



Strength Characterization of Clay Deposits at College of Engineering, FUNAAB Abeokuta and Environs

Benedict U. ANYANWU^{1*}, Lawrence O. JAYESIMI², Enemona O. SANNI³

¹Department of Mechanical Engineering, Federal University of Agriculture, Abeokuta, Nigeria

²Department of Industrial and Production Engineering, University of Ibadan, Nigeria

³Department of Mechanical Engineering, Federal Polytechnic, Ilaro, Nigeria

*anyanwubu@funaab.edu.ng, ²lo.jaiyesimi@ui.edu.ng, ³enemona.sanni@federalpolyilaro.edu.ng

Abstract

Most clay deposits in Abeokuta, Southwest, Nigeria, do not have comprehensive data on their general properties, making it difficult to utilize them in any engineering application. In order to establish whether the clay deposits at the college of engineering (COLENG), FUNAAB, Abeokuta and environs were suitable for use in ovens or furnaces, some of their physico-mechanical and thermal properties were examined. Clay deposits from the location were collected, pre-calcined to 120°C and mixed with up to 20 wt% Portland cement, as binders. The samples were used to produce several bricks following recommendations from standard codes. Important physio-mechanical and thermal properties: bulk density (BD_c), apparent porosity (AP_c), linear shrinkage (LS_c), compressive strength (CS_c), refractoriness (R), thermal shock resistance (TSR_c), thermal conductivity (TC) of the produced bricks were determined. The results for BD_c, AP_c, LS_c, CS_c, R, TSR_c and TC of the developed bricks ranged from 1.46– 1.67 g/cm³, 14.0 – 21.4%, 10.5 – 15.0%, 6.0 – 6.8 MPa, 800 – 1010°C, 4.1 – 5.8 cycles and 0.185 – 0.221 W/mK, respectively. These results are close to those of the control sample which for the same parameters, were 1.60 g/cm³, 20.0%, 10.0 %, 7.0 MPa, 1050°C, 5.9 cycles and 1.000 W/mK, respectively. Sample B (90 wt% pre-calcined clay, 10% OPC) had the best combined properties evaluated, close to the control samples. The study showed that the clay deposits at COLENG, FUNAAB, Abeokuta and environs can be employed in ovens operating with temperature lower than 1000°C.

Keywords: Clay, Deposits, Properties, Oven, Furnace.

1.0 Introduction

Clay is among the earliest and most important minerals utilized by humans in industrial and other applications (Gina *et al.*, 2020). They are materials made of various structural levels of powder-like minerals that can be moulded into various shapes and sizes. Their particles are smaller than 2 µm (Heckroodt, 1991; Njoka *et al.*, 2015). According to chemical and mineralogical analysis, clay is a complex aluminosilicate material that is formed due to the mechanical and chemical breakdown of rocks like granite (Nwajagu, 2005).

The main component of clay, which is a naturally occurring substance, are fine-grained minerals. When exposed to various water contents, these minerals show flexibility; and when dried or heated, they become solidify. Most clay deposits are made up of clay minerals (phyllosilicate minerals), which give it its flexibility when burnt and/or dried, together with varying amounts of water that becomes polar attraction, trapped inside the mineral structure (Odubiyi, 2010).

Furthermore, clay is most frequently found in form of sediments, hydrothermal deposits, and sedimentary rocks in nature (Velde, 1992). Usually, weak solvents and low carbonic acid concentrations are used to weather silicate-containing rocks gradually over an extended period of time (Odubiyi, 2010). The composition of the starting materials, physicochemical conditions of the local weathering environment, and other elements, all influence the production of different kinds of clay materials (Wilson, 1999). More so, due to its adaptability, clayey materials are used for a wide range of purposes, especially with the onset of nanotechnology. In recent years, it has gained a lot of popularity among scientists because of how easy its size, shape and composition can be changed to suit different goals, owing to the possible reduction of its size from micron to nanometer. These nanoparticles have undergone substantial modification and their characteristics, studied largely because of their flexible structural design and small particle size (Murphy and Sawyer, 2004).

