THE INTERNATIONAL JOURNAL OF SCIENCE & TECHNOLEDGE

Compositional Features and Functional Industrial Applications of the Lateritic Clay Deposits in Oye-Ekiti and Environs, Southwestern Nigeria

Akinola
Department of Geology, Ekiti State University Ado-Ekiti, Nigeria
Oluwatoyin O.
Department of Geology, Ekiti State University Ado-Ekiti, Nigeria
Ademilua
Department of Geology, Ekiti State University Ado-Ekiti, Nigeria
Oladimeji L.
Department of Geology, Ekiti State University Ado-Ekiti, Nigeria

Abstract:
Geochemical characteristics and industrial suitability of lateritic clay occurrences in Ire and Ishan areas of Oye-Ekiti are investigated and reported. Systematic geologic mapping revealed that gneiss, granite and charnockite constitute the basement rocks of the area. Intensive chemical weathering of these rocks resulted in the formation of the two residual clay deposits. The clays were subjected to mineralogical determinations (using X-ray diffraction) and geochemical analysis (using the Inductively Coupled Plasma-Atomic Emission Spectrometry) in Activation Laboratories, Ontario Canada with a view to determining physicochemical features that relates to industrial suitability of the clay.
Mineralogical determination indicates that kaolinite is the dominant clay mineral, illite occur in traces while quartz occur as the non-clay impurities. Analytical result shows dominance of SiO_2, Al_2O_3 and K_2O in the clays. Average SiO_2 value of the Ire and Ishan clays are 52.50%, and 55.41% respectively. Similarly, mean Al_2O_3 values are 33.17% and 24.80% while K_2O values are 4.30% and 6.29% respectively. The chemical composition of the clays is comparable to other notable in situ clay occurrences within Nigeria.
Assessment of the industrial suitability of the clays based on physicochemical parameters and consistency limits indicate the clays are inorganic and are adequately mouldable with moderate plasticity. The thermal characteristics and water absorption capacities of the clays are within the range recommended for some industrial specifications. The deposits could serve as raw materials for brick making, structural wares, pottery and ceramics.

***Keywords**: lateritic, weathering, residual, kaolinite, Oye-Ekiti*

1. Introduction
Clay is a valuable industrial raw material for the manufacture of many domestic and commercial products. The role these weathered products could play in the socio-economic development of the communities in which they occur cannot be overemphasized. This is particularly true when several industries could depend on the high tonnage of the locally sourced raw material that is available. Such deposits are easily accessible due to their closeness to the surface (Okunlola, 2008). Residual clay deposits occur extensively in southwestern Nigeria. The prevalence of these deposits is due to the strategic location of the country within the tropics and a climate characterized by alternating dry and wet seasons and relatively high humidity that encouraged intensive weathering. Unfortunately, clay deposits are underutilized in Nigeria considering the quality and quantity that occur in the country. Underutilization of the clay deposits may be attributable to insufficient geological information on the properties of the various clay deposits on one hand, and shallow knowledge about their industrial suitability on the other. Hence, the present study aims at elucidating the physicochemical features and functional industrial applications of the residual clays.

2. Regional Geological Setting
The Nigerian basement complex lies east of the West African Craton in a mobile belt affected by the Pan-African thermotectonic events. The basement complex form prominent topographic features outcroping in the southwestern and the north central parts of the country (Fig. 1). It also occur in smaller areas in the eastern and sourheastern parts of the country notably around Jalingo and the Oban massif (Ekwueme, 2000). The study area is underlain by the basement complex of southwestern Nigeria. The basement rocks are broadly divided into three major lithological groups: the migmatite gneiss complex, the schist belts and the Pan-African Granite. The migmatite gneiss complex comprises polycyclic metamorphic rocks ususally gneisses and migmatites that are preserved in amphibolites facie metamorphic grade. Migmatite gneiss complex forms the oldest rock into which other rocks of the basement are emplaced. It is of Achaean-Proterozoic age, and display chemical variations indicating they are product of

