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Original Article

Investigating Refractory Properties of Ipetumodu Clay for Industrial Applications

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Abstract *- Nigeria is endowed with vast clay deposits with desirable refractory properties. Yet, her continuous dependent on imported refractories still remains unending. Therefore. in this study, the refractory properties of the Ipetumudu clay deposit in Osun State, Nigeria, were investigated for the purposes of industrial applications. Three (3) samples were collected from the study areas at a depth of 1.5m each based on ASTM 2004 D.1452, using a stratified random sampling method. The samples were broken into pieces, mixed thoroughly to achieve homogeneity, and slurred in water to form a clay solution. It wet sieved and allowed to thicken by decanting the clear water on the slurry until plastic mass was obtained, sun-dried for 72hrs to obtain dry mass and subjected to consecutive crushing and grinding using Denver jaw crusher– Model and Denver ball mill- Model, respectively, until final sample with fine and smooth particle size was obtained. 525g of each sample was measured; this was poured into a set of sieves of 850 µm, 600 µm, 425µm, 300 µm, l50 µm, and -150 µm mesh sizes and pan, and operated on electrically driven sieve shaker – Model for 20 minutes. The weight retained on each sieve was measured and recorded, and a clay sample on 150 µm sieve size was selected. A small portion of the clay sample was used for chemical analysis using an atomic absorption spectrometer (AAS) - model 210 VGP. The remaining portions were thoroughly mixed with 10% water, rammed into oil-lubricated cylindrical moulds of 30 mm diameter and 45 mm height, using a 30 kg rammer, and oven-dried at 105°C for 24 hours. A suitable plunger was applied to remove the cylindrical specimens and tested for the various refractory properties. From the results, the clay sample was comprised mainly of aluminum oxide (Al_2O_3) and silica (SiO_2). The average values of bulk density, apparent porosity, permeability numbers, permeability numbers, thermal shock resistance and refractoriness were 2.34 g/cm^3, 20.63%, 49.50, 13.2%, 19.1 cycles and 1098°C, respectively. Therefore, the clay deposit is most suitable for use as a lining material for applications requiring low temperatures (oven and furnace kilns). Moreover, as burnt brick for structural purposes in brick brick-making industry, clay pots, plates and cups in the pottery/ceramic industry, and tiles and sanitary wares.*

Keywords *- Crushing, Grinding, Particle size, Refractory properties, Weight retained, Slurred.*

1. Introduction

Clay is fine particle-size material, which is consisted of aggregates of clay minerals, typically hydrated alumino-silicates [(Al_2 (SiO_2) $(OH)_4$)]^4 [1, 2, 3 4] Attah, 2008; Apeh *et al.*, 2011; Amuda *et al.*, 2019; Sadik *et al.*, 2014). Clays are utilized in a wide range of industrial applications such as the ceramic industry, making industry, pottery industry and pharmaceutical and cement industries [5, 6,] Ojo *et al.*, 2014; Manukaji, 2013). Industrial properties of the crude clays are contingent upon their composition, distribution of the particle size and shape of the grain. Clay deposit across the various states of Nigeria is estimated to cover a proven reserve of billions of tons [7, 8] (Babalola *et al.*, 2014; Oloruntola *et al.*, 2010). Refractories are derived from clay minerals and are comprised of silicon, aluminum, magnesium, calcium and zirconium oxides, while carbides, nitrides, borides, silicates and graphite are present. Refractory materials are characterized based on good physical, chemical and mechanical properties, this is in addition to very high thermal properties [9] (Agbajelola *et al.*, 2015;.). In the metallurgical industry, for instance, refractories must be able to resist high temperatures, mostly above 1500°C below the physical and chemical stroke of molten metal, slag and gases in the furnace [10,11, 12] (Hassan and Aigbodion, 2014; Sayel *et al.*, 2012; Yami and Umar, 2007).