Clay deposits are widely employed in several sectors such as construction, automobiles, power, agriculture, sports, etc. However, prior to their usage for any industrial application, it is crucial to evaluate and understand their qualities and features through several mineralogical, morphological, physico-mechanical and thermal auditing of the deposits. Several literatures have established that these properties generally varies with locations of deposits (Sanni *et al.*, 2025). Most deposits of clay are employed as refractories

and linings in furnace walls, owing to their natural ability to be thermally stable at elevated temperatures. This is so because they can survive temperatures up to 1580°C without disintegrating, deforming, or altering their composition (Aiyedun *et al.*, 2012). Common properties that makes it suitable as refractories include its high melting point, otherwise known as refractoriness; thermochemical stability; mechanical strength at high temperatures; high shock resistance; low thermal shrinkage; resistance to chemical attack, low porosity and permeability (Omotoyinbo and Oluwole, 2008).

Furthermore, naturally obtained clay has many benefits as listed above, but it also has certain drawbacks as well. Clay can shrink and crack when exposed to high temperature, which could result to instability issues, loss of strength and durability over time. Most developed countries that utilize clay refractory materials, normally carry out comprehensive characterization studies to ascertain its properties before being applied (Borode *et al.*, 2000). Nigeria has a huge pile of clay deposits, scattered across different geopolitical zones, but unfortunately, they are not included as part of the major sources of solid mineral income in the country. This is partly because, the deposits are grossly underutilized for general engineering applications in Nigeria (Sanni 2025). In fact, most industrial outlets in Nigeria prefers to import clayey materials for their production lines and this is largely due to the inadequate characterization data of the deposits.

More so, with the recent advancement and diversification of the Nigerian economy, there may be need to characterize and record information on the clay deposits in the different locations in Nigeria. In a bid to assess the strength of clay in the Osiele area of Abeokuta, Ogun State, Aiyedun *et al.* (2012) looked at the physical and chemical makeup of the clay deposits. The following properties of the refractory were measured: density, porosity, water absorption, cold crushing strength, and shrinkage. The qualities were thoroughly examined, and experimentally obtained data were juxtaposed with those that were already in use. Temperatures of 1100, 1200, 1300, 1400, and 1500° C were applied on the bricks. Their results concluded that Osiele clay is great for producing refractory bricks for furnace lining with minimal to no additives. They also submitted that the physical attributes of the clay compares strongly with the worldwide standard for fire clay refractory bricks.

Fakolujo *et al.* (2012) investigated the clayey materials from five locations in Abeokuta, South West Nigeria, to determine their applicability for various uses. The deposits were from Asero 1, Fajol 1, Agba-akin 1, Ile-ise Awo 1, and Ajebo 1. They were milled into powder and then sieved. Experimental tests were conducted on them to determine their mass per volume ratio, shrinkage (linear), %shrinkage (dry), %total shrinkage and refractoriness. Although they differ after the compressive test, the physico-mechanical characteristics of the five selected clay samples were identical. Agba-akin1 had the least formation of cracks, while Ile-ise Awo1 had the greatest.

Although these authors and others in literature have reported the morphological and physico-mechanical properties of selected clay deposits across different locations in Nigeria. However, detailed and comprehensive data are still grossly inadequate.

These issues highlight the significance of auditing clay deposits scattered around several locations in Abeokuta, Southwestern part of Nigeria, as most deposits do not have comprehensive data on their general properties, making it difficult to utilize them in any engineering application. Hence, in order to establish whether the clay deposits at the College of Engineering, Federal University of Agriculture, Abeokuta (COLENG, FUNAAB) and environs are suitable for use in ovens or furnaces, some of their physico-mechanical and thermal properties were examined. The distinctive features of the clay deposit at COLENG, FUNAAB and environs may be discovered by undertaking a comprehensive audit, allowing for well-informed decision-making.

