Industrial Potentials of Adiabo Clay in Calabar Municipal of Cross River State, South-South Nigeria.

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ABSTRACT

Adiabo clay, reddish-brown plastic clay found in commercial quantities in Calabar, Cross River State, and South-South Nigeria was investigated for industrial utilization and even for domestic purposes. The test carried out include, Plasticity Index, Swelling Index, Flexural Strength, Linear Shrinkage, Refractoriness, Loss on Ignition, Water Absorption, Bulk Density, Porosity, Chemical Composition Analysis, and FT – IR. At the green stage (110^o C), the sample had strength of $18.286 KgF/cm^2$ which is even stronger than most clays reported in the literature. From the plot, the strength increased with increase in temperature. The linear shrinkage values vary from 1.27% at 800^0C to 8.4% at 1200^0c which is within the internationally accepted standard values of 7 – 10% for alumino-silicates, kaolinite and fireclays. The bulk density of the sample was found to be in the range of 1.70 - 1.71 g/cm^3 which is within the internationally accepted range of 1.7 – 2.1g/cm^3 for building and fireclays. The LOI of 12.56% reveals the amount of combustible organic impurities in the clay capable of defining the green property behavior and application. The moderate refractory property makes it unsuitable for the production of refractory linings and furnaces. The silica content of <50% means that it is not kaolinitic. The clay also had free swell index of 48% which is less than half its volume important for use as bentholitic clay in drilling operations. High swelling index is also reported to mean good molding properties of a clay binder. The Fe^{3+} content of about 5% accounted for the color and may discourage its application in some industrial processes. The Fe^{3+} content makes this clay unsuitable for the production of electrical porcelain insulators since this clay would crumble before the required temperature for total vitrification for such purposes is achieved. The high plasticity of this clay makes it suitable for application in colors and glazes, kaolinite clay modifier, table ware and other ceramics wares production and industrial uses.

(Keywords: Adiabo clay, Atterberg limits, swell index, plasticity, flexural strength, linear shrinkage, porosity)

INTRODUCTION

Clay is an unconsolidated rock matter, with very fine grain which is plastic when wet and undergoes ceramic change to become hard and stony when heated. The ceramic industries are the major users of clay. These industries consume about 70% of all clays marketed in crude or beneficiated form and those marketed only as finished products (Fakolujo et al., 2012).

Clay is composed of silica (SiO_2), Alumina (Al_2O_3) and water (H_2O) plus appreciable concentration of oxides of iron, alkali and alkaline earth, and contains groups of crystalline substances known as clay minerals such as quartz, feldspar, and mica. These other minor oxides components (impurities) which occur in variable quantities are important as their presence impart some properties to clay which are of technical value. It is important to note that the amount of impurities allowable in clay depends on the purpose for example; when white wares are needed, coloring impurities such as Fe_2O_3 must not be in the clay and for those to be used as refractory must be free as possible from fluxes, which compromise their thermal resistance. Knowledge of the clay available in any region helps in its applicable and general usage either in ceramic, drilling mud, refractories, plastics, paints, textiles and adhesives, paper foundry, pharmaceuticals, rubbers, etc.

Through the years, investigations have been carried out by ceramics researchers into the clays found in different parts of Nigeria, for their different applications (Abia-Bassey et al., 2006; Lawal and Abdullahi, 2010; Elueze et al., 1999; Gbadebo, 2002; Irabor, 2002). Consequently, such clays as Nsu clay, Ukpor clay, Enugu fireclay, Jos kaolin, Afuze clay, Usen clay, Uzalla clay, Kankara kaolin, and Getzo kaolin have been characterized and found useful applications for pottery and refractory uses.

Omotoyingbo and Oluwole (2008) Investigated the working properties of some clay deposits in ekiti and found that Ara clay 2 and a blend of two different Ara clays in equal proportions were most suitable for the production of crucibles and furnace lining for non-ferrous metals processing, such as aluminium, lead, and bronze. The setting behavior of Nigerian kaolinite clay in the absence of flocculants was reported and it was found that setting Rate was higher at low pH than at high pH (Benneth, 2008).

The Maastrichtian clays in Bida Basin Nigeria were found to compare favorably with the plastic fire clays of St. Louis and Florida active kaolinite and if beneficiated would be suitable as raw materials for ceramics, pharmaceuticals and paints (Ojo et al, 2011).

Physio-chemical and mineralogical studies on alluvial clay sample obtained from the confluence of River Niger and Mimi River in lokoja (Kogi state) showed that the sample had limited industrial potential because of the high silty organic contents. The clay was however found to be suitable for making building blocks, traditional ceramic pots, and insulation bricks (Lawal and Abdullahi, 2010).

Amankwo Afikpo and Okposi clays as extenders at varying concentrations in alkyd paints were studied and compared with a commercial whiting. The results showed the formulated alkyd paints to be suitable and the local clay found to be even better than the commercial whiting (Igwe and Ezeamaku, 2010). The use of local clays in drilling operations has also been investigated (Onwuachi-Iheagwara, 2010) and found suitable albeit more research was recommended.