In Nigeria, more than 80% of total refractory requirements is being used up by metallurgical industries as lining materials in furnaces, kilns, reactor vessels and boilers, while the outstanding 20% is utilized by non-metallurgical industries, which include cement, glass and hardware industries [13, 14, 15, 16,] (Aremu *et al.*, 2013; Hassan and Adewara, 1993; Adondua, 1988; Aderibigbe and Chukwuogo,1984). The estimated refractories requirements for Ajaokuta Steel and Delta Steel Companies refractory requirements at full operation were put at 43,505 and 25,000 tons per year, respectively [17] (Elakhame *et al.*, 2016). Undoubtedly, the Nation is endowed with huge clay reserves. However, refractory needs are still being sourced through importation with hard-earned foreign currencies, even with the dwindling state of the economy.

In addressing this urgent need, efforts have been made by past researchers to explore the viability of different clay deposits for refractory applications. For instance, [7] Babalola *et al.* (2014) evaluated Igbara-odo clay property for refractories, and they revealed its suitability as an insulating refractory material for furnace lining, but not the inner core (hot zone) of the furnace. Due to its good insulating and thermal shock resistance properties, it can also be used as a lining material for soaking pits and reheating furnaces, steel ladles, and kilns in the cement industry. [17] Elankhame *et al.* (2016) characterized Ujugbo clay deposits in Edo State and revealed that the clay samples from the two sites showed high potential for ceramic and refractory applications. They recommended that for it to be used as a high-temperature refractory material, its high alkali content should be reduced through leaching, while a more inert additive with up to 44% chamotte should be used as against the 25% that was used. This is necessary for guaranteed better performance. [18] Olalere *et al.* (2019) evaluated the chemical and thermo-physical properties of locally aggregated kaolin based on refractory materials and reported that the refractoriness of grouped clay was higher than those recommended for fireclay, which they attributed to the high percentage of alumina content that resulted subsequently the aggregated kaolin was fire.

Ugwuoke *et al.* (2018). [19] Characterized Iboko and Nduage-Echara clay deposits in Ebonyi State and reported that two clay samples were refractory clays, and due to their richness in silica (SiO_2) and alumina (Al_2O_3), they can be developed into aluminosilicate refractory. [20]Adamu *et al.* (2018) investigated the refractory properties of Kona clay in Jalingo, Taraba state, and revealed that due to the low melting points of both Kona white and Kona black clay samples, utilizing them as refractory materials were limited for the lining of furnaces for non-ferrous metal casting. The results of physical and chemical analysis of Duku, Jega and Yauri clay deposits in Kebbi State were compared; this has shown that Duku and Yauri clay deposits possessed refractory properties suitable for foundry applications, while Jega clay can only be exploited for commercial purposes upon further processing, due to high level of iron, quartz and other associated impurities [21] (Salihu and Suleiman, 2018). Muhammed et al. (2019) [3] investigated the refractory properties of a blend of alumina/silica. The blend was fired at 800, 900 and 1,000^o C for varying times of 30 minutes, 1, 3, and 5 hours. Moreover, they validated the results against those of standard indigenous kaolinitic clay. From their report, the indigenous clay was essentially siliceous alumina-silicate containing about 51% silica and 40% alumina with a high content of alkali oxide but low ferrous oxide content. The firing temperature and time only had a significant effect on the phase transformation at a temperature of 1,000^{o}C and a time of 5 hours. At this condition, the marginal presence of tridymite was identified in the alumina/silica blend. The refractory tests (shrinkage, bulk density, water absorption rate, apparent porosity, cold compression strength) revealed marked colour variation in only the indigenous kaolinitic clay across the firing conditions. The synthetic alumina/silica blend exhibits refractory properties that are approximately equal to those of standard alumina-silicate for refractory purposes. Linear shrinkage in the refractory blend was within the permissible limit of 0-4%, bulk density 1.55-1.89 g/cm3, and water absorption was 21.7-30.4%. At the same time, compressive strength was in the range of 1,125-2,017 KN/M^2. However, the apparent porosity at 45% was outside the standard for fireclay refractory. Moreover, from these results it is suggestive that a blend of alumina/silica can be suitable utilized for refractory purposes.

