Experimental Analysis of the Refractory Properties for Kaolinite Clay in Southern Sates: Nigeria

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***Abstract*—The requirement for refractories in Nigeria, as a fast-rising industrialized country, is potentially huge. The vast amount of money being spent on foreign exchange importing refractories is too much. Meanwhile, large quantities of clay deposits are in this nation, which can be processed to meet our needs locally. The analysis of some kaolinite clays as refractory raw materials in Nigeria was studied. The model data was simulated using MATLAB and the results obtained were compared with the four states experimental values. The ratios of alumina-silica are 0.54 for Abia; 0.34 for Akwa Ibom; 0.61 for Imo and 0.50 for Rivers (as compared to the theoretical value of 0.84 for pure kaolinite) makes the clay appropriate for other industrial applications.**

Keywords: Refractory Properties, Kaolinite, Experimental Analysis, Raw materials, Clay

I. Introduction

A refractory material is a material that retains its strength at high temperatures, without them losing their chemical, mechanical and integrity. They are non-metallic materials having those chemical and physical properties that make them applicable for structures. In refractory mixtures, the most common oxides found are those of aluminum (Al_2O_3) and silicon (SiO_2), high silica and alumina (SiO_2) are the chief constituents of all aluminosilicate minerals particularly the clays. The possibility of using aluminosilicate refractory raw material depends on the quantity of alumina clay mineral present. The kaolinites have the highest content of alumina (up to 39.50% by weight) among the clay minerals as revealed by the chemical formula, $Al_2O_3.2SiO_2.2H_2O$. The requirement for refractories in Nigeria, as a fast growing industrialized nation, is potentially enormous. The vast amount of money being spent on foreign exchange importing refractories is too much. Meanwhile, large quantities of clay deposits are in this country, which can be processed to meet our needs locally. Previously, a study on different clay in Nigerian deposits shows that numerous of them have high silica content and low in alumina (NMDC, Jos, 1999; Hassan, 2001). For the meantime, many of the deposits were found to be suitable for use as refractory raw materials; if they are processed properly (Onyemaobi, 2002). Complete chemical analysis of clays involves a true mineralogical analysis. Clays are mostly aluminosilicates made up of alumina-silica (SiO_2) and ($A1_2O_3$) with a number of ionic substitutions, and chemically bound water. Some of the frequent impurities include compounds likes oxides of Ca, Ba, K, Na, and Fe, and little organic matter (Callister, 2003). An entire chemical study of the clay particles, for this reason, the minerals identifies shows the exact quantities of compounds or elements that are present (soilscijournals.org). One complexity in the standard chemical investigation of clay is to find a reagent for detecting the existence of certain mineral or element. Though established methods (based on wet chemistry techniques) are still in use these days, currently, the instrumental techniques are faster and accurate (Reed, 1988; Chalmers, 1968). The relative size of kaolinite or refractory clays of alumina and silica are necessary, because the higher the proportion of alumina, the higher the temperature (i.e. higher refractoriness) necessary to form the glassy ceramic bonding (vitrification) material which explain ceramic products (ILO/UNIDO, 1984; Idenyi and Nwajagu, 2003).

The major properties of any refractory material depend on the make-up of the mineral, the size distribution of minerals particle and environments of the furnace and the method these minerals respond to temperatures increase. The size of the particles varies from 6mm to 7.4mm made up of unfired refractories. Upon firing, the fines from a ceramic bond between the larger particles and the fired refractory are made up of bonded crystalline mineral particles and glass or smaller crystalline particles, which depend on the composition of the refractories (Ruh, 1986; Callister, 2003). If you want to select a refractory for a particular application, different physical properties must be put into consideration, e.g. apparent porosity, bulk density and also the strength at room temperature (Ruh, 1986). The strength, density and porosity of fired products are influenced by different factors like the quality of materials, the size and fit of the particles, the content of moisture at the point of moulding, pressure of moulding, temperature and duration of firing, kiln atmosphere and cooling rate (Idenyi and Nwajagu, 2003). The process for making bricks can be described under five different headings: lay excavation and winning, clay processing or preparation, forming or molding of bricks, drying of bricks, and firing of brick (Nash, 1979; Rajput, 2004). It is obvious that in all the works reviewed, the researchers who studied the refractory characteristics of various clays in Nigerian did not add any inert (non-plastic) material to the clay. The addition of an inert substance (chamotte) to the plastic clay to form a molding mass is where this study differs from earlier works carried out on the refractory properties of Nigerian clays. Viz.: Borode et al., (2000); Nnuka and Agbo (2000); Hassan (2001); Omowumi (2001); Obadinma (2003); Lawal et al., (2005); and Hussein et al., (2005). The chamotte addition is to reduce the shrinkage and also the fireclay bricks cracking (Krivandin and Markov, 1980). It has been exploited already in the kitchen wares and ceramic table where the grog addition, flint or quartz, and other non-plastic materials give strength to the ceramic body. Take note that the chamotte used in this study have the same composition as the clay. Therefore, at the suitable elevated temperatures, they would fuse together and change to mullite and tridymite/cristobalite. While Hassan (2001) included silicon carbide while Lawal, Amuda, and Adeosun (2005) incorporated cow dung and graphite; the reality remains that these materials are unknown to clay composition. Silicon carbide or carborundum are rated as a first class refractory material and hence costly, was reported to improve the clay refractory properties, while cow dung unfavorably affected them even if it was meant to provide the much-needed phosphate bond. The addition of quartz or silica as did Samuel and Adeyemi (2004), in the case of ceramic tiles, may be considered nearer to what obtains in the SiO_2 - Al_2O_3 system, but it will tend to lower the refractoriness (softening point), in the case of refractory bricks as predicted by the phase diagram. In contrast, the addition of a grog or chamotte made from the similar clay would support the integrity of the constitutional refractory clay while improving its refractory properties. In fact, Schumann, Jr. (1952), and Krivandin and Markov (1980) alluded to the fact that the addition of a pre-fired or calcined clay (grog or chamotte) has the effect of reducing shrinkage, and increase the density of packing and strength. It is obvious, that other processing parameters distribution of size, the content of moisture, and molding pressure must be adequately controlled. As earlier stated, this study is different from those cited previously because it considered the use of pre-fired clay as a non-plastic additive. Though, the testing techniques used in this study are in conformity with standard practices. Hence, it follows the same refractory testing methods used by earlier investigators. This, of course, makes the results obtained in this study to be comparable with those cited in earlier investigations using the same yardstick of measurement. This study carried out an experimental investigation on the refractory properties of Kaolinite clay deposits in four Niger delta states in Nigeria.