This study was therefore aimed to evaluate the physico-mechanical and thermal properties of the clay deposits at COLENG, FUNAAB, Abeokuta and environs, with a possible view to applying them in oven or furnace applications.

2.0 Methodology

2.1 Sample Preparation

The deposits were mined from three distinct locations at a depth of 1.23 meters. It went through a number of processes such as picking, sorting, crushing/grinding, sieving/sizing, blending, mixing, and tempering (pre-calcined). Following a 24-hour immersion in water, the deposits were crushed in a hammer mill, cleaned, and the sizes separated via sieves with 75, 100, and 200 µm mesh sizes. The goal of this filtration procedure was to remove any dirt or contaminants that had accumulated with the clay. Moistures were then drained from

the slurry by sun drying for six days. Desiccators were used to store the dried clay samples for 14 days before been pre-calcined in a furnace at temperature of 120°C.

2.2 Production of prototype bricks / physico-mechanical and thermal properties determination

The process outlined by Sanni (2025) was adopted to create the prototype bricks. The pre-calcined clay was combined with Ordinary Portland Cement (OPC) up to 20 wt% (Table 1). The mixture was then carefully casted into the moulds (200 x 100 x 100 mm) and a plunger was placed on each face of the charged mould, hand rammed, and compressed by a 12 Ton hydraulic pressing machine. The produced bricks were then carefully discharged from the moulds and weighed. Thereafter, important physio-mechanical and thermal properties: bulk density (BD), apparent porosity (AP), linear shrinkage (LS), compressive strength (CS), refractoriness (R), thermal shock resistance (TSR), thermal conductivity (TC) of the produced bricks were determined following ASTM-C27-98 guidelines as highlighted by Sani (2025). Bricks employed in bakery ovens were adopted as the control sample in this study.

Table 1: Percentage Proportion of Materials Mixes

Experiment	Clay (wt%)	Binder (wt%)	Sample Identity
1	100	0	A
2	90	10	B
3	80	20	C

2.2.1 Determination of Bulk Density, BD_c

The BD_c was computed from equation (1) as stated by Aiyedun *et al.*, (2012).

$$BD_c = \left[\frac{g}{cm^3} \right] \left(\frac{DPW}{Ws - Ss} \right) \quad (1)$$

Where;

D = dried weight
 Ws = soaked weight
 Ss = suspended weight
 PW = Water density

2.2.2 Determination of Apparent Porosity, AP_c

The AP_c was calculated from Equation (2) as suggested by Sanni (2025).

$$AP_c = \frac{W-D}{W-S} * 100\% \quad (2)$$

Where;

W = Suspended weight
 D = Dry weight
 S = Soaked weight

2.2.3 Determination of Linear Shrinkage, LS_c

The LS_c was calculated from Equation (3) as suggested by Sanni (2025).

$$LS_c = \frac{L_1 - L_2}{L_1} * 100 \quad (3)$$

Where

L_1 = Dried green length
 L_2 = Fired length

2.2.4 Determination of Compressive Strength, CS_c

The CS_c was determined by a universal testing machine (UTM). The bricks were put on the specimen platform and loaded until fracture.

2.2.5 Determination of Refractoriness

The refractoriness of the samples was measured by a pyrometric cone equivalent test (PCE). The samples were moulded on cones and then fired continuously in a furnace for temperatures up to 1200°C at 15°C/min heating rate. Thereafter, the cone that softens and bends at a given temperature was recorded.

2.2.6 Determination of Thermal Shock Resistance, TSR_c

To get the TSR_c , selected samples placed in a furnace, at a temperature of 1000°C for 60 minutes and then removed, cooled in water for about a minute, then air-cooled for another five minutes. Thereafter, the samples were placed back in the furnace for 10 minutes at 1000°C before immersion in water. The procedure was

continued until visible snaps were seen on the samples. The quantity of full cycles that caused the snaps were then recorded.