In another survey to document, utilize and suggest possible application of clay minerals deposit in Kaduna state, Nigeria, it was reported that Refractory bricks have proven at onibode near Abeokuta with refractoriness of about 1,750^{0}C (Adelabu, 2012). Refractory materials from Alkaleri and Barkin-ladi were found to be suitable for construction of furnace due to high thermal shock resistance, crushing strength, bulk density and refractoriness values (Abolarin et al, 2004).

Some clay deposits in Kogi state, North central Nigeria were also investigated for their industrial potentials and were found to have acceptable physical and chemical requirements suitable for refractory purposes (Manukaji, 2013). In spite of this the Nigerian ceramics industry is moribund.

Local demands for ceramic products are very high considering the population yet the supply is met through importation. The Nigeria nation currently spends about N5Bn annually importing ceramics products. Nigeria imports more than 50 containers of ceramics products daily into the country, in spite of the availability of both raw materials and human capacity for research, production and development of quality ceramics products of international standard and safety. Also, worrisome is the fact that most of the imported ceramic wares are made with colors, glazes and body recipe that are not consumable and very dangerous to the human body.

With the growing demand for ceramics wares such as dinner wares, sanitary wares, pottery wares, floor and wall tiles, ceiling fittings, spark plugs, Beryllium oxide ceramics, chemical and refractory porcelains, Electrical porcelain insulators, combustion chambers for engines and furnaces, decorative wares, etc. therefore, in response to the challenges posed by high demand for clay base materials in Nigeria, indigenous clays with industrial potentials need to be investigated.

When clay body is fired, after processing, the resulting physical properties usually determine their suitability for intended use. The chemical and mineralogical composition of the samples bears enormous influence on the physical characteristics (Abia-Bassey et al., 2006). Clay swells in water, creating a thixotropic gel (particularly benthonite) as a consequence of interlayer water adsorption. The swelling index affects green compression strength, dry compression strength, flowability and other properties but no correlation is made between swelling index and strength properties of clay mold (Paul et al, 2006; RMRDC, 1999). High swelling index is reported to mean good molding properties of a clay binder but while studying the impact of swelling index on sokoto clay, a contrary result was obtained (Paul et al, 2012).

Porosity and fired strength are key properties. These parameters are highly affected by firing temperature, method of production, physical, chemical and mineralogical properties of raw material. Firing rate could also affect the strength, as rapid firing may cause cracks or bloating in the bodies. Prolonged firing at the finished temperature increases the proportion of fusible material therefore affecting the cold strength of the materials.

Water adsorption measures the available pore space and is expressed as a percent of the dry weight. Firing shrinkage is expected to increase with higher temperatures but few types of clay have shown a contrary result.

Adiabo clay is relatively abundant and in commercial quantity found at Calabar municipality area of Cross River state South – South Nigeria. The clay has numerous uses traditionally including direct consumption of the beneficiated form with the belief that it neutralizes toxins and cleanses the internal body system. Pregnant and nursing mothers rub this clay on their bodies and that of the newborn to reveal their fertile state and purify the skin of the neonates. The beneficiated form is used to make facial designs and decorations during traditional marriage rites.

The clay was therefore brought to the ceramics research and production department for testing and subsequent production of pottery and sanitary wares to see its suitability with a view to proposing other uses such as drilling muds, micro-filtration membranes in effluent treatment and refractory processes.

MATERIALS AND METHODS

Raw Materials

The Adiabo representative clay samples were dug out from five different locations in Adiabo at a depth of 1.52m in order to get a good representation of the site. The mined clay samples were mixed properly and a representative sample of 10kg of the sample was produced using the cone and quartering system as stipulated by ASTM and brought to the Ceramics Research and Production Laboratory of projects Research & Development Institute (PRODA), Federal ministry of Science and Tech, Enugu for detailed study.

Characterization of the Adiabo Clay Samples

The physical and chemical analysis was carried out in the ceramics research and production department institute. The infra – red studies was also carried out. The result generated was compared with standards published in literature, to ascertain the suitability of this clay for the purpose intended as stated earlier.

Sample Preparation and Processing

Sample Preparation for Physical Analysis: A portion of the processed sample now in powdery form was measured out and a calculated amount of water was added to bring it to plastic state. Rectangular test pieces of dimensions 8cm x4.1cm x2.1cm were molded for the shrinkage test, water absorption, apparent porosity; density (bulk and apparent), etc., cylindrical test pieces were also made which were used for the breaking load/triaxial flexural strength test. Also semi-spherical t load/triaxial flexural strength test. Also semi-spherical test pieces were molded and used for the plasticity test. The test pieces were dried at 110^{o}C and subjected to firing using the Wenger web cot kiln at various temperatures ranging from 800^{o}C-1250^{0}C.

Sample Processing: The unprocessed clay brought into the laboratory was in the form of agglomerated lumps of 10kg. The clay was then crushed, screened, pulverized (size reduction), sieved using 140mm mesh. The sample was there after soaked in water and allowed to stand for 20mins for the suspended particles which were mostly organic impurities to be decanted. The resultant mixture was then poured into a blunger and blunged for 10mins to homogeneity and to reduce their particles size. The slurry was removed from the blunger, sieved using electro-magnetic shaker fitted with a <140mm mesh. The now processed sample was poured into P.O.P (Plaster of Paris) baths to dewater and was allowed in the baths for 4 days to dry up and separate out of the baths. The resultant dried processed clay was put into the dryer (Fisher isotherm oven model 175) and set at 109^{0}C for 3 hrs.