heterogeneous progenitors (Elueze, 1981). The schist belts on the other hand comprise pelitic and psammitic assemblages, paraschists and meta-igneous rocks, calc-silicates, schistose and talc-bearing rocks that are preserved in low-grade metamorphism and occupy mainly N-S trending belts (Rahaman, 1988; Turner, 1983). Russ (1957), Oyawoye (1964) and McCurry (1976) interpreted the schist belts as relics now preserved in synclinal keels of a once widespread cover of sedimentary rocks deposited in a single basin. However, based on the different lithological associations within the basins, Black (1980), Elueze (1981) believed that the belts developed separately. Ajibade (1980) believes that the schist belts have all undergone the same deformational histories and so, are of the same age and origin. The Pan-African Granites intrudes the migmatite gneiss and the schist belts and bear the most pervasive tectonic fabrics symbolizing the 600Ma pan-African orogeny. The suite comprise rocks of wide spectrum of compositions ranging from granite to granodiorite, diorite, syenites, charnockite, pegmatite and dolerite dykes that belongs to the terminal stage of Pan-African magmatism (Truswell and Cope, 1963).

3. Lithological Association

The study area is located within geologic map sheet 61 of Akure. It is located between Latitude 7^{o}45'N to 7^{o}55'N and Longitude 5^{o}15'E to 5^{o}25'E. Oye-Ekiti is located 35km NNE of Ado-Ekiti, the Ekiti State capital. Oye-Ekiti and environs is underlain by gneisses, granite and charnockite (Fig. 2). The gneisses are essentially migmatite which grade into biotite gneiss in some areas, contact relationship indicates that it is the country rock into which the other rocks are emplaced. The gneissic rock occur as highly weathered, low-lying, denuded and poorly exposed bodies that covers about one half of the landmass of the area. It occupies the northern and southwestern parts of the study area. Structural features of the rock include poorly developed foliations that are so faint in some places and become indiscernible around west of Aiyede. The granite on the other hand is mainly porphyritic in texture and are rich in biotite. Sometimes hornblende becomes prominent associated mineral and the rock grade into biotite-hornblende-granite in some localities. Specimen samples reveal the coarse porphyritic granite as containing quartz, plagioclase feldspar, orthoclase feldspar, biotite and hornblende. Generally, the granitic bodies form an elongated north-south trending body that underly Ilupeju and Itapa areas (Fig. 2). Charnockite is more prominent in western part of the study area forming conspicous massive bodies, however, smaller inselbergs of the rock occur scattered along the southern and north central parts of the study area.

4. Materials and Methods

4.1. Sampling and Sample preparation

Fifteen (15) samples each weighing 5kg were collected from the clay deposit at Ire-Ekiti and Ishan using standard geological techniques. The clays were collected at 2m interval from the exposure of the deposits along a horizontal traverse in an east-west direction. As part of the methodological approach, the exposed surface of the clay was scraped to remove any dirt using a trowel. Point sampling method was adopted for the clay. All the clay samples were carefully labelled in sample bags for laboratory processing. Samples were air-dried in the laboratory for two weeks to facilitate the seiving process. The clays are marcerated and dissagregated with the hand and were later subjected to grain size analysis.

4.2. Granulometry and Physical Tests

For the grain size analysis, 2kg of the clay samples were loaded into a set of sieves arranged in order of decreasing apperture and stacked in an electric shaker. Grain size analysis was determined through dry seiving in accordance with the British Standards by comparing the percentage of particles retained in each seive to the original it received. Physical properties including Water Absorption Capacity (WAC), Unconfined Compressive Strength (UCS), Specific Gravity (SG), Consistency limits and pH were also determined. Water Absorption Capacity was determined on fired clay pellets produced using standard press after heating in a Gallenkamp Muffle Furnace Model S2 set at 600^{o}C for two hours. On cooling, the clay pellets were immersed in water for 24 hours. Unconfined Compressive Strength was determined by loading a dried clay lump to fracture in a triaxial machine. Specific Gravity (SG) was determined using the density bottle method. Consistency Limits: Liquid Limits (LL); Plastic Limits (PL) and Plasticity Index (PI) determinations were undertaken in accordance with British Standards specification using the Cassagrande (1948) apparatus. The pH was determined directly by dipping a digital multi-parameter Testr Tm 35 series pH meter in a soft clay paste after diluting with distilled water. The pH meter was calibrated before and during fieldwork using buffer solution as prescribed by the manufacturers. Thermal characteristics, specifically Fired Shrinkage Value (FSV) and Loss on Ignition (LOI) were determined. Linear shrinkage was determined as the percentage decrease in length when a moulded clay is fired. Loss on Ignition was determined as the weight difference between the dried and fired pellets. All physical tests were carried out at Trevi Foundations, Lagos.

