Investigation Of Physio-Mechanical Properties Of Ogijo Clay Deposit For Refractory Applications

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Abstract:
Ogijo clay deposit in Ogun state, Nigeria was characterized to establish its use industrially. The major properties investigated were drying and firing behavior, bulk density, water absorption, plasticity index, Sieving analysis, compressive strength, shrinkage, and chemical compositions. The results from the analysis showed a chemical composition of 57.09%SiO_2, 40.38%$A1_2O_3$, 0.200%Fe2O_3, 0.055% MgO. 0.050% Na_2O, 0.044% K_2O and 0.126% CaO. The clay has a moderate plasticity index of 29.35%, Cumulative mass% passing (undersize) of 86, Compressive strength ranging from 1.021 MPa to 1.968 MPa and the color ranged from red brow to dark brow on firing. The properties signify that Ogijo clay is stoneware clay. It can be used for the production of stoneware, flowerpot, source of silica for floor tiles and brick making. It can also be used as a binder in the absence of standard binder.
Keywords**: Compressive, Investigation, Ogijo clay, Plasticity Index and Apparent porosity.**

1.0 INTRODUCTION

Clay is a fine textured earth that is plastic when wet but hard and compact when dry or a term used to refer to the finest grain particles in a sediment, soil or rock. Clay occurs most abundantly in nature in soils, sediments, sedimentary rocks and hydrothermal deposits [1].
There are two general types of clay: expandable and non-expandable clay [2]. Expandable clay swells up when water is added to it and can become liquid when or if enough water is added to it. Non-expandable clay called Bentonites is used to make drilling mud in the petroleum industry. Non- expandable clay is used in the ceramics industry to make bricks, tiles, pottery and porcelains. The important properties of clay are plasticity, colour, clay strength, drying and firing shrinkages. The percentage of the mineral's oxides (Fe_2O_3, MgO, CaO, Na_2O etc) in the clay ultimately determine the areas of applications of the clay such as in bricks, floor, tiles, paper etc, while the quantity of the alkali metal oxides (Na_2O, K_2O, CaO etc) indicate their suitability for making ceramic products [3].
Nigeria has appreciable distribution of industries engage in metal and process industries, hence there need for adequate & sustainity of raw materials to support their growths. Clay products such as ceramics wares, burnt bricks, and roofing and floor tiles are cheaper and durable building materials than cement especially under tropical conditions [4]. These materials therefore need be as urgently utilized to reduce over dependency on cement another refractory materials particularly in Nigeria.
There are vast deposits of clay spread across every region in Nigeria, though their properties differ from site to site on account of geological differences. Ironically, the bulk of clay requirements of the nation is imported from the United Kingdom, USA and Japan [4]. The present economic state imposes the need for internal sourcing of raw materials to meet up increasing demands.

Presently the Ogijo clay deposit in Ogun state is used for earthenware pots. This paper is however aimed at extending its uses through characterization of the clay deposit by determining its properties and determine its possible suitability for different application (Industrial/ Refractory).

2.0 MATERIALS AND METHODS

2.1 Materials

The clay samples were obtained from various points by random sampling. The samples were dark gray in color and dry in appearance. The clay material was sourced from Ogijo area of Shagamu L.G.A, Ogun state. Sample of the raw clay in solid form and fired specimens for characterization is shown in fig. 1 below.

Fig 1. Shown samples of the solid raw clay directly from the site and fired samples used for characterization.

2.2 Methods

2.2.1 Preparations of Clay Materials

The clay materials was prepared using ASTM – guidelines. To remove debris and other unwanted materials in the clay samples, the clay was soaked in water for two (2) days, sieved with a mesh of 250µm and dried at room temperature for one week (1 weeks). Meanwhile, the dried sample was milled and sieved into 1500 µm sizes in line with the practice of [5].

The clay was crushed using Hammer Milling Machine (Model; 000T, PUISSANE; 1.5KV, S/N; 13634) and milled into fine size particles using ball milling machine (Model; 87002…. Limoges-France, Type; A50---43), and then sieved with a Vibro-Sieve (Model; Fritsch GmbH, D-55743.1 Dar-Oberstein Germany) into 100 µm particles size in line with the practice of [6].

2.2.2 Chemical Analysis of Clay Samples

A 0.1 g of the samples was weight into a Teflon crucible and moistened with Aqua regia (mixture of HCl and HNO_3 in the ratio of 3:1 by volume). A hydrofluoric acid (1 5m1) was added to form the mixture, covered and then heated in a fumed chamber at 100°C until the solution became clear. The solution was allowed to cool and then transferred into a 250m1 plastic (Hydrofluoric Acid attacks glass) volumetric flask which was made up to 250ml marked with distilled water. Different chemicals standard equipment and analytical methods were used to determine the % composition of the following oxides: SiO_2, $A1_2O_3$, Na_20, K, O, CaO, MgO and Fe_20_3.

