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CHARACTERIZATION AND EVALUATION OF THE REFRACTORY PROPERTIES OF LOCAL CLAY DEPOSITS IN KWARA STATE, NIGERIA.

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ABSTRACT

This study characterised seven different clay samples obtained across Kwara State of Nigeria to ascertain their suitability as raw materials for refractory applications. The clay samples were analysed using B.S 1377:1975, I.S. 1498-1970 and ASTM standards to obtain their physical and refractory properties, such as chemical composition, refractoriness, moisture content, loss on ignition, clay content, apparent porosity, bulk density, linear shrinkage, permeability, crushing strength, and thermal shock resistance. The results revealed that the clays belong to Alumino-Silicate Refractories through chemical analysis, since the major constituents of the claysamples (more than 75%) were Alumina (Al_2O_3)and silica (SiO_2). The sample percentage clay contents ranged between 36.8 and 89.6; Apparent porosity (22.99-29.76%); Moisture content (13-27.3%); Refractoriness (>1300°C); Permeability (79-87x10^{-3}N/mm^2); Crushing strength (510-881N/mm^2) and Bulk density (2.26-2.77 g/Cm^3).The sample clays'properties met the required standards for fireclay refractorymaterials, and could suitably replace imported clays / ceramics in refractory applications, such as in production of earthen wares, chalk; as insulating refractories for casting and melting of low and medium temperature iron and steel.

KEYWORDS: Clay, Refractoriness, Porosity, Strength and Resistance

1.0 INTRODUCTION

A refractory material is a non-metallic/inorganic material that resists the action of high temperature and remains undistruptedwithout softening at a very high temperature. Sullayman and Ahmed [1] defined refractories as inorganic materials produced through high temperature firings that are capable of resisting moderate load at extreme temperatures.Refractories are greatly employed in large quantities in the metallurgical heat treatments, power generation, ceramic and glass making industries. These materials are formed into a variety of shapes, which are used for lining furnaces, kilns, burner blocks, acid slag tanks, and other devices that process materials at very high temperatures [2]. Many refractory materials possess unusually good combinations of high melting point and chemical inertness, because of the high strengths exhibited by their primary chemical bonds [1].

Refractory materials play very crucial roles in the industrial development of any nation.Presence of clay deposit, which is primary source of refractories in a country, should be a blessing towards economic stability of that nation. Nigeria is being blessed with abundant clay deposits [1, 3, 4, 5, 6]. Clay deposits in Nigeria cover estimated proven reserves of billions of tones, which are present all over the states of the country [7].Badejoko [8]also confirmed the presence of clay in large quantities in Nigeria at various location. Odo and Nwajagu in their study discovered that many of the clay deposits in Nigeria have not been identified and more research still needs to be carried out to discover possible industrial and technological applications of the identified ones [9]. Thus, the extensive clay mineral deposits available in the country are under-utilized or not fully exploited.

Chemical composition plays significant role in characterization of clay, since chemical analysis is an essential step to establish the nature of minerals in the material [10].Table 1 provides information on different categories of clay. The data in Table 1 include the chemical compositions of different clayscollated from technical literatures. The categories of the clay involved include china clay, ideal kaolin, ball clay high melting clay, fireclay, refractory and ceramics. The main components of the clay samples as shown in Table 1 are silica, alumina and oxides of iron, calcium, magnesium, sodium and titanium.

Table 1: Chemical Composition of Clays collated from Technical Literatures

S/N	Clay Samples	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	CaO	MgO	Na_2O	K_2O	L.O.I	Classification
1	*China Clay*[11]	49.99	37.65	0.09	0.88	0.03	0.13	0.21	1.60	ND	China Clay
2	Refractory brick [12]	51.70	25.00 – 44.00	ND	0.50 – 2.40	0.10 – 0.20	0.20 – 0.70	0.80 – 3.50	ND	ND	Refractory
3	Ceramic [13]	67.50	26.50	ND	0.50 – 1.20	0.18 – 0.30	0.10 – 0.19	1.20 – 1.50	0.10 – 3.10	ND	Ceramic
4	Ball clay [14]	40.00-60.00	25-60		0.250 - 4.000	-	-	-	0.000-0.750	0.50-4.00	Siliceous (Ball clay)
5	High melting clay [15]	53-73	16-29	ND	1-9	0.50 -2.60	0.5-2.6	ND	ND	4 – 12	
6	English Clay [16]	46.20	39.20	0.09	0.23	0.06	0.07	0.21	0.09	3.80	Kaolinite
7	American Clay [16]	45.20	39.20	1.21	0.17	0.06	0.08	0.02	0.03	13.30	Kaolinite
8	Siliceous fireclay [17]	65% (Minimum)	30% Maximum (Al_2O_3 + TiO_2)	-	-	-	-	-	-	-	-
9	Fireclay [18]	40-60	25-45	-	1 - 5	0.50 –1.50	0.1 10.0	-	Other oxides		
10	Ball Clay [19]	67.20	18.20	1.380	2.830	0.306	0.363	0.1850	= 3.0 0.975	5 – 14 8.10	Fireclay P_2O_5 (0.049) MnO_2 (0.026)
11	Uganda Kaolin [19]	48.80	36.00	0.004	0.238	<0.090	0.038	0.0480	1.140	12.60	P_2O_5 (0.026) MnO_2 (0.049)
12	Fireclay [20]	46.00-62.00	25-39	-	0.400 - 2.700	0.200--1.000	0.200 - .000	0.300 0 – 3.0000	0.300-0.300	8.00 - 18.00	Fireclay
13	Refractory Clay [20]	46-62	25-39	ND	0.4-2.7	0.20 – 1.00	0.2 – 1.0	ND	ND	8 – 18	Refractory