I. Details of Experiment

In this study, all the experimental analysis carried out apart from those involving winning of clays and chemical analysis, firing, and softening point test; were performed at the Centre for Industrial Studies (CIS) and Institute of Erosion Studies (IES), different samples of the four clays were analyzed to find out their chemical constituents (quantity of SiO_2, Al_2O_3, etc.) and mineralogical composition (amount of quartz or free silica, kaolinite, feldspar, etc). The mineralogical and chemical were investigated. Atomic absorption spectrophotometer analysis, X-Ray Diffractometer analysis, plastic limit test and liquid limit test of the clay samples were carefully conducted.

II. Materials and Methods

Some equipment and material that were used for this investigation include a hoe or spade, raw (as-mined) clay, XRD, and AAS. Others are mortar and pestle, ASTM sieves, hydraulic molding press/compression strength machine, electric furnace and oven, electric water heater, beam lever balance, a pair of tongs, drying cloth, strong thread or fine cord, Hilton heat conduction equipment, standard pyrometric cones and a ceramic kiln. Different samples of the four clays were analyzed in order to find out their chemical constituents (quantity of SiO_2, Al_2O_3, etc.) and mineralogical composition (amount of quartz or free silica, kaolinite, feldspar, etc).

III. Materials and Methods

A. *Chemical/Mineralogical Composition*

The chemical analysis results and XRD mineralogical analysis are shown in Tables.1 and 2 respectively. For the raw clays (Table Ia), Imo State gave the highest alumina content (29.45%) followed by Abia (27.87%), Rivers (26.42%), and Akwa Ibom (19.05%). There was a decrease in the total alkaline oxide content (resulting from soaking/washing treatment) as shown in Table I(b) when compared with Table .I(a). The alumina-silica ratios of the firebricks produced from the clay are shown in Table .I(c). It can be seen (when Tables Ia and b are compared) that the content of alumina increases after constitutional water (LOI) and likely organic matter content were driven off during firing. Mineralogical compositions of Table 2 as determined by X-ray diffraction show that the samples are basically fireclays. With kaolinite as the major constituents, other mineral constituents detected include free silica or quartz (SiO_2), illite $\{KAl_2(Si_3,AL)O_{10}(OH)_2\}$ Chlorite $\{Mg,Fe)_3(Si,Al)_4O_{10}(OH)_2$. $(Mg,Fe)_3\ (OH)_6\}$, Feldspars $\{(K,Na)AlSi_3O_8\}$, and montmorillonite $(Ca,Na)_{0.2-0.4}(Al,Mg,Fe)_2(Si,Al)_4O_{10}\{OH)_2\}$, Feldspars $\{(K,Na)AlSi_3O_8\}$, and traces of calcite ($CaCO_3$) and haematite (Fe_2O_3), etc.

Table.1a: Chemical Composition of Raw Clay Samples Different States (AAS)

Composition (%)	Abia	Akwa Ibom	Imo	Rivers
SiO_2	52.06	60.21	48.23	53.65
Al_2O_3	27.87	19.05	29.45	26.42
Fe_2O_3	3.25	3.78	3.58	2.50
MgO	1.43	1.50	1.49	1.52
CaO	0.34	0.30	0.22	0.28
Na_2O	0.38	0.42	0.29	0.45
K_2O	2.99	2.16	2.56	2.78
LOI (H_2O)	9.3	10.2	13.4	12.2

Table 1b: Composition of Alkaline Oxides in Washed Clay Samples (AAS)

Composition (%)	Abia	Akwa Ibom	Imo	Rivers
Na_2O	0.17	0.22	0.19	0.23
K_2O	2.34	2.15	2.03	2.08
Combined	2.51	2.37	2.22	2.31

Table 1c: Composition of Al_2O_3/SiO_2 in Fired Clay Samples (AAS)

Composition (%)	Abia	Akwa Ibom	Imo	Rivers
Al_2O_3	31.8	21.30	36.2	29.18
SiO_2	59.2	62.47	54.10	57.86
Al_2O_3/ SiO_2 Ratio	**0.54**	**0.34**	**0.67**	**0.50**

Table 2: Mineralogical Composition of Raw Clay Samples (Based on XRD)

Constituents (%)	Abia	Akwa Ibom	Imo	Rivers
Kaolinite	67	53	76	62
Free Quartz	13	32	6	11
Illite	4.6	2.5	3.7	3
Chlorite	6	5.3	2.4	17
Montmorillonite	3.6	-	7	-
Feldspar	2	5	2	4

A. Atterberg Limits

The results obtained from the liquid limit and plastic limit tests are presented in Tables 3 and 4 respectively. Figures 1 to 4 are the flow curves for Abia, Akwa Ibom, Imo, and Rivers respectively. From these, the liquid limit (LL) values shown in Table 5 were derived. The plasticity index, PI (Table 5) falls within the range 10-60% recommended for ceramic clays by (Grimshaw, 1971; and Nnuka and Enejor, 2001).