4.3. Mineralogical Investigation using X-ray Diffraction

About 5g of the clay fraction passing through 40µm seive was subjected to X-ray diffraction analysis by heating to a temperature of 600^{o}C. It was subjected to cobalt k-alpha radiation 40kv, 20mA, chart sp = 1200mn/hc and count rate = $1x10^3$ cps using Phillips PW 1011 model diffractometer. Interpretation of X-ray diffraction curves is by comparing peaks of notable intensities with those of standard minerals established by Carrol (1971). Relative proportions of the identified minerals were calculated using the areal method.

4.4. Geochemical Analysis

Thirty representative clay samples were subjected to chemical analysis for the determination of major elements using the Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES) analytical method in Activation Laboratories, Ontario, Canada. The analytical procedure involves addition of 5ml perchloric acid ($HClO_3$), trioxonitrate (V) (HNO_3) acid and 15ml of hydrofluoric acid (HF) to 0.5g of sample. The solution was stirred properly and allowed to evaporate as it is heated at a low temperature for three hours. 4 ml of hydrochloric acid (HCl) was then added to the cooled solution and warmed to dissolve the salts. The solution is then introduced into the ICP torch as an aqueous aerosol. The light emitted by the ions in the ICP was converted to an electric signal by a photomultiplier in the spectrometer. The intensity of electrical signal produced by emitted light from the ions was compared to a standard and the element concentrations computed. The concentration of the major elements in weight percent SiO_2, Al_2O_3, MnO, MgO, CaO, Na_2O, K_2O, TiO_2, P_2O_5, Cr_2O_5, and total iron as Fe_2O_3 and Loss on ignition were determined with 0.001% detection limit.

