



Full Length Research Paper

Investigation of mechanical/physico-chemical properties of kaolinite ore (clay) from Umuariaga-Umudike, Abia State of Nigeria

***Chukwu GU and Ajuamiwe CF**

Department of Physics, Michael Okpara University of Agriculture, Umudike, P.M.B. 7267, Umuahia, Abia State, Nigeria

Abstract

The study on some ceramic clays from Umudike, Ikwuano local government area of Abia state of Nigeria entailed collecting samples from outcrops around Umuariaga community. Physical and chemical parameters of four samples were investigated which constitute their mechanical strength and property. There has been some mixtures of other observable particles like mud, kaolin (white or grey, floury material), red particles and in general it showed relatively low potassium oxide (K_2O), nitrogen dioxide (NO_2), calcium oxide (CaO), among other compounds. Most of the samples were rich in aluminum oxide (Al_2O_3) and silica (SiO_2). The relatively light colors after firing were due to the presence of low iron (II) oxide (Fe_2O_3) contents. The clay in part of Ikwuano constitutes intercalation layers within the coastal plain sands of the eastern Niger delta which is porous, permeable and constitutes a fresh water bearing zone. Due to the high alumina and silica contents with low amount of flux materials, these clays are presently being used in the ceramic industry to produce household wares like plates, cups, electrical sockets (insulators), toilet seats, bath tubs, flower vases and for casting.

Keywords: Plasticity, physico-chemical properties, shrinkage, kaolinite clay, minerals, quartz.

INTRODUCTION

Clay is a natural substance occurring in great abundance in nature. It is constantly being formed on the earth's surface as a result of the weathering of a very common form of rock called feldspar. The great bulk of material found on the earth's surface are less dense substances that are relatively light in weight and thus 'float' to the earth's surface and in sedimentary rocks but make up very small portion of the crust. The heavier materials such as metals occupy the earth's core. Of the materials found on the surface of the earth, silica is the most abundant (it constitutes about 60% of all material on the earth's surface). The second most abundant is alumina (15%). These materials are chemically referred to as compounds; as they are made up of two or more elements that are chemically bonded together. In nature, very few materials exist as pure elements; most have formed chemical bonds with other elements mainly oxygen. For instance, silicon and aluminium combine with oxygen to become silica and alumina, respectively.

Feldspar, from which clay is formed, is the mineral name for a family of compounds which results from chemical bond between silica, alumina, and one of three different metals (potassium, sodium or lithium). This rocky substance occurs in great abundance and its exposure to air and water causes it to change very slowly over long periods of time into clay. This weathering process results in water, replacing the metal in feldspar into a new substance referred to as clay. The weathering process of clay formation results into a number of variations in clay types that are important to man. These clay types are as a result of variations in their particle size of a particular deposit and/or quantity of impurities (usually metals or silicon) that have been mixed up with the clay during weathering. These are kaolinite, illite, dickite, stoneware, fire clay, ball clay, earthenware, etc.

Clays are generally classified as either primary or secondary minerals according to geologic history. A primary clay also known as kaolin is always found or located at the site of formation as feldspar from which they were formed. While the secondary clays are transported by weathering action of wind and water from their original site of formation. The weathering process

*Corresponding Author Email: chukwug@yahoo.com

tends to mix in other minerals (notably iron). If clay is heated to a sufficiently high temperature as in a pottery kiln, it is chemically transformed into a new substance. The principal difference between this new substance and the original clay is that the water portion of the clay molecules have been driven off leaving a compound of silica and alumina. This new substance is monolithic; the individual particles are fused and will no longer dissociate into a plastic mud when wet. Clay minerals are very relevant to man. Its significance is high due to its economic importance. Some clay minerals are edible, some are used in medicine (to manufacture pharmaceutical products), also used to make earthenwares etc. Generally, clays are muddy sediments composed of minute clay minerals of the order of 0.002 mm diameter or less, which were deposited very slowly in still water on the continental shelf or in lakes/estuaries. The general formula for the clays is $K_xAl_4(Si_{8-x}Al_x)O_{20}(OH)_4$ where the value of x varies between 1.0 and 1.5 (Blyth and de Freitas, 1984). The OH-content may exceed 4 out of a total of 24 for O+OH.

Sedimentary clays are mostly mixtures of illite and kaolinite. The aim of this work is to carry out experimental measurements on the sampled material and study its mechanical and physico-chemical properties. By doing this, the main ceramic properties would serve as guidance for more detailed surveys of other clay deposits that may be discovered by potential ceramists. The main parameters to be investigated are physical properties, green strength, firing strength, modulus of plasticity (or modulus of rupture) and shrinkage (Rajamannan et al., 2012 and Baulz et al., 2003).

Location and geology of the study area

Umuariaga community lies within Umudike and directly opposite Michael Okpara University of Agriculture, Umudike. It is located nine kilometers south-east of Umuahia-Ibeku. The site is situated on latitude $5^{\circ}23'9''$ - $5^{\circ}23'30''$ N, longitude $7^{\circ}9'10''$ - $7^{\circ}09'30''$ E approximately, and it is about 122 m above mean sea level in elevation. The location is separated from the university campus by a trunk B road from Umuahia-Ibeku township to Ikot-Ekpene where it joins a trunk A road from Aba to Ikot-Ekpene (Figure 1). The geology of Abia state as a whole (in which Ikwuano is a local government area) is in a sedimentary terrain. Some parts of Ikwuano are also underlain by the Benin Formation (Iloeje, 1992). This Benin Formation is the coastal plain sands of Pleistocene age (Thomas, 2009). It is composed of fine-coarse grained sands and sandstone which is seldomly punctuated by thin layers of dense shale clays with about 80% of quartz content and a little feldspar content (Akpokodje and Etu-Efeotor, 2007; Etu Efeotor, 1981).