The dried cake sample was then removed from the dryer, allowed to cool at room temperature and then crushed again using porcelain mortar and pestle, sieved using 100mm mesh and the fine powder obtained was used for the physical and chemical analysis, consistency analysis, and FTIR. The unprocessed but pulverized sample was used for the particle size analysis.

Sample Preparation for Chemical Analysis

The processed powdered sample was analyzed using AAS, XRF, and FTIR. For the AAS analysis, a known mass of the dried sample was measured and digested using Aqua-Regia (Hydrochloric acid: Nitric acid in a ratio 3:1).After the digestion for about 20mins using the platinum crucible on a heating mantle, a known volume of Hydrofluoric acid was added to ensure complete digestion. The FTIR analysis was also carried out in accordance with standard for testing of ceramics materials (AOAC, SON).

Refractoriness

The rectangular test pieces molded from the sample using calculated amount of water to achieve plasticity were dried and fired to temperature beginning from 900^{0}C in a muffle furnace fitted with a digital pyrometer. Heating was performed at temperatures ranging from 900^{0}C-1500^{0}C.The corresponding test pieces were then analyzed to see the refractoriness of the clay. Pyrometric cones (Orton standard pyrometric cones) designed to deform at 1000, 1250, 1300, 1400, and 1500^{0}C were used in accordance with the ASTM standard. Temperature was raised at 10^{0}C/min as was programmed in the digital pyrometer fitted to the kiln. The kiln had a maximum temperature of 1300^{0}C and the test pieces did not show any sign of failure or deformation, meaning that the clay sample have > 1300^{0}C refractoriness.

Modulus of Plasticity

Cylindrical test pieces of dimension 3.7cm x 3.3cm were molded and used for this test. The distance of drop was 10.05cm high. The heights before deformation of the various molded test pieces were noted before deformation. The plastometer drop had a mass of 777.5g with a drop height in the range 10cm – 10.20cm. The deformation was performed in triplicate and the average result was taken to represent the deformation height from where the modulus of plasticity was computed. The plastic modulus and water of plasticity were computed using the equation below.

Plastic Modulus = H_i / H_f.

Where H_i= Initial height of test piece before deformation and H_f = final height of test piece after deformation.

Also the Atterberg limits were determined following a method commonly used in ceramics industry but with a slight modification (JNSCE, 1987).

Triaxial Flexural Strength Test

The modulus of rupture/transversal strength machine fitted with a salter scale was used. The test pieces of dimension 10.2cm x 1.5cm x 2.1cm were used for this test and were supported on the ends of three cylindrical rods arranged in an equilateral triangle form and a load electrically applied by the rupture machine until it failed. The test was performed in triplicate and the average was used as the triaxial flexural strength of the clay body.

Linear Shrinkage

The rectangular bar test pieces of dimension 8.0cm x 4.1cm x 2.1cm were molded and a mark of 5cm apart was made at their centers. The green samples were allowed to dry at room temperature while the others were dried at room temperature and then fried to the corresponding temperatures intended for them in a kiln. After drying at room temperature, they were again dried in an oven at 110^{0}C to constant weight. The drying shrinkage was determined using the equation.

$$\textit{Dry Shrinkage}\ (\%) = (\textit{plastic Length} - \textit{oven dried Length})/\textit{plastic Length}) \times 100$$

The linear/firing shrinkage was determined using the equation:

$$\textit{linear shrinkage}\ (\%) = (\textit{Dry length} - \textit{Fired length})/\ \textit{Dry length})\ x\ 100$$

Total shrinkage was computed as:

$$\textit{T.S}\ (\%) = ((\textit{Plastic length} - \textit{Fired length})/\ \textit{Plastic length})\ x\ 100$$

Pressing Moisture

The cylindrical test pieces made for modulus of plasticity were used for this test. They were used as a representative batch of the pressed test pieces and weighed as soon as they were molded (W_1). They were then oven dried at 110^oc for 24hrs, cool in a desiccator for 30mins and then weighed again (W_2).The test was carried out in triplicate and the pressing moisture/making moisture was computed as:

$$\textit{M.C}\ (\%) = ((W1 - W2)/W1)\ x\ 100$$

Where MC = Making moisture content; W_1 = Weight of sample before drying; and W_2 = Weight of sample after drying at 110^oC.