Omotoyinbo and Oluwole (2008) [22] evaluated the working properties of some clay deposits in Ekiti State, Nigeria. This was with a view to determining their suitability for use as refractory bricks. The samples obtained are Ara, Awo and Isan, all in Ekiti State. Clay samples were obtained from two locations in Ara and tagged Ara 1 and 2, and two from two locations in Isan, tagged Isan 1 and 2. At the same time, only one type was collected from Awo. The clay samples were treated separately, blended together in different proportions, moulded into bricks, dried and fired to 1050^{o}C and tested for refractoriness, thermal shock resistance, shrinkage, thermal expansion, bulk density, porosity, and compressive strength. They reported that Ara 2 and Ara 1, 2 combined in equal proportions displayed the highest thermochemical stability and also possessed comparatively high cold crushing strength and high thermal shock resistance, but not the highest. The apparent porosity of all the batch specimens was found to be high, as well as the bulk densities, which is in contrast to the shrinkage of all the specimens. They concluded that 100% Ara 2 and a blend of Ara 1 and 2 in equal proportions are most suitable for the production of crucibles and furnace lining for non-ferrous metals processing, such as aluminium, lead and bronze.

Kamar et al. (2017) [23] investigated the suitability of using Ipetumodu potter clay for the production of ceramic pot filters. Rice husks and sawdust were the two combustible materials used for the pot filter production. Consequently, 10%, 20%, 30%, 40% and 50% by volume of these additives were prepared and added to the clay samples, and the resulting filter pots were tested for flow rate and effectiveness in removal of turbidity, suspended, and dissolved total solid. Moreover, they reported that the filter with 20% rice husk revealed the most acceptable flow rate and effluent water quality and, hence, the most efficient. Folorunso, 2014) [24]. Studied comparative responses of three clay deposits to iron removal using a leaching approach in oxalic acid. The clay samples used were obtained from Ifon in Ondo State, Ipetumodu in Osun State and Iseyin in Oyo State. These three clay deposits are situated in the southwestern part of Nigeria. Sieve analysis of the clay samples was done to the uniform size distribution of grains, and the samples were characterized using an X-Ray Diffract meter and X- Fluorescence machines and a scanning electron microscope. The samples were treated with oxalic acid of different concentrations. Moreover, from the results, it was reported that the iron contents were reduced by 53.4%, 80.61% and 48.27% for Ifon, Ipetumodu and Iseyin clay deposits respectively.

Fatai et al. (2014) [25] characterized clay minerals from Ifon, Ondo State, Ipetumoda, Osun State and Iseyin, Oyo State, all in southwest Nigeria. This is with the aim of ascertaining their appropriate industrial applications. From the reports, the three clay deposits revealed kaolinite, microcline, muscovite/illite, plagioclase/albite and quartz as the major phases, though in varied percentages. They showed from their conclusions that Ifon clay, which is characterized by very low kaolinite (5.63%), could be utilized for making high-temperature refractories. Also, due to its feldspars contents, it can be further processed for use in glass and iron-making industries. Ipetumodu clay is characterized by 23.74% kaolinite and feldspars, comprising 26.12% microcline and 11.28% plagioclase/albite. This composition was reported to be most appropriate and necessary for mullite fibers production in the ceramic matrix at a temperature of around 1400°C, and the Iseyin clay deposit, which is characterized by very low feldspars and high kaolinite content, was recommended for further processing for high-temperature caliber refractories.

