INVESTIGATION OF THE POTENTIALS OF JANI AND MALUMFASHI CLAY FOR USE IN METALLURGICAL INDUSTRIES

[1]Mushahid Magaji Dansarai[*], [2]Bawa Muhammed Ahmed, [3]Tokan Aje
[1]Department of Metalwork, Federal College of Education (Technical) Bichi, Kano, Nigeria*
[2]Department of Mechanical/Production Engineering, Abubakar Tafawa Balewa University Bauchi, Nigeria
[3]Department of Mechanical/Production Engineering, Abubakar Tafawa Balewa University Bauchi, Nigeria
[1]Correspondence email address: mushahid417@gmail.com;*
[1]Telephone Number: +2348032128603*
[2]Co-author email address: mabawa@atbu.edu.ng
Co-author email address: ajetokan@atbu.edu.ng
Authors Contribution: This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Abstract:
This research investigates the properties of Jani and Malumfashi clays to employ them for large-scale applications in metallurgical industries. The result of the physical properties showed that Jani and Malumfashi clay samples possessed a thermal shrinkage of 21cycle and 24cycle respectively indicating their ability to withstand abrupt temperature changes. Cold crushing strength for Jani is 247.13kg/cm^2 while that of Malumfashi is 335.95kg/cm^2. Linear shrinkage for Jani is 7.46%, and for Malumfashi is 8.8%. Apparent Porosity for Jani is 23.2% and For Malumfashi is 29.08%. Moreover, the result indicated that Jani clay has a Refractoriness of 1350^{o}C and Malumfashi 1448^{o}C respectively. The modulus of Rapture for Jani is 6.68 kg/cm^2 and Malumfashi 8.6 kg/cm^2. The orientation of the clay samples was examined using SEM analysis. The XRD analysis, the result showed that the Jani clay sample contains three crystalline phases which include Quartz(71.3)%, Orthoclase(16.8)% and, Kaolinite(11.9)% while Malumfashi contains four crystalline phases including Quartz (63)%, orthoclase (17)%, Kaolinite (8)% and Albite (12)%. The composition of chemical oxides present in the clay samples was studied using the XRF analyzer. The results showed the presence of SiO_2, Al_2O_3, MgO, Fe_2O_3, and K_2O as the major oxides present in both the clay samples while CaO, TiO, and MnO were present in trace amounts. These results conclude that Jani and Malumfashi clay can be applied in metallurgical industries. Improvement of the clay through use of suitable additives or blending, and beneficiation is recommended.

***Keywords**: Refractory Material, Clay, XRD, XRF, SEM*

Introduction

Clay is used in metallurgical industries for various applications due to its binding properties, thermal stability, and other desirable attributes. It is used in foundry sand binders, iron ore pelletizers, and the production of refractory materials [1]. Refractories, heat-resistant materials used in high-temperature applications like furnaces and kilns, are produced with the help of clay minerals. These minerals provide thermal stability and resistance to chemical reactions in extreme environments [3]. Most refractories are made from naturally occurring high melting point oxides such as SiO_2, Al_2O_3, MgO, Cr_2O_3, and ZrO [2]. Refractory materials are categorized based on their chemical composition, constituent substances' chemical properties, location of use, resistance to high temperatures, and method of production, physical form, and applications [3]. In recent years, significant research has been conducted on clay deposits from various regions of Nigeria. The results demonstrate the potential suitability of th~~se~~ deposits for use in metallurgical industries. For instance, [4] evaluated Nigerian clay samples for foundry and refractory applications. They found the clays suitable for replacing imported ones in the production of insulating refractories for casting and melting of low and medium-temperature iron and steel. [6] Investigated selected kaolin clay deposits in Nigeria for furnace lining applications. Based on the refractoriness under load (RUL) test, the clay samples could be used for oven and furnace lining with temperature limits not exceeding 1400°C. Similarly, Katsina state is rich with plenitude amount of clay deposits across its local government areas. Despite this abundance, the clay is only utilized for local pottery making due to a lack of scientific records on the clays which limit their applications. Industries such as Dana Steel Rolling Mill situated in Katsina rely on importation of refractory materials for their usage. The clay found in the Jani district of Mani and the Malumfashi district of Malumfashi local governments has not been characterized