Water Absorption

Water adsorption measures the maturity of a fired clay body. The rectangular bars test pieces of dimension 8cm x 4.1cm x 2.1cm were used for this study according to British standard EN (1991). The test pieces fired to the various temperatures were weighed to the nearest cm. The fired test pieces were then boiled for 2hrs and then allowed to cool. The surface of the bar (test pieces) were dried with a dry towel and then weighed again. The % water adsorption was then computed using the equation:

$$\%\ \textit{water adsorption} = \frac{(\textit{Saturated weight} - \textit{Dry weight})}{\textit{Dry weight}} \times 100$$

Sieve Analysis

The BA 200N Cisa stainless steel electromagnetic sieve shaker was used. 500g of the pulverized sample was weighed out using the METLAR MT-2000 electronic weighing balance and poured into prearranged electromagnetic sieve shaker of mesh size 710, 500, 300, 180, and 125 microns. The timer on the vibrator/shaker was set at 20 mins at amplitude of 1.5mm and the motor switched on for shaking to begin. At the end of the shaking duration, the total mass retain on each sieve was determined. Also, the amount retained (%) and passed (%) was computed using the equations below:

$$R\ (\%) = \frac{M_f}{M_i}\ x\ 100$$

$$P\ (\%) = 100 - R\ (\%)$$

Where Mi = Initial mass of clay before shaking, Mf = Final mass of clay retained on the sieve, R(%) = Percentage retain, and P(%) = Percentage of clay samples that passed through.

Loss on Ignition (LOI)

This test measures the organic combustible matter present as impurities. This impurities leads to gas evolution and reduces the refractoriness of clay. 50g of oven – dried clay after cooling in a desiccator, was measured into a clean flat surface porcelain crucible of known mass (Mi). The crucible and its content was placed in a muffle furnace and incinerated to a temperature of 800^0c. The crucible and its content were then put back into a desiccator to cool. After cooling, the incinerated crucible and the clay content were then weighed again to constant weight (M_3). The loss on ignition was then computed using the equation below:

$$\textit{Loss on ignition}\ (\%) = \frac{M_2 - M_3}{M_2 - M_1}\ x\ 100$$

Where: M_1 = Mass of crucible, M_2 = Mass of crucible + sample before heating, and M_3 = Mass of crucible + sample after heating.

pH

This was carried out using the digital PHS – 25 precision pH/mV meter and calibrated using buffers of pH - 9.18, pH – 6.86 and standard pH. The mercury in glass thermometer was used to check the temperatures of the buffers and the samples slurry respectively and the pH – meter adjusted accordingly before calibration. After the calibration, 2g of samples was measured into a beaker and an estimated amount of distilled water added to make it slurry. Then the pH meter sensor was dipped into the slurry to determine the pH of the clay.

Swelling Index Test

The testing procedure adopted was as reported (Puvvadi et al, 1987). 10g of oven dried sample of Adiabo clay passing a mesh of 0.425µm was measured into 100cm^3 graduated transparent measuring cylinder containing distilled water. The mixture was stirred continuously for thorough mixing, stopper and allowed to stand for 24hrs. The sediment volume was measured against the graduations of the measuring cylinder. The free swelling index can be computed using equation below:

$$F.S\,(\%) = \frac{(V - V_0)}{V_0} \times 100$$

Where, V = the soil volume after swelling (cm^3) and V_0 = the volume of dry soil (cm^3)

RESULTS AND DISCUSSION

Consistency Analysis

The rupture resistance between 1000^{0}C – 1200^{0}C was very hard (80 to < 160N). Consequently, the sample test-piece fired at the temperature cannot be crushed between thumb and forefinger. The sample was moderately sticky at green stage. By this, the sample adhered to both fingers after release of pressure with some stretching on separation of fingers. The moist sample consistency was firm.

Firing Color Change

The sample showed a lighter pinkish color change with increasing temperature to 1200^{0}c from the initial color of dark brown.

Chemical Analysis

Table 1 shows the chemical composition analysis of the processed clay sample. The values for silica and alumina are expectedly high when compared with other associated oxides in the chemical make-up of the sample. The high value of Fe^{+3} may have accounted for the brownish color of the clay and this invariably affects the insulating application of this clay.

High temperature is required for the production of impervious electrical porcelain insulators. The Fe^{3+} content which acts as a flux lowers the vitrification temperature of the clay and is as high as >5%. This would make the clay crumble at such required temperatures (minimum of 1250^{0}C for low voltage low frequency and 1500^{0}C for high voltage insulators).

From the spectrum in Figure 1 above, several adsorption peaks are shown, confirming the presence of various functional groups in the sample. The presence of these groups which are responsible for binding of the cations has been explored in the application of clays in adsorption studies (Akpomie et al, 2012).

The bands at 3695.73cm^{-1} and 3620.51cm^{-1} corresponds to the inner –OH stretching vibration while that at 3423.76cm^{-1} represents the outer surface –OH stretching vibration. The band at 1629.9cm^{-1}is assigned to the OH bending vibration of water and can also be assigned to the symmetric $–COO^-$ stretching vibration (Li et al., 2011). The presence of the outer surface –OH and the symmetric $–COO^-$ vibration might suggest the presence of smectite in the kaolinite (Ekosse, 2011). The vibration observed at 1112.96cm^{-1}, 1033.88cm^{-1} and 1008.8cm^{-1}are assigned to Si – O bending vibration while the bands observed at 694.4cm^{-1} and 796.63cm^{-1} are the stretching vibration. Band seen at 912.36cm^{-1} corresponds to the Al-O bending vibration.

Table 1: Summary of Percentage Chemical Composition of Adiabo Clay.