5. Results and Discussion

- *Mineralogical composition:* X-Ray diffractograms (Fig. 3a, 3b) indicate that kaolinite and illite are the major clay minerals. Kaolinite however dominates the mineralogy and account for 60% and 52% in Ire-Ekiti and Ishan clays respectively. Non-clay impurity in the deposits is mainly quartz which accounts for 25% and 19% in Ire and Ishan clays respectively. A simple comparison of the mineralogical composition of the clays with other notable clay deposits (Table 1) indicates that the clay is similar to Ara-Ijero and Ikerre clay deposits in southwestern Nigeria. The kaolinite content of the two clay bodies is marginally lower than that of Ikerre clay (64%) Talabi et al., 2012, Itakpe clay (61.6%) (Okunlola, 2008) but higher than Ara-Ijero clay (48.27%) (Okunlola and Akinola, 2011). Illite content of Ire-Ekiti clay (4.0%) is marginally lower than that of Ara-Ijero clay (4.7%) and significantly lower than Ikerre clay (8.0%). The value however, is higher than that of Ibadan kaolinite (3.0%) (Emofurieta and Salami, 1986) and Itakpe clay (2.3%) (Okunlola, 2008). Quartz content in Ire-Ekiti clay (25.4%) is significantly lower than Ara-Ijero clay (47.1%) and marginally lower than that of Ikerre clay (28%). The mineralogical composition of any clay deposit affects its industrial applications. The mineralogy however falls within certain industrial specifications.
- *Granulometry:* Grain size distribution is important in assessing clay material for characteristics required for various industrial applications. The grain size composition of clay controls ceramic strength, shrinkage, paper filling, coatings, and its glossiness (Aref, 2002). Forbus et al, (1993), Veglio et al, (1993) and Ryan, (1979) specified that fine-grained minerals such as kaolin are very useful industrially, in making paper, pulp filler coating, also it is an essential pharmaceutical and ceramic raw material. The grain size of most kaolinitic clay, range from 1µm - 50µm (Heinskanen, 1996). Ire-Ekiti and Ishan clays fall in this category because the particle size distribution of the clays revealed a substantial percentage (≈52% and ≈46% respectively) of clay and silt size particles passed 75 µm sieve. Grain size analysis (Tables 2a and 2b) indicates that Ire- Ekiti clay contains 47.4 percentage clay, 36.8% silt, 11.5% sand and 0.4% gravel; while the Ishan clay contains 53.6% clay, 34.9% silt, 13.1% sand and 2.1% gravel suggesting that the clays are well graded (all particle sizes are represented).
- *Physical and Mechanical Features:* Industrial application of clay is largely dependent, not exclusively though on physical properties. Result of specific gravity determination of Ire-Ekiti and Ishan kaolinitic clay indicates an average value of 2.7 and 2.5 respectively (Table 3). The specific gravity values indicate that the clays are close to kaolin based on the classification of mineral (Gary, 2008). Consistency limits designate the relative ease a clay soil can be deformed and is used to describe the degree of firmness of the clay soil mass. Consistency limits include amongst others; the liquid limit, plastic limit and shrinkage limit. In this study, Table 3 shows that the average liquid limit value for Ire-Ekiti and Ishan clay is 52.3 and 45.6; plastic limit are 24.3 and 22.9; while average shrinkage limit is 1.8 and 3.0 respectively. Plasticity indices for Ire-Ekiti and Ishan clays are 28.0 and 22.7 respectively. Liquid limit and plasticity index are used to classify fine-grained soils. All liquid limit values in this study are less than 100%, classifying the clay as inorganic clay. Plasticity indeces indicate that the clay is sufficiently plastic meaning that the clays could easily be moulded and satisfy requirements for brick and pottery. The Ire-Ekiti clay and Ishan clay have unconfined compressive strength of 3.6 N/mm^2 and 3.48 N/mm^2 respectively. These values are lower than the average (5.6N/mm^2) reported by Nigerian Building and Road Research Institute (NBRRI) and Mesida (1978) on some clay deposits in Nigeria. However, the average compressive strength for the clays ccompares favourably with 3.0 N/mm^2 recommended for construction of bungalow and one storey building (Aribisala, 1989). This observation supports that the clays could be used as building construction material.
- *Geochemistry:* Analytical result (Table 4) shows dominance of SiO_2, Al_2O_3 and K_2O over other oxides and constitutes over 80% of the bulk composition of the two clay deposits. Average silica content in Ire-Ekiti (52.50%) and Ishan (55.41%) clays are higher than that of Ara-Ijero clay (48.50%) (Okunlola and Akinola, 2012); Ibadan Kaolinite (44.98%) (Emofurieta and Salami, 1986); Florida non-active kaolinite (45.47%) and China Clay (49.88%) (Huber, 1985). The Ire-Ekiti clay has average SiO_2 content similar to Itakpe Clay (Okunlola, 2008), and Ishan clay has an average value comparable to the Plastic Fire Clay of St Louis (Table 4). Mean Al_2O_3 content of Ishan clay (24.8%) is similar to the plastic fire clay of St Louis but lower than Itakpe clay (27.24%) (Okunlola, 2008), and Ara-Ijero clay (28.8%). Ire-Ekiti clay has alumina content comparable to clay specified for the rubber industry. Average K_2O content of the clays in this study are higher than similar deposit in some parts of Ekiti; this sharp difference may be attributable to abundant K-feldspar consequent on albitization processes, even though these values are within the range specified for ceramics industry (Singer and Sonja, 1971). Mean Fe_2O_3 content in Ire Ekiti clay is similar to that of Ibadan Kaolinite while that of Ishan clay compares well with plastic fire clay of St Louis. Average Na_2O, CaO and TiO_2 contents fall within the limits for varied industrial applications for clays and are similar to other residual clay bodies.

6. Conclusion

Geological appraisal reveals that the clay developed over the basement rocks as a result of in situ weathering. X-ray diffraction indicates dominance of kaolinite while Illite and quartz occur in traces. High K_2O content of clay in Oye-Ekiti area may indicate high level of albitization and chemical decomposition of potassium-rich minerals like augite and other ferromagnesian minerals in the source rocks. Adequate plasticity, and chemical features that falls within certain industrial specifications make the residual clays useful industrial raw material for the manufacture of bricks and ceramic wares.