ND – Not determined Source : Refs [10 - 20]

The demand for refractories for different high temperature processes and building in Nigeria is enormous as a result of rapid involvement of Nigerian industries in high temperature processes [3]. Delta Steel Company (DSC) is said to consume N1.4 million worth of fire clay (Alumino silicate) materials annually in the steel melt shop, whileAjaokutaSteel Complex at full capacity will require 36,000 tonnes of refractory bricks annually, worth of N5,034 billion Naira annually [1]. Refractory products are used either domestically or in industries in the construction of oven and furnace walls, ceilings, and associated elements of iron and steel industry blast furnaces, glass manufacturing tanks, cement kilns, hot stoves, ceramic kilns, open hearth furnaces, non-ferrous metallurgical furnaces, and steam boilers[21]. To meet the high local demand of refractory products, Nigeria depends greatly on importation of refractory materials to cater for its domestic and industrial needs.Most industries in Nigeria now import a lot of refractory related consumables on demand and specifications[21].

Bulk of the clay consumed in Nigeria is imported from United States of America, United Kingdom and Japan [22]. Large amounts of already lean exchange earnings are continuously spent on importation of refractories and ceramic wares [1,9]. Aderibigbe affirmed that virtually all refractory requirements in all metallurgical industries in Nigeria are imported [23]. About 27 million metric tonnes of refractory materials were imported to Nigeria in 1987 [24]. Considering the present situations (rise in population, demand for industries revolution, and inflation rates) in the country, the importation rate will definitely be in multiple tonnes.Sullayman and Ahmed also revealed from their study that export earning of Nigeria in clay/refractory within 1996-2011 stood only $394,000.00, while Italy in 1997 alone exported $3,442,653,000.00 worth of clay/refractory products and related materials [1].

The shift for alternative source of income apart from oil and gas is the call of the day in Nigeriaat all levels. There is also quest for local materials that can substitute (if not total elimination) the importation of materials, such as refractory products, iron and steel, agricultural products, among others as result of the economic situation in the country. With proper planning, the available clay deposits (if fully identified and characterised) can be used to cater for internal refractory and ceramic wares needs in Nigeria and boost exportation rate of the nation. This will assist in addressing the problem of unemployment, insecurity and over-dependence on foreign goods.

This work examined various properties (such aschemical composition, refractoriness, moisture content, loss on ignition, clay content, apparent porosity, bulk density, linear shrinkage, permeability, crushing strength, and thermal shock resistance) of some selected local clays within Kwara State of Nigeria to determine their suitability for refractory applications. The results of this work will also provide information required to harness the clay deposit in production of ceramic wares and refractories for improvement of the nation's economy and its technological advancement.

2.0 MATERIALS AND METHODS

2.1 MATERIAL

The clay samples were collected randomly from the following seven (7) clay deposits in Kwara State of Nigeria, namely:

A - Alapa clay sample
B - Malete clay sample
C - Baruten clay sample
D - Okelele clay sample
E - Oloje clay sample
F - Akerebiata clay sample
G - Share clay sample

2.2 METHODOLOGY - (Experimental Analysis)

The samples collected were air-dried, crushed, grinded and sieved through 75μ, 200μm and 600 μm sieves at the Federal Polytechnic Ado-Ekiti Civil Engineering Materials Laboratory where the refractory analysis were carried out. The specimens for various experiments were rolled and pressed, dried and kept in a crucible in a plastic form before different parameters were determined.

2.2.1 Grain Size Analysis

For this analysis, 500g of each of the clay samples was taken and dried in the oven for 15 minutes at 110°C and later cooled in desiccators. Each sieve pan in a set of Indian Standard (I. S.) was weighed. The sieves were assembled and the sample was sieved using a mechanical sieve shaker machine. After shaking, each sieve and pan with clay sample retained in each of them were weighed and recorded. The percentagesof clay retained and percentagesof clay passed were calculated.

2.2.2 Chemical Composition

Representative samples of the selected clay materials were analysed to determine their chemical constituents at the Federal Institute of Research Organisation (FIIRO), Oshodi, Lagos, Nigeria using Atomic Absorption Spectrophotometer (AAS) in line with the recommendation of Chestie[25] that x-ray fluorescence (XRF) or Atomic Absorption Spectrophotometer (AAS) can be used for that purpose. The chemical constituents of the clay samples are presented in Table 3.1.