Sample name	Chemical Composition (%) – Oxides Value										
	Si	**Al**	**Fe**	**Mn**	**Mg**	**Ca**	**Zn**	**K**	**Cu**	**Na**	**LOI (at 800^0C)**
Adiabo Clay	49.81	22.57	5.59	0.02	1.81	2.8	0.02	1.17	0.03	0.62	12.556

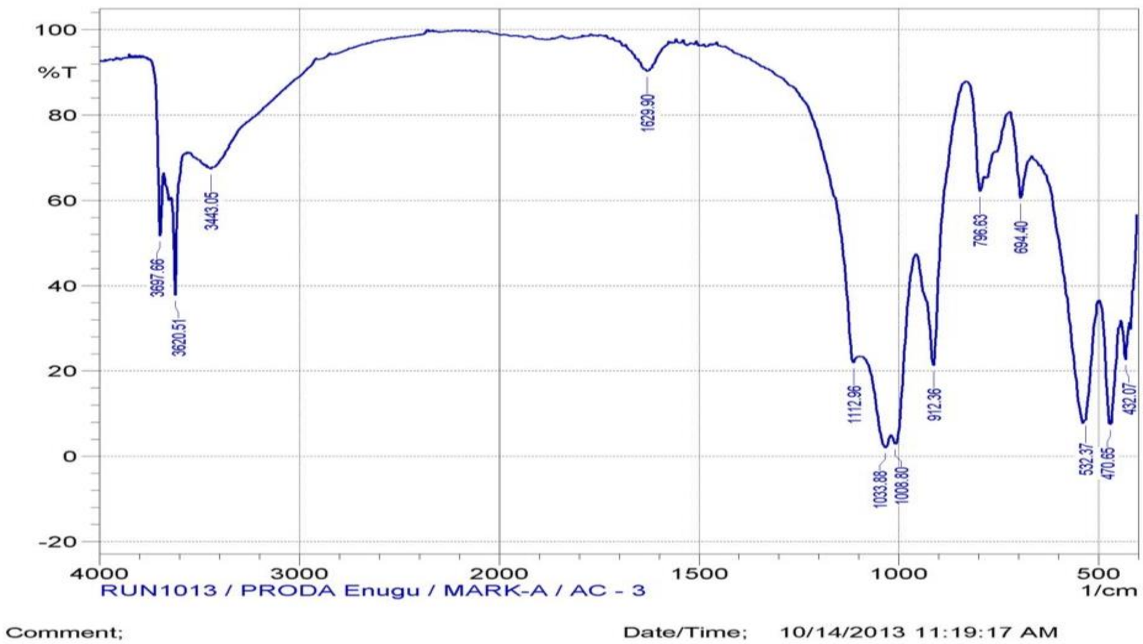

Figure 1: FT-IR Spectra of the Adiabo Clay.

Peak intensities observed at $532.37cm^{-1}$, $470.65cm^{-1}$ and $432.07cm^{-1}$ are due to skeletal vibrations of Al-O-Si (Vempati et al, 1996; Njoya et al, 2006).The use of infra – red spectroscopy in the study of clay structures takes its place beside X–ray diffraction, thermal methods, and chemical analysis, in a combination which is inevitably more powerful than any one alone (Farmer, 1968).

Refractoriness

At 1200^0C, the sample did not show any sign of failure but at much higher temperature of 1300^0C, signs of failure were observed. This means that although the sintering level is high, it is not enough to fall within the internally accepted range of 1580^0C -1750^0C. However, Adiabo clay has moderate refractory qualities and can withstand moderately high temperatures up to 1250^0C without failure. For very high temperature the clay may be subjected to during operation, user's discretion is strongly advised.

Bulk density and Apparent Density

For the values of bulk and apparent density, see Table 3. At 1000^0C – 1200^0C, the bulk density of the sample was found to be in the range of 1.7 - 1.710 which is within the internationally accepted range of 1.7 – $2.1g/cm^3$ for building and fireclays (Thring, 1962). The apparent density of the sample was found to be in the range of 2.408 – $2.654g/cm^3$ which fell within the internationally accepted standard range of 2.3 – $3.5g/cm^3$ (Ryan, 1978; Manukaji, 2013).

Water Absorption

For the values of water absorption, see Table 3. The range of water absorption for the experimental temperatures of 1000^0C – 1200^0C

Table2: FT – IR spectrum band assignment of Adiabo Clay.

FT – IR Frequencies(cm-1)	Bands Assignment
3697.66 3620.51	Inner surface – OH stretching vibration
3443.05	Outer surface – OH stretching vibration
1629.9	- OH Bending vibration
1112.96 1033.88 1008.8	Si – O bending vibration
912.36	Al – O bending vibration
796.63 694.4	Si – O stretching vibration
532.37 470.65 432.07	Al – O – Si skeletal vibration

Table 3: Physical Properties of Adiabo Clay.