Methodology

5kg each of the clay samples was collected from Jani ~~district of Mani~~ and Malumfashi districts of Malumfashi local government areas of Katsina state. The samples were air-dried, and crushed (grounded to powder) with a pestle and mortar to achieve homogeneity of the particle size. The ground samples were sieved with a mesh of 1.13µm. The ground and sieved samples were mixed, weighed, and dried in the oven at a temperature of 110 °C for 24 hours to ensure complete moisture removal. The grounded samples were thoroughly mixed with water to a pester state. The samples were poured into a rectangular box size 10cm × 5.0cm × 5.0cm, made compacted with a hydraulic press pressure of 656.25KN/m^2 according to ISO standards [3]. The prepared samples were dried in the oven at a temperature of 110°C. The temperature increased by 100°C gradually in intervals of ten minutes until the temperature of 1200^0C was attained. The samples were then soaked in water for 8 hours and allowed to cool in the furnace for 24 hours [3]. The physical properties of the clay samples were tested and compared with international standards. X-ray fluorescence analysis (XRF) and Scanning Electron Microscopy (SEM) analysis were conducted to determine the percentage composition of minerals present in the clay samples. The orientation of the clay samples was also studied using Scanning Electron Microscopy (SEM) analysis.

Result and Discussion

Table 1 displays the physical properties of clay based on international standards, while Table 2 presents the experimental results of the clay samples. The obtained results were compared to the international standards, depicted in the charts below.

Table 1: Physical and Thermal Properties of Jani and Malumfashi Clay compared with International Standard

PROPERTIES	STANDARD	JANI	MALUMFASHI
Linear shrinkage (%)	2-10	7.46%	8.8%
Apparent porosity (%)	20-30	23.2	29.08
Bulk density (g/cm^3)	1.71- 2.8	1.99	1.98
Cold crushing strength (Mpa)	15.0 min.	247.13	335.95
Thermal shock resistance, cycle	20-30	21	24
Refractoriness (°C)	1500-1750	1350	1448
Modulus of Rapture (kg/$cm^{2)}$	1.4 – 105	17.2	13.5
Moisture content (%)	1-13	4.8	4.5

Source: [10]

Linear Shrinkage:

The Jani clay sample (7.46%) and Malumfashi clay (8.9%) both showed a linear shrinkage within the recommended range of 2.0-10%. Finer grains in the clay samples enhance the strength of the refractory and improve firing efficiency. However, high shrinkage values can lead to spalling, warping, and cracking of refractory bricks, resulting in heat loss in the furnace [10].

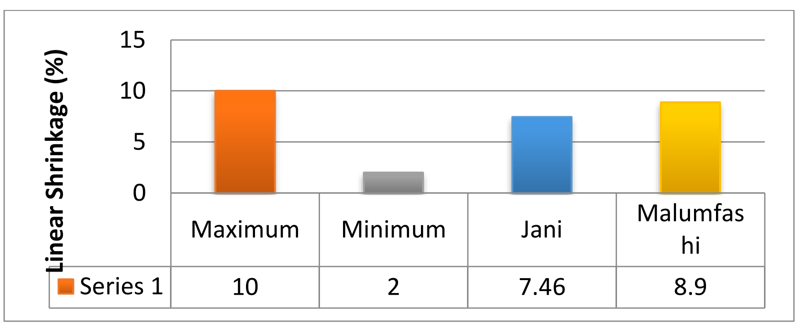

Figure 1: Percentage of linear shrinkage

Cold Crushing Strength

Jani and Malumfashi clay have demonstrated high cold crushing strength above the recommended standard value, as shown in Figure 2. This indicates good crushing strength. Clay samples with low crushing strength typically exhibit lower resistance to tension, load, and shear stresses than those with high crushing strength, as observed by [13]. The crushing strength analyzed in this study is high enough for refractory purposes [14].