2.2.3 Moisture Content

Samples of the clays were air-dried and weighed. They were then heated in a furnace for 24 hours to a constant temperature of 110°C. The samples were cooled in desiccator and weighed. The moisture content (M.C.) of each of the clay samples was determined using the equation below.

$$M.C. = \frac{Weight\ before\ drying - Weight\ after\ drying}{Weight\ before\ drying} \times 100 \quad (1)$$

2.2.4 Loss on ignition (LOI)

Samples of the clay tests were dried in oven at 110 °C and cooled. The samples were placed in a clean and dried crucible, heated in muffle furnace to a temperature of 900 °C for 3 hours. The Loss on ignition was determined using the equation below :

$$Loss\ on\ Ignition\ (LOI) = \frac{Weight\ of\ Dried\ Clay - Weight\ of\ Clay + Crucible}{Weight\ of\ Clay + Crucible - Weight\ of\ Crucible} \times 100 \quad (2)$$

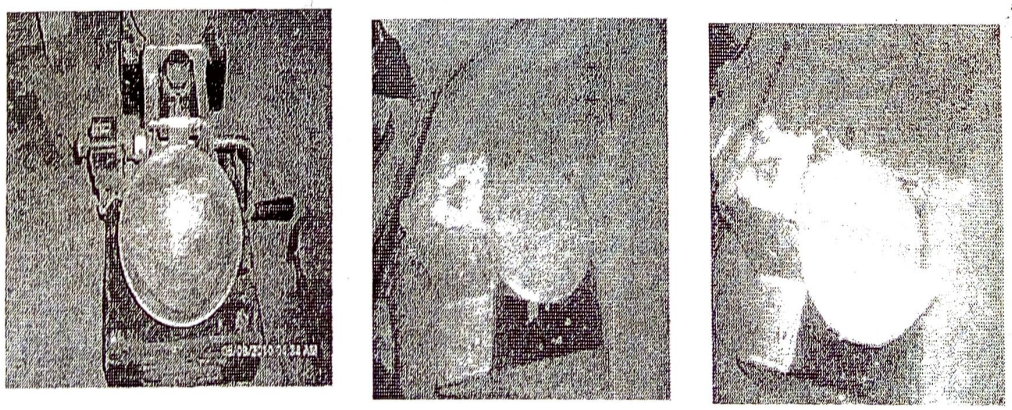
$$= \frac{\text{Moisture Content}}{\text{Weight of Clay}} \times 100$$

2.2.5 Atterberg Limit (Consistency Tests)

In carrying out refractory clay materials' consistency tests; liquid limit, plastic limit and plastic index were determined.

(a) Liquid Limit

The clay sample weighing 100g that has been made to pass through 425 µm sieve was taken and mixed thoroughly with distilled water in evaporating dish to form a uniform paste. A portion of the paste was placed in the cup of the liquid limit device (Plate 1a). The mix was levelled to have a maximum depth of 1cm (see Plate Ib). The grooving tool was drawn through the sample along the symmetrical axis of the cup by holding the tool perpendicular to the cup as shown in Plate Ic below. The handle of the device was then rotated and the numbers of blows were counted till the two parts of the clay particle came into contact at the bottom of the groove. In the case where some clays slide on the surface of the cup instead of flowing, the results were discarded and then repeated. The water content of the clay was determined by oven drying method. The operations were repeated five times in accordance with BS 1377: part 2:1990 guideline[26]. Five readings were obtained in the range of 25 blows. The liquid limit was determined using required Atterberg Table and by plotting the graph on semi-logarithmic graph between the numbers of blow.



(a) (b) (c)

Plate I: Determination of a Clay Sample Liquid Limit

(b) Plastic Limit

Clay sample weighing 15g that has been made to pass through 425 μm sieve and mixed thoroughly with distilled water until the clay mass became plastic to be easily moulded into a ball with fingers. The portion of the ball was taken and rolled with the palm (hand) on a glass plate to form clay mass of thread of uniform of 3mm throughout its length. The clay was re-moulded again into a ball repeatedly until the thread started to crumble at the diameter of 3mm. The crumbled thread was kept in desiccators for water content determination.

A portion of the plastic clay was weighed, sieved through a set of sieve and then fired at 115°C for 30 minutes. It was then cooled in desiccators for 15 minutes and re-weighed. The difference was calculated and result was recorded. The test was repeated with two more samples. The average plastic limit was then taken as average of the three water content values.

(c) Plasticity Index

The plasticity index was calculated using equation iii given below.

Plastic Index, PI = Liquid Limit – Plastic Limit (3)

2.2.6 Hydrometer Analysis

Clay sample was dried in an oven. The dried sample weighing 50g was made to pass through 75 μm sieve, and later placed in an evaporating dish. Distilled water and deflocculating agent solution measuring 100cm^3 each were added to the sample in the dish and left for 10 minutes. Deflocculating agent solution comprises of 33g of sodium hexametaphosphate and 7g of sodium carbonate in 1000ml distilled water.