Parameters	Temperature (^{0}C)					
Parameter/Temperature	**Green**	**800**	**900^{0}C**	**1000^{0}C**	**1100^{0}C**	**1200^{0}C**
Linear(Dry fired) Shrinkage (%)	-	1.27	2.76	6.23	6.53	8.39
Fired Linear(Total) Shrinkage(%)	-	6.77	8.3	13.4	13.67	14.87
Apparent Porosity (%)	-	39.533	37.423	30.793	29.349	28.959
Apparent Density (g/cm^3)	-	2.654	2.60	2.445	2.415	2.408
Bulk Density (g/cm^3)	-	1.605	1.626	1.692	1.706	1.710
Water Absorption (%)	-	24.636	23.037	18.20	17.20	16.931
Porosity		0.395	0.375	0.308	0.294	0.290
Breaking load (Kg)	6.65	8.33	8.633	>12	>12	>12
Modulus of Rupture (kgF/cm^2)	18.286	24.036	25.12	>47.48	>39.55	>46.18
Modulus of Plasticity	1.33					
Making Moisture (%)	29.924					
Mass of sample(g)	2500					
Volume of liquid used(Cm^3)	900					
Water of plasticity (%)	41					
Moisture content (%)	43					
Free swelling Index (%)	48					

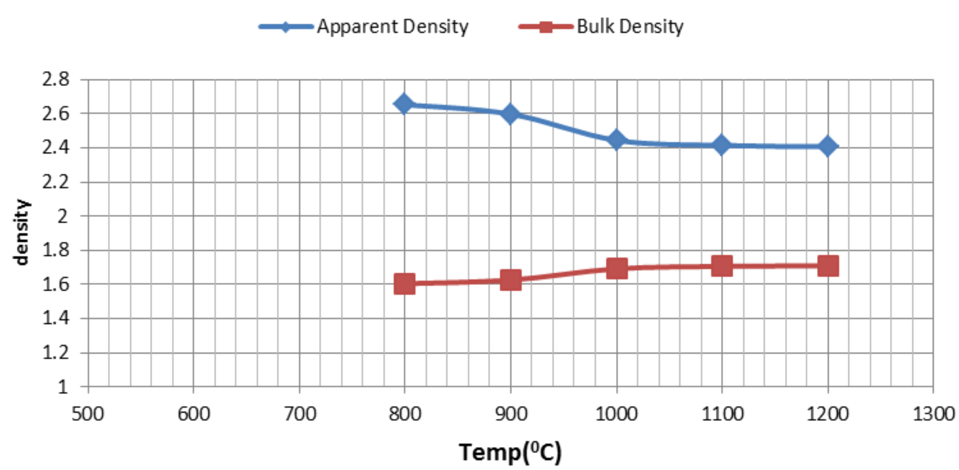

Figure 2: Density Plot for Adiabo Clay.

commonly used for production was within 16.9 – 18.2. When glazed, the water absorption will further drop to below 15% which is the ASTM-allowable value for ceramics tiles on sale.

Apparent Porosity

Table 3 also shows the apparent porosity value for this clay. There are no values for the green stage (110^{0}C because the sample (unfired) did not survive the boiling test. The plot is also shown in Figure 3. The values for the temperature range of 800^{0}c – 1200^{0}c were in the range of 28- 40% which is within the internationally permissible value of 20 – 80% [28], [14] for fired bricks. From the plot (Figure 3), the apparent porosity decreased with increasing temperature as expected, although a few clays have shown contrary trend as reported in some literatures for highly silicaceous clays. The decrease in apparent porosity with increasing temperature indicates the closure of the pores. For the purpose of insulation, this can be enhanced by the addition of carbonaceous materials such as saw-dust, rice husk, corn husk, etc. (Olusola, 1998).

Triaxial Flexural Strength (Modulus of Rupture)

The 3-point strength test values of the samples at the various experimental temperatures are as shown in Table 4. At the green stage (110^{o}C), the sample had a strength of 18.286KgF/ cm^2 which is even stronger than most clays reported in literature. From the plot, (Figure 4), the strength increased with increase in temperature. At 1100^{0}c, slight drop was observed which may be due to Experimental error, human, machine or power supply may be said to be responsibly, it is rather still speculative. However, the values for the temperature range of 1000^{0}c - 1200^{0}c were > 39.553KgF/cm^2 which shows a very strong clay.

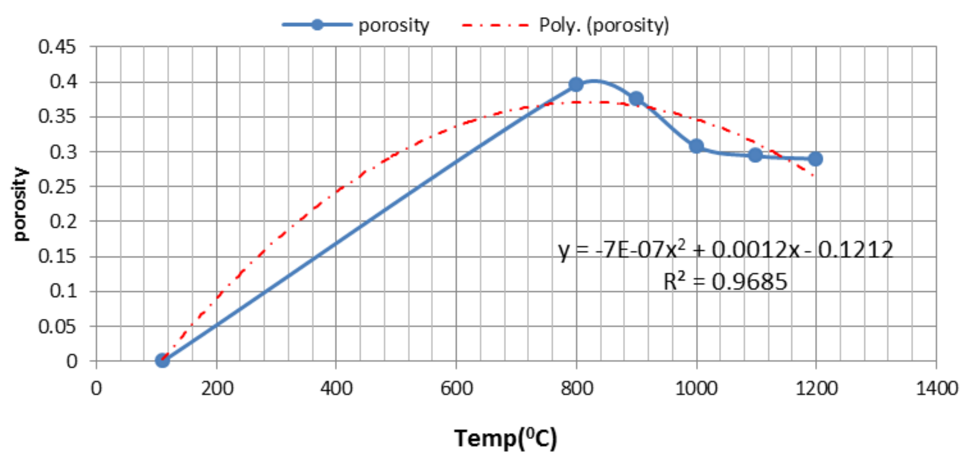

Figure 3: Porosity Plot for Adiabo Clay.