It can be seen that Imo has the highest plasticity index followed by Abia, as indicated by their PI values of 41 and 31 respectively. Akwa Ibom and Rivers, each has a PI of 23. The plasticity chart (Figure 5) shows that Akwa Ibom and Rivers are of medium plasticity (CI); Abia is of high plasticity (CH); while Imo is of very high plasticity (CV). These results are in agreement with the specifications by Head (1984).

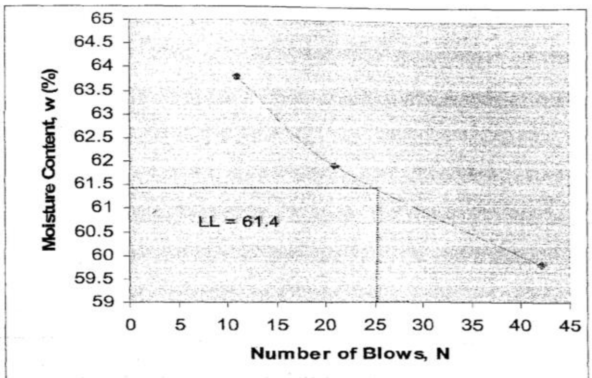


Figure 1: Liquid Limit Flow Curve (casangrade test) for Abia

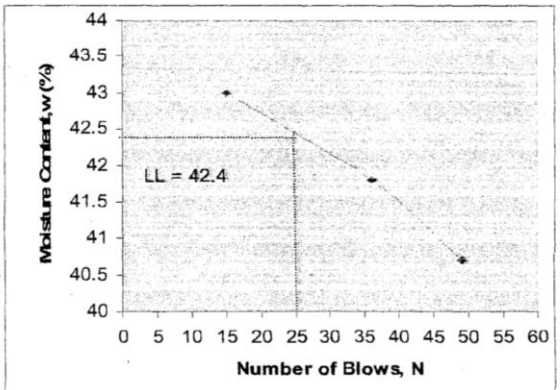


Figure 2 Liquid Limit Flow Curve (Casangrade test) for Akwa

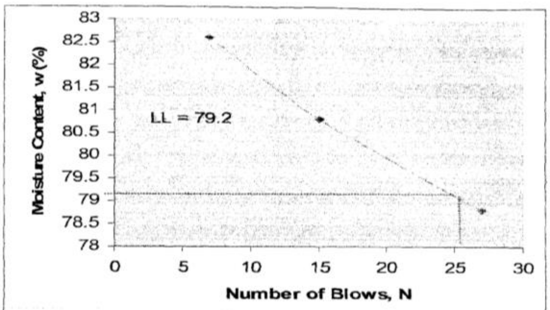
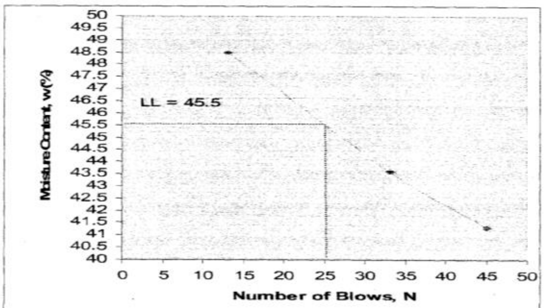


Figure 3: Liquid Limit Flow

Table 3: Result of Liquid Limit Test (Casagrande)

Description	Abia			Akwa Ibom			Imo			Rivers		
Test Number	1	2	3	1	2	3	1	2	3	1	2	3
Can identification	1A	IB	1C	2A	2B	2C	3A	3B	3C	4A	4B	4C
Number of Bumps, N	11	21	42	15	36	49	7	15	27	13	33	45
Can + Wet Clay, m_2 (g)	35.4	35.8	33.1	35.4	37.2	31.6	32.4	33.0	35.7	35.4	37.9	33.8
Can + Dry Clay, m_3 (g)	30.3	29.8	27.9	30.8	33.1	28.1	26.7	27.3	30.5	30.5	30.1	25.8
Can, m_1 (g)	22.3	20.1	19.2	22.3	20.1	19.2	19.8	19.4	23.7	20.4	22.3	17.8
Dry Clay, $m_3 - m_1$ (g)	8.0	9.7	8.7	10.7	9.8	8.6	6.9	6.8	6.6	10.1	7.8	8.0
Moisture Loss, $m_2 - m_3$ (g)	5.1	6.0	5.2	4.6	4.1	3.5	5.7	5.5	5.2	4.9	3.4	3.3
Moisture Content, $w = \frac{m_2 - m_3}{m_3 - m_1}$	63.8	61.9	59.8	43.0	41.8	40.7	82.8	80.8	78.8	48.5	43.6	41.3