Davies et al. (2012) [26] investigated the effect of alumina cement (Fe_2O_3) on the refractory properties of leached Ipetumodu clay. The raw clay was analyzed using a scanning electron microscope. In order to determine the purity level of the clay sample, an X-Diffractometer and X-Fluorescence machines were used, and different concentrations of oxalic acid (0.4, 0.8, 1.2, 1.6 and 2.0 mol/dm^3) were prepared and used to purify the clay through hydrometallurgical route at different times of 30, 60, 90, 120 and 150 minutes, temperatures of 30, 50, 70 and 90oC and agitation speeds of 120, 160, 200 and 240 rev/min. Moreover, from the result of Atomic Absorption Spectrometry (ASS), they reported that the Fe_2O_3 content of the clay was reduced to 0.96%. Further, samples of the leached clay, containing different quantities of alumina cement, silica, sand and sawdust, were prepared, dried at 110°C for 24 hours and fired at 900, 1100, 1300 and 1500°C at the rate of 4°C/min, soaked for 2 hours and tested for permanent linear shrinkage change, refractoriness under load, bulk density, cold crushing strength and apparent porosity. They reported that for all the properties tested, the sample, comprising 20% silica sand and 10% alumina additives, showed optimum results with reliable phase integrity, as revealed by the Scanning electron microscope.

Moreover, based on the reviewed works of past researchers, it is obvious that most of the clay deposits across the country have the potential for use as refractory materials. Moreover, despite a plethora of studies on the Ipetumodu clay deposit, there have not been adequate deliberate research efforts on its exploration for the refractory lining. This is in spite of its vast deposit.

Consequently, efforts were made in this study to carry out further investigations on the deposit. This is with the sole objective of determining its viability for utilization as lining material for the Nation's foundry industry, which is even more important now due to the fast-growing foundry activities in Southwest Nigeria.

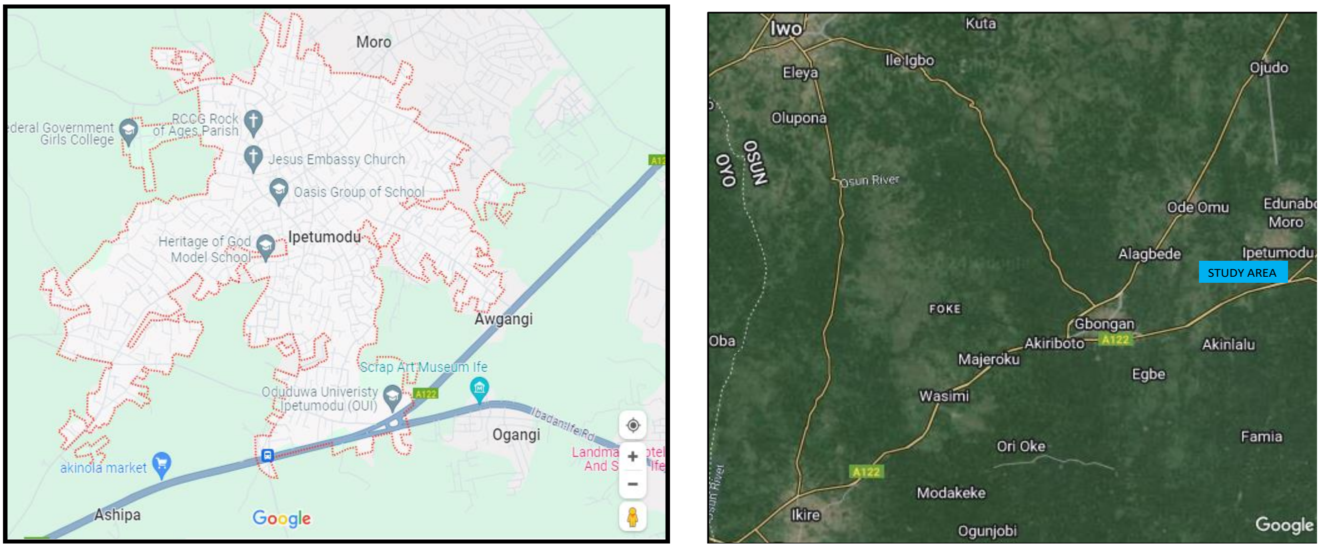

Fig. 1(a) & (b) Location and geomorphological landform map of the study area (Goggle Explorer, 2006)[28]