2.2.3 Analysis of Clay Samples' Physio-mechanical properties

2.2.3.1 Determination of Porosity, Shrinkage, Bulk density and Color – ASTM Standards

The grinded sample was poured into a plastic basin and moistened with about 396ml of water added to the point of wedging (which is the state whereby moistened clay material remained packed into a ball-in-hand until intentional vibration causes the mixture to flow). The wedged sample was cast in brass molds coated with thin film of machine oil. The oil was to facilitate easy removal when dry. Eight-test clay bars of 7.5 x 3.5 x 1.5cm dimension were prepared. Two points of 5cm interval were marked on each of the molded clay using venier caliper. The bars were allowed to air-dry for 24 hours and each sample weighed. The bars were dried in an oven at 110°C for 24 hours after which the marked distance was recorded as dry length [7]

Wet-dry shrinkage was determined using equation 1.

$$\textbf{Wet - Dry Shrinkage} = \frac{\textbf{Original Length} - \textbf{Dry length}}{\textbf{Original Length}} \times 100 \qquad (1)$$

Then eight clay bars were charged individually into an electric furnace along with 4 pieces of American standard pyrometric cones of 900°C, 1000°C, 1100°C and 1200°C and fired approximately for 10 hours. At each temperature of the temperatures, the samples bearing the same temperature were removed from the furnace, allowed to cool and each bar observed for color change, cracks formation fired length and fired weight.

The following parameters (as expressed in equation 2-7 were determined from the following formulae as resorted in [8]:

Dry – Fire Shrinkage = $\frac{\text{Dry Length} - \text{Fire length}}{\text{Dry Length}} \times 100$ (2)

Percentage Shrinkage = $\frac{\text{Oven Dry} - \text{Fire length}}{\textit{Oven Dry}} \times 100$ (3)

The samples were then immersed in water. Bubbles were observed as the pores in the samples were filled with water. After 8 hours, the samples were weighed and the soaked weight and recorded. They following expression were used to obtained result as follows:

Apparent Density = $\frac{\text{Dry Weight}}{\text{Soaked Weight} - \text{Suspended Weight}} \times 100$ (4)

Bulk Density = $\frac{\text{Dry Weight}}{\text{Dry Weight} - \text{Suspended Weight}} \times 100$ (5)

Percentages Apparent Porosity = $\frac{\text{Soaked Weight} - \text{Dry Weight}}{\text{Soaked Weight} - \text{Suspended Weight}} \times 100$ (6)

Percentages water absorption = $\frac{\text{Soaked Weight} - \text{Dry Weight}}{\text{Dry Weight}} \times 100$ (7)

2.2.3.2 Compressive Strength

Eight test clay bars of 10 x 1.5 x 1.2 cm dimension were prepared. The dry samples were moistened and mixed to a workable state. The wedged sample was cast in wooden molds coated with thin film of machine oil. The bars were air-dried for 48 hours. Six of the bars were (temperature marked) were then charged into an electric furnace separately along with American Standard Pyrometric Cones of refractoriness 900°C, 1000°C and 1200°C and fired for approximately 10 hours removed from the furnace and allowed to cool. Each batch of bars were broken at the center bending on a Dimension strength testing machine at 7.0 cm span and Modulus of Rupture was calculated from the expression as follows [8]:

MOR = $\frac{\mathbf{3PL}}{\mathbf{2bh3}}$ (8)

Where P = breaking load in KgF; L = distance between support; b = breath, h = height. Pfefferkorn Plasticity

A 50g of clay sample was put into a container and a little amount of water added to it. The moistened clay was molded into cylindrical shape by a cylindrical mould. The molded clay was deformed by dropping onto it from a fixed height a flat-headed plunger of know weight. The distance traveled was read from the graduated scale. The modulus of plasticity (MOP) for the clay sample was obtained from the expression:

MOP = $\frac{\text{Original Height}}{\text{Deformed Height}}$ (9)

Also, the percentage making moisture for the clay samples were obtained from the expression:

%Making Moisture = $\frac{\text{Wet Weight} - \text{Dry Weight}}{\text{Net Weight}} \times 100$ (10)