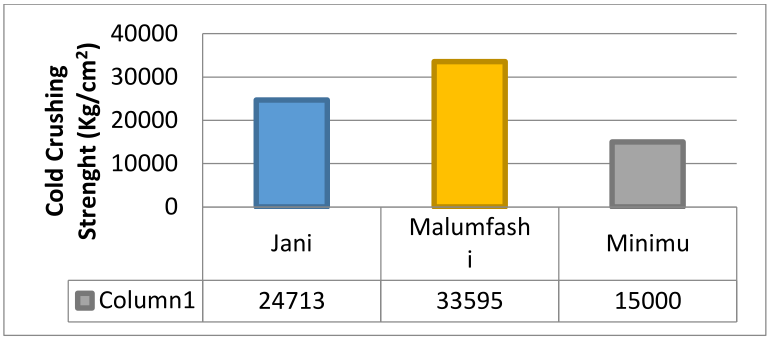

Figure 2: cold crushing strength of the samples

Apparent porosity

The Jani and Malumfashi clay samples fall within the recommended standard porosity range of 20-30%, indicating a good lifespan as a refractory material. However, a low percentage of apparent porosity in clay can cause gas entrapment in refractory bricks, which can influence lifespan [15].

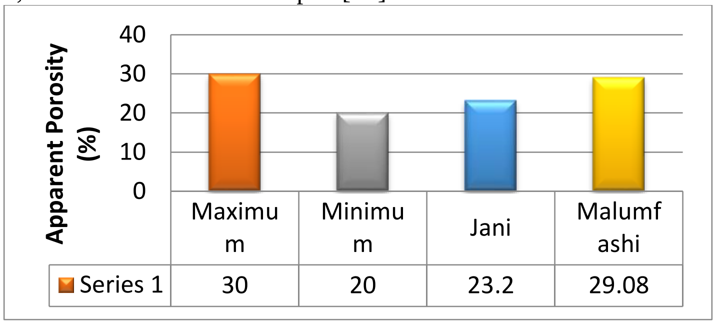

Figure 3: Percentage Apparent Porosity

Refractoriness

The refractoriness test results in Figure (7) show that Jani clay can withstand temperatures up to 1350^{O}C, while Malumfashi clay can withstand up to 1448^{O}C. This makes both clay samples suitable for lining furnaces and high-temperature devices used for melting low and medium-temperature metals.

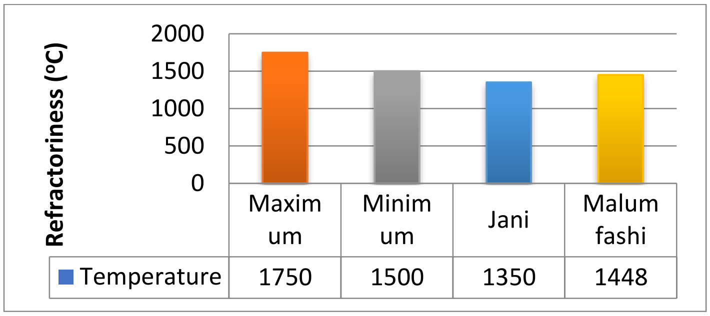

Figure 4: refractoriness of the clay samples

Thermal Shock Resistance

The clay samples can withstand abrupt temperature changes without cracks for 21-24 cycles, classifying them as good refractory fire clay [13].

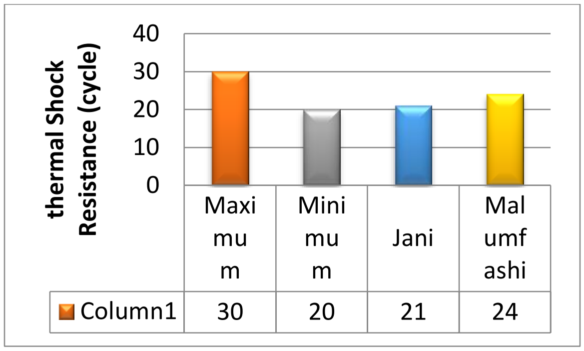

Figure 5: thermal shock resistance of the clay samples

Chemical Composition Analysis

The X-ray Diffraction Analysis (XRD) identified the crystalline phases in the Jani and Malumfashi clay samples. Jani clay consists of Quartz (71.3%), Orthoclase (16.8%), and Kaolinite (11.9%). Malumfashi clay contains four crystalline phases: Quartz (63%), Orthoclase (17%), Kaolinite (8%), and Albite (12%).

