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Evaluation of Ubakala and Owerri clays for use in lightweight refractory insulation bricks

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Abstract
The properties of clay, including strength and color, are influenced by firing, and this effect varies at different temperatures. The primary objective of this study was to evaluate the mechanical and physical properties of two Nigerian clays mixed in a 50:50 ratio, both in their dried (unfired) and fired states. The strength of the dried and fired mixed clays from Ubakala in Umuahia, Abia State, and Owerri in Imo State was examined.The experimental results indicated that the strength (modulus) of the unfired clay was measured at 3.078 MPa, while the average of that fired at 1150 °C was 18.94 MPa. Additionally, the apparent porosity and bulk density of the sintered clay at 1150 °C were found to be 22.13% and 1.04 g/cm³, respectively, with a percentage drying shrinkage of 18.27%. At the firing temperature of 1150 °C, the firing shrinkage was determined to be 12.81%. The standard deviations for apparent porosity and bulk density were estimated to be 0.0487 and 0.0664, respectively.In conclusion, the results demonstrate that the clay samples are suitable for light-weight refractory insulation bricks applications.

Keywords: *Ubakala and Owerri clay**,** sintered and unsintered clay, mechanical properties, physical properties, lightweight refractory bricks.*

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I. Introduction

Refractory bricks are essential components used in high-temperature industrial settings, including furnaces, kilns, and reactors. These insulation bricks must withstand extreme thermal conditions, reduce heat loss, and improve energy efficiency. The previous studies and thermal characterization indicate that the clays have promising potential for application in lightweight insulating refractory materials, as evidenced by recent advances in porous refractory composites which exhibit improved thermal insulation and reduced bulk density(Zhong *et al*., 2025).

Lightweight insulation bricks are known for their high porosity and minimal thermal conductivity. Their reduced density, typicallyranging from 0.6 to 1.2 g/cm³,is achieved by incorporating additives, pore-forming agents, or naturally porous substances such as kaolin, fireclay, and sawdust (Sutcu et al., 2012; Abadir et al., 2024). The pores function as insulating air pockets, reducing heat conduction and cutting the overall thermal mass of the lining, which enhances heating response and decreases fuel consumption (Soliman and Shahat 2025).

The functionality of insulation bricks is highly influenced by the raw materials used. The general raw materials in brick production include refractory clays (kaolinite, fireclay), silica, alumina, and various waste products from agro-industries. Organic additives such as sawdust and rice husk are frequently incorporated as burnout agents to enhance porosity during the firing process (Omowumi et al., 2021). In selecting these materials, their refractoriness, mineral compositions, and local availability are considered.

There is a growing interest in the utilization of locally sourced materials for refractory applications in Nigeria and other developing countries. The use of indigenous or local raw materials provides several advantages, such as lowering the foreign exchange costs related to imports, reducing production expenses, generating employment opportunities, and promoting sustainable resource use. This approach is also in agreement with the United Nations Sustainable Development Goals (SDGs), notablyincluding:Goal 9 (Industry, Innovation, and Infrastructure), Goal 12 (Responsible Consumption and Production),Goal 13 (Climate Action), andGoal 8 (Decent Work and Economic Growth) (UN, 2015).

Claysare a natural, fine-grained earth material that contains some minerals. It is highly abundant in most areas in Nigeria and widely used as a refractory material. The clay is plastic when wet and hard when dried or fired. The major components of clay are silica (SiO_2) and alumina (Al_2O_3), whichmakeitfit for the production of both heavy and lightweight refractories. Clays are used in the manufacture of bricks, tiles, kiln furniture, crucibles, and ceramics. However, the appropriateness of clay for industrial use depends on mineral contentand the level of impurity.Hence, not all the local clays are sufficiently analyzed for their utilization in high-temperature insulation (Shuaibet al., 2018).

This research focuses on Ubakala clay and already prepared clay from Owerri, located in Abia and Imo State, Southeastern Nigeria, respectively. While clays, such as those from Okpella, Kutigi, and Kankara, have been thoroughly investigated and in some cases commercialized for refractory and ceramic uses (Obadina et al., 2020; Adekunle et al., 2015), Ubakala and Owerri clays have not been extensively researched despite theiravailability. Initial field studies and thermal behavior show that the clay materials indicate increased porosity, reduced bulk density and improved thermal behaviour, which make them potentialcandidates for use in lightweight insulating refractory bricks (Shahat & Soliman, 2025).