2.2.7 Determination of Thermal Conductivity

Using the hot guided plate technique, the fireclay brick's thermal conductivity was assessed. Thermocouple sensors were placed underneath and above the samples, which was encased between two iron rods, to detect the temperatures at the sample's top and bottom surfaces, respectively, as heat passes through the material. The temperature was continuously recorded by the thermocouple, attached to a data logger.

3.0 Results and discussion

Results obtained from the study were compared with bricks used as liners and walls in bakery ovens. The values deduced from the liners and walls were used as the control in this study.

3.1 Bulk Density Test

The bulk density values (Table 2) for all samples ranged from 1.46 - 1.67 g/cm³. The table shows slight decrease 0.16 - 0.21 gcm⁻³ in the density value of the sample brick produced from 0 wt% OPC addition (sample A). The OPC additions must have altered the mass to volume ratio of the samples B and C, leading to more uniform and properly distributed grains (Sanni 2025). Sample B had the highest density of 1.67 gcm⁻³ among the samples. This means that it has a greater mass or weight per unit volume compared to the others.

Table 2: Results of Bulk Density Test

Sample	Control	A	B	C
Bulk Density (gcm ⁻³)	1.60	1.46	1.67	1.62

3.2 Apparent Porosity Test

One crucial aspect of brick characteristics is its porosity, which is the volume of its pores expressed as a proportion of the brick's overall volume. The apparent porosity test values of the brick samples are presented in Figure 1. Sample A has the highest percentage of porosity at 21.4% which proves that there are more pores or voids in the brick, and the capacity of these pores is relatively high compared to the total capacity of the other bricks. Sample B had the lowest percentage of porosity, corresponding to a 70% decrease compared with the control. However, standard recommendations for porosity values of low duty fire clay bricks is between 10 - 28% (ASTM C27-98). Results obtained are within the range specified, and thus, could have the potentials for thermal stability in oven or furnace applications.

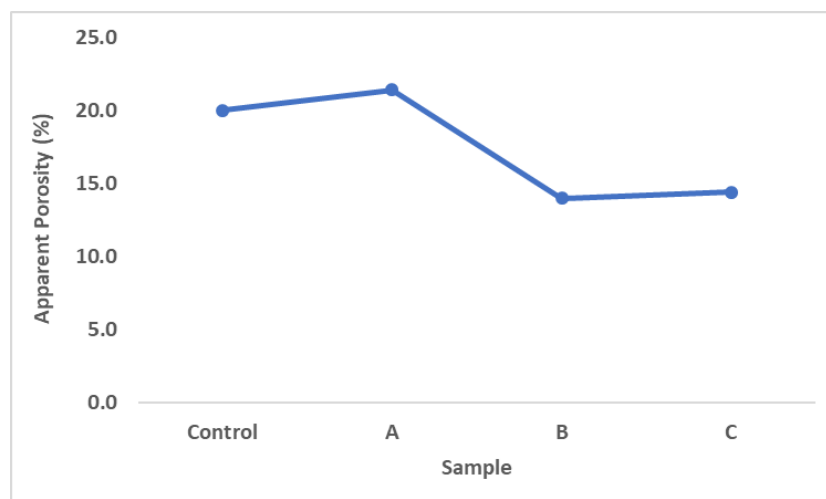


Figure 1. Results of Apparent Porosity Test

3.3 Linear Shrinkage Test

The rate at which the clay's volume changes after burning is expressed by linear shrinkage, LS_c . Figure 2 presents the values obtained from the LS_c tests. Manukaji (2013), reported that the recommended LS_c value for clay brick should be <10%, while (Chesti, 1986; ASTM, 1982) recommended that the value should be between 2 - 10%. Results of the test indicates that Sample A had the highest linear shrinkage of 15%. When compared with the control, whose linear shrinkage was 10.0%, sample B had values (10.5%) closer it. This is not unconnected with the high weight to volume ratio added by the OPC in the sample (Sanni 2025). Fire clay

bricks from clays' firing capacity is indicated by linear shrinkage, with a smaller linear shrinkage value being preferred (Ogbebor *et al.*, 2010).