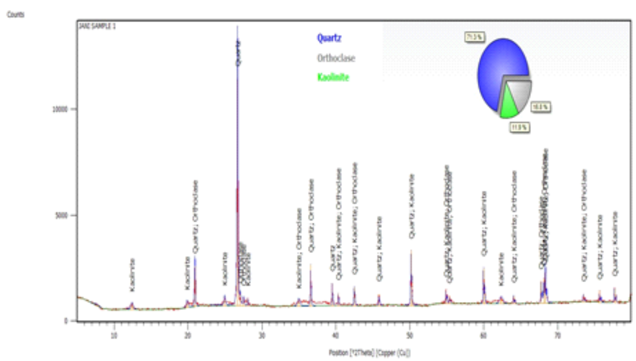

Figure 6: X-ray Diffraction results for Jani Clay's sample

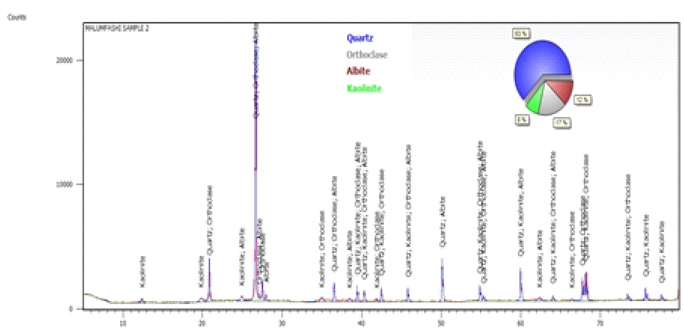

Figure 7: X-ray Diffraction Analysis for Malumfashi clay sample

Additionally, Tables 3, present the percentage constituents of oxides detected through XRF analysis. The results were compared against recommended standards (Table 3) to determine their usefulness.

Table 3: Chemical composition of Jani & Malumfashi clay compared with International Values for Refractory clay.

Constituent	Fired clay (%)	Refractory brick (%)	JANI	MALUMFASHI
SiO_2	46-62	51-70	46.101	40.462
Al_2O_3	25-39	25-40	19.849	14.543
Fe_2O_3	0.4-2.7	0.5-2.4	7.1653	2.185

K_2O	0.3-3.0	1.0801	1.137
MgO	<2.0	3.41	4.25
CaO	0.2-1.0	0.571	0.502

The silica oxide content of Jani and Malumfashi clays, as shown in Figure 8, indicates that Jani clay satisfies the specifications for use in low-melting steel and refractory materials.

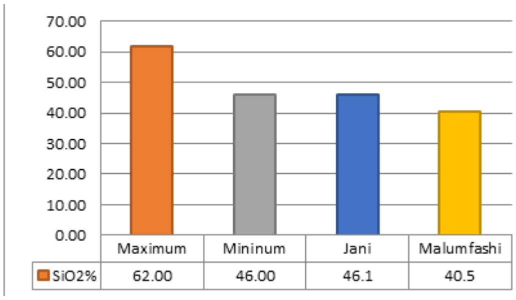

Figure 8: percentage composition of silica oxide of the samples

Table 3 shows Jani clay has 19.85% alumina content, while Malumfashi clay has only 14.54%. Jani clay is suitable for furnace-lining bricks due to its high melting point, while Malumfashi clay is not as suitable due to its low melting point. A high aluminum oxide proportion indicates good refractoriness in clay [3].