2.2.4 Loss on Ignition (LOI)

A 0.5g of the clay sample in clean a dried platinum crucible was put into a furnace at 600°C for 3 hours. It was then cooled in the desiccators and weighted. Weight lost is the loss due to ignition, LOI was then determined using the relationship r in equation 11:

LOI = $\frac{\textbf{Weight Loss}}{\textbf{Weight of Sample Mud}} \times 100$ (11)

3.0 RESULTS AND DISCUSSIONS.

3.1 Table 1. Chemical Composition of the clay Sample

CLAY SAMPLE	% Composition									
Ogijo Clay	SiO_2	$A1_2O_3$	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	Moisture	LOI
Level of Detection	57.09	40.38	1.101	0.126	0.055	0.050	0.044	0.005	1.341	0.002

The result for chemical analysis in Table 1 shows a high silica content (SiO_2 > 57.09%) which must likely mean that Ogijo clay exist as quartz and comparing the result to that obtained for other clays, suggest their use as source of silica for the production of floor tiles [6]. The percentage alkali oxides (CaO, K_2O and Na_2O) is high and this explains the plasticity characteristics of the clay [8]. The alkali oxides (flux) especially with soda more than 0.06% and high aluminum content made the clay also capable for refractory production, paper and Ceramics. Comparing the properties of Ogijo clay with other type of clay, it proved the clay was comparable, favorably with Ujogba clay, which is widely used for the production of ceramic tiles [9].

3.2 Shrinkage and Modulus of Rupture

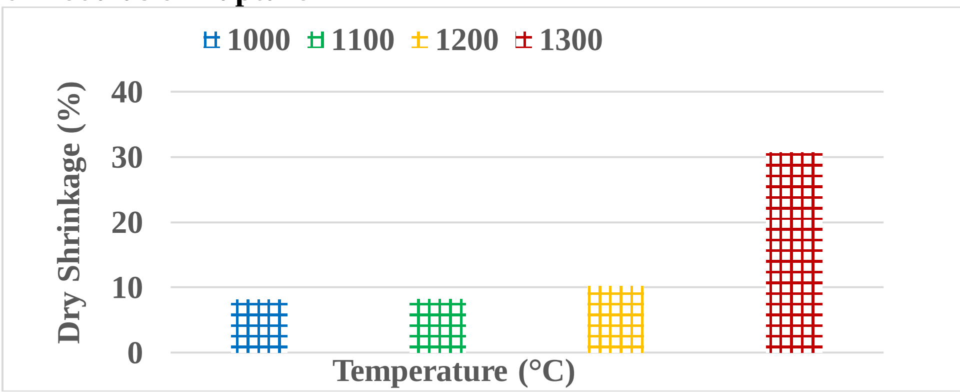

Fig1. Average shrinkage values at different temperatures

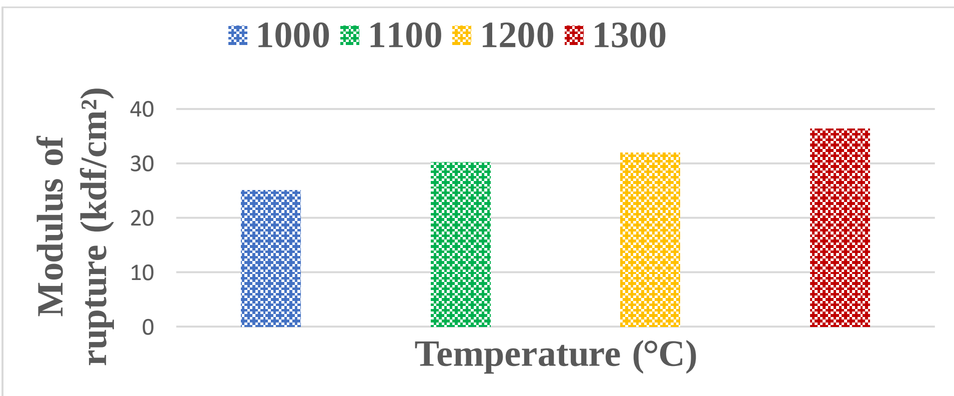

Fig 2. Average modulus o rupture values at different temperatures

The result obtained from the fired shrinkage at average values ranged from 8.12-30.7%, shows that the clay deposit lies within standard value for refractory and ceramic production. The firing temperature shows significant values from 1000 to 1100°C for ceramic production while from 1200-1300°C indicated significant values for refractory production. Hence, the magnitude of the shrinkage increases directly proportionally to temperature. Shrinkage is the property of clay that is important for ceramics making hence the clay can be suitable for ceramics production.