Fiaure 4: Liauid Limit Flow

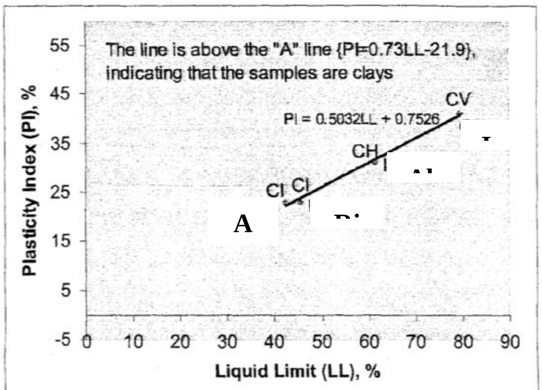


Figure 5: Plasticity Chart for the

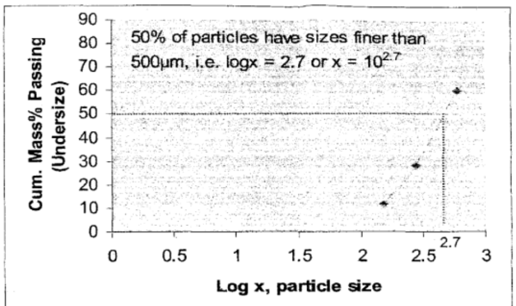


Figure: 6a Cumulative Undersize Semilog Plot of Abia

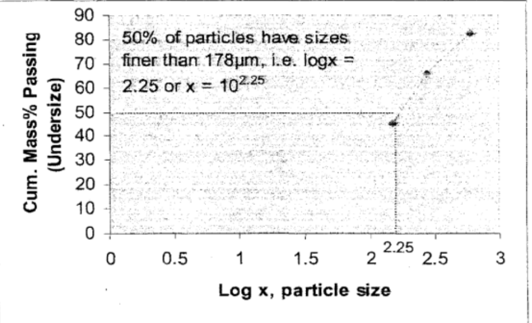


Figure 6b: Cumulative Undersize Semilog Plot of Akwa Ibom

Table 4: Results of Plastic Limit Test

Description	Abia		Akwa Ibom		Imo		Rivers	
Test Number	1	2	1	2	1	2	1	2
Can Identification	1D	1E	2D	2E	3D	3E	4D	4E
Can + Wet Clay, m_2 (g)	25.9	26.3	28.0	24.3	26.4	31.5	29.7	29.6
Can + Dry Clay, m_3 (g)	24.5	24.7	26.7	23.2	24.0	29.5	28.6 .	28.6
Can, m_1 (g)	19.3	19.7	19.7	17.4	17.8	24.1	23.9	24.0
Dry Clay, m_3-m_1 (g)	5.2	5.0	7.0	5.8	6.2	5.4	4.7	4.6
Moisture Loss, $m_2 - m_3$ (g)	1.4	1.6	1.3	1.1	2.4	2.0	1.1	1.0
Moisture Content, w = $\frac{m_2 - m_3}{m_3 - m_1} x\, 100$	27.0	32.0	18.6	19.0	38.7	37.0	23.4	21.7
Plastic Limit =Ave.w (%)	30		19		38		23	

B. Sieving Results

The results from the sieving test are presented in Table 6. It shows that the percentage of material finer than 600μm is 60.27 for Abia, 82.62 for Akwa Ibom, 62.08 for Imo, and 69.54 for Rivers. Semi-log plots are shown in Figures 4.6a (Abia), 4.6b (Akwa Ibom), 4.6c (Imo), and 4.6d (Rivers). It is revealed that 50% of particles have sizes (i.e. the median size) finer than 500μm (for Abia), 178μm (Akwa Ibom), 447μm (Imo) and 316μm (Rivers). Similarly, Figures 7a, 7b, 7c, and 7d are the log-log plots for Abia, Akwa Ibom, Imo, and Rivers States respectively. The distribution modulus (m) for Abia, Akwa Ibom, Imo, and Rivers is respectively 1.2, 0.43, 0.78, and 0.46. Similarly, the size modulus (k) is 129μm, 4μm, 60μm, and 9μm for Abia, Akwa Ibom, Imo, and Rivers States respectively. The results show that Akwa Ibom has the finest particle size distribution while Abia has the coarsest.

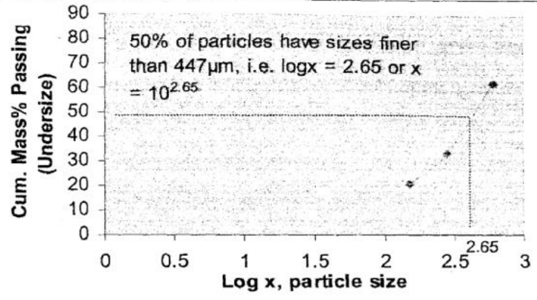


Figure 6c: Cumulative Undersize Semilog Plot of Imo

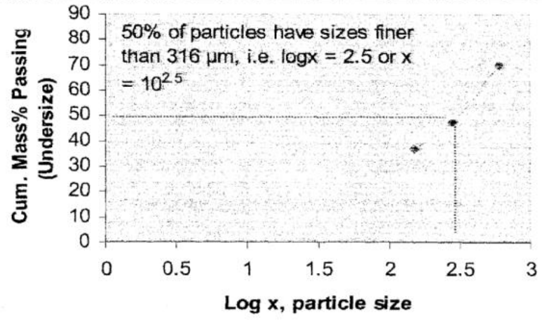


Figure 6d: Cumulative Undersize Semilog Plot of Rivers

Table 5: Plasticity Indices of the Clays

Description	**Liquid limit, LL (%)**	**Plastic Limit, PL (%)**	**Plasticity Index, PI = LL-PL (%)**
Abia	61.4	30	**31**
Akwa Ibom	42.4	19	**23**
Imo	79.2	38	**41**
Rivers	45.5	23	**23**