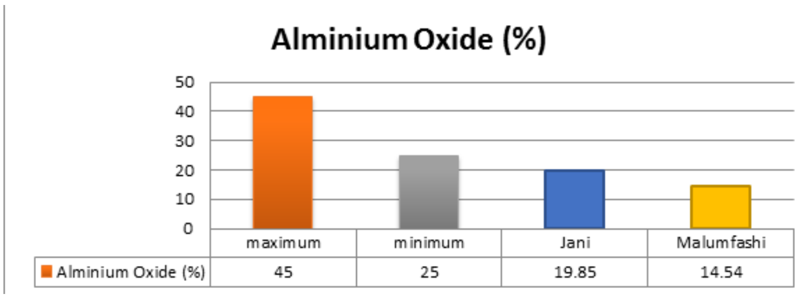

Figure 9: Percentage of Al_20_3 of the samples

Figure (10) shows that all clay samples have a high iron oxide content, qualifying them as high melting clays (fireball clays and refractory brick). However, excessive amounts of iron oxide cause exothermic reactions at elevated temperatures, which creates pores and reduces refractoriness in the clay.

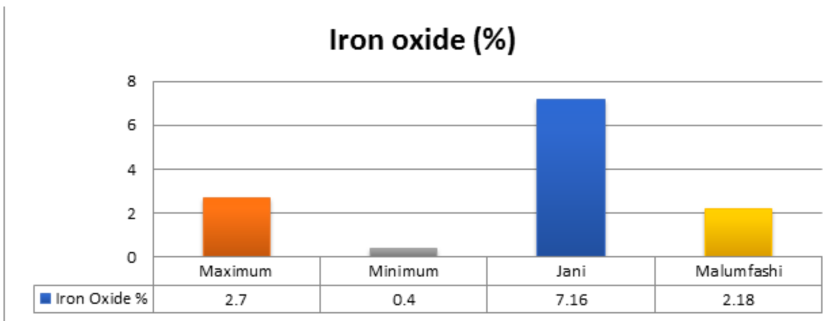

Figure 10: percentage composition of Iron Oxide

Table 3 indicates that the percentage composition of potassium oxide in both Jani and Malumfashi clay samples falls within the recommended range for refractory materials, as showing

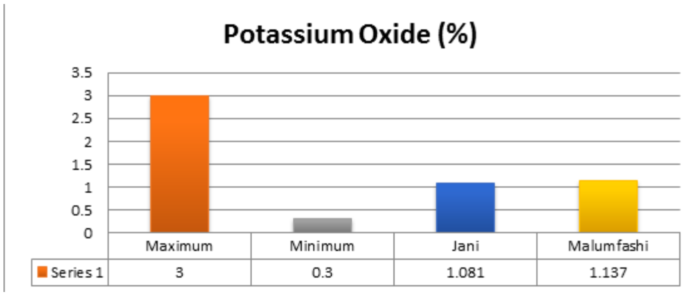

Figure 11: percentage composition of Potassium oxide

The morphology and orientation of the clay particles were determined using SEM in conjunction with EDXRF.