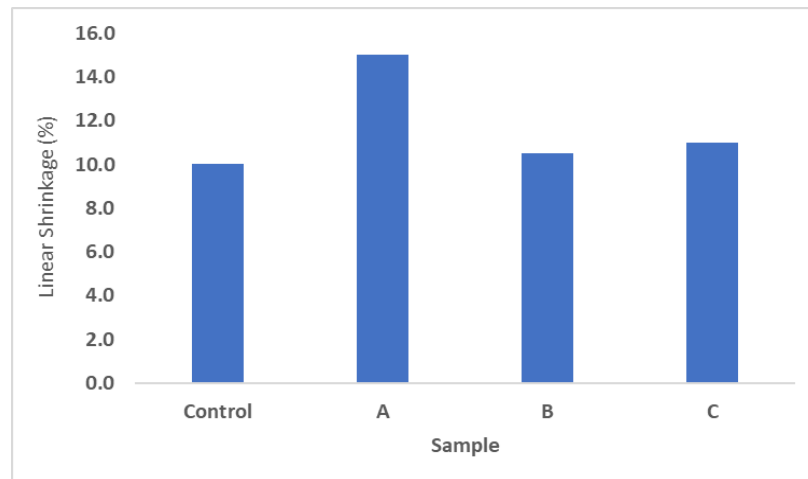


Figure 2. Results of Linear Shrinkage Test

3.4 Compressive strength test, CS_c

The values obtained for the CS_c are provided in Figure 3. A range of values from 6.0 - 6.9 MPa on the samples of interest were obtained. Sample A had the least compressive strength value of 6.0 MPa, while sample B recorded value (6.9 MPa) closer to the control (7.0 MPa). This again is connected with the well compacted and highly distributed grains in the sample. According to Shuaib-Babata *et al.* (2017), clay samples with low compressive strengths will be less resistant to load, tension, and shear stresses than clay samples with high compressive strengths. For this reason and considering the samples of interest, sample B had the best load resistance compared with the control.

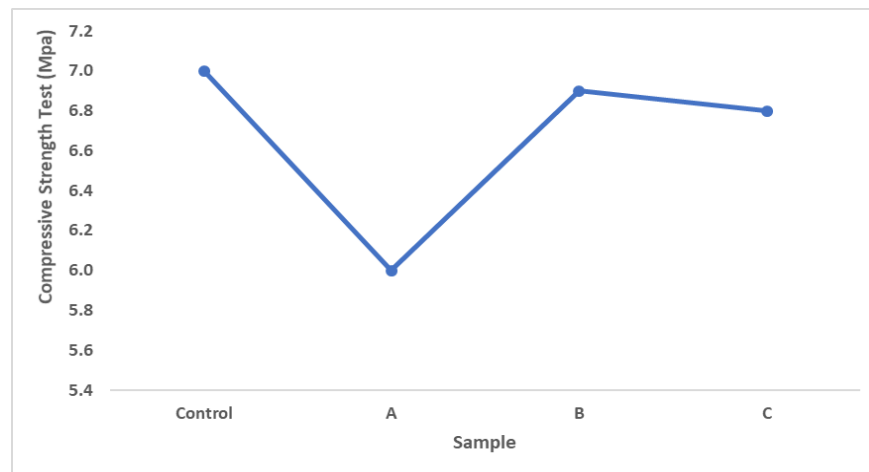


Figure 3. Results of Compressive Strength Test.