The Benin Formation is of the Tertiary Niger Delta which occupies approximately 6400 km² of the

sedimentary basin of southern Nigeria. Allen (1996), Short and Stauble (1967), Weber (1971), Adeleye (1976) and Enyadike (2004) discussed extensively the geology and stratigraphy of the Niger delta, particularly those of the coastal plain sands, stating that the lithology of the alluvial deposits consist of clay-silt, fine sand, coarse sand and gravels.

The climate of Umudike is of the humid tropics, with fairly even temperatures throughout the two seasons (dry and rainy) of the year. The rainy season which usually starts from April/May and ends in October/November is characterized by clouds driven by light winds, relatively constant temperatures, frequent rains and high humidity. From early November, when the dry season starts, the weather clears rapidly as the northeast trade wind shifts to become the dusty 'Harmattan' bringing in the drier air from the Sahara desert. The season, notably dry with little or no rainfall, hotter days, cooler nights, and lower humidity, ends in March/April.

The soils were derived from semi-consolidated sand and sandy-clay deposits with occasional intercalations of shale and sandstone fragments at varying depths. Soil type distribution (Figure 2) tends to grade into a toposequence following the occurrence of a natural ridge running across the community in a west-easterly direction with the land sloping towards the southern boundaries. Towards the western half, the ridge is dissected by the youthful stage of the Qua-Iboe stream into whose narrow basin the ridge tends to phase out. Within this landscape the following soil series have briefly been identified and recognized:

Umudike series (Figure 3) - this consists of well-drained red to yellowish sandy loam to sandy clays occurring at the summits and upper slopes of the ridges. The vegetation is thick mangrove in very swampy environment. The ground level however slopes gently towards the Cross River flood plains dissected mainly by the Qua-Iboe river systems.

Umuariaga series (Figure 2) - this occupies the broad terraces adjoining the ridges characterized by gentle to moderate slopes. They are well-drained soil having greyish-brown humid sandy clay loam top soil grading to yellowish brown sandy clays.

Other series (Figure 2) - are the Olokoro series (D on the soil map), Amaoba series (E on the soil map) and the Qua-Iboe series (F on the soil map) (NRCRI, 1979).

Groups and types of clay

Clays are generally classified as either primary or secondary according to geologic history (Enyadike, 2004). Primary clay also known as kaolin ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$) is always found or located at the site of formation as feldspar from which they were formed, they are relatively uncontaminated by other minerals and remain unsorted by particle size. Kaolin is relatively rare

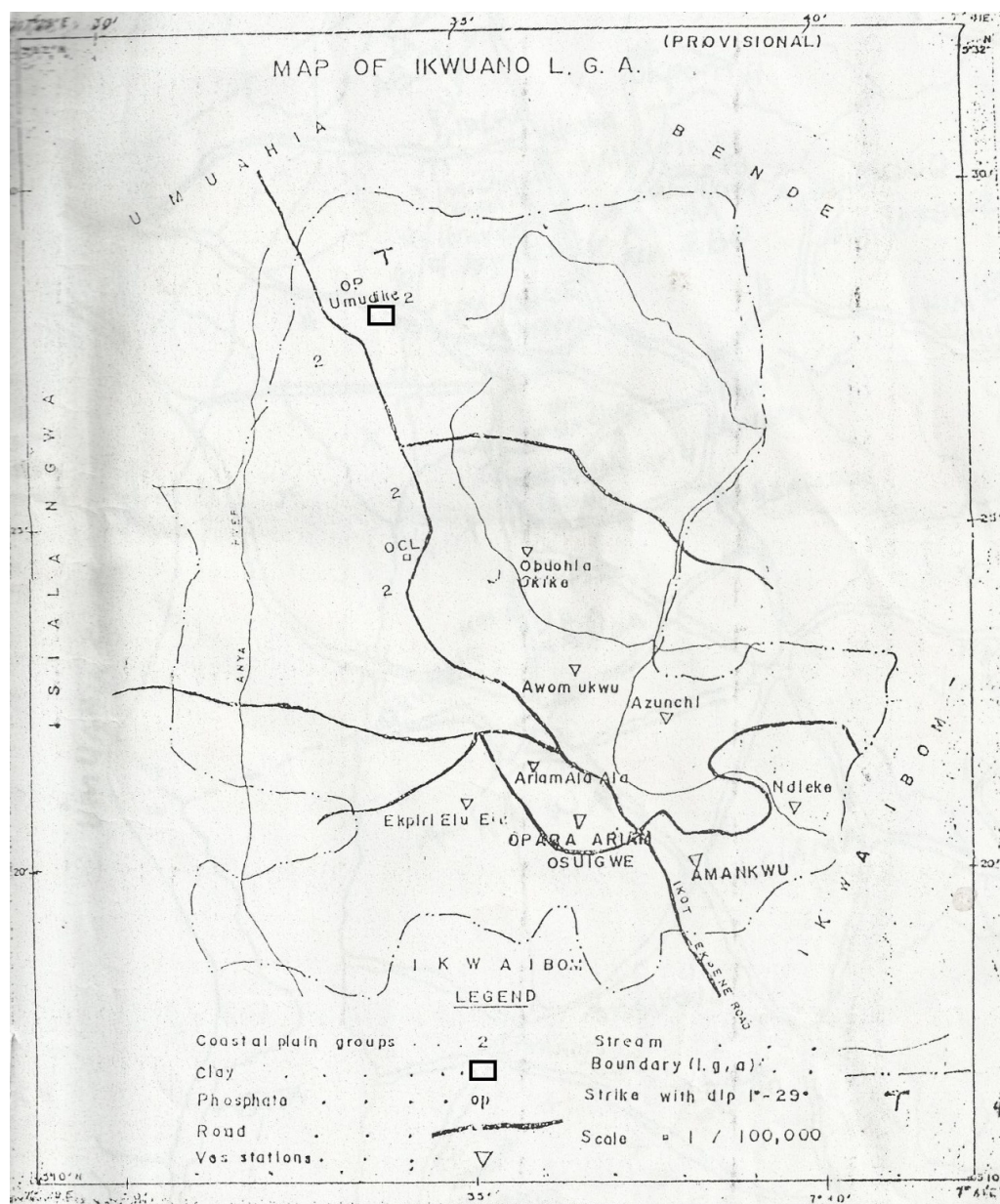


Figure 1. Map of Ikwuano LGA showing the study area Umudike

in nature and difficult to work with because of its low plasticity.