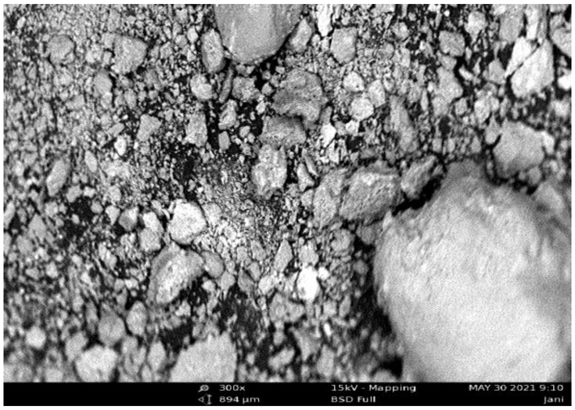

Plate I: Jani Clay sample at 300x magnification and 894µm particle size

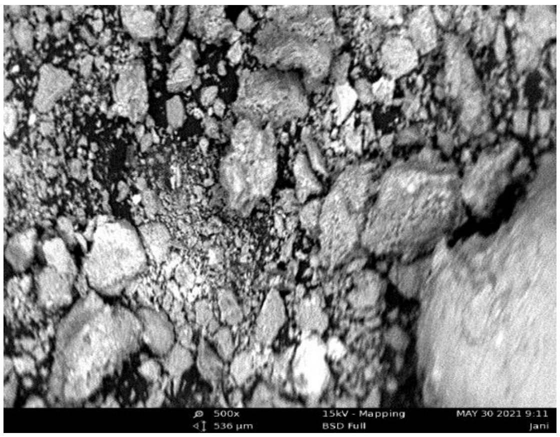

Plate II: Jani Clay Sample at 500x magnification and 536µm particle size

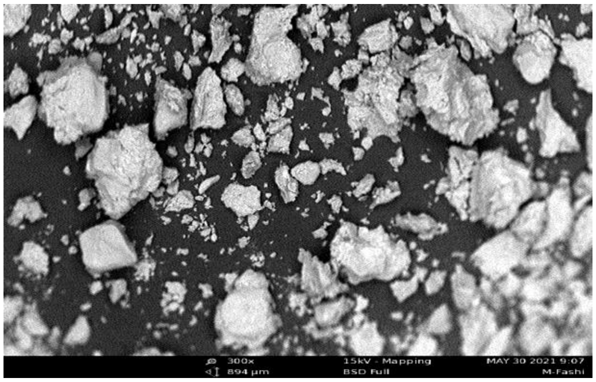

Plate V: Malumfashi clay Sample at 300x Magnification and 894µm particle size

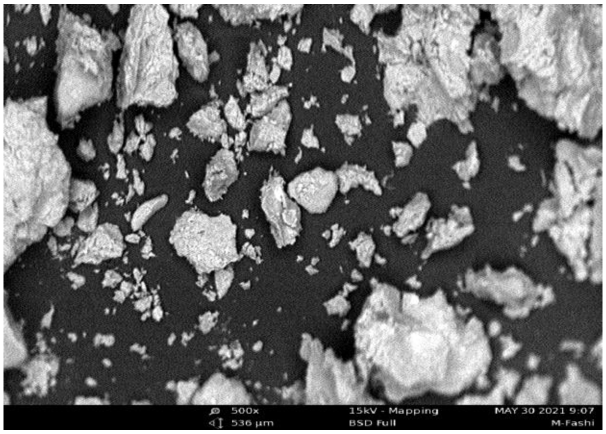

Plate VI: Malumfashi clay Sample at 500x Magnification and 536µm particle size

4.0 Conclusion

Based on the obtained results, Jani clay sample (7.46%) and Malumfashi clay (8.9%) both showed a linear shrinkage within acceptable range, preventing the refractory material from spalling, warping, and cracking of the refractory bricks, resulting in heat loss in the furnace. The thermal shock resistance (21-24) cycles exhibited by Jani and Malumfashi clay samples showed that the clays can be use repeatedly under esteem temperature without abrupt failure. The refractoriness of the clay samples for Jani 1350^{O}C, and Malumfashi 1448^{O}C indicates that the clay can only be used where temperature less than 1500ºC is required. The Silica content for both Jani (46.101%) and Malumfashi (40.4620%) clay samples qualify the clay for use as refractory material and low-melting clay respectively. However, Jani clay's high iron oxide percentage (7.165%) may reduce its refractoriness by creating pores in the clay. Both clay samples' alumina content falls within the range of low-melting clay, and their moderately lower alkali oxide content qualifies them for use as refractory materials such as Kilns lining and for the manufacture of furnace lining bricks. These potentials qualify the exploration of Jani and Malumfashi clay deposits for Metallurgical applications for the economic development of the country.

References

Abolarin, M. S., Olugboji, O. A., & Ugwuoke, I. C. (2018). Determination of Moulding Properties of Locally Available Clays for Casting Operations. *International Journal of Engineering Research. P.238-242*

Christidis, G. & Mitris, J. (2016). A New Ni-rich steven site from the Ophiolite- Complex of Othrys, Central Greece. Clay and Clay Minerals, 54, pp. 653-666.