The modulus of rupture (MOR) is the load bearing capacity of the clay. From Figure 2, the MOR ranged from 25.17 to 36.48 kgF/cm^2, as temperature increased from 1000°C to 1300°C. The strength behavior was found to increase with temperature and this could be attributed to bond formation in the glassy phase. The soda in the clay component would have combined to form some considerably low temperature melting compounds, which increase the strength of the bulk on cooling. However, the values ranged from 1.4 to 105 kgF/cm^2 in figure 2 shows that magnitude of the modulus also increases directly proportionally to temperature [10].

3.3 Water Absorption and Apparent Porosity

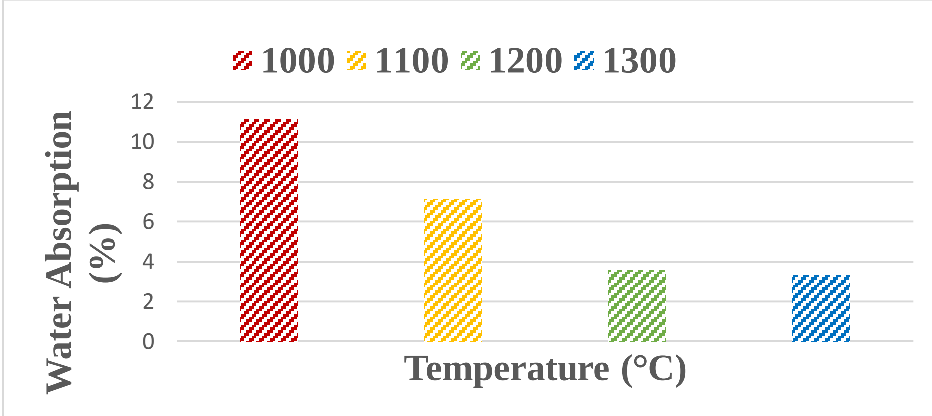

Fig 3. Average water absorption values at different temperatures

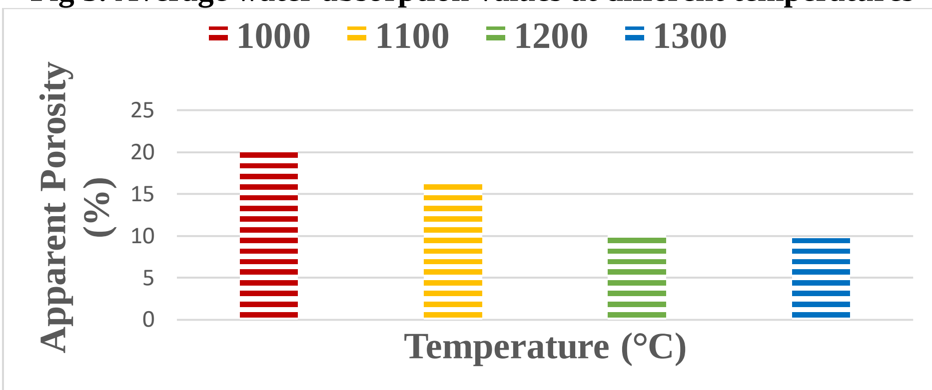

Fig 4. Average apparent porosity values at different temperatures

Figures 3 and 4 show that the increase in temperature is inversely proportional to the apparent porosity and the water absorption ranged from average values of 20.54-9.71% and 11.13-3.29% respectively. The water absorption capacity of the clay has a very strong relationship on its drying behavior, as during drying this absorbed water must be driven out. This usually leads to a high drying shrinkage [11].

3.4 Apparent Density and Modulus of Plasticity

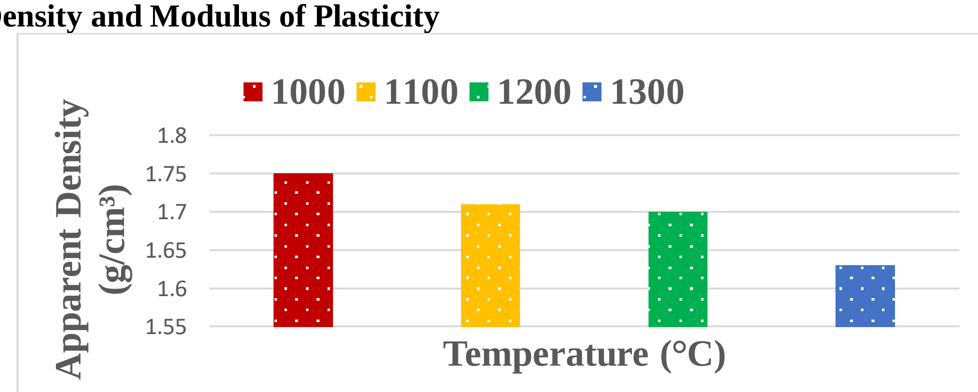

Fig 5. Average apparent density values at different temperatures

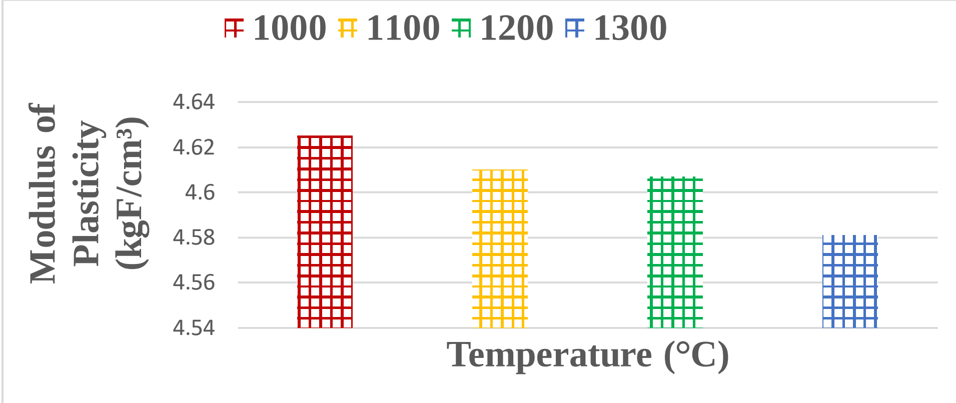

Fig 6. Average modulus of plasticitty values at different temperatures

The results from figures 5 and 6 show that the apparent density and modulus of plasticity decrease with increase in temperature ranged from 1.75-1.63g/cm³ and 4.625-4.581 kgF/cm^2 respectively. The clay has a good workability which can be worked into shape. The plasticity makes it good for many industrial products with low level of impurities. The results were comparable with that Ujogba clay and it suggests that it can be used as a binder in the absence of standard binder like phosphoric acid.

3.5 Bulk Density

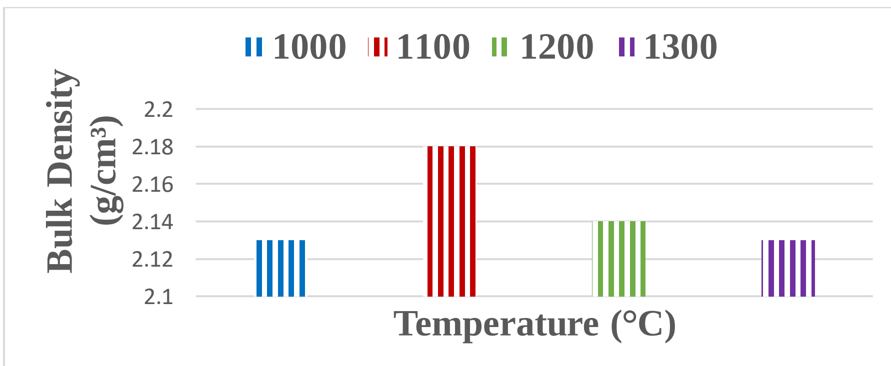

Fig 7. Average bulk density values at different temperatures

The bulk density of various samples at different temperatures are shown in figure 7 above, which is neither directly nor inversely proportional to increase in temperature. However, the values ranged from 2.13-2.18% fall within the accepted range [12].

3.6 Colour Formation

Table 2. Shows the colour of samples at different temperatures.

Temperature (°C)	1000	1100	1200	1300
Colour formation	Light red	More light	Very red	Dark red

The color of the clay deposit varied from grey to red on firing as shown in Table 2. This could be attributed to the content of iron oxide of 1.101%. The ferrous iron impacted a red color on the fired sample due to conversion from ferrous to ferric compound. The color variation is considered usable for the manufacture of sanitary ware and earthenware [12].

CONCLUSION

The physico-mechanical properties of the Ogijo clay was characterized using standard methods to determine its suitability as industrial raw materials. The clay was found to have moderate plasticity of 4.614 kgF/cm^2, moderate shrinkage of 10.8 – 13.11 %, thes color characteristics ranged from grey to red on firing and good strength of 25.17-36.48 kgF/cm^2. It was discovered that the magnitude of the shrinkage and modulus of rupture increases directly proportionally to temperature. While increase in temperature is inversely proportional to the apparent porosity, water absorption , apparent density and modulus of plasticity. From this study, it is inferred that, Ogijo clay can be used for tiles, sanitary wares, utensils and refractory production.

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