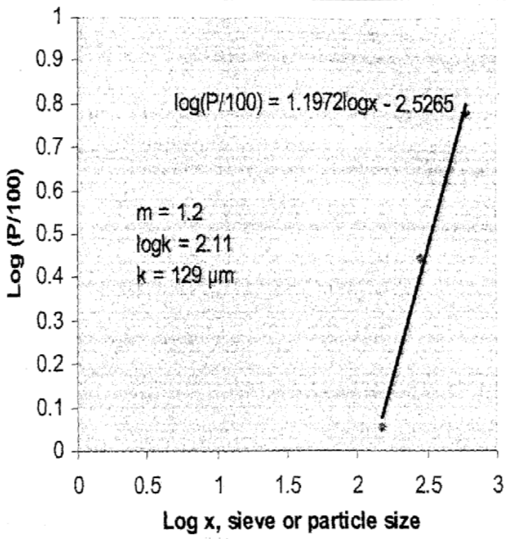


Figure 7a: Gates-Gaudin-Schuhmann's (log-log) Plot of Abia {log(P/100) = mlogx – mlogk}

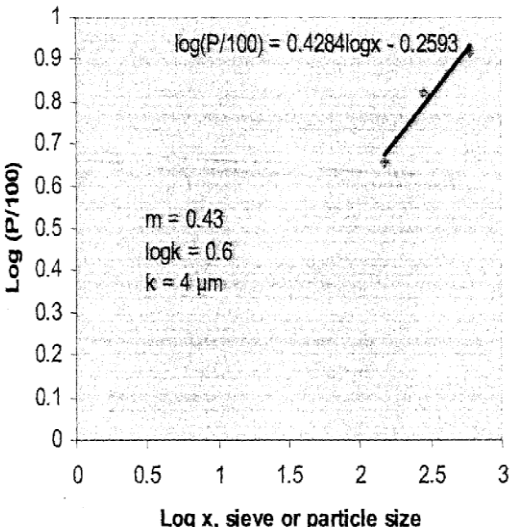


Figure 7b: Gates-Gaudin-Schuhmann's (log-log) Plot of Akwa Ibom {log(P/100) = mlogx – mlogk}

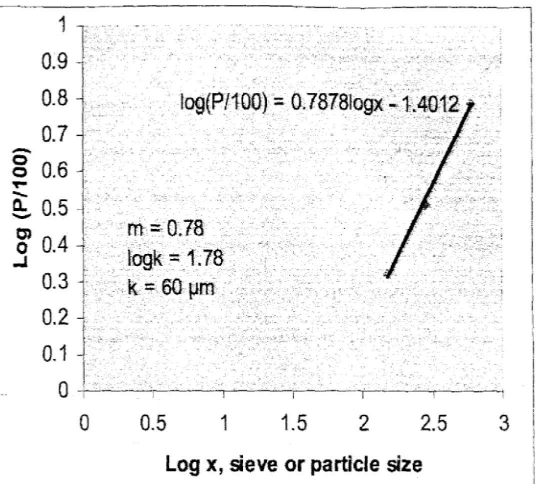


Figure 7c: Gates-Gaudin-Schuhmann's (log-log)

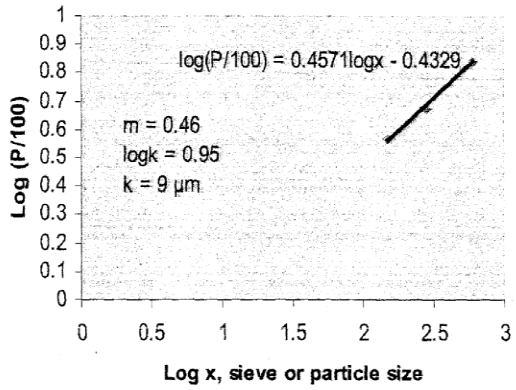


Figure7d:Gates-Gaudin-Schuhmann's (log-log)Plot of Rivers {log(P/100)=mlog x –mlogk}

Table 7: Moisture Content of Molding Mass

Description	Abia	Akwa Ibom	Imo	Rivers
Can (g)	23.7	22.3	20.4	19.5
Can + Wet Clay (g)	50.0	41.3	42.4	44.8
Can + Dry Clay (g)	42.6	36.8	35.1	39.5
Wet Clay (g)	26.3	19.0	22.0	25.3
Dry Clay (g)	18.9	14.5	14.7	20.0
Moisture Loss (g)	7.4	4.5	7.3	5.3
Moisture Content, wet basis (%)	**28**	**24**	**33**	**22**
Moisture Content, dry basis (%)	39	31	49	27

C. Moisture Content Test

The moisture content that gave a molding mass of suitable plasticity for each of the clay is given in Table 7. On the as-received (wet) basis, Abia required 28% moisture; Akwa Ibom, 24%; Imo, 33%; and Rivers, 22%. These values compare well with the plastic limit values and plasticity indices in Table 5.