The vast majority of clays are called secondary because they have been transported by weathering action of wind and water (Davis and de Wiest, 1966) from their original site of formation. This is referred to as secondary sedimentary process after they have been eroded, and these clay deposits are typically associated with very low energy depositional environment such as swamps and lakes. This process involves the loss of certain mineral particles like alumina (Al_2O_3) and silica (SiO_2) concentration is diminished. Other materials like mud (wet loam and silt) are absorbed in this process by

the deposited clay (Griffiths and King, 1965; Alabo and Odigi, 1998; Blyth and de Freitas, 1984; Benson and Trast, 1995).

Bone china - this type of clay consists of up to 50% animal bone, ground and mixed with other clay types. These types of clay have very little or no plasticity.

China clay - this is kaolin. It consists of mainly of aluminium silicate ($\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$). The basic difference in all these clay types lies in the difference of firing temperatures (Hajjaji et al., 2002). It is not very plastic but ball clay can be added to it to make it more plastic.

Ball clay - this is mainly secondary clay, its composition

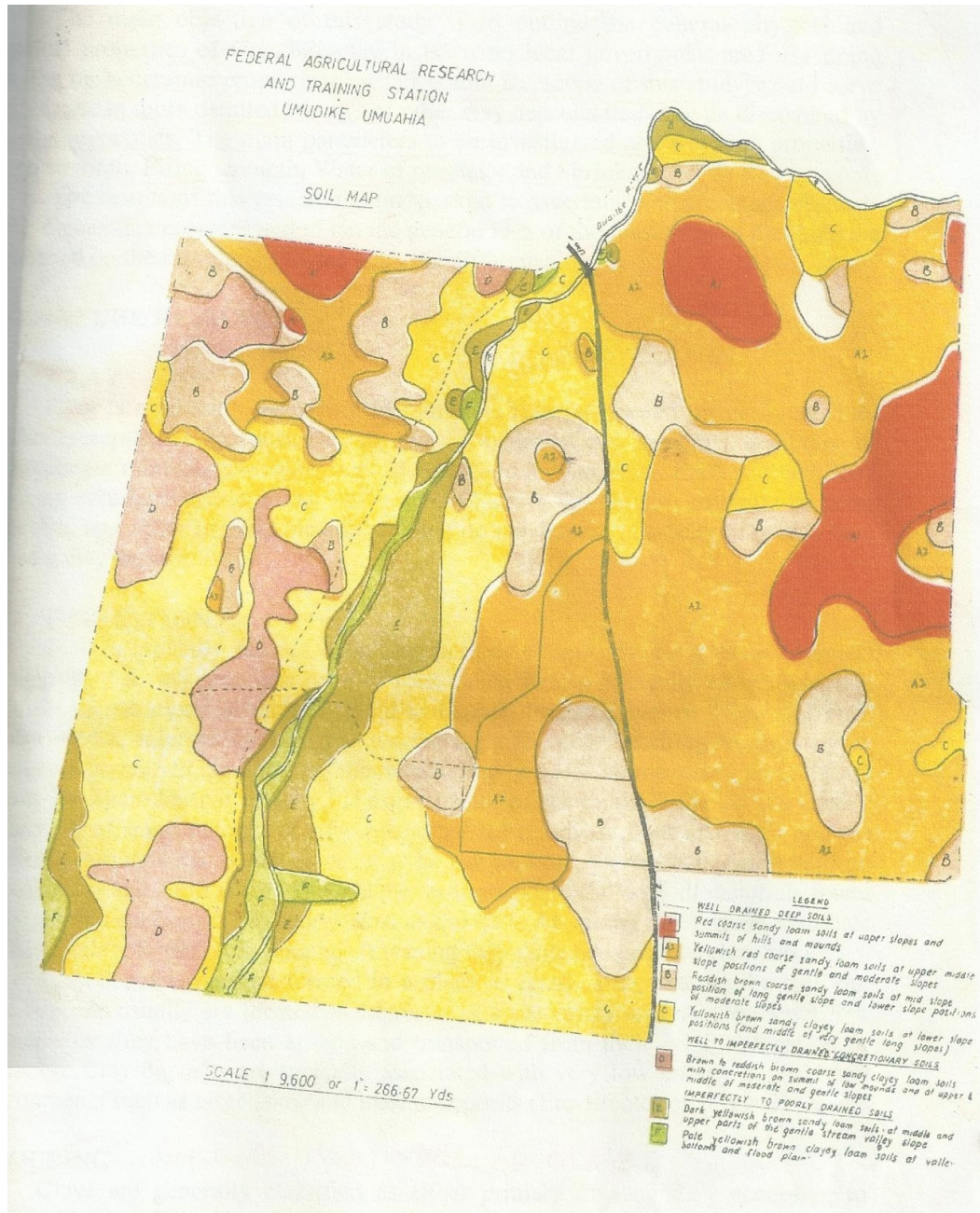


Figure 2. Soil map of Umudike (Source: NRCRI,1979)

varies but it is said to be more plastic especially the darker ones which have higher organic content. They are normally added to pottery materials to increase their strength in the plastic state.