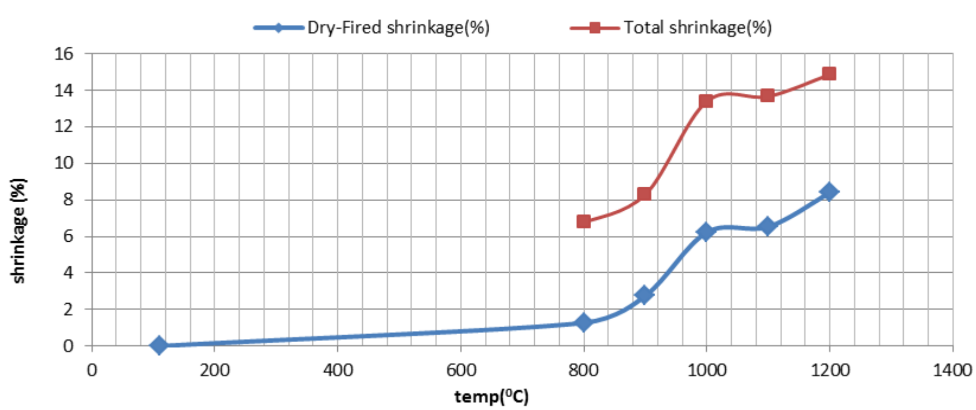

Figure 4: Shrinkage Plot for Adiabo Clay.

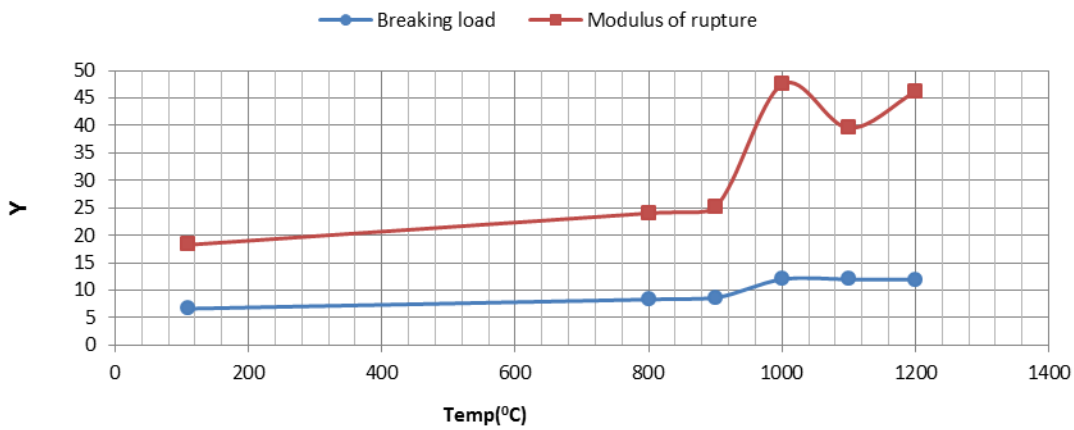

Figure 5: Modulus of Rupture of Adiabo Clay at Different Temperatures.

The breaking load for the clay within the experimental temperature range of 1000°C - 1200°C was greater than 12kg indicative of the high shear strength of the sample.

Linear Shrinkage

Table 3 shows the linear (dry-fired) shrinkage and the total (fired) shrinkage of the sample from green stage (110°C to 1200°C). The linear shrinkage values vary from 1.27% at 800°C to 8.4% at 1200°C which is within the internationally accepted standard values of 7 – 10% for alumino-silicates, kaolinite and fireclays (Zubeiru, 1997; Manukaji, 2013). The slightly lower values for this sample when compared with the kaolinites and fired clays suggest a high content of non-fluxing impurities. The total (wet – fired) shrinkage was in the range of 6 – 14%. The total shrinkage and dry shrinkage are of little importance since their values changes with moisture content during casting (JNSCE, 1987).

pH

The pH value for the clay was found to be 5.51 showing acidic clay. The pH of clay is important because it affects the chemical, biological and physical processes of the clay/soil. This is why the pH is often considered the Master variable of soil. The low pH of 5.51 shows biological transformation of ammonium to nitrate. Availability of nitrogen, phosphorus, sulphur, calcium, magnesium, molybdenum and sodium is limited under acidic conditions.

Plasticity

Table 3 shows the modulus of plasticity of the clay. The Atterberg limits are as shown in Table 4. The water of plasticity was found to be 41.33%. The plasticity index was found to be 29%, meeting the plasticity requirement (API of 25) of refractory clays demanded in the iron making shop of iron and steel industry (JNSCE, 1987).

Table 4: Atterberg Limits.

Properties	Result
Liquid Limit (%)	61
Plastic Limit (%)	32
Plasticity index (%)	29
Color	Reddish brown

Swelling Index

The swelling index analysis examines the tendency to swell (hydrate) over a period of time (Onwuachi-Iheagwara, 2012). The free swelling index for Adiabo clay was found to be 48% which was high. This is below the recommended standard needed for application as drilling mud as is evident in most bentholitic clays but suitable for other uses. Other test is necessary if application as drilling mud must be considered. High swelling index is also reported to mean good molding properties of a clay binder.