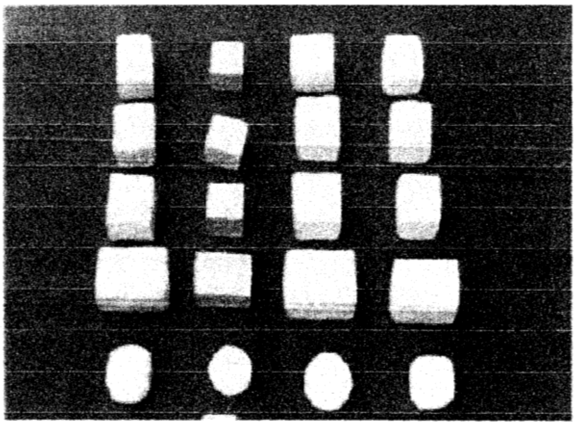


Plate A: Fireclay Bricks Produced from the Four Clays

Table 9: Linear Shrinkage Results

Description		Abia	Akwa Ibom	Imo	Rivers
Green Dimensions, (mm)	Lg_l	38.85	39.02	39.16	39.14
	Lg_2	47.90	47.92	47.91	47.92
	Lg_3	49.34	49.32	49.33	49.34
	Lg_{av}	45.36	45.42	45.80	45.46
Fired Dimensions, (mm)	Lf_1	36.02	38.03	30.06	39.94
	Lf_2	41.12	44.48	34.44	44.19
	Lf_3	45.49	48.83	37.79	47.77
	Lf_{av}	40.87	43.78	34.10	43.96
Linear Shrinkage = $\frac{Lg_{av} - Lf_{av}}{Lg_{av}} x\ 100, (\%)$		**10**	**3.6**	**25.5**	**3.3**

V. Surface Appearance/Fired Colour

The surface appearance and coloration observed after firing to 1200°C are presented in Table 8. Abia fired white, while Akwa Ibom turned to cream. Imo is buff/yellow while Rivers is gray/ash color. Plate 4A shows the surface appearance. It was also observed that after calcining to 800°C, Imo turned black, whereas the rest of clay retained their unfired color respectively. However, the calcined clays lost their plasticity, the most characteristic property of all clays.

Table 8: Colouration and Surface Appearance after Firing

Sample Identification	Fired Colour	Surface Appearance
Abia	White	No Cracks
Akwa Ibom	Cream	Slight Crack
Imo	Buff /Yellow	Slight Crack
Rivers	Grey / Ash Colour	Heavy Cracks

A. Linear Shrinkage

The average total (drying and firing) shrinkage values are presented in Table 9. It is shown that the highest shrinkage of 25.5% was obtained for Imo, followed by 10% recorded for Abia. As for Akwa Ibom and Rivers, the values are 3.6 and 3.3% respectively.

B. Apparent Porosity and Bulk Density

Table10 displays the results obtained. It can be observed that the porosity varies inversely with the bulk density. Rivers with the highest porosity of 37.40% also recorded the lowest bulk density of 1.54g/cm^3. Imo has the lowest porosity of 4.36% as well as the highest bulk density of 2.35g/cm^3. Abia and Akwa Ibom recorded 26.2% and 30% for porosity; 1.81g/cm^3 and 1.66g/cm^3 for bulk density respectively.

C. Cold Crushing Strength

The results are given in Table 11. Imo gave the highest value of 33MPa followed by Abia which gave 18MPa. Rivers and Akwa Ibom recorded 12.7MPa and 8.IMPa respectively.

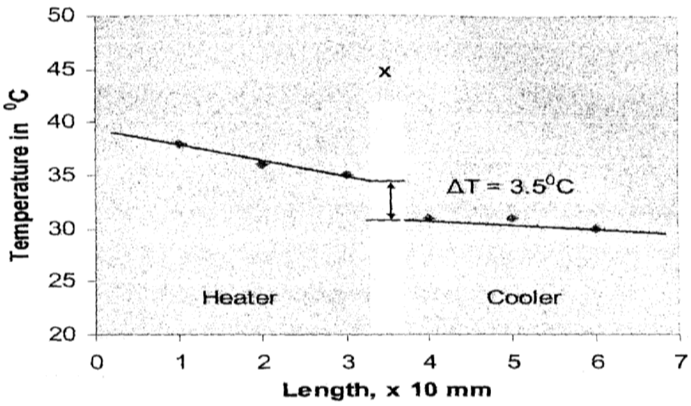


Figure 8a: Temperature Profile for Abia

Table 10: Apparent Porosity and Bulk Density Results

Description	Abia	Akwa Ibom	Imo	Rivers
W_{da} (g)	114.31	133.95	92.60	118.96
W_{sw} (g)	67.65	76.79	54.93	70.82
W_{sa} (g)	130.87	157.22	94.32	147.72
Apparent Porosity, P_a (%)	26.2	29.90	4.36	37.40
Bulk Density, D_b (g/cm^3)	**1.81**	**1.66**	**2.35**	**1.54**

Table 11: Results of Cold Crushing Test

Description	Strength along direction of forming, CCS_V (MPa)	Strength across direction of forming, CCS_H (MPa)	Average Strength, CCS (MPa)
Abia	21	15	**18**
Akwa Ibom	9	7.2	**8.1**
Imo	34.5	31	**33**
Rivers	15	10.3	**12.7**

D. Thermal Shock (Spalling) Resistance

The thermal spalling resistance values are shown in Table12. Imo gave the highest value of 31 cycles, followed by Abia 28 cycles. Akwa Ibom recorded 16 cycles while Rivers recorded the poorest value of 9 cycles.

Table 12: Thermal Spalling Resistance Values

Sample Identification	Abia	Akwa Ibom	Imo	Rivers
Number of Cycles	28	16	32	9

E. Thermal Conductivity

The thermal conductivity test results are shown in Table13. Temperature profile plots of the heater and cooler are extrapolated to the interfaces (Figures 8a, 8b, 8c and 8d). The actual temperature gradient ΔT across the disc was determined as shown; x being the disc thickness (3mm). The results were used to calculate the thermal conductivity k of the clay, using the Fourier's Law. As shown in Table 13, Abia and Akwa Ibom recorded 4.73 6W/m-°C and 4.6W/m-°C respectively, while Imo and Rivers gave 2.474W/m-°C and 1.744W/m-°C respectively. It can be seen that high-temperature gradient, ΔT, results to poor conductivity, k.