2. Regional Geology of Ipetumodu and its Environs

Ipetumodu stands located in the southwestern basement complex, specifically on the Ilesha schist belt; it is located on geographic coordinates between 07° 31.00′ and 07° 51.66′N, and longitudes 004° 7.00′ and 004° 45.00′E respectively. The area under study narrates a terrain that is undulated, mainly metamorphic rocks [27]. The community always observe two seasons, namely, the dry and rainy seasons. The Ilesha schist belt is one of the major schist belts in Nigeria (Figure. 1). It is linked with gold mineralization (Obaje, 2009) [28]. It is structurally separated into two main fracture zones, namely, the Iwaraja fault by the east, while the Ifewara fault is towards the western part of the belt (Elueze, 1986; Folami, 1992) [29, 30]. Ifewara fault zone is acclaimed among the longest linear features in the Nigerian basement complex. Kayode (2006) [31] reported that the belt expands from the eastern end of Ijebu Ode through Ifewara and Okemesi to Lafiagi (the south end of the middle Niger basin). A potential connection between the fault and the subterranean Okitipupa Ridge around the Atlantic Ocean was proposed by [32] Hubbard (1975). It continues northeast into Zungeru as the Zungeru mylonites (Ajibade, 1979) and beyond the Nupe Basin. According to Anifowose and Adetunji (2015) [33] and Adelusi et al. (2013),[34] a large NNE-SSW fault zone is thought to cross the Ilesha schist belt. It extends southward to the Omifunfun region and northward to Ifewara, with a major bifurcation that goes through Iwaraja.

The Ilesha schist belt experiences two occurrences of gold mineralization, including gold mineralization, both primary and alluvial [35, 36] (Akande et al., 1992; Ajayi and Ogedengbe, 2003). The main mineralization, which is distributed along quartz veins, is connected to the gneisses or lithologies of the schist belt. Wright et al. (1985) [37] proposed that veins, lenses, stringers, reefs, and comparable masses of quartz, quartz-feldspar-tourmaline rocks are the sites of orogenic gold mineralization in the Ilesha schist belt.

3. Materials and Methods

3.1. Material

Clay samples from clay deposits at Ipetumodun, Osun State, Nigeria, were collected indiscriminately from three different sampling locations at a depth of 1.5m in accordance with ASTM 2004 D.1452. The geological map of the location is displayed in Figure 1.

3.2. Methods

Preparation and size analysis of the clay sample Each clay sample was shattered into pieces with a hammer and thoroughly mixed mechanically to achieve homogeneity. The homogenized sample was slurred in water to form a clay solution, wet sieved and allowed to thicken by decanting the clear water on top slurry until plastic mass was obtained. Then, sun-dried for 72 hours to obtain a dry mass. After this, it was subjected to consecutive crushing and grinding using the Denver jaw crusher– Model and Denver ball mill- Model, respectively, until a final sample with fine and smooth particle size was obtained.

525 grams of each sample was measured on a weighing machine; this was poured into a set of sieves of 850 µm, 600 µm, 425µm, 300 µm, l50 µm, and -150 µm mesh sizes and pan and operated on electrically driven sieve shaker – Model for 20 minutes. The weight retained on each sieve was measured and recorded. Moreover, the retained clay sample on 150 µm sieve size was selected because it gave the highest retained weight and hence was the size close to the mean particle size on sieve analysis [20, 38, 39] (Amuda *et al.,* 2005; Chester, 1983.; Grimshaw, 1971). A small portion of the clay sample was used for chemical analysis using the Atomic Absorption Spectrometer (AAS) - model 210 VGP; the result is displayed in Table 1. While remaining portions were thoroughly mixed with 10% water and rammed into oil-lubricated cylindrical moulds of 30 mm diameter and 45 mm height, using a 30Kg rammer, and oven dried at 105°C for 24 hours. An appropriate plunger was used to remove the cylindrical specimens [40, 5] (Osarenmwinda and Abel, 2014; Adamu *et al.,* 2018), which were adopted to determine the various refractory parameters.