Fire clays are more refractory and are difficult to use. They have little shrinkage on firing and drying. They confer volume stability on refractory goods and can be mixed together with other plastic clays.

Porcelain is known as the tri-axial mixture of quartz, kaolin and feldspar. It is a high temperature product. It does not fuse below temperatures less than 1400°C.

Earthenware - this is a product range which occurs at temperature just below 1050°C. It is quite porous and hence keeps water very cool. Thus, it is mainly used in the production of local ceramic cooling pots for water.

Stone ware/Terracotta - this brand of clay product contains grained unsorted quartz, and other ore materials, which make it to be more porous than other clay types. It is used in the manufacture of fancy clay designs, for instance; it is mixed with marble in the production of fancy tiles, which are used to design banking halls and other business premises.

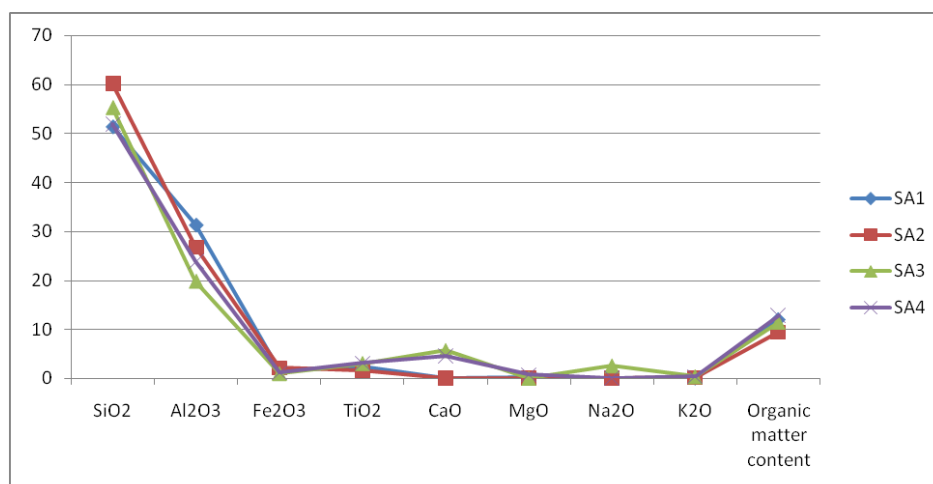


Figure 3. Graph showing relative chemical contents of the samples

MATERIALS AND METHODS

Instruments and materials

This study entails the use of certain instruments and materials which include plastometer, an instrument used to test for plasticity of samples; thermal expansion instrument used to measure expansion per unit length when a clay sample is subjected to a temperature of 1000°C, modulus of rupture (MOR) machine which determines the strength of a sample whether transverse or tensile. It shows the point at which a force applied would cause the sample to rupture. It throws light at the intrinsic binding properties. This test is affected by the grain size, crystallinity and shape. Global Positioning System (GPS) instrument was used to determine the coordinates and elevations at the sample sites. Other instruments used are dryer, weighing machine (scale), kiln, flash shakers, crusher, bunsen burner and hand-held drilling machine. Each implement was used at the appropriate time in the course of the study (Ajuamiwe, 2012). For the purpose of obtaining fresh samples, the researchers dug depths of 0.5 m or more to collect clay samples from fresh outcrops and filled about $\frac{2}{3}$ portion of a normal polythene bag with the fresh samples. Physical appearance and condition of the samples from vivid observation shows a grey color of wet material with patches of white particles suspected to be kaolin. These samples were subjected to various tests and analyses in the laboratory. The tests were carried out to determine among other things, the drying and firing properties, moisture contents, water of plasticity and organic matter contents, some non-clay minerals were identified. The drying sensitivity and the strength of the materials under different conditions were keenly observed and also determined. The moisture absorption and density tests were as well performed. All weighed measurements were in grams.

For organic matter content

The organic matter content was determined by the roasting method. It involved the weighing of a certain amount of clay in a weighed crucible. It was roasted to temperatures between 1050°C and 1200°C. Organic matter is assumed to be destroyed at these temperatures. The crucibles with contents were now reweighed. Thus:

Weight of crucible = W_1

Weight of crucible + clay sample = W_2

Weight of crucible + clay sample after heating = W_3

→ Weight of clay sample = $W_2 - W_1$

→ Weight of clay sample after heating = $W_3 - W_1$

Loss in weight of sample = $W_3 - W_1 - (W_2 - W_1)$
 $= W_3 - W_2$

Percentage organic matter content = Loss in weight of sample / (Weight of crucible + fresh sample)

$= (W_3 - W_2) / W_2 \times 100 \%$

For moisture content

Certain amount of clay in a beaker was weighed. It was then left over at a temperature of 110°C for four (4) hours. After drying, the sample was left to cool. Later the beaker and sample were reweighed. The difference in weight gave the weight of water contained in the sample. Thus:

Weight of wet clay sample = W_1

Weight of wet clay sample after heating = W_2

Weight of water in sample = $W_1 - W_2$

Percentage moisture content = Weight of water in sample / Weight of wet clay sample

$$= (W_1 - W_2)/W_2 \times 100 \%$$

For water of plasticity

This investigation was undertaken to determine the amount of water which is required to make clay plastic and workable. The more water clay requires, the finer its grain structure is apt to be, and therefore the more it is likely to shrink on drying.