Therefore, this study aims to characterize Ubakala and Owerri, claysfocusing on their physical, thermal, and structural characteristics to assess their suitability for insulation refractories. The existing literature indicates lack of a documented scientific assessment of these clay deposits regarding their performance when formulated into lightweight refractory bricks. This research aims to fill the gap by promoting the sustainable utilization of local clay materials and providing valuable data for possible industrial applications. In this investigation, two distinct Nigerian clays were combined. The goal of the study was to examine the mechanical and physical properties of two blended clays from Owerri, Imo State, and Ubakala Umuahia, Abia State, as well as their shaping using the slip casting technique to determine their industrial applications.

II. Materials and Methods

2.1 Sample Collection and Preparation

The major raw clay materials used for the investigation were collected from Ubakala, Umuahia, Abia State, andOwerri, Imo State. The clay from Owerri was already processed clay (CITD clay). The clay sample from Ubakala Umuahia was collected from an existing clay deposit, and it was in lumps about 3-5 cm. With the aid of a pestle and mortar, the lumps of clay were crushed and ground into smaller pieces or particles to make the green clay body. Thereafter, the clay was dry sieved using a 150-micron mesh to get a uniform particle size. The already prepared clay (CITD clay from Owerri, Imo State, Nigeria) and the dry-sieved Umuahia clay were combined in a bucket at a ratio of 50:50, and the mixture was then wet-sieved with a mesh size of 150 microns.
The resultant slurry of the wet sieved clay in the bucket was allowed to settle down. The settling of the slurry was facilitated by pouring a hot, dissolved alum into the slurry. Then the supernatant liquid on the settled slurry was decanted. The slurry was then poured on the prepared Plaster of Paris batt (POP) for de-watering (Figure 1). The resultant plastic mass of the clay was kneaded and wedged to remove trapped air. The resultant kneaded and wedged plastic mass was placed into the extruder, and extruded into cylindrical rods or forms having approximately 7.50mm diameter x 80mm, and placed on a wooden board for drying.

2.2 Preparationof Pop Batt

To prepare the POP batt, the following measurement ratio was followed;
90 parts by weight of water against 100 parts by weight of POP.
i.e., 90 parts by weight of H_2O = 100 parts by weight of POP

$$X = 5000\text{g of POP}$$

$$X = \frac{5000 \text{ X } 90}{100} = 4{,}500 \text{ ML of } H_2O = 4{,}500\ cm^3 \text{ of } H_2O \quad \ldots\ldots\ldots\ldots\ldots\ldots 1$$

4,500cm^3 of water was used to mix 5000g of POP in a bucket. The mixture was stirred thoroughly for about 11 minutes and was poured into the prepared form and allowed to solidify. The POP batt cast is shown in Figure 1.

Figure 1: Plaster of Paris (POP) batt

2.3Determination of Apparent Porosity (Ap) And Bulk Density (Bd) of The Sintered Clay Samples

In fired ceramics, the pores can either be interconnected or closed. The apparent porosity measures the interconnected porosity and determines the permeability, or how easily gases and fluids flow through the ceramic component. Apparent porosity is calculated by weighing the dry ceramic sample (Wd), then reweighing it when suspended in water (Ws), and finally, after it is withdrawn from the water (Ww). This process allows us to determine its apparent porosity and bulk density (ASTM C20-00 (2000). The methods for determining apparent porosity and bulk density are as follows:

Apparent porosity (AP) $= \frac{W_w - W_d}{W_w - W_s}$... (2)

Bulk density (BD) $= \frac{W_w - W_d}{W_w - W_s} \times D$...(3)

where D = density of immersion liquid at the temperature of the test.

2.4 Modulus of Rupture

This can be described as the material's ability to resist deformation under load according to ASTM C133 – 97. Eleven (11) cylindrical samples,were made and air-dried for eight (8) days. These samples were then oven dried at 105°C and subsequently fired in a GK4 1300°C electric furnace at 1150°C. The firing process involved heating at a rate of 150°C/hr up to 450°C, followed by a rate of 130°C/hr up to 1150°C. The samples were soaked at 1150°C for fifteen (15) minutes and then cooled in the furnace. The modulus of rupture for both the sintered and unsintered clay samples was measured using a three-point bend test with the Monsanto tensiometer, employing a span of 50 mm at room temperature. The cylindrical samples were approximately 5.57 mm in diameter and 55 mm in length. The eleven dried, extruded samples of the clay were measured.

The modulus of rupture of the broken sample was calculated using the formula:

$Modulus\ of\ rupture\ (MOR) = \frac{8PL}{\pi D^3}$ .... (4)

Where: P = Load required to break the bar in kg

L = Length of the span in mm.