3.2.1. Refractory Properties

Plate 1. Moulded test specimens of Ipetumodu clay

Bulk Density

The clay specimens were fired for 30 minutes in a muffle furnace at 1200oC; this was placed in desiccators for 24 hours in order to cool down. This was measured and was recorded as W1. The clay samples were suspended using the in-elastic cord. These were later moved and submerged into a beaker filled with water. The beaker was subjected to heating for 30 minutes, allowing for the release of trapped air within their pores, and with the pores being filled with water [18, 22] (Olalere et al., 2019; Omotoyinbo and Oluwole, 2008). The mass of each specimen was measured and recorded as W2. After that, the samples were suspended in a water beaker set on a weighing balance, and their weights were determined and recorded as W3. The bulk density was calculated using Equation 1.

$$\text{Bulk density} = \frac{W_1}{W_2 - W_3} \qquad (1)$$

Where,

W_1 = weight of the dried specimen,
W_2 = weight of immersed specimen,
W_3 = weight of the suspended specimen

Apparent Porosity

The test specimens were put in a muffle furnace fired to 1200oC for 45 minutes, and this was allowed to cool in the desiccators for twenty-four (24) hrs. After this, the weights of the dry specimens were measured to the nearest 0.01(dried weight) and recorded as WD. The samples were carefully submerged in a beaker filled with water, and this was left for an hour, ensuring that there were no bubbles from them, and their weight was measured, the results were recorded as WS. Each sample was then suspended in a beaker occupied with water and placed on a weighting balance. The suspended weights were measured, and the results were then recorded as WW. The apparent porosity was calculated using Equation 2.

$$\text{Apparent porosity} = \frac{W_S - W_D}{W_S - W_W} X100\ \% \qquad (2)$$

Where,

W_D = weight of the dried sample
W_S = weight of the immersed sample
W_W = weight of the suspended sample

Linear Shrinkage

The test specimens were marked after heat treatment to keep the same location along a line. The distance between the two ends of each of the specimens was measured with a vernier calliper, and the lengths were measured and recorded as L1. The specimens were further fired in an oven at a temperature of 110oC for 6 hrs. This was allowed to cool at room temperature, and the length was measured and recorded as L2. The linear shrinkage was then worked using Equation 3.

$$Firedlinearshrinkage = \frac{L_1 - L_2}{L_2} X\ 100\% \qquad (3)$$

Where,

L_1 = initial length before firing, and
L_2 = initial length after firing

Permeability

The test specimens were entirely scaled at the edges, while the bottom surface was exposed to a vent. When the aperture was opened, the bell jar was set, and the cylinder was filled with 2000 cm of water. The period it took for 2000 cm of water to push an equal volume of air through each sample was recorded. The difference in pressure between the surfaces of each sample was measured using a manometer. The permeability number (PA) was determined using Equation 4.

$$\text{Permeabilitynumber (PA)} = \frac{VH}{APT} \qquad (4)$$

Where,

V = volume of air,
H = height of the specimen,
A = cross-sectional area of the specimen,
P = pressure of air in water, and
T = time taken for the water to displace an equal volume of air

Thermal Shock Resistance

Test specimens, 50 mm diameter by 50 mm height, obtained from air-dried specimens, were introduced into a furnace heated for ten minutes to 900 degrees Celsius. They were taken out using a pair of tongs, and were allowed to cool to room temperature on a brick platen. The samples were brought back to the furnace, then heated to 900oC for another 10 minutes, later removed and cooled to room temperature. The cycle was maintained until cracks on the samples were detected. The resistance of the test specimens through the number of cycles before cracking was counted and determined to be their thermal shock resistance.

Cold Crushing Strength

Test specimens of 50 mm diameter and 50 mm height obtained from the air-dried test specimens were introduced into the furnace and heated to 1050oC for 10 minutes. After which, they were removed with a pair of tongs, placed on brick platen and cooled to room temperature.