A dried amount was passed through a 30-mesh screen. About 500 grams of the screen clay was then weighed on the glass slab. A certain amount of water was then added, a little at a time. The clay was then kneaded and water was added again until a smooth mass of about the right consistency for modeling was formed. The amount of water added to the clay was noted and the percentage water of plasticity (water of absorption) calculated thus:

Weight of screened clay sample = W_1

Weight of plastic sample = W_2

Weight of water in sample = $W_2 - W_1$

Percentage water of plasticity = Weight of water in sample/Weight of screened sample

$$= (W_2 - W_1)/W_1 \times 100 \%$$

For drying and firing shrinkages (mechanical properties)

This test was performed to determine the drying shrinkage, color changes during firing and the firing shrinkage. The amount of shrinkage is a very important characteristic of clay. In this test the linear shrinkage was determined thus:

Two bars of clay of about 14 cm long and 4 cm wide and about 1 cm thick were made from a well kneaded mass of clay average modelled consistently. A sharp scratch exactly 10 cm long was made on each face. The tiles were then allowed to dry in an oven at 110°C. The tiles were turned frequently to avoid warping. Then a pair of vernier callipers and a metre rule were used to obtain the new length, breadth and thickness consequently, thus:

Plastic volume (V_1) = $L_1 \cdot B_1 \cdot W_1$

where L_1 , B_1 , W_1 are length, breadth and thickness of sample respectively.

Also, shrink volume (V_2) = $L_2 \cdot B_2 \cdot W_2$

where L_2 , B_2 , W_2 are length, breadth and thickness of shrink sample respectively.

Note: Volume = multiplication of length, breadth, and width of all the six sides of the tiles measured with the vernier callipers and metre rule.

Percent drying shrinkage= Shrink volume/Plastic volume

$$= (L_2 \times B_2 \times W_2) / (L_1 \times B_1 \times W_1) \times 100 \%$$

or

$$= V_2/V_1 \times 100 \%$$

For test for firing shrinkage

The dried bars made from the previous tests were heated at temperature range of 1050°C to 1200°C for about three hours. After cooling, the length of the scratch on the fired bar was then measured, with the vernier callipers, the meter rule, the various lengths are noted;

Dry length = L_1

Fired length = L_2

Percentage linear shrinkage = (Dry length – Fired length) / Dry length

$$= (L_1 - L_2)/L_1 \times 100 \%$$

The color change after firing over the temperature ranges were noted for each sample of clay.

Green Strength

The green strength (another mechanical property of materials) was tested by air-drying a sample for forty-eight (48) hours and its “dry leather state” as the intrinsic binding properties were probed by using the rupture machine where a certain load was added to see any deformation either of tranverse or tensile in nature. It was observed that the test is affected by the crystallinity and shape of the sample, thus a well suited shape was carved out and dried completely and then subjected to pressure on the rupture machine.

All the parameters, both physical and chemical are stated in Tables 1, 2, 3, 4, 5, 6 and Figures 3, 4, 5, 6, 7 respectively. There are certain standards which the clay samples have to conform to in the ceramic industry. These are discussed in the subsequent section.

RESULTS AND DISCUSSION

The ceramic investigation performed on the SA_1 , SA_2 , SA_3 , and SA_4 samples are shown on Tables 1 to 6. All the fourteen (14) tests were performed on the samples and these tests like the fired shrinkage, apparent porosity and transverse strength were done over a range of temperature 1050°C to 1200°C and assumed that all impurities like particles of leaf, wood or roots are decomposed thermally at those points of temperature

Table 1. Data from some mechanical and physical investigations

Parameter measured	Sample 1 (SA ₁)	Sample 2 (SA ₂)	Sample 3 (SA ₃)	Sample 4 (SA ₄)
Moisture as received (%)	6.10	6.15	6.12	6.12
Making moisture (%)	25.70	27.96	27.12	27.92
Slakable plasticity (%)	99.70	100	100	100
Plasticity ratio	5.2:1.0	5.0:1.0	1:1.18	1:1.25
Modulus of plasticity	3.10	3.10	3.10	3.15
Wet-dry shrinkage (%)	6.80	7.60	7.66	6.60
Green strength (Nm ⁻²)	15.90	11.90	18.50	19.51
Firing colour	Dark pink	Light yellow	Dark pink	Pink

Table 2. Mechanical/physical parameters at temperature (T) for sample 1

Parameters measured	T=1050 ⁰ C	T= 1100 ⁰ C	T=1150 ⁰ C	T=1200 ⁰ C
Apparent porosity (%)	38.83	37.70	27.30	20.30
Fired shrinkage (%)	2.80	3.00	7.51	10.52
Apparent density (kgm ⁻³)	2.17	2.70	2.69	2.66
Bulk density (kgm ⁻³)	1.75	1.80	2.04	2.06
Tranverse strength (Nm ⁻²)	32.90	35.33	73.03	72.10
Water absorption (%)	22.30	22.00	13.90	9.80

Table 3. Mechanical/physical parameters at temperature (T) for sample 2

Parameter measured	T=1050 ⁰ C	T =1100 ⁰ C	T=1150 ⁰ C	T=1200 ⁰ C
Apparent porosity (%)	39.50	38.50	33.20	25.20
Fired shrinkage (%)	3.25	3.46	6.06	9.09
Apparent density (kgm ⁻³)	2.70	2.65	2.63	2.63
Bulk density (kgm ⁻³)	1.71	1.80	1.95	2.10
Tranverse strength (Nm ⁻²)	44.90	122.90	127.10	197.96
Water absorption (%)	23.50	21.70	16.30	11.20