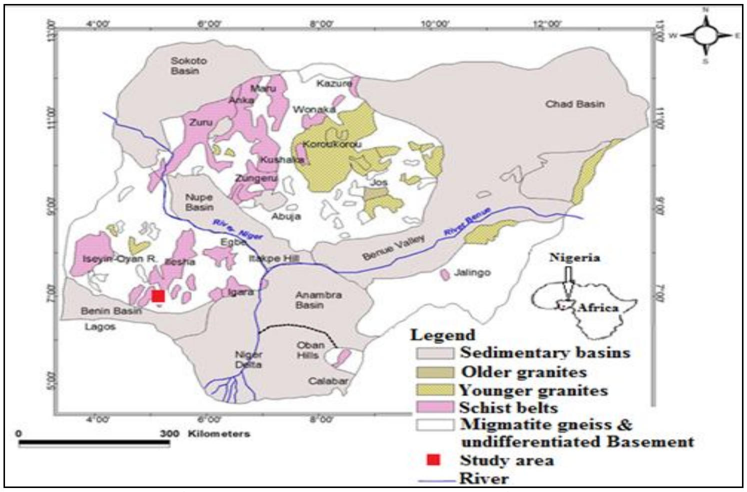

Figure 1: Map of Nigeria showing the location of Oye-Ekiti (study area)