The samples were placed in a compressive testing machine and were applied axially at a uniform rate until fracture occurred using a well-calibrated scale. The load at fracture (Kg) on a cross-sectional area (cm2) was noted, and the cold crushing strength (CCS) was calculated using Equation (7).

$$Coldcrushingstrength(CCS) = \frac{L}{A} \qquad (5)$$

Where,

L is the fractured load (Kg), and
A is the cross-sectional area (cm$^{2)}$ height of the specimen

Refractoriness

From the air-dried test specimens, 50mm diameter and 50mm height specimens were cut and inserted in a refractory kiln, which was heated at the rate of 10oC/min up to the value of 1200oC.

The heating rate was reduced to 5oC/min and continued until each of the test samples bent over its own weight. The final temperature was recorded, and the test pieces were removed and, allowed to cool to room temperature and examined under the microscope.

4. Results and Discussion

4.1. Chemical Composition

Table1.Chemical composition of Ipetumodun clay sample

Comp.	**%**		
SiO_2	59.48	Cl	0.02
Al_2O_3	22.7	Cr_2O_3	0.05
FeO_3	8.65	Cu	0.03
TiO_2	1.51	MnO	0.11
CaO	0.76	Ni	0.08
MgO	0.01	P_2O_3	0.03
K_2O	1.26	SO	0.03
Na_2O	0.37	Zr	0.103
Ba	0.08	Total	98.57

From Table 1, aluminum oxide (Al2O3) and silica (SiO2) are the major constituents of Ipetumodu clay deposit, and hence it is an aluminosilicate clay type [2, 3, 1] (Amuda *et al.*, 2019; Apeh *et al.*, 2011; Attah, 2008)

Table 2. Sieve analysis result of the experimental Ipetumodu clay

S/N	Sieve size Range (µm)	Nominal Aperture (µm)	Weight Retained (g)	%Weight Retained(g)	Cumulative % Retained
1	850	850	85.17	16.22	16.22
2	600	600	33.88	6.45	22.67
3	425	425	37.95	7.23	29.90
4	300	300	57.91	11.03	40.93
5	150	150	134.63	25.64	66.57
6	-150	-150	176.33	33.59	100.16

Total weight = 520g

Table 3. Fireclay clay refractory properties

Refractory Properties	Fireclay
Bulk density (g/cm^3)	2.30
Apparent porosity (%)	20-30
Permeability	25-90
Linear fired shrinkage (%)	7-10
Thermal shock resistance (cycles)	20-30
Cold crushing strength KN/m^3	15000
Refractoriness (°C)	1500-1700

4.2. Sieve Analysis

Table 2 shows the result of the Ipetumodu clay sieve analysis. The experimental test specimen (i.e. sample with 150 µm mesh size) was dense and compact with the lowest density gradients due to good mixing that resulted from the fine size particles [9, 13, 38] (Agbajelola *et al.*, 2015; Aremu *et al.*, 2013; Chester, 1983).

4.3. Refractory Properties

Table 3 outlines bulk density, apparent porosity, permeability, linear shrinkage on firing, cold crushing strength and refractoriness refractory of fireclay (reference) with that of the corresponding results of average values of Ipetumodun clay experimental test specimens.

4.4. Bulk Density

Standard range of bulk density for fireclay is 2.2 – 2.8 g/cm^3 (Omowumi, 2000; Chester,1983) [41,38], average bulk density value of Ipetumodu clay is 2.34 g/cm^3, which is above the reference value. Indicating that Ipetumodu clay is characterized by less resistance to slag penetration and abrasion relative to fireclay and, therefore, more suitable for use as an insulator and oven and kiln lining (2.34).