Table 4. Mechanical/physical parameters at temperature (T) for sample 3

Parameter measured	T=1050 ⁰ c	T = 1100 ⁰ c	T=1150 ⁰ c	T=1200 ⁰ c
Apparent porosity (%)	36.79	31.83	25.33	23.66
Fired shrinkage (%)	9.13	11.75	13.53	13.90
Apparent density (kgm ⁻³)	2.70	2.69	2.67	2.67
Bulk Density (kgm ⁻³)	1.71	1.85	2.00	2.04
Tranverse strength (Nm ⁻²)	140.87	255.58	258.58	267.51
Water absorption (%)	26.56	17.33	12.70	11.59

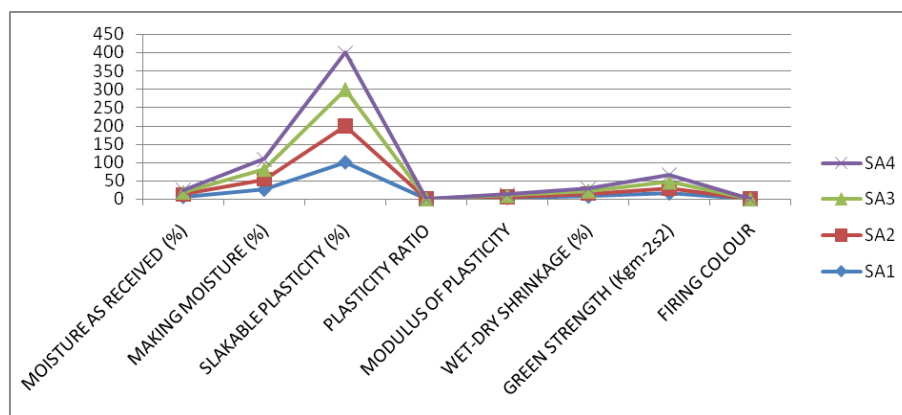
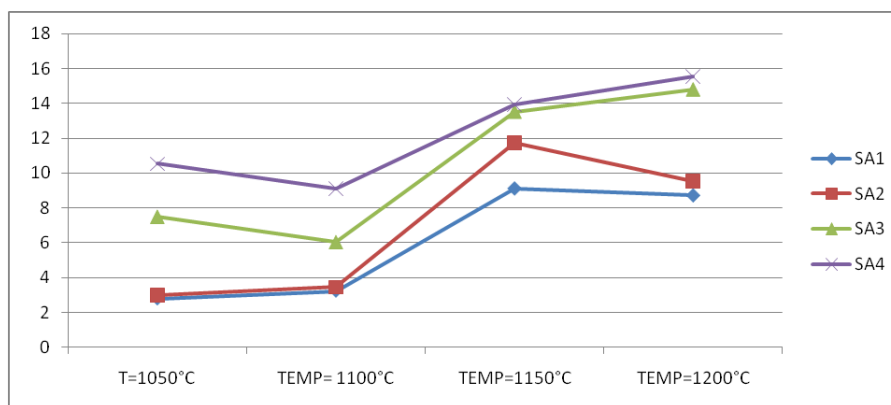
Table 5. Mechanical/physical parameters at temperature (T) for sample 4

Parameter measured	T=1050 ⁰ C	T=1100 ⁰ C	T=1150 ⁰ C	T=1200 ⁰ C
Apparent porosity (%)	39.27	32.36	25.37	22.10
Fired shrinkage (%)	8.73	9.53	14.80	15.53
Apparent density (kgm ⁻³)	2.73	2.17	2.69	2.09
Bulk density (kgm ⁻³)	1.66	1.76	2.01	2.10
Tranverse strength (Nm ⁻²)	95.21	105.04	285.19	243.30
Water of absorption (%)	23.71	19.97	12.63	10.54

Table 6. Data from chemical investigations

Sample	Organic matter content	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	CaO	MgO	Na ₂ O	K ₂ O
SA ₁	12.04	51.43	31.34	1.63	2.43	0.06	0.14	0.04	0.10
SA ₂	9.41	60.15	26.78	2.16	1.70	0.12	0.11	0.03	0.17
SA ₃	11.56	55.28	19.91	1.09	3.15	5.78	0.11	2.64	0.44
SA ₄	12.98	51.91	23.90	1.25	3.20	4.69	0.84	0.11	0.45

NB: All values in table 6 are in the unit of percentage (%)

**Figure 4.** Graph showing relative mechanical/physical parameters of the samples**Figure 5.** Graph showing percentage fired shrinkage of the samples

range. The increments, loss or reaction to certain factors were recorded and expressed as either percentages or in kilogram units per centimeter cubed.

The physical test results from SA₁ to SA₄ clay samples are shown in Table 1. Here, nine (9) laboratory tests were run on each sample and the colors when fired over the range of temperatures chosen were noted and recorded. Tables 2 - 5 show the physical test results of all SA₁, SA₂, SA₃ and SA₄ over a selected temperature range of 1050⁰C, 1100⁰C to 1150⁰C and 1200⁰C respectively. Each test was performed at each range of temperature and values noted. Table 6 shows the chemical tests for

all the samples. The percentage contents of the chemical constituents in the clay sample is thus expressed; they range from SiO₂ (silicon (IV) oxide/silica), Al₂O₃ (aluminium (III) oxide/alumina), Fe₂O₃ (Iron (III) oxide), TiO₂ (tin oxide), CaO (calcium oxide or quicklime), MgO (magnesium oxide), Na₂O (sodium oxide) and K₂O (potassium oxide).