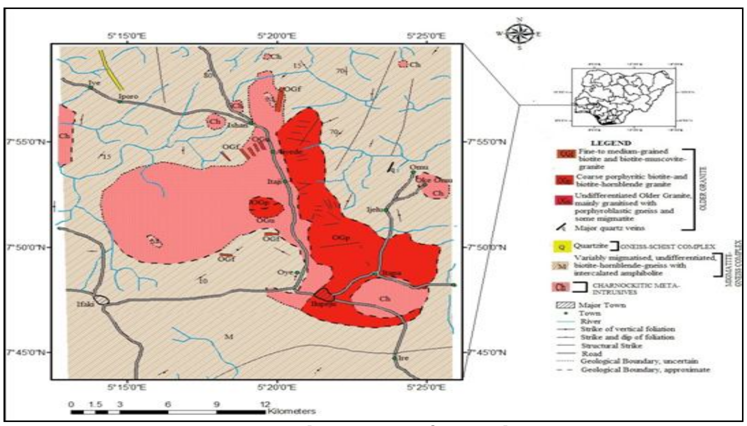

Figure 2: Geologic map of Oye-Ekiti area

Figure 3: Exposure of Ishan clay deposit under a reddish brown lateritic cover

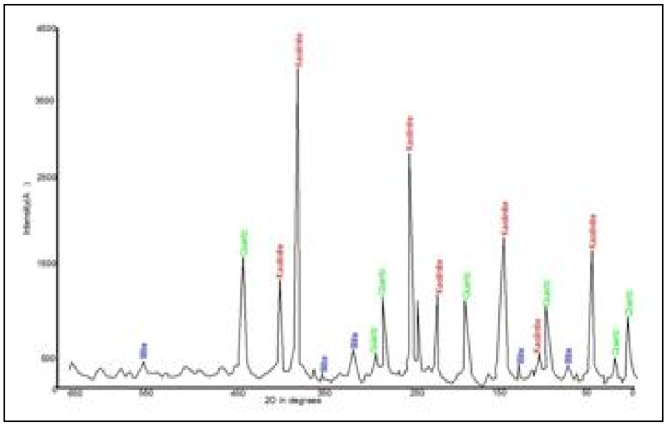

Figure 3a: X-ray diffraction trace of Ire-Ekiti clay

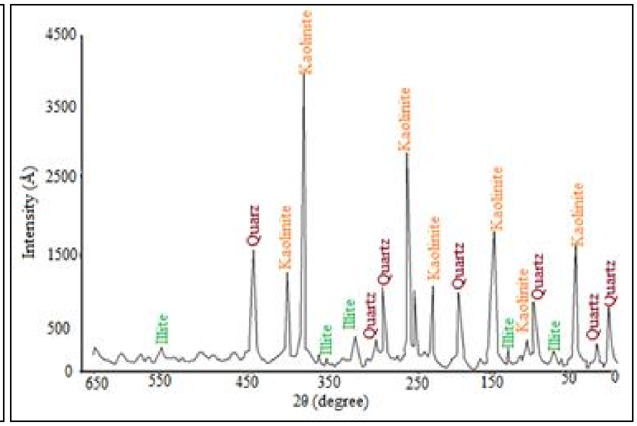

Figure 3b: X-ray diffraction trace of Ishan clay

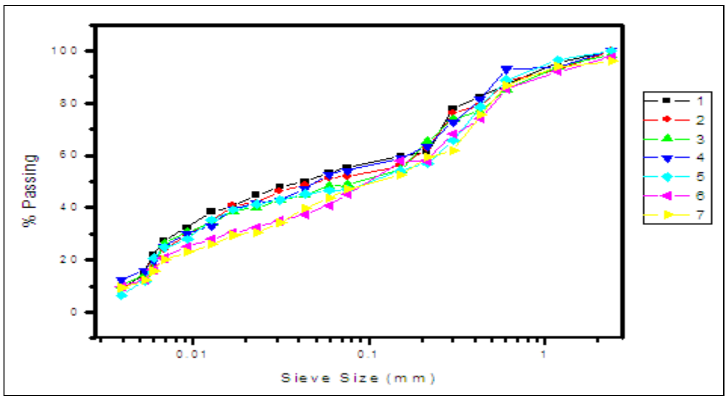

Figure 4: Grannulometric analysis of the Clay samples. (1-4 Ire clay, 5-7 Ishan clay)

Minerals %	Ire clay* (A)	Ishan clay* (B)	Ara Clay (C)	Itakpe clay (D)	Ikerre Kaolin (E)	Ibadan Kaolin (F)
Kaolinite	60	52	48.27	61.60	64	91
Quartz	25	19	47.05	32.30	28	6
K-Feldspar				4.10		
Illite	4	2	4.68	2.30	8	3
Smectite				0.50		

Table 1: Mineralogical composition of Ire-Ekiti and Ishan clays compared with others
C (Okunlola & Akinola, 2011), D (Okunlola, 2008), E (Talabi et. al., 2013), F (Emofurieta and Salami, 1986)

Sieve Size (mm)	Percentage Passing for each sample								
	1	2	3	4	Average	5	6	7	Average
2.36	100	100	98.5	100	99.6	100	97.6	96.0	97.9
1.18	95.5	92.6	94.1	93.7	94.0	96.4	92.0	94.0	94.1
0.600	87.2	88.4	85.3	93.1	88.5	88.8	85.2	86.7	86.9
0.425	82.3	79.0	77.0	81.4	79.9	78.6	73.8	75.4	75.9
0.300	78.0	76.1	73.8	72.8	75.2	65.6	68.0	61.8	65.1
0.212	61.2	62.7	65.4	63.5	63.2	56.8	58.0	59.2	58.0
0.150	59.7	55.9	54.4	59.0	57.3	54.1	57.6	52.5	54.7
0.075	55.3	52.0	48.9	54.2	52.6	46.9	45.2	47.1	46.4

Table 2a: Particle size distribution of Ire-Ekiti and Ishan clay samples (Dry sieving)
Samples 1, 2, 3 and 4 (Ire-Ekiti clay); 5, 6 and 7 (Ishan clay)

Sieve Size (mm)	Percentage passing for each sample								
	1	2	3	4	Average	5	6	7	Average
0.0588	53.4	51.2	48.3	52.6	**51.8**	46.5	40.8	43.5	**43.6**
0.0429	50.1	48.5	44.8	47.3	**47.7**	45.3	37.5	39.8	**40.9**
0.0310	48.1	46.4	42.9	42.9	**45.1**	43.0	35.0	34.1	**37.4**
0.0227	44.9	41.8	40.1	41.9	**42.2**	41.3	32.4	30.4	**34.7**
0.0168	40.3	40.7	38.6	39.4	**39.8**	39.2	30.5	29.6	**33.1**
0.0127	38.6	35.0	34.2	33.1	**35.2**	35.4	27.7	25.7	**29.6**
0.0092	32.4	29.6	30.5	30.2	**30.7**	28.0	25.1	22.9	**25.3**
0.0068	27.5	23.9	26.3	25.3	**25.8**	24.8	20.8	20.1	**21.9**
0.0059	21.8	18.1	16.7	20.0	**19.2**	20.7	16.4	15.9	**17.7**
0.0053	15.2	12.7	14.5	15.8	**14.6**	11.8	12.3	12.0	**12.0**
0.0039	8.9	9.4	10.0	12.5	**10.2**	6.5	9.9	9.5	**8.6**