4.5. Apparent Porosity

The standard apparent porosity value of fireclay lies within 20- 30% [1,38] (Attah, 2008; Chester, 1983), while the average value of apparent porosity of Ipetumodu clay is 20.63% (refer to Table 5), which is within the standard range for fireclay. [6] Ojo et al. (2014) and Grimshaw (1971) [39] revealed that porosity is size dependent. The average porosity value of Ipetumodu clay was accounted for by fine size. Ipetumodu clay may not be easily penetrated by molten slag due to low porosity, and it may not shrink easily when subjected to increasing temperatures [42] (Manukaji, 2013). In addition, its low average apparent porosity value was due to the decreased presence of combustible materials, which are usually burned off upon firing [23] (Omotoyinbo and Oluwole, 2008).

4.6. Permeability

The average permeability number of Ipetumodu clay is 49.50 (Table 66). And the permeability number of fireclay is in the range of 25-90 [7, 3, 38] (Babalola et al., 2014; Amuda et al., 2005; Chester, 1983). Moreover, since Ipetumodu permeability clay is within the standard, it is, therefore, impervious and capable of eliminating leakage of gases and penetration of liquid through the walls of the furnace. Hence, it can be used as a lining material [18] (Olalere et al., 2019;).

4.7. Linear Shrinkage on Firing

The value of linear shrinkage on the firing of fireclay is ranged between 4 to10% [7] (Babalola et al., 2014), and the Ipetumodu clay sample showed 13.2%, which is an indication that the is characterized by more volume change, low volume stability and heat capacity. Therefore, when used as lining material for a furnace, the possibility of heat loss is high, and when used as refractory bricks for a kiln, the firing kiln will be characterized by cracking due to due to warping and cracking of the brick's high [31] (Kayode, 2006).

4.8. Thermal Shock Resistance

Thermal shock resistance for fire clay is in the range of 20-30 cycles [23, 38] (Omotoyinbo and Oluwole, 2008; Chester, 1983), while the average value of thermal shock resistance of Ipetumodun clay is 19.1 cycles. The decrease in the number of cycles to failure later may be hinged on the relative particle size fineness. This is because e refractory materials with a low thermal coefficient of expansion and coarse textures have increased resistance to sudden changes in temperature [22] (Omotoyinbo and Oluwole, 2008). Moreover, refractory properties, including thermal shock resistance, coefficient of linear expansion and thermal conductivity, are influenced by particle size [41] (Omowumi, 2000).

4.9. Refractoriness

Refractoriness of fireclay ranges from 1500 to 1,700oC [12] (Yami and Umaru, 2007), and the Ipetumodu clay average refractoriness value is 1098 oC. High alumina content, low alkali metals (lower fusion temperature of clays), and high porosity charactering the latter may have accounted for its relatively poor refractoriness (Omotoyinbo and Oluwole, 2008) [22].

5. Conclusion

The following conclusions were drawn based on the results of the research:

The Ipetumodu clay sample is comprised mainly of aluminum oxide (Al2O3) and silica (SiO2).

The average bulk density value of Ipetumodu clay is 2.34 g/cm3, which is above the range (2.2 – 2.8 g/cm3) for fireclay. It offers less resistance to slag penetration and abrasion as compared to fireclay. The average value of apparent porosity of Ipetumodu clay is 20.63%, which is within the range (20- 30%) for fireclay.

The average permeability number of Ipetumodu clay of 49.50 lies within the range of 25 – 90 for fireclay. The average value of linear shrinkage on firing of Ipetumodu clay of 13.2% lies higher than the range of value of 4-10% for fireclay.

The average value of thermal shock resistance of Ipetumodun clay is 19.1 cycles, which is lower than the range of value of 20-30 cycles for fireclay. The average refractoriness value of Ipetumodu clay is 1098oC, which is below the range of 1500 – 1,700oC for fire clay.

Ipetumodu clay is most suited for applications requiring medium temperatures rather than high temperatures in the metallurgical industry, as lining for oven and furnace kilns, for tiles, sanitary wares and plates in the ceramic industry, for burnt brick, for structural purposes in brick making industry, and for clay pots, plate cup in the pottery industry.

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