Particle Analysis

IMR = Individual Mass Retained: is the weight of the sample retained on the individual sieves.

IPR = Individual Percentage Retained: is obtained by dividing the mass retained on each sieve by the total mass of sample sieved and multiplying by 100%

CMR = Cumulative Mass Retained: is the sequential sum of the individual masses retained on the sieves.

CPR = Cumulative Percentage Retained: is the sequential sum of the individual percentages retained on the sieves.

CPP = Calculated Percentage Passing: is obtained by subtracting the CPR from 100%.

The graph shows the point of intersection (0.57mm) of both plots which gives an indication of the general aggregate size of the sample. In this case 50% of samples passed the 0.5mm sieve showing a considerable amount of fine particles.

Table 5: Particle Size Analysis Result.

Sieve Sizes (mm)	IMR (g)	CMR (g)	IPR (%)	CPR (%)	CPP (%)
0.71	212.6	212.6	42.52	42.52	57.48
0.50	52.6	265.2	10.52	55.04	46.96
0.36	40.3	305.5	8.06	61.1	38.9
0.25	43.2	348.7	8.64	69.74	30.26
Pan	151.0	499.7	30.2	99.94	0.06

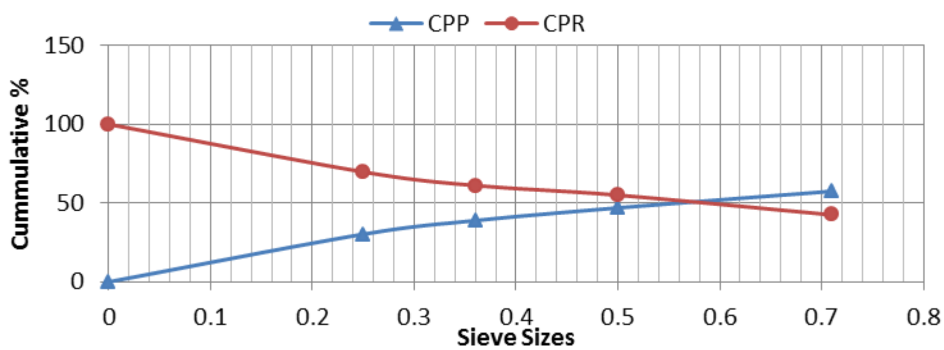

Figure 6: CPP versus CPR of Test Sample.

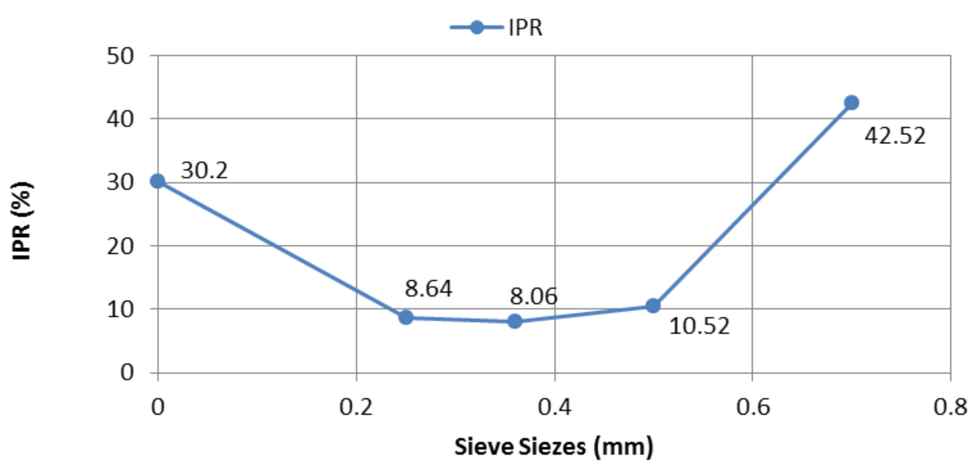

Figure 7: IPR vs CPR.

Fineness modulus indicates the uniformity of grind in resultant product. It is determined by adding the weight fractions retained above each sieve and dividing the sum by 100. For this work, the fineness modulus was found to be 4.997. The average particle diameter is defined by the following equation; (Sahay and Singy, 1994).

$$D = 0.135 (1.366)^{FM} = 0.64.$$

The particle diameter of <1 means smooth and fine particle sizes and this influences the choice of the clay for various engineering operations depending on specification.

CONCLUSION AND RECOMMENDATION

From the results reported, it is clear that:

1. Adiabo clay has engineering properties suitable for application in ceramics production.

2. The moderate refractory properties of this clay suggest that it may not be suitable for construction of furnace linings and refractory.

3. From the geotechnical and chemical properties of the clay, the high strength and plasticity makes this clay suitable as modifier for short clays, also as being suitable for construction ceramics as building materials such as roof tiles, bricks and clay pipes all contain plastic clays.

The anti-toxicity efficacy of this clay was not investigated which is an area suggested for further studies.

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