The sample was transferred into container of stirrer using distilled water until the container was three – quarter (¾) filled. It was put on the stirrer and the stirrer was operated for ten (10) minutes. After stirring, the sample was poured into an identified sedimentation jar and distilled water was added to bring the level to 1000ml and covered with a closed rubber bung. The jar was vigorously shaken for proper and thorough mixing. It was placed on a flat surface and a stop-watch was immediately started to record the time used for the experiment. The hydrometer (shown in Plate II) was inserted in the flat surface. Hydrometer readings of half, one, two and four minutes were recorded. The hydrometer was gently removed after four (4) minutes, rinsed in distilled water and kept in another sedimentation jar (No 2), which has been earlier filled with distilled water and 100cm^3 of deflocculating agent solution. The temperature of the clay suspension was noticed. The hydrometer was re-inserted and the readings at eight (8), fifteen (15) and thirty (30) minutes recorded, while other readings at one (1), two (2), four (4), eight (8) and twenty four (24) hours recorded after shaking. The hydrometer was inserted in the jar No 2 for thirty (30) seconds for each of the readings mentioned above before the given time to make stable at the time of taking the observations. The readings of the solution in the sedimentation jar No.1 were recorded simultaneously and recorded them for deflocculating agent corrections.

Temperature of the suspension recorded once during the first fifteen (utes at subsequent observation. The readings were plotted on graphs and record own in Table 3.

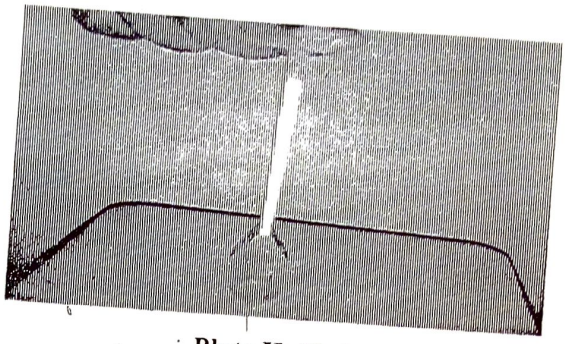


Plate II: Hydrometer

2.2.7 Cold Crushing Strength

The samples were prepared from the clay samples materials, which we ulded into a flat shape size 7.62cm³. The specimens were fired at 110°C for 6 hours furnace. The specimens were cooled to room temperature. The compressive stren of the cooled specimens were determined using a Computer attached Universa sile Machine (Testometric materials testing machines), where axial load was uniform plied on each specimen of known dimensions till when failure occurred. The com sive strengths were automatically determined by the system and then recorded from th puter screen.

2.2.8. Refractoriness

The specimens (cones) were prepared from each of the selected clay nples. Each clay sample was thoroughly mixed water to attain adequate clay plastic, ch was moulded into cone shape and dried to a temperature of 900°C. The specim were arranged around a refractory plaque to test for the refractoriness of clay sples. The plaque containing the test cones with some standard cones whose melting ints were slightly above/or below that of expected test cones were placed in a fu ace. The furnace temperature was raised at the rate of 100°C per minute until the tes one bent over and levelled with the baseof the disc. The final temperatures were then rorded at the end of the experiment.

2.2.9 BrickProduction

The plastic clay was moulded into block form withrectangular bricksf dimensions 5 cm x 5 cm x 2cm using hydraulic press. The bricks were dried in hot air oven and fired and used to determine the refractory properties of the clay samples.

2.2.10 Fired Refractory Analysis

All brick samples produced from each of the selected clays were tested in accordance with ASTM standard test methods for plasticity, drying shrinkage. firing shrinkage, apparent porosity, water absorption, apparent specific gravity and bulk density [27].

(a) Apparent Porosity

Two (2) pairs of the brick samples were dried in air for 24 hours and subsequently dried in oven for 24 hours at temperature of 100 °C. The brick samples were fired at 110°C, cooled and kept in desiccators. Each sample was later weighed to determine its dried weight nearest to 0.01g.The sample were fully immersed and soaked in 250 ml beaker containing boiled water for 30 minutes. The samples were agitated from time to time to ensure that the tapped air bubbles were released. The weights of the soaked samples (W) were determined. They were then transferred into another empty vacuum desiccators and allowed to cool. The samples then suspended in water in a beaker and weighed.

The Apparent porosity (A.P.) of the clay samples were then determined using the relationship below

$$A.P. = \frac{Soaked\ Weight\ (W) - Dried\ Weight\ (D)}{Soaked\ Weight\ (W) - Suspended\ Weight\ (S)}\ x\ 100\ . \qquad (iv)$$

(b) Bulk Density

Fresh two (2) pairs of each sample of the clay bricks were selected to determine the bulk density of the clay samples. The samples were dried for 24 hours in air and later in oven at 110°C for 24 hours. The samples were cooled in desiccators. The dried weights of the samples were also measured nearest to 0.001g. The weighed samples were transferred into separate beakers and soaked with water. They were heated for 30 minutes to release the trapped air the samples. The samples were cooled and the weight of each sample was taken. Each sample was suspended in water in the beaker and the suspended weight was measured.