Table 2b: Hydrometer test (Wet seiving) result on Ire-Ekiti and Ishan clay samples
Samples 1, 2, 3 and 4 (Ire-Ekiti clay); 5, 6 and 7 (Ishan clay)

Physical Tests	Ire clay*	Ishan clay*	Ara clay (w)	Itakpe clay (X)	Ikerre Kaolinitic Clay (Y)	Ilukuno clay (Z)
FSV (%)	1.8	3.0	9.08	0.95	3.23	
WAC (%)	12.8	12.0	6.14	13.58		
SG	2.7	2.5	2.78	-	2.61	2.56
UCS (N/mm^2)	3.60	3.48	3.87	-		
LL	52.3	45.60	47.80	26.88	33.0	56.11
PL	24.3	22.90	26.42	15.51	17.5	
PI	28.0	22.7	21.48	10.38	14.5	
pH	6.8	6.7	5.8			

Table 3: Results of physical tests on the clays compared to similar deposits
*FSV= (Fired shrinkage value), WAC= (Water absorption capacity); SG= (Specific gravity); UCS= (Unconfined compressive strength); LL= (Liquid limit), PL= (Plastic limit), PI= (Plasticity index), pH= (Acidity/ alkalinity). (*Average of 10 samples), W= (Okunlola and Akinola, 2011), X= (Okunlola, 2008), Y= (Talabi, et. al,.2013), Z= (OlaOlorun and Akinola, 2011)*

Oxide	Ire*	Ishan *	References						References (#)				
			A	B	C	D	E	F	G	H	I	J	K
SiO_2	52.50	55.41	48.50	44.98	45.47	49.88	57.67	52.65	49.88	44.90	45.00	67.50	46.07
Al_2O_3	25.17	24.80	28.82	37.54	38.45	37.65	24.07	27.24	37.65	32.35	38.10	26.50	38.07
Fe_2O_3	2.50	3.20	9.84	2.35	0.75	0.88	3.23	3.01	0.88	0.43	0.60	0.50	0.33
MnO	0.56	0.03	0.03	0.01	-	-	-		-		-	1.20	
MgO	0.38	0.83	0.96	1.72	0.05	0.13	0.30	0.38	0.13		-	0.19	0.01
CaO	0.62	0.39	0.58	0.09	-	0.03	0.70	0.19	0.03		-	0.30	0.38
Na_2O	0.19	0.11	0.23	0.19	-	0.21	0.20	0.37	0.21	0.14	-	1.50	0.27
K_2O	4.30	3.29	2.49	1.01	0.06	0.60	0.50	1.44	1.60	0.28	-	3.10	0.43
TiO_2	0.51	0.2	1.02	1.42	0.10	0.09	-		0.09	1.80	1.70	-	0.50
P_2O_5	-	-	0.12	-	-	-	-		-	-	-	-	-
Cr_2O_3	-	-	0.02	-	-	-	-		-	-	-	-	-
LOI	13.05	11.34	14.16	12.60	-	12.45	10.50	13.80	12.45	14.20	14.70	12.51	13.47
Total	99.80	99.6	98.84	99.91	84.98	99.92	97.10	99.52	99.92				99.93

Table 4: Chemical composition of the clays compared with other clay and industrial specification
**This study (Average of ten samples) A= Ara clay (Okunlola and Akinola, 2011), B= Ibadan Kaolinite, (Emofurieta and Salami, 1986); C= Florida non active kaolinite, (Huber, 1985); D= China clay, (Huber, 1985); E= Plastic fire clay, St Louis, (Huber, 1985), F= Itakpe clay, (Okunlola,2008); G= Agricultural, (Huber, 1985); H= Rubber, (Keller, 1964); I= Textile, (Keller 1964); J= Ceramics, (Singer and Sonja, 1971); K= Fertilizer, (NAFCON, 1985); (#) Adapted from Emofurieta et al,. 1992.*

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