3.5 Refractoriness test

Refractoriness of fire clay bricks is normally adjudged the most significant property for selecting bricks in high temperature applications such as ovens and furnace. It measures the thermal stabilities at different temperature conditions of the bricks. The refractoriness values of the bricks studied, are presented in Figure 4. Among the samples of interest, sample B had the highest refractoriness value (1010°C), while sample A had the least (800°C). This means that, the samples of interest cannot survive temperatures more than 1010°C. The obtained values are lower than the recommended values for high duty fire clay applications (1500 - 1700 °C), but are however, suitable for low duty fire clay applications (1000 - 1300°C), as reported by Omowunmi (2001) and Sani (2025). The samples particularly that of sample B, can be used in oven applications, where temperatures hover around 800 to 1100°C. The OPC binders offered some thermal stabilities in the mix, since there is proof that clay materials only, cannot tolerate deformation at temperatures of above 1000°C without buckling or fretting (Omowunmi 2001).

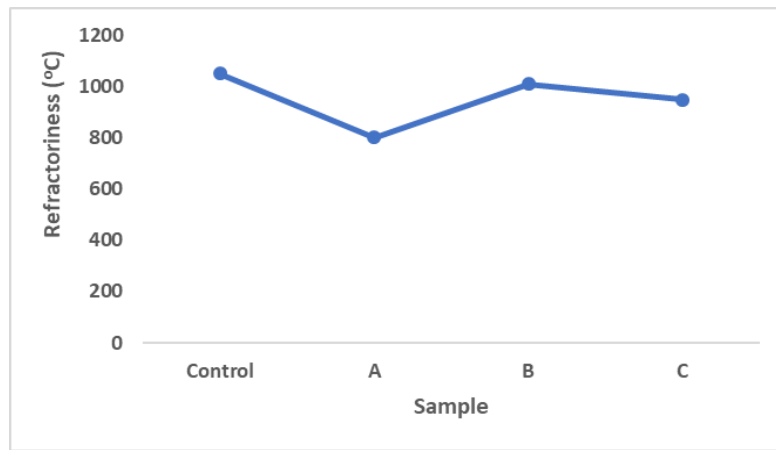


Figure 4. Results of Refractoriness

3.6 Thermal Shock Resistance Test

Figure 5 presents the results of the TSR_c test carried out on the samples. Samples B and C had the highest thermal shock resistance after 5.8 cycles while, Sample A had the lowest thermal shock resistance after 4.1 cycles which indicates that the material is more likely to fail when exposed to sudden temperature changes. The results generally showed close proximity in values to that of the control sample, with 5.9 cycle resistance before failure. The performance is not unconnected with enhanced compactness offered by the OPC on the samples of interest. It has been recounted that materials with low conductivity tend to have higher shock resistance (Sani 2025). This evident in the results derived for thermal conductivities of the samples.