D = Diameter of the samples in mm

2.5Determination of Shrinkage

This property is used to determine both dry and fired shrinkage of the produced clay samples. After molding of the cylindrical test samples, a pair of dividers set at 50mm was used to make two parallel marks, 50mm (5cm) apart, each drawn on eleven (11) cylindrical samples for the determination of linear shrinkage. This measurement was recorded as the original length L_o (cm). Thereafter, the test samples were then air dried for 8days and then oven dried at 105°C until a constant weight was obtained. The shrinkage from the 5cm mark was then obtained and recorded as the dried length, L_d (cm). Afterwards, the dried samples were fired up to atemperature of 1150°C. The shrinkage of the test samples from the 5cm mark was then determined and recorded as the fired length, L_f (cm). The dry and fired shrinkage of the test samples was determined using the formula:

Drying Shrinkage (%) $= \frac{L_o - L_d}{L_o} \times 100$ .... (5)

Fired Shrinkage (%) $= \frac{L_d - L_f}{L_d} \times 100$ .... (6)

Total Shrinkage (%) $= \frac{L_o - L_f}{L_o} \times 100$ .... (7)

where:
L_0 = Original Length
L_f = Fired Length
L_d = Dry Length
L_f = Fired Length

2.6Determination of Standard Deviation

The results of the standard deviation (SD) of materials such as clay measure the degree of variation in properties like porosity, shrinkage, or bulk density in test analysis. The low standard deviation of the material (e.g., clay) indicates that the properties are uniform, which is preferable for dependable refractory performance. At the same time, high SD suggests notable deviation that can lead to the material's defects, such as uneven cracking, firing, or structural instability that can lead to failures due to mechanical load and thermal stress (Albert et al (2022); ASTM E2282-14). The standard deviation is estimated using this equation.

$$\text{Standard deviation (SD)} = \frac{\sqrt{\Sigma(X-\bar{x})^2}}{n-1} \quad \ldots\ldots (8)$$

2.7Determination of Coefficient of Variation

The coefficient of variation (CV) expresses the extent of variation of data in a sample relative to the mean of the population. A material with a low coefficient of variation of less than 20% suggests good uniformity in properties like density or porosity. This is important for the production of reliable and consistent refractory brick products. On the other hand, a high CV greater than 20% indicates significant deviation that can improve thermal stability and mechanical efficiency (Albert et al.,(2022); ASTM E2282-14). The standard deviation is determined using this equation.

$$\text{Coefficient of variation} = \frac{S.D}{Mean} \times 100 \quad \ldots\ldots (9)$$

III. Results and discussion

The physical and mechanical properties of the produced clay samplesare presented in Table 1.

Table1. Sample properties

Sample properties	Average Values
Dry shrinkage (%)	18.27
% Firing shrinkage	12.81
MOR (MPa) of green sample	3.078
MOR (MPa) of the sintered sample	18.94
Coefficient of variation of green MOR (%)	46.654
Coefficient of variation of sintered MOR (%)	13.99
Standard Deviation of the Modulus of Rupture of the Green	1.436
Standard Deviation of the Modulus of Rupture of the Sintered Sample	2.65
Apparent porosity (%)	22.13
Coefficient of variation of Apparent porosity (%)	22.0
Bulk density(g/cm³)	1.0448
Coefficient of variation of Bulk density (%)	6.36
Standard Deviation of the Apparent Porosity of the Sintered Strength (%)	0.0487
Standard Deviation of the Bulk Density of the Sintered Strength	0.0664

3.1 Shrinkage

The percentage drying and firing shrinkage of the clay is shown in Table1. The average percentage drying and firing shrinkage were determined to be 18.27% and 12.81% respectively. These results showed that there was higher shrinkage during drying and less during firing.

However, the shrinkage values of both dried and fired samples fall above the recommended standard range of 4-10% for fireclay-based refractorymaterials (Chukwudi et al., 2020). The high shrinkage indicates high degree of plasticity and finer particle size distribution. Though, this is beneficial for good mouldability but, may lead to cracking and size-related instability if additives are not added to improve the samples.

3.2Modulus of Rupture

The results of the modulus of rupture (MOR) of the unfired and sintered clay at 1150ºC are shown in Table 1. The average modulus of rupture of the unfired and sintered clay was 3.078MPa and 18.94MPa, respectively. The results show that the modulus of rupture of the clay samples was greater after sintering than that of the unfired samples. This significant increase in strength after the samples have been sintered has direct implications for performance and reliability as a refractory material. This notable increase in MOR from 3.078 MPa to 18.98 MPa after sintering suggests that firing significantly improves the mechanical properties of clay. Sintering at a temperature of 1150ºCinitiates vital transformations or changes, which include densification, phase development, and particle bonding. These transformationsimprove the internal structures of the clay, and this makes it more resistant to mechanical stress. The high-temperature sintering regarding modulus of rupture suggests that the material can withstand mechanicaland thermal loads experienced during service without failure. In practical refractory applications, increasedmodulus of rupture (MOR) is vital property to withstand thermal shock, abrasion, cracking, and structural collapse in furnaces, kilns, and ladles. The results show that the clay samples have been improved from a weak green state to a material capable of working under hightemperatures. This result agreed with the findings of Mgbemere et al (2020), who confirmed that the firing of clays from Nigeria significantly improves their thermal and mechanical performance. Also, a study by Dutta and Mandal (2018) stated that an increase in MOR value after the samples have been sintered is a key quality for high-temperature refractory products or bricks.
Therefore, the results of the MOR obtained in this study fall within the recommended range of 5–10 Mpa (Olusola, 2025)for lightweight insulating refractories which confirm the potential suitability of clay samples.