The bulk density of the clay samples was determined using the relationship below

$$Bulk\ Density\ (g/cm^3) = \frac{Dried\ Weight}{Soaked\ weight - Density\ of\ Water} \qquad (v)$$

(c) Linear Shrinkage

The specimens were rolled in rods of 12cm and marked along a line to maintain the same position after heat treatment. The specimens were dried in still air for 24 hours and later fired at temperature of 110°C in oven for 6 hours, allowed to cool at room temperature and transferred into desiccators. The dried lengthsof the specimens were recorded and their linear shrinkage values of the specimens were determined using the relationship below.

$$Linear\ shrinkage = \frac{Dried\ Length\ (D)}{Fired\ Length\ (F)}\ x\ 100 \qquad (4)$$

(d) Resistance of Refractory Clays to Slag Attack

Hole was drilled into each of the refractory brick made from the studied clay samples. The hole was packed with the sample of iron slag. This iron slag was assumed to be expected slag the clay samples were likely to encounter in service. The brick were heated to 1300°C and maintained at the temperature for one hour. The refractory brick was then cooled and sectioned. Through examination, the degree of slag attack and penetration was observed.

(e) Thermal Shock Resistance

The specimens for thermal shock resistancewere put in furnace fired up to 1300°C. The temperature was maintained for 30 minutes. The specimens were removed from the furnace, allowed to cool in a dry environment. They were returned to the furnace for further heating for 10 minutes. The process of heating and cooling was repeated until the specimens cracked. The numbers of the heating and cooling cycles for each of the specimens was found to be 30 cycles.

3.0 RESULTS AND DISCUSSIONS

3.1 Chemical Composition of the Clay Samples

The results of the chemical composition tests showing the main components of the clay samples are as shown in Table 3.1.

Table 3.1 : Chemical Composition of the Clay Samples

Clay Samples	Composition (Weight %)									
	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	CaO	MgO	Na_2O	K_2O	L.O.I	Appearance (Colouration)
A	48.60	33.80	0.45	1.67	0.06	0.33	0.03	0.26	11.8	Reddish
B	53.40	29.80	1.19	1.00	0.30	0.20	0.25	2.10	11.70	Reddish
C	56.82	28.73	1.02	0.32	0.24	0.24	0.68	2.61	9.34	Black/Ash
D	57.40	24.62	2.22	3.12	0.21	0.20	0.40	0.20	11.30	Reddish
E	47.30	37.40	0.06	1.37	0.10	0.25	0.01	0.63	12.82	Reddish
F	45.58	34.40	0.87	0.61	0.07	0.08	0.04	0.20	17.77	Black/Ash
G	50.90	33.38	2.87	0.86	0.07	0.15	0.06	0.23	11.48	Black/Ash

The chemical analysis of the studied clay samples obtained from Kwara State in Nigeria as shown in Table 3.1reflects that the clays comprise of Silica (SiO_2) and Alumina (Al_2O_3), oxides of iron, calcium, magnesium, potassium and titanium (Fe_2O_3, CaO, MgO, Na_2O, K_2O, TiO_2) and loss on ignition (L.O.I). The chemical compositions of samples were comparable to that of clays/ceramics from previous research works obtained from technical literatures in Table 1. The clay samples were generally found to be Siliceous in nature having silica as the highest proportion of the elements present in the clays, ranging between 45.58 and 57.40%. The presence of Alumina (Al_2O_3) with the range of 24.62 – 37.40% also made the clay samples to fall within the class Alumino-Silicate Refractories. This is in line with the views of Hassan,[2] and Hassan and Adewara[28] that clay that contained Aluminum Oxide between 25 – 45% belongs to Alumino-Silicate Refractories. Atanda, *et al* [21] also affirmed that fireclay whichis essentially of kaolinite groupis usually found to contain 24-32 per cent Al_2O_3, 50-60% SiO_2 and LOI between 9 to 12%.

The different oxide forms of the major elements contained in the clay samples as revealed by the chemical analysis (see Table 3.1) are at various percentages. About 80% of the clay materials are characterized by eight elements, while the remaining is attributed to water, trace elements and organic matter. For the studied clays, variability of average silica (SiO_2) and alumina (Al_2O_3) content, which are the major constituents of clays is apparent as shown in Table 2. SiO_2 and Al_2O_3 in the clay samples are fairly stable ranging from 45.58%to 57.40%and 24.62% to 37.40% respectively. The elemental compositions of the clay samples in Table 2 were in agreement with the view of Sanni[29]that any fireclay to be used in refractories should have at least 30% Alumina (Al_2O_3) and less than 1.8% Iron (III) oxide (Fe_2O_3). This means that the clay samples are suitable as refractories chemically. Though, clay with appreciable amounts of iron is not suitable source of aluminium, since the effect of the iron tends to be deleterious on extraction process of aluminium [30].But the clay samples are fit for the production of earthen wares and chalk.