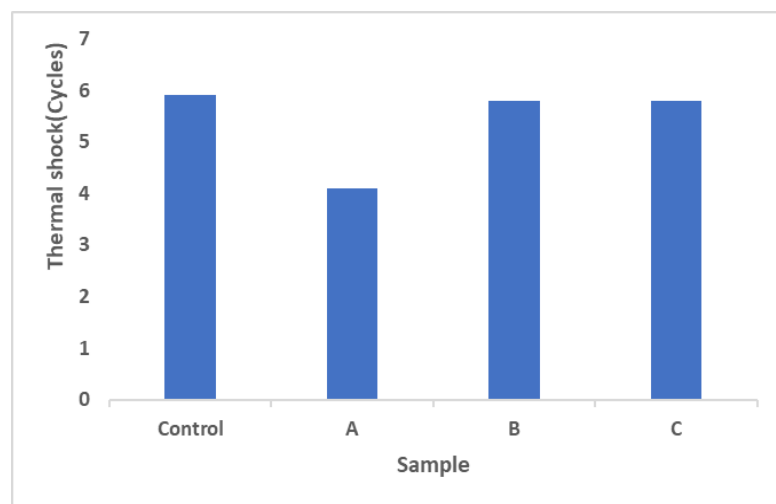


Figure 5. Results for Thermal shock resistance

3.7 Thermal Conductivity Test

Values obtained for the thermal conductivity are presented in Table 3. The values ranged between 0.185 – 1.000 W/mK and falls within the standard thermal conductivity values of 0.01 – 1.1 W/mK for typical low duty fire clay bricks (Sanni, 2025). Sample A had the lowest thermal conductivity property, while a value of 0.221 W/mK was obtained for sample B. The OPC addition in samples B and C, visibly modified their structures, thus making their thermal conductivities to be marginally higher than their initial forms. Comparing the values of the thermal conductivities of the OPC enhanced samples, it is observed that control samples recorded a far more value (1.000 W/mK) than both of them combined. This may not be unconnected with the attendant impurities and lower number of phonons introduced by the OPC in the OPC modified samples. As have been recounted in literatures, the total thermal conductivity values of a material are affected by number of phonons (lattice waves), impurities in the parent material, lattice vibrations and presence of free electrons (Calister, 2007).

Table 3: Results of Thermal Conductivity Test

Sample	Control	A	B	C
Thermal Conductivity (W/mK)	1.000	0.185	0.221	0.218

4.0 Conclusion

Clay deposits at COLENG, FUNAAB, Abeokuta and environs were successfully collected, pre-calcined and mixed with up to 20 wt% Portland cement, as binders. Several bricks were successfully produced from the deposits. Thereafter, some selected physio-mechanical and thermal properties of the bricks were determined. The following deductions can be drawn from the study:

- i. The bricks produced were thermally stable up to a temperature of 1010°C.
- ii. The linings contributed an average thermal shock resistance of about 5.8 cycles when heated to 1000°C.
- iii. Sample B (90 wt% pre-calcined clay, 10% OPC) had all physical-mechanical and thermal properties evaluated to be close to the control samples.
- iv. The study showed that the clay deposits at the College of Engineering, Federal University of Agriculture, Abeokuta and environs can be employed for linings in ovens operated below a temperature of 1000°C.

Acknowledgements

The support of FUNAAB Management and the Tertiary Education Trust Fund (TetFund) is hereby acknowledged, for their roles in the execution of this study.

References

- Al-Taie M. H., Aishammari A.H and Al-Attar A.F (2014). Characterizations of Semi-Silica Refractory Bricks Produced from Local Iraqi Materials. *Journal of Engineering & technology*, 10 (2): 2268-2276.
- Aiyedun, P. O, Olokode, O. S., Fakolujo, S. O and Anyanwu, B.U (2012). An Evaluation of Strength Characteristics of Osiele Clay. *The Pacific Journal of Science and Technology*, 13 (1):78-82.
- ASTM-C27-98 (2020). Standard classification of fireclay and high-Alumina Refractory bricks. *ASTM International Manual, Peter Book Press, California*, 304 – 370.
- ASTM (1982). Annual Book of ASTM Standards, Part 17: Refractories, glass, ceramics materials, carbon and graphite Products. *ASTM International*, 9:601-657.
- ASTM C24-89 (1989). Standard Test Method for Pyrometric Cone Equivalent (PCE) for Fireclay and High Alumina Refractory Materials. *ASTM International*, 15:236-301.
- Borode I.O, Onyemaobi O and Omotoyinbo J.A (2000). Suitability of some Nigerian Clays as Refractory Raw Materials. *Nigerian Journal of Engineering Management*, 3(5):14-18.
- Callister D. W (2007). Materials science and engineering: an introduction. *John Wiley and Sons, Inc, USA*, 1-975.
- Cengel Y.A and Ghajar A.J (2015). Heat and Mass Transfer: Fundamentals and Applications. *McGraw Hill*, 5:18-22.
- Chesti A.R. (1986). Refractories – Manufacture, Properties and Applications. *India Prentice-H*, 6:231-230.
- Chidozie I. F. and Thompson C.O (2022). Characterization and Application of Nigerian Clay Raw Resources for Porcelain Formulation and Manufacture. *Journal Miner Science Materials*, 3(2): 1036-1050.
- Fakolujo O. S, Olokode O. S, Aiyedun P.O, Oyeleke Y. T, Anyanwu B. U and Lee W. E (2012). Studies on the Five (5) selected clays in Abeokuta, Nigeria. *Pacific Journal of Science and Technology*, 13(1): 83-89.
- Gina O.I, Josiah N.S, Kingsley I.O, Godwin M.K, Iheoma C. N and Azikiwe P. O (2020). Characterization of certain Nigerian clay minerals for water purification and other industrial applications. *Heliyon, Cell Press*, 6:452-464.
- Heckroodt R. O (1991). Clay and clay materials in South Africa. *Journal of South African Institute of Mining and Metallurgy*, 91: 343 -363.
- Manukaji J. U (2013). The effect of sawdust addition on the insulating characteristics of clays from Federal Capital Territory of Abuja. *International Journal of Engineering Resource Application*, 3(2): 6-9.
- Myo M, Maung T and Myat M (2020). Study on the physical and mechanical properties of clay brick samples in four different locations. *Journal Miner Science Materials*, 2(1): 1233-1240.
- Murphy T. B and Sawyer A. J (2004). Advancement of Natural and Synthetic Clays in Personal Care Applications, Business Briefing, Global Cosmetics Manufacturing. *Global Journal of Science and Technology*, 7(3):73-99.
- Njoka E. N, Ombaka O, Gichumbi J. M, Kibaara D. I and Nderi O. M (2015). Characterization of clay from Tharaka. *Journal of Engineering Materials*, 10 (4): 266-300.
- Nwajagu C. O (2005). Foundry Theory and Practical: Abridged Edition. *Olico Publications*, 3:59-76.
- Odubiyi J.A (2010). Properties of clay. *Multidisciplinary Journal of Research Development*, 15(4):201-236.

