective values, indicate a set of measurements related to the strength properties of a material.

4. Conclusion

This work has successfully revealed the type of raw materials used, preparation, characterization and physio-mechanical properties of earthen whiteware body fired at low temperature. The results showed that the pink colour of Ehime Mbano kaolin in raw state, which turned white at the temperature of about 1000^{o}C is actually the result of impurities embedded in the raw kaolin. The overall white appearance of the samples produced showed that white earthenware can be produced from the raw materials composition. The lowest shrinkage value of the samples produced is revealed in sample Fv1 as 6.08% while sample Fv6 has the highest value of 7.58%. Sample Fv5 has the lowest porosity value of 18.91% and sample Fv2 has the highest value of 26.92%. Sample Fv1 has the lowest bulk density of 1.61g/cm^3 and Fv3 has 1.76 g/cm^3. The lowest impact value of the samples is sample Fv5 with 55.9j/m^2 while sample Fv1 and Fv3 has the highest impact values of 64.3 j/m^2 each.

References

[1] William, Carty and Udayan, Senapati (1998). Porcelain-Raw Materials, Processing, Phase Evaluation and Mechanical Behavior. *Journal of America Ceramics* Society, 81(1), 3-20.
[2] Ogundare Toluwalope, Fatile Babajide Oluwagbenga, Lamidi Yinusa Daniel, (2015). Development of White ware Bodies Using China Clay from Selected Deposits in Edo and Ekiti State of Nigeria*. I-Manager's Journal on Material Science, 3l (2l); 14-20.*
[3] Kashim I.B (2003). Developing Local Technology with Abundant Clay Reserves in Nigeria. Ashakwu, Journal of Ceramic, Vol. 1, 51-56.
[4] Mulenga, M. (1995). Quantitative Phase Analysis of a Novel Whiteware Body Using the Ratio of Slopes X-ray Powder Diffraction Method. M.Sc. dissertation, University of Sheffield.
[5] Kashim I.B., Jegede F.I., Adelabu S.O (2020). Developing A Ceramic Base Engobe from Locally Avialable Raw Materials in Nigeria. Ceramic Art + Perception #116 (146).
[6] Prasad C.S., Maiti K.N., Venugopal R., (2001). Effect of rice husk ash in whiteware composition*, Ceram. Int. 27; 629–635***.**
[7] Idowu, I.O, (2003). Processing and uses of Kaolin: A Means of Enhancing Economic Growth in Nigeria. *Ashakwu Journal of Ceramics,* 65.
[8] Ologunwa T.P., (2018). Effect of Particle Size and Forming Techniques on Porcelain Insulator Properties Using Raw Materials from Edo State, Nigeria. A Thesis in The Department of Industrial Design Submitted to The School of Post Graduate Studies, The Federal University of Technology, Akure, Ondo State, Nigeria in Partial Fulfillment of The Requirements for The Award of Doctor of Philosophy (Ph.D.) In Industrial Design (Ceramics).
[9] Furlani, E; Tonello, G; Maschio, S (2010). Recycling of Steel Slag and Glass Cullet from Energy Saving Lamps by Fast Firing Production of Ceramics, *Waste Management;* 30 (8-9), 1714–171.
[10] Blengini G.A., Busto M., Fantomi M., Fino D., (2012). Eco-efficient Waste Glass Recycling Integrated Waste Management and Green Product Development through LCA. Waste Manag. 32(5), 1000 – 1008.
[11] Santos W.J. (2009). Caracterizaco De Vidros Planos Transparentes. Scientia Plena 5; 1-4.
[12] Numfor Bih, Assia Aboubaka Mahamat, Chukwuemeka Chiweze and Olugbenga Ayeni (2022). The Effect of Bone Ash on the Physio-Chemical and Mechanical Properties of Clay Ceramic Bricks.