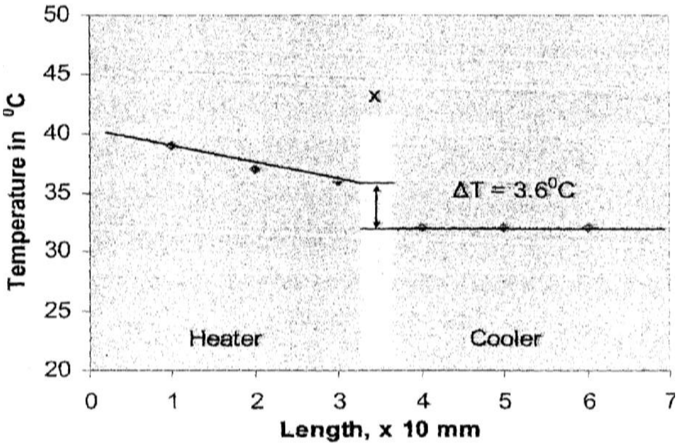


Figure 8b: Temperature Profile for Akwa Ibom

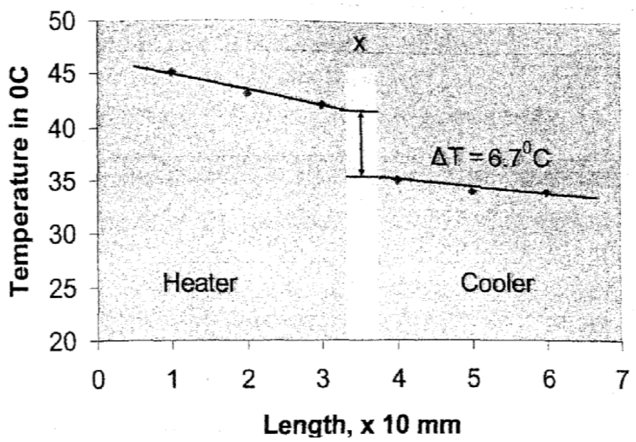


Figure 8c: Temperature Profile for Imo

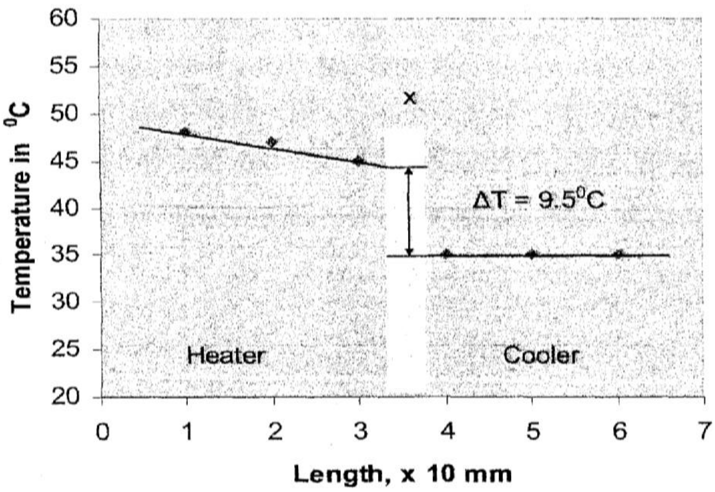


Figure 8d: Temperature Profile for Rivers

Table 13: Thermal Conductivity Test Results, at 30°C

Description	**Abia**	**Akwa Ibom**	**Imo**	**Rivers**
Thickness, x (mm)	3	3	3	3
Diameter, d (mm)	48	48	48	48
Area, A (mm^2)	1810	1810	1810	1810
Input Power, Q (W)	10	10	10	10
T_1 (°C)	38	39	45	48
T_2 (°C)	36	37	43	47
T_3 (°C)	35	36	42	45
T_4 (°C)	31	32	35	35
T_5 (°C)	31	32	34	35
T_6 (°C)	30	32	34	35
ΔT (°C)	3.5	3.6	6.7	9.5
Conductivity, k (W/m-°C)	0.004736	0.0046	0.002474	0.001744
Conductivity, k (W/m-°C)	**4.736**	**4.6**	**2.474**	**1.744**

Table14: Pyrometric Cone Equivalents

Description	**Abia**	**Akwa Ibom**	**Imo**	**Rivers**
Cone No. (PCE)	29	23	31½	15-16
Softening Point (°C)	1660	1605	1700	1460

Table 6: Sieving Results

Description	**Abia**			**Akwa Ibom**			**Imo**			**Rivers**		
Sieve Aperture Size or Particle Size, x (μm)	600	300	150	600	300	150	600	300	150	600	300	150
Initial Mass on 600μm Sieve, m_1 (g)	112			126			106			131		
Mass Retained on Sieve, m_1 (g)	44.5	36.2	18.6	21.9	20.9	26.1	40.2	31.2	12.5	39.9	29. 2	13.4
Mass % Retained = m/m_1 x 100	39.73	32.32	16.61	17.38	16.58	20.71	37.92	29.43	11.79	30.46	22.30	10.23
Cumulative Mass% Retained (Oversize), R	39.73	72.05	88.66	17.38	33.96	54.67	37.92	67.35	79.14	30.46	52.76	63.00
Cumulative Mass% Passing (Undersize), P=100-R	60.27	27.95	11.34	82.62	66.04	45.33	62.08	32.65	20.86	69.54	47.24	37.00
(P/ 100)	6.027	2.795	11.34	82.62	66.604	4.533	6.208	3.265	2.086	6.954	4.724	3.700
Log(P/100)	0.780	0.446	0.055	0.917	0.820	0.656	0.793	0.514	0.320	0.842	10.674	0.568
Log x	2.778	2.447	2.176	2.778	2.447	2.176	2.778	2.447	2.176	2.778	2.447	2.176

F. Softening Point (Refractoriness)

The clays softening points are shown in Table14; they are in pyrometric cone equivalents (PCEs) as well and the corresponding temperatures.