Results from the organic matter are also shown for each sample. Figures 3 and 4 show the relative chemical parameters and relative physical contents of all the samples investigated, while figures 5, 6 and 7 show percentage fired shrinkage, percentage density and

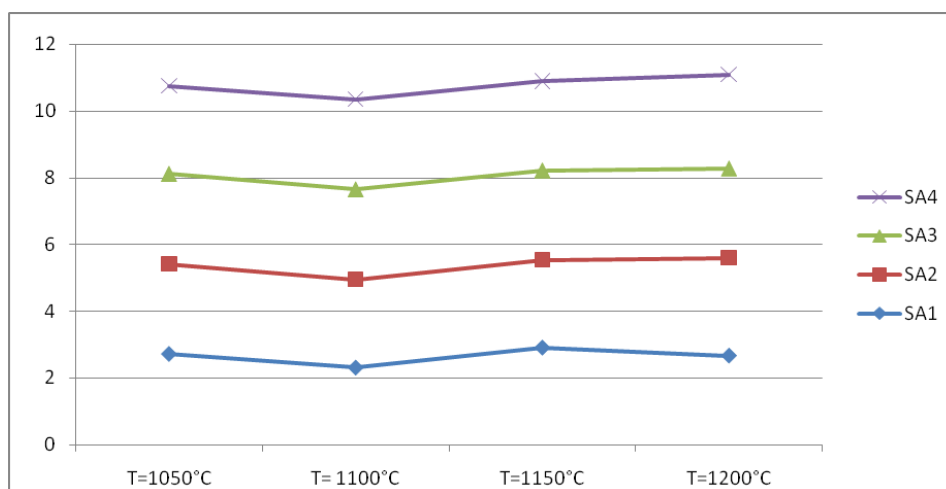


Figure 6. Graph showing percentage density of the samples

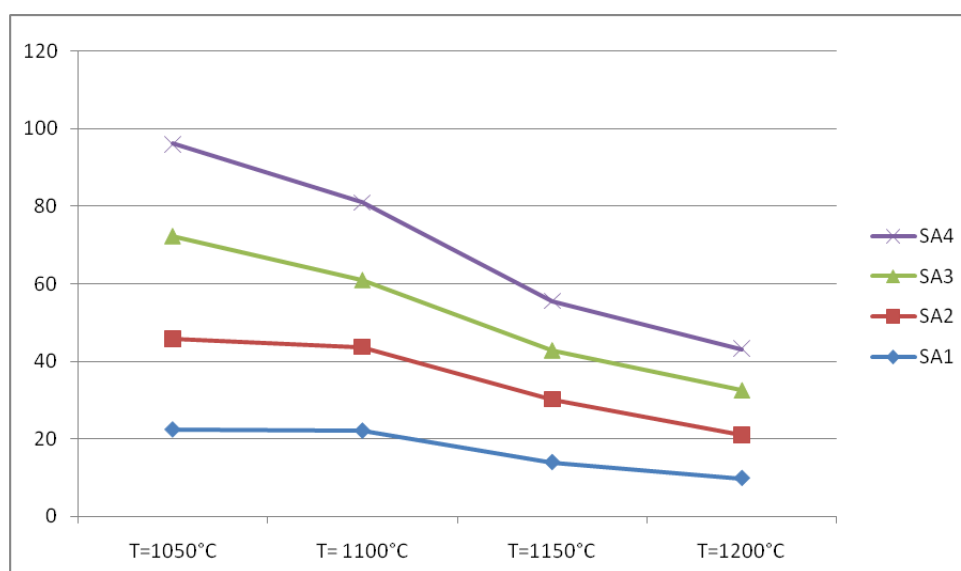


Figure 7. Graph showing percentage water of absorption of the samples

percentage water absorption of the samples SA₁, SA₂, SA₃ and SA₄ respectively. The implication here is to indicate using lines on a graph to represent the data obtained from the investigation carried out on this samples. Doing these shows at a glance the possible phenomenological process possible to take place within that particular area in time to come, for potential ceramists. Materials microstructure defines the decisive effect of the chemical-thermal reactions which are the basic prerequisites for achieving an optimum firing cycle. The rate controlled sintering is used to achieve high densification of functional ceramics while avoiding cracking, by maintaining a linear rate of sintering (Rajamannan et al., 2012). This implies that a linear rate in shrinkage is preferred to a linear rate of heating; thus,

modifying the temperature profile of the kiln and adjusting the sintering rate.

For the physical tests SA₄ recorded the highest making moisture and the SA₁ clay sample had the lowest 27.92 as compared to 25.70. The plasticity ratio 5.2:1 from SA₁ clay sample was the highest and that of 1:18 for the SA₃ was the lowest. Then firing shrinkage for the samples were seen to be highest for SA₄ and lowest for SA₁ clay sample at 1200°C was the lowest and 11.59 for the SA₃ was noted to be the highest. From the chemical analysis it was seen that the SA₂ clay had the highest SiO₂ content of 60.15 Al₂O₃ of 31.34 for the SA₁ was also noted to be highest. The high CaO content of the SA₃ which recorded 5.78 and 4.69 for SA₄ were much more pronounced than for the SA₁ and SA₂ clay samples. The

SA₄ sample had the highest organic content by recording 12.98 while the SA₂ had only a value of 9.41. Though the firing colours of all the samples SA₂ revealed to be the best i.e. light yellow. If a clay sample contains too much Fe₂O₃ it affects the firing temperature and colour. If its content is greater than 2% then it is not good for use in making ceramic products.

CaCO₃ (calcium trioxocarbonate (IV)) or limestone (chalk), it is also in natural like calcite and dolomite. If mixed in limestone its acceptable but at 1100⁰C it decomposes and the equilibrium is affected; therefore the percentage must be minimal (2% or less). Any amount of lead (Pb) is not tolerated for making ceramic products for the obvious fact that lead is very poisonous. Radioactive materials are not tolerated either, but low quantities of manganese oxide (MnO), tin oxide (TiO), for instance 2% can be tolerated but copper (Cu) is not admissible at all because of its radioactive affinity.