Elakhame, Z. U., Omowinmi, O. J., Arungwa, O. P., Alausa, N. A (2016). Compositional Features and Industrial Application of Afuze Clay, South-South Nigeria. International *Journal of Scientific and Engineering Research,* 7(1), January. ISSN: 229-5518.

Hazen, R. M., Downs, R.T., Jones, A., Kah, L., and Oganov, A. (2013). The Mineralogy of Carbon. In Hazen, R.M., Boriss, R.J., Hemley, and Jones, A., Carbom in Earth 97, 1013-1042. Review in Minerology and Geochemistry, *Minerology Society of America, Chantilly, Virginia.*

Ibrahim, M. E., Adamu, H. A., Isah, I. K., and Jimoh, S. O. (2018). Investigating the Refractory Properties of Jalingo Clay Deposit. *International Journal of Scientific & Engineering Research, Vol. 9(2), February, pp.253-260.*

I.C.C Iloabachie, I.D Adiele, C.N Onya and B.O Okpe (2020). Eha Ndiagu *Clay Deposit: Physic-Chemical Characterization for Industrial Refractory Application. World Journal of Engineering Research and Technology. ISSN 2454-695X, Vol. 6, Issue 1, 47-62*.

Lydia, S. J., Alexender, A. J., Okon, E. E., & Aliyu, J. (2018). Investigating the Potentials of Some Selected Nigerian Clay Deposits. *Journal of Minerals and Material Characterization and Engineering*, 6, 569-586. ISSN: 2327-4077.

Mokwa, J. B., Lawal, S. A., Abolarin, M. S., and Bala, K. C. (2019). Characterization and Evaluation of Selected Kaolin Clay Deposits in Nigeria for Furnace Lining Application. Nigerian *Journal of Technology* (NIJOTECH), vol.38, No.4 October, Pp.936-946.

Ovat, F. **A.** and Bisong, M. **A.** (2017). Assessment of the Potentials of Some Nigerian Kaolinitic Clay Deposits. European *Journal of Engineering and Technology,* 5(2), ISSN: 2056-5860.

Rong Chuan, Zheng Fang, Man Jin and Yu Shang (2022). Study on the activity of Metakaolin Produced by Traditional Rotary Kiln in China. *Minerals* 2022, *12*(3), 365; *https://doi.org/10.3390/min12030365*

Saed, U. A., Tokan, A., Bawa M. A., Dandakuta, H. (2020). *Development of Furnace lining Brick for Steel Smelting Using Nasaru, GadaUku, and Gwaram Clay. A Review. International Journal of Research Publications (IJRP), 27(2), April*.

Sani, A., Bashir, G., Danshehu, B. G., & Isah, A. D. (2013). Studies on the Chemical and Physical Characteristics of Selected Clay Samples. *International Journal of Engineering Research and Technology* (IJERT), ISSN: 2278-0181, 2(7).

Ugwuoke, J. C., & Amalu, N. I. (2018). Characterization of Obe Clay Deposit for Refractory Production. *American Journal of Engineering Research*, 6(12), pp. 74-77, ISSN: 2320-0936.

Umar Saeed, A., Tokan, A., Bawa M. A., Dandakuta, H. (2020). *Development of Furnace lining Using Nasaru, GadaUku, and Gwaram Clay. A Review. International Journal of Research Publications (IJRP), 27(2), April*.

Yusuf, L. S., & Abdulhafeez, N. A. (2018). Evaluation of Chemical and Physico-Mechanical Properties of Some Nigerian Natural Clay Sample for Foundry Applications. *Journal of Engineering and Technology*, 3(2), September. ISSN: 2597-0625.

Y.L. Shuaibu-Babata, S.S. Yaru, S. Abdulkareem, Y.O. Busari, I.O. Ambali, K.S. Ajao, and G.A Muhammed (2018). Characterization of Baruten Local Government Area of Kwara State (Nigeria) Fire Clay as Suitable Refractory Materials. *Nigeria Journal of Technology (NIJOTECH), Vol. 37, No.2 April 2018, pp 374-386. Print: ISSN 0331- 8443, Electronic ISSN: 2467 – 8821. www.nijotech.com*