- Ogbebor O. J, Okiemien F. E and Uzoma M. O (2013). Characterization of Ugbegun clay deposit. *Global Journal of Science and Technology*, 13(2): 30-41.
- Omotoyinbo J. A and Oluwole O. O (2008). Working properties of some selected refractory clay deposits in South Western Nigeria. *Nigerian Journal of Mechanical Engineering*, 3(1): 2-11.
- Omowunmi O.J (2001). Characteristic of some Nigerian clays as Refractory materials for furnace lining. *Nigerian Journal of Engineering Management*, 3(2): 1-4.
- Sanni E.O, Anyanwu B.U and Adiyeloja, I. T (2025). Mineralogy of Ilaro Clay with Melon Shell Ash and Rice Husk Ash Additives towards Production of Refractory Bricks. *APWEN Journal of Engineering, Science and Technology*, 8(1):209-218.
- Sanni E.O (2025). Effect of Melon Shell and Rice Husk Ashes as Reinforcements on Ilaro Kaolin Clay Deposits for Refractory Brick Production. *Masters Dissertation Submitted To the School of Post-graduate Studies, Federal University of Agriculture, Abeokuta*, 1- 111.
- Shuaib-Babata Y. L and Mudiare E (2017). Characterization and evaluation of the refractory properties of local clay deposits in Kwara State, Nigeria. *Nigerian Journal of Mechanical Engineering*, 7(1): 1-21.
- Tsepav M. T, Yakubu A, Niranjana K, Aliyu-Paiko M, Dastsugwai M. S, Gimba A and Uthman A (2022). Geophysical characterisation of native clay deposits in some parts of Niger state, Nigeria. *Journal Physics Theory and Application* 6(1), 43-54.
- Ugheoke B.I, Onche E.O, Namessan O.N and Asikpo G.A (2006). Property optimization of kaolin -rice husk insulating fire-bricks. *China Refractory* 4: 17-23.
- Velde, B (1992). Introduction to clay minerals Chemistry, origins, uses and environmental significance. *Chapman and Hall. London* 12:244-260.
- Wilson M (1999). Formation of clay minerals in soil: past, present and future perspective. *Clay Miner.* 34:7-25.