Lithium oxide (LiO) can be added to clays to reduce its coefficient of linear expansion. The ratio Al₂O₃.SiO₂.H₂O (kaolin), K₂O.Al₂O₃.6SiO₂ (Mica) or Al₂O₃.2H₂O (bauxite ore) is worked out to determine the percentage composition of other elements and how best they can be eliminated if necessary. That is where the loss of ignition test comes into consideration during this investigation.

RECOMMENDATIONS AND CONCLUSION

Recommendations

From the analyses performed on the samples it was observed that they were non-beneficial samples and it is of the researchers' opinion that if purification process is carried out on any of these samples namely Okponton clay (SA₁), Okoro Abaukwu clay (SA₂), Umuokwo I (SA₃), and Umuokwo II (SA₄) clay samples, the results would be of better economic utilization. For instance, by adding fluxes like potassium feldspar (K-feldspar), sodium feldspar (Na-feldspar), or calcium feldspar (Ca-feldspar), it would be of good ceramic advantage in the body formulation of ceramic products and thus increases the durability.

Other flux materials that can be used to help in the glazing of ceramic products to achieve fusion and subsequently maturity are lead oxide, dolomite. Naphelene cyanite and cornish stones are used in the developed actions of fluxes. Further research work should be carried out to fully ascertain the potentials of Nigerian clays (Robb et al., 1980) with a ceramic bias. This can also lead to working out modalities for the export of the products to earn needed foreign exchange for the country.

CONCLUSION

Clay generally has wide range of economic importance

such as its application in pharmacy (drug making), industrial ovens, burnt bricks, etc just to mention but a few. From the analyses performed on these samples SA₁, SA₂, SA₃, and SA₄ Okoro Abaukwu clay (SA₂) turned out to be the best grade for the ceramic industry followed by the Umuokwo II (SA₄) and the Okponton (SA₁) and finally the Umuokwo I (SA₃) clay type. In conclusion SA₂ sample is very suitable for the production of homewares like plates, cups, tiles, bath-tubs, etc by the ceramic industry. Ajuamiwe (2012) maintains that this is a preliminary study; with further research, some non-governmental organizations and governmental bodies could explore and exploit this clay mineral for the benefit of man. This will also go a long way to encourage the development of non-oil or solid mineral development and hence improve our country's revenue base.

ACKNOWLEDGEMENT

We hereby acknowledge the assistance of Engr. Omunakwe Awonda of Wilbros Nigeria Limited, Port Harcourt, Nigeria for processing the data used in this study.

REFERENCES

- Adeleye DR (1976). The Geology of the middle Niger Basin, (In) The Geology of Nigeria_(Ed.) C.A. Kogbe, Elizabethan Press Lagos Pp.283-287.
- Ajuamiwe CF (2012). Physico-chemical characteristics of some ceramic clays in Umudike, Abia State. B.Sc thesis (unpublished), Michael Okpara University of Agriculture, Umudike, Nigeria.
- Akpokodje OL, Etu-Efeotor JO (2007). Compositional characteristics of ceramic clay products. Unpublished thesis in the Department of Geology, University of Port Harcourt, Port Harcourt, Nigeria.
- Alabo EH, Odigi MI (1998). Geotechnical properties as an aid to the assessment and identification of industrial clays. Mineralogical publications, Port Harcourt, Nigeria pp.11-17.
- Allen JR (1996). Late Quaternary Niger delta and adjacent areas of sedimentary environment and lithofacies. AAPG reprinted series 5:547-600.
- Baulz B, Mayayo MJ, Fernandez-Nieto C, Cultrone G, Lopez JMG (2003). Assessment of technological properties of calcareous and non-calcareous clays used for the brick-making industry of Zaragoza, Spain. Applied Clay Science, 24: 121-126.
- Benson CH, Trast JM (1995). Hydraulic conductivity of thirteen compacted clays. *Clays and Clay Minerals*, 43(6): 669-681.
- Blyth FGH, de Freitas MH (1984). Geology for Engineers. Edward Arnold (Publishers) Ltd. New York pp.108-136
- Davis S, de Wiest R (1966). Hydrogeology. John Wiley and Sons, New York 462p.
- Enyadike E (2004). Physico-chemical properties of some ceramic clay. Unpublished B.Sc thesis in the Department of Geology, University of Port Harcourt, Nigeria.
- Etu-Efeotor JO (1981). The preliminary hydrogeochemical investigation of subsurface water in parts of Niger delta. *J. Mining Geol.* 18:103-105
- Griffiths DH, King RT (1965). Applied Geophysics for Engineers and Geophysicists, Pergamon Press New York pp. 35-107.
- Hajjaji M, Kacim S, Buolmane M (2002). Mineralogy and firing characteristics of a clay from the valley of Ourika, Morocco. Applied Clay Science, 21: 203-212.
- Iloje N (1965). A New Geography of Nigeria. Longman Nigeria Limited,

- Ikeja (Lagos), pp. 221
- NRCRI (1979). Guide to National Root Crops Research Institute, Umudike, Abia state, Nigeria, pp. 2-8.
- Rajamannan B, Ramesh M, Viruthagiri G, Ponnarasi K (2012). Mechanical properties of ceramic whiteware samples with different amount of quartz addition. *International J. Physics and Mathematical Res.* (IJPMR) 1(1): 001-004.
- Reyment RA (1985). Aspects of the Geology of Nigeria. Ibadan University Press, Ibadan pp. 48-58.
- Robb RR, Yaker C, Burd L (1980). Ceramic cores for manufacturing hollow metal castings. V.S. Patent no. 4190450.
- Short KC, Stauble AJ (1967). Outline of the Geology of Niger Delta. AAPG 51:761-779
- Weber KJ (1971). Sedimentological aspects of oil fields in Niger Delta, Geol. Eng. Min. Bulletin, 50(3): 559-576