3.3 Apparent porosity

The results of the average apparent porosity of the sintered clay samples, as shown in Table 1is 22.13%. The results of clay samples sintered at 1150ºC gave an insight into the thermal efficiency, performance, and reliability of the clay as a refractory material. The value of apparent porosity as indicated above falls within the acceptable range of 20-30% for fireclay-based refractories, which is also suitable for general-purpose applications (Shuaib-Babata & Abdulrahaman,2018*)*. This suggests that the clay material sample shows a good balance between mechanical stabilityand thermal insulation.

The porosity obtained suggests a good balance between thermal insulation and moderate strength which makes the clay samples suitable for light-weight refractory bricks. Reducing the porosity variation can significantly improve long-term durabilityand service reliability. These findings are in agreement with the work by Alexander et al (2013), who reported that Nigerian clays with consistent porosity (~20-28%) and density value (~2.8-3.5 g/cm^3) were suitable for medium-duty refractory applications after sintering. Soliman & Shahat (2023) also stressed the importance of controlling porosity and density to improve the performance of fireclay, noting that optimal thermal behaviour requires a uniform pore structure.

3.4 Bulk density

The result of the bulk density of the sintered clay samples was 1.0448 g/cm^3 (Table 1). This value is the characteristics of light-weight insulating refractory bricks. A lower bulk density of the clay samples usually suggests better insulating properties and reduced mechanical strength. According to Ogbu et al. (2019), the densities of insulating firebricks range from 0.8-1.5 g/cm^3. The observed low bulk density (1.0448 g/cm^3) of the clay suggestsimproved thermal insulating refractory material, indicating that the clay is not suitable for a load-bearing structural refractories, until it is modified.

Therefore, this result suggests that the clay is a candidate for insulation applications which requires low-temperature storage, such as furnaces, kilns and thermal back-up layers.

3.5 Standard Deviation and Coefficient of Variation

The values of the standard deviation (SD) and the coefficient of variation (CV) for the unfired and sintered clay samples for modulus of rupture (MOR) as indicated in Table 1, were 1.436, 46.65%, and 2.65, 13.99%, respectively.The SD of 1.436, and the CV of 46.65% for the unfired samples show higher variability,

which may lead to shrinkage and poor predictability during the firing process (ASTM E2282-14).The SD and CV of the sintered MOR samples at 1150 ºC were 2.65 and 13.99%, shows improved uniform and structural reliability after firing (Albert et al, 2022). According to Albert et al (2022) and ASTM E2282-14, CV values between 10-20% are considered suitable and acceptable for refractory and ceramic materials quality control.
The standard deviation (SD) of the apparent porosity and bulk density of the clay samples sintered at the temperature of 1150°C as indicated in Table 1 were 0.0487and 0.0664 respectively. These low values of SD suggests that the clay samples showed good homogeneity and also that, the processing conditions at the temperature of 1150 ºC supported uniform microstructural development, which led to little variations in porosity and density. The CV of both apparent porosity and bulk density were 22.0% and 6.36% respectively, which indicated acceptable variation. As the porosity variation is moderate, the low value of CV for bulk density suggests good process control during the shaping and firing of the samples (Dutta & Mandal, 2018).

IV. Conclusion

This study evaluated the suitability of Ubakala and Owerri clays for producing light-weight refractory insulation bricks. The results obtained from the study suggest that the physical and mechanical properties of clay samplespossess the key characteristics needed for insulating refractories, which include low bulk density of 1.0448 g/cm^3, moderate apparent porosity of 22.13%, and a notably improved modulus of rupture (MOR) of 18.94 Mpa. These properties jointly show good thermal insulation suitability and significant structural integrity for light weight refractory applications.

However, the drying and firing shrinkage values of the samples were a little above the recommended ranges. These problems can be mitigated through modification of the sample, by incorporating grog or other additives.

The entire results confirm that the clays are good raw material for the production of light-weight refractory insulation bricks, as long as the proper processing conditions are observed. The results of the thermal, physical, and mechanical properties are uniform with international standards and agreed to other clays from Nigeria as reported in literature.

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