VI. Conclusion

Clay Samples from four States of the Niger Delta in Nigeria have been investigated for refractory applications. Based on the results of mineralogical and chemical analyses, based on the experimental results it is confirmed that the clays are kaolinitic. From the physical and service properties tests conducted, the results show that the two clays from Abia and Imo possess the refractory qualities needed to replace all the imported fireclay refractories used in some chemical, ceramic, metallurgical and allied industries. Two of the clay analyzed belong to the medium duty fireclay class of aluminosilicate refractories. Therefore, for this reason, they are suitable for processing refractory bricks necessary for lining the furnaces walls, soaking pits, ovens, ladles, crucibles, and kilns. From the analysis, it was observed that clay from Akwa Ibom states belongs to the class of semi acid or semi-silica of aluminosilicate refractories. Though, blending with a more plastic-clay may be needed in order to improve its properties. Rivers clay has high alumina content (26.22%), is not very good as a refractory because it has a very poor thermal shock resistance. It should be processed so that it can be used to manufacture things like paint, fertilizer, paper, etc. Based on the conclusion, the incorporation of inert additives like chamotte or grog is vital for the best performance of refractory clays and that the amount of grog should increase in the molding mass with the clay plasticity. These clays can be processed so that it can be useful and also exploited for other industrial uses besides refractory bricks. Clays from Abia, Imo, and Rivers can be used as sources of alumina and hence, aluminum.

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References

[1] Borode, J. O; Onyemaobi, O. O., and Omotoyinbo, J. A. (2000). *Suitability of Some Nigerian Clays as Refractory Raw Materials NJEM*, Vol. 1, No.3, pp. 14-18.

[2] Callister, JR. W. D. (2003). *Materials Science and Engineering: An Introduction, Sixth Edition*. New York: John Wiley. pp. 384-410, 425-443.

[3] Chalmers, R. A. (1968). *Aspects of Analytical Chemistry*. Edinburgh: Oliver & Boyd Ltd. Pp. 14, 74-76. HASSAN, S. B. (2001). *Effects of Silicon Carbide on Some Refractory Properties of Kankara Clay Proc*. of the Nigerian Metallurgical Society, the 18th Annual Conf. Pp. 46-52.

[4] Hassan, S. B. (2001). *Effects of Silicon Carbide on Some Refractory Properties of Kankara Clay Proc*. of the Nigerian Metallurgical Society, the 18th Annual Conf. Pp. 46-52.

[5] Hussein, A. S; Eti, M. C., and Jombo, P. P. (2005). Investigation into the Refractory Properties of Igbodoka Clay for the Production of Furnace Crucible Nigerian *Journal of Engineering Research and Development (NJERD)*, vol. 4, No. 2, p. 18.

[6] Idenyi, N. E. and Nwajagu, C.O. (2003) *Non-metallic Materials Technology*, Enugu Olicon Publications, pp1-47.

[7] Krivandin, V. A. and Markov, B. L. (1980) *Metallurgical Furnaces* (Translated from the Russian by V. V. AFANASYEV) Moscow: Mir Publishers. Pp.229-261, 279-81

[8] Lawal, G. I; Amuda, M. O. H., and Adeosun, S. O. (2005). *The Effects of Cow Dung and Graphite on the Properties of Local Refractory Clays* NJERD, Vol. 4, No. 2, pp 1-8

[9] Nash, W. (1979) *Brick Work One, Ninth Impression*. London: Hutchison. Pp. 1-7

[10] Nnuka, E. E. and Agbo, U. J. B. (2000). *Evaluation of the Refractory Characteristics of Otukpo Clay Deposit.* NSE Technical Transactions, vol. 35, No. 1, pp. 32-41.

[11] NMDC, JOS. (1991) *Research and Development Efforts at Nigerian Metallurgical Development Centre, Jos, Towards Arresting the Declining Fortunes of the Nigerian Metallurgical Industry* Proc. of the Nigerian Metallurgical Society, the 16th Annual Conf. pp. 8-29.

[12] Obadinma, E. O. (2003). Development of Refractory Bricks for Heat Treatment Facilities. *Journal of Science and Technology Research*, Vol. 2, No. 2, pp. 13-17.

[13] Omowumi, O. J. (200l). Characterization of Some Nigerian Clays as Refractory Materials for Furnace Lining *NJEM*, Vol. 2, No.3, pp. 1-4.

[14] Onyemaobi, O. O. (2002) Engineering Properties of Amuro-Okigwe Fired Clay Bricks for Building Work, NSE Technical Transactions, Vol.32, No.1, pp.32-40.

[15] Rajput, R. K. (2004) Heat and Mass Transfer in S.I. Units, 2nd Edition New Delhi: S.Chand and Co Ltd. pp.1-21.

[16] Reed, J. S. (1998). Introduction to the Principles of Ceramic Processing New York: John Wiley. Chapters 3, 5-7, 13, 16.