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A STUDY OF PHYSICAL PROPERTIES OF SELECTED NIGERIAN CLAYS FOR FURNACE BRICK LINING PRODUCTION

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Abstract

The *physical properties of some clay deposits from six locations spread over three States in Nigeria have been investigated for furnace brick lining (refractory) production. The principal properties of the clays determined were: sticking point temperature, sintering temperature, cold crushing strength, bulk density, apparent porosity, shrinkage/growth and thermal shock resistance. Shuwari clay has a refractoriness of 1500°C, apparent porosity, 14.02%, bulk density, 1.88 Mgm*$^{-3}$*, cold crushing strength, 7.75 MPa, shrinkage/growth, 1.52% and thermal resistance of 6 cycles. Pulka clay has a sintering temperature of 1250°C with corresponding refractoriness of 1400°C, cold crushing strength, 9.25 Mpa, apparent porosity, 15.87 %, bulk density, 1.61 Mgm-3 and thermal shock resistance 1 cycle. Ngala clay has a low firing temperature of 1000°C, sintering temperature, 1200°C. Its cold crushing strength, apparent porosity and thermal shock resistance were not determined. Ubulu-Uku clay sintering temperature was 1700°C, its estimated refractoriness 1900°C; apparent porosity, 17.0 %, bulk density 1.70 Mgm-*^{3}*, and its estimated thermal shock resistance was 14 cycles. Eruemukohwarien clay has sintering temperature of 1400°C, estimated refractoriness, 1650°C, cold crushing strength, 7.74 Mpa, bulk density, of 1.78 Mgm*$^{-3}$*, apparent porosity, 16.77 % and thermal shock resistance of 12 cycles. Ijetu clay has sintering temperature of 1450°C, estimated refractoriness, 1700°C, cold crushing strength was 17.21 Mpa, bulk density, 1.74 Mgm*$^{-3}$*, apparent porosity, 15.70% and thermal shock resistance 12 cycles. The possible areas of application of the clays have been suggested in this paper.*

Keywords: Clay, refractory, equatorial zone, arid zone, principal properties

INTRODUCTION

Clay is naturally occurring sediment produced by chemical action resulting during the weathering of rocks. Often clay is the general term used to identify all earth's that form a paste with water and harden when heated. Clay generally are grouped into two parts on the basis of mineral formation that is primary and secondary clays. The primary clays are those located in their place of formation. While secondary clays are those that have been moved after formation to other locations by natural forces, such as water, wind and ice. The U.S. Department of Agriculture distinguishes clay as having small grains, less than 0.002mm in diameter (Brady. and Clauser, 1991). Some clays derive much of their plasticity from colloids or organic material, and since all clays are of secondary origin from weathering and decomposition of rocks, they may vary greatly in composition.

The hardness of a clay depends on its texture as well as on the cohesion of its constituent particles. Plasticity involves the ability of the clay to be moulded when wet, to retain its shape when dry, and to have the strength to withstand handling in the green, or unfired condition. Clays that require large amounts of water for plasticity tend to warp when dried. Owing to the almost universal presence of iron, clays with as much as 1% iron burned, and titanium increases this colour ((Brady and Clauser, 1991). Clays can be classified as low melting, high melting and refractory. The typical composition of each type is shown in Table 1.

Table 1: Typical Chemical Composition of Clay Types (Skestoperov, 1983)

	Composition %					
Clay Type	SiO_2	Al_2O_3	Fe_2O_3	CaO+MgO	K_2O+Na_2O	LOI
Low melting	35-80	7-21	3-12	0.5-3	1-5	3-15
High melting	53-73	16-29	1-9	0.5-2.6	0.7-3.2	4.12
Refractory	46-62	25-39	0.4-0.7	0.2-1.0	0.3-3.0	8-18

Clay is the oldest and most common of the refractoriness. Materials with a melting point above 1580°C are called refractory and those with melting point above 1790°C (seger cone 36), are called highly refractory (Brady and Clauser, 1991). Refractories may be considered to be composed of three types of phases (Nwajagu and Orumwense, 1996). These are the high performance phases, the low melting point phases and holes. The high performance phases are mechanically strong, chemically almost unreactive and with good thermal shock resistance. They are volume stable up to their temperature limits. The low melting points phased on the other hand are chemically vulnerable, weaker mechanically and have strong wetting tendency towards the high performance phases. The holes have low chemical and spall resistance, and low thermal conductivity. Refractories may be acid, such as silica, or basic, such as magnetise and bauxite, for use in acid or basic-process steel furnaces. The natural refractories are kaolin, chromite, bauxite, zirconia, graphite and magnesite, which are natural minerals. Synthetic minerals are often used to manufacture refractory products; powders of the raw materials are mixed and usually dry-pressed to form the desired shape. The refractoriness of materials depends on its chemical and mineralogical composition as well as its dimensional stability on heating, and to some extent, its texture. The chemical composition, and the properties of the clay specify the area of its applications. Recent studies of the chemical composition of some clay deposits in some State of Nigeria showed that some of them can be used as refractory products (Inegbenebor et al, 2000). The results of the chemical compositions showed that the clays studied belong to fireclay group. Most importantly, the content of silica and alumina oxides were found to be in the range of 39-51% of silica and 29-42% of alumina.