The flux oxides found in the raw clay samples exhibit a distinct significant dispersion. This can be attributed to different proportion of contamination from the impurities available at the various locations where the clay samples were obtained. High percentage of potassium oxide (K_2O) in samples B and C shows presence of mica content, an indication that the clay samples are suitable for casting than others [31].

The appearances of the raw clay samples were in major two colourations; namely red colourand black/ash colour as indicated in Table 3.1. The reddish colour can be attributed to the presence of iron oxide in accordance with the view of Huber [11] that sometimes iron containing minerals could be part of the kaolinite. The iron oxide concentration ranges from 0.32 to 3.12%. The higher values of Fe_2O_3 in some clay samples (sample D with 3.12%, sample A with 1.67% and sample E with 1.37%) reflect their reddish colour, while those with relatively low Fe_2O_3 value (sample B with 1.0%) reflects lighter reddish colour of the clay. The slight blackish colouration in some samples can also be due to the presence of carbonaceous (organic) matter (like vegetable), as in the case of samples C, F and G with Fe_2O_3 value of 0.32, 0.61 and 0.86% respectively.Other fluxing agents (impurities) in the clay such as CaO, MgO, K_2O and Na_2O, are within the acceptable ranges as shown in Tables 1and 3.1. Kirabira [19]was of the view that impurities, such as CaO, MgO, Na_2O, $CaSO_4$, $CaCO_3$, MnO_2, P_2O_5, Fe_2O_3 and TiO_2 in an ideal kaolinite should be in small quantities.

The values of the constituents of clay samples derived from the chemical analysis carried out are within the recommended values for either refractory materials or ceramic, similar to standard local and international clays as shown 1. Based on the analysis above and comparison of the results with results from previous research works and standards, the studied clay samples may be used as suitable major raw materials for different applications as ceramic, refractory and fireclay, if other major criteria (physical and mechanical properties) were met.

The refractory properties of the clay samples are presented in Table 3.

Table 3.2 : The Refractory Properties of the Clay Samples

Clay Sample	Atterberg Limit				Particle Distribution (% clay contents)	Apparent Porosity (%) X10^{-3}	Bulk Density (g/Cm^3)	Permeability (X 10^{-5}	Cold Crushing cmsec^{-1}) (N/mm^4)	Moisture Content Strength	Slag Resis (%)	Therma Shock tance	Refrac torin ess (° C)
	Liquid Limit (LL) %	Plastic Limit (PL)%	Plastic Index (PI) %	Linear Shrinkage (%)									
A	77.7	30.4	47.3	7.8	86.90	24.84	2.77	85	840	21.3	Good	+29	>1300
B	77.7	25.1	52.6	10.0	58.00	29.76	2.26	87	510	27.3	Good	+29	>1300
C	35.6	16.7	18.9	6.3	36.80	22.99	2.86	80	851	21.0	Good	+29	>1300
D	68.4	29.0	39.4	10.0	82.96	29.24	2.28	82	600	24.9	Good	+29	>1300
E	58.0	24.3	33.7	4.4	64.00	22.67	2.92	82	881	13.0	Good	+29	>1300
F	72.9	29.3	43.6	9.2	89.60	27.29	2.34	83	650	22.6	Good	+29	>1300
G	38.2	25.2	13.0	8.8	40.00	25.75	2.66	79	810	22.0	Good	+29	>1300

3.2 Analysis of the Distribution of the Grain Size

The particle distribution of the clay samples are shown in Table 3.2The results of the sieve analysis of the clay indicates that the samples of clay fall within silt-clay materials as their clay contents were greater than 35% (as shown in Table 3.2) in line with American Association of State Highway and Transportation Officials (AASHTO) classification of soils and Soil-Aggregate Mixtures [32].

3.2.1 Apparent Porosity

The Apparent porosity of the clay samples were within the range of 22.67 – 29.76%, with Samples C and D as having the least and highest values of Apparent Porosity respectively. These fell within the standard values of 22 – 30% for fired bricks [15]. It is an indication of likely good life span for the studied refractory clay materials if used in operation. Low percentage of apparent porosity enhances the trapping of gases in the clay materials which has adverse effect on refractory material life [33]. The higher the value of porosity of clay material the higher the material insulating properties[34].

3.2.2 Water Absorption (Water Content)

The experimental results in Table 3.2 reveal that the clay sample E had the lowest percentage of moisture content of 13%, while clay sample B had highest value of 27.3%. Water content affects the level of soil compaction, which is indicated by its bulk density [35]. Low moisture content value of sample E can be attributed to its low porosity(amount of pore or open space between soil particles).Percentage of moisture content, plasticity and strength of clays depend on the amount of water present [10].

Generally, the moisture content in the clay samples were within the range of 13 – 27.3%. An indication that the clay samples contains water adequate for proper mixing, ensures simple handling and better moulding capacity into any desired shapes. This agrees with Hassan's view that good water contents make ease mouldability of the clay possible [36].

Bulk Density

The clay samples bulk density values range between 2.26 and 2.92g/cm^3 as shown in Table 3.2 The bulk density values fell within acceptable range for refractory materials of 2.2 – 2.8g/cm^3.Though, sample E had the highest value of 2.92g/cm^3, while sample B had the least value of 2.26g/cm^3. Higher bulk density of clay sample E is an indication of its low porosity and compaction as shown in Table 3.2. Higher bulk density impacts available water capacity, which is reflected in the low value of its moisture content. Higher water in clay normally attracts low bulk density value [35]. More so, higher bulk density usually result to higher strength due to low porosity, as reflected in the results of the tests presented in Table 3.2.

The bulk density of clay plays significant role in its economic value when fired as a refractory, filler, coater, and absorbent among others. It is desired that clay refractories possess high bulk density, due to the fact that high fired-density usually confers high physical strength at high service temperature and high resistance to corrosion in service, slag penetration, and abrasion [34]. Thus, the clay samples have desirable values of bulk density for standard refractory materials.

3.2.4. Cold Crushing Strength

From the results in Table 3.2, the clay samples possessed lowest and highest cold crushing strength valuesof 510 and 881N/mm^2 respectively. That is, the clay samples possessed appreciable strength values.Clay samples with low crushing strength usually have low resistance to load, tension and shear stresses than the clay samples with high crushing strength. However the crushing strengths for all the clay samples considered in this study were high enough for a refractory material, which accounts for good bonding and vitrification during firing [37].

3.2.5 Linear Shrinkage

The results in Table 3.2 show linear shrinkage values within 4.4 and 10.0% for the clay samples. Sample E had the least value of 4.4%, while samples B and D have highest value of 10.0% each. It is an indication of good efficiency of firing since the values fell within the acceptable / recommended linear shrinkage value (2.0 – 10.0%) for alumina-silicates, kaolin and fire clays [18]. The result shows indication of better interlock of grains that enhances strength of refractory in operation. Too much shrinkage of refractories usually leads to spalling, warping and cracking of the brick [21].Loss of heat in furnace is associated with cracking of brick. Clay samples B and D with value of 10.0% each likely possess higher finer grains and moisture content than other clay samples, while clay sample E (with value of 4.4%) likely possess the least finer grains and moisture content, since linear shrinkage of clay increases with moisture content and consequently finer grains[34]. The result of the experimental tests also reflected this trend as shown in Table 3.

3.2.6 Permeability

The permeability of the clay samples were within the range of 79 – 87 as shown in Table 3.2.Sample G has the least value of 79% while sample B has the highest value of 80% The values are within the standard values of 25 – 90 acceptable for fireclay [33, 38]. This is an indication that the clay materials were suitable insulating refractories.

3.2.7 Plasticity (Percentage of Clay Content)

Experimental analysis (see Table 3) shows moisture content of the studied clay samples to be naturally between 21 and 33% and the clay contents to be in the range of 36.8 to 89.0%. It indicates that all the clay samples contain clay proportion above 35%. Through sieve analysis of the clay samples, it is also shown that all the studied clays possess liquid limit greater than 35%. This analysis reveals that the major clays studied belong to medium to high plasticity clay.Medium to high plasticity clay usually possess liquid limit between 30 - 77.7%with compressibility shrinkage characteristics[32],higher value of liquid limit of clay indicates high compressibility of the clay. Clay sample C out of all studied clays had least plasticity with liquid limit of 35.6% and plastic index of 18.9%. Medium to high plasticity of the clay samples is an indication that the clays may belong to kaolinite or illite group. Reduction in the value of plastic index increases permeability and decreases compressibility. This is reflected in the results in Table 2. However, clay samples with low plasticity will possess low clay contents. According to Cansagrande chart (Figure 1), clay with Plastic Index less than or equal to 10% and liquid limit less than or equal to 30% is of low plasticity [32]. Illustration of the relationship between plastic index, plasticity, compressibility and Liquid limit is shown in Fig 3.1

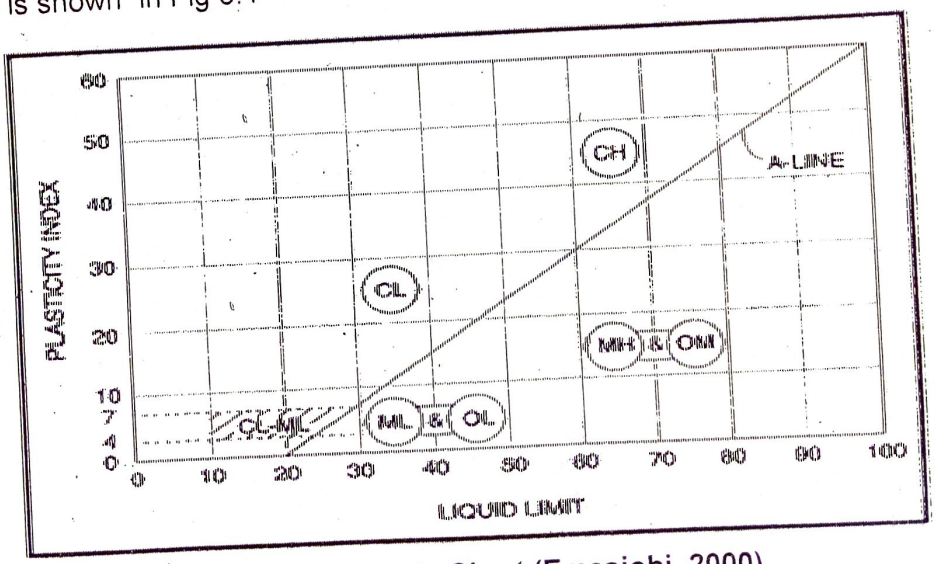


Fig 1: Cansagrande Chart (Emesiobi, 2000)

3.2.8 Refractoriness

This is the property to determine the ability of clay material to withstand the deformation temperature at temperature before fussing or bend under its own weight[4]. That is, the ability to use the material without fear of thermal deformation of the furnace wall. The refractoriness of all the clay samples was above 1300°C. The samples did not show any sign of failure at temperature of 1300°C. This is a sign that the sintering levels of the sample were high; dues they have good qualities of refractoriness. The samples can therefore be used for lining of furnaces and other high temperature devices for melting low and medium temperature metals.

3.2.9 Slag Resistance

The clay samples exhibited good slag resistance as shown in Table 3.2 This means that the clay samples had the ability to resist penetration of corrosive vapours and fumes without deformation if used as furnace lining.

3.2.10 Thermal Shock Resistance

The clay samples survived 30 cycles without any crack as presented in Table 3.2 This indicates that the clay samples could withstand abrupt changes in temperature. The acceptable thermal shock resistance value for fire clay is between 20-30 cycles [4]. This result indicates good characteristics thatsuggest the suitability of the clay samples for production of fire-brick.

4.0 CONCLUSION AND RECOMMENDATIONS

This study revealed that the clay samples from Alapa, Malete, Baruten, Okelele (Ilorin), Oloje (Ilorin), Akerebiata and Share clay deposits possessed the following qualities and be used as follows:

The chemical characterization of the clay samplesrevealed that the clay samples were Siliceous in nature as result of higher percentage of silica present in the clays. The clay samples were also within the Alumino-Silicate class of refractories due to the presence of Aluminum Oxide between the ranges of 24.62 – 37.40%. This class of clay sample can be used as fire fireclay refractory raw materials for furnace and kiln lining; and as suitable potential raw material for ceramics, paper, paints and other industries.

The clay samples were dense and well porous, which made them to be suitable for improved thermal insulation influences in many applications, such as in pyrolysis plant where linings are not exposed to fumes and vapour.The studied clay materials exhibited better refractory properties of acceptable international standards, such as clay contents, linear shrinkage, slag resistance, crushing strength thermal shock resistance and refractoriness. Thus the clay samples either in their raw conditions or at higher temperature were suitable as high melting and fireclay refractory and ceramic raw materials of acceptable standards.
This study recommends the need to adequately utilize available local clay materials for local production of ceramic wares and other refractory products instead of relying on

imported ceramic products, to boost the lean economic of the country, Nigeria. The government and individuals need to focus on establishment of small and middle scale refractory firms within the identified clay deposits (environments) to enhance local; capacity building, reduce unemployment rate in Nigeria and possibly rates of crimes among the youths.

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PLATE III: Some of the Bricks made from the Clay Samples

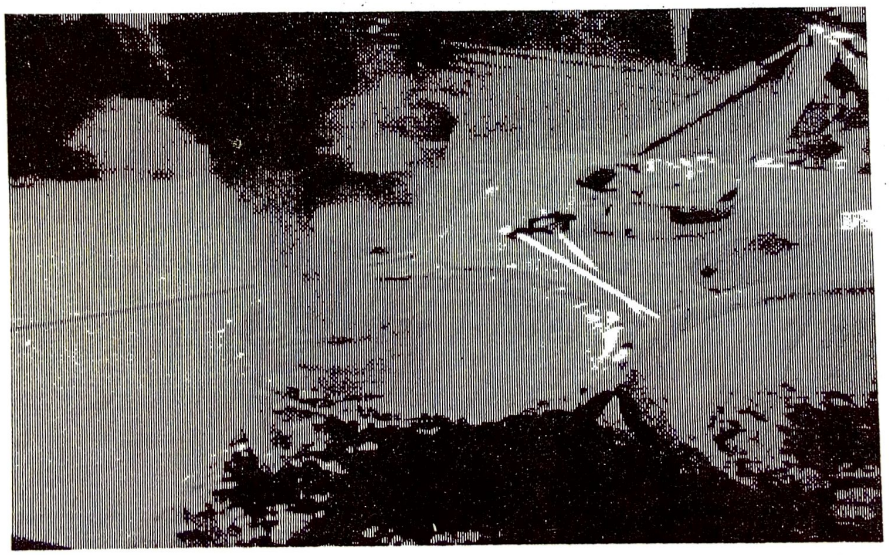


PLATE IV: Loading of Clay Sample in Permeability Apparatus mould.