In Nigeria, abundance of fireclay has been reported to exist in coal fields in Enugu State, (Orumwense, 1992). Also they are present in Onibode and Oshiela in Ogun State (Anagbo, 1981). Fireclay, refractories are the most common refractories in general use because of their cheapness (Nwajagu and Orumwense 1992). In iron works, they find use in blast furnace stack, bosh and hearth, and in laddles. In steel works, they appear in open hearth, not exposed to the steel making temperatures, fill the checkers, line and laddles, form its stopper and appear in the casting bay as runners and guide tubes. Also in the soaking pit and reheating furnace, fireclay is the basic building material in red brick industry. Therefore, it became necessary to look into the physical properties of the clays before recommending them for refractory production. The physical properties of the clay samples must be studied as these would have a greater effect on the final quality of the refractory production. These properties include, sintering and sticking points, cold crushing strength (C.C.S.) bulk density, apparent porosity (AP) shrinkage/growth, and thermal shock resistance. The aim of this work is to determine the physical properties of the clay samples in some States of Nigeria with a view to establishing their suitability or otherwise for refractory production in Nigeria.

MATERIALS AND METHODS

Two zones of Nigeria were considered for collection of clay samples for this work. They are equatorial zone (Ijetu, Ubulu-Uku and Eruemukohwarien in Edo and Delta States) and arid zone (Shuwar, Pulka and Ngala in Borno State) of Nigeria. The reasons for the choice of the deposits has been given elsewhere (Inegbenebor et al 2000).

Enough quantities of the various clay samples were dug with shovel from the deposits and sun-dried for a day to reduce the moisture content and enhance grinding. Some quantity of each sample was crushed using a jaw crusher. They were further ground, passed through a sieve of 2mm mesh and mixed with water at 7%, 15%, 9%, 5%, 14% and 16% by mass for samples A,B,C,D,E and F respectively. The plastic mass was then introduced into a cylindrical ramming mould of 5cm x 5cm which was greased. Fifty (50) blows of the machine rammer head was delivered before the brick sample was extracted from the ramming mould, which is open at both ends, using a plunger. The prepared samples were then dried in an oven at a temperature of 110°C for 24 hours. These samples were then transferred into an electrical muffle furnace and fired at an interval of 100°C for every 10 minutes until the desired firing temperature for each sample was reached. The samples were soaked for further 3 hours at the desired firing temperature; 1000°C for samples B and E, 1200°C for samples A,C, D and F and then allowed to cool in the furnace for 24 hours. The samples were each subjected to the following analysis:-

Table I: Samples Information (Inegbenebor et al, 2000)

	Samples	State	Location	Appearance/Colour
1	A	Borno	Shuwari, on Maiduguri-Damboa Road	Grey
2	B	Borno	Pulka, Gwoya L.G.A Council	Dark Brown
3	C	Edo	Ijetu, Etsako West L.G. Council	Brownish with dark patches
4	D	Delta	Ubulu-Uku, Aniocha South L.G.A Council	Reddish with grey patches
5	E	Borno	Gamboru-Ngala, Ngala L.G Council	Blackish
6	F	Delta	Eruemukohwarien Ughelli North L.G. Council	Light Brown/Grey

(i) **Sintering and sticking points**

The shuttle -like combustion boat was filled with crushed clay powder and placed in the electric muffle furnace preheated to 750°C and fired at intervals of 50°C per 5 minutes. After each five minutes, the boat was removed, cooled and observed. The boat content was then pierced with a needle. The sticking point was recorded when the grains only adhere to each other. The sintering temperature was recorded when sintering is achieved.

(ii) **Cold crushing strength (C.C.S)**

The hydraulic compression testing machine was used to subject the 5cm x 5cm bricks to a gradually increasing load until fracture occurred. The observed load at fracture and the surface area of the brick was used to calculate the C.C.S. That is crushing force divided by the surface area in Mpa C.C.S = Force/Area.

(iii) **Bulk Density**

The specimen was cut into convenient sizes so that they can enter the volumenometer cup easily. The pieces were weighed and recorded. The test pieces were then introduced into the volumenometer cup which was then operated. The mercury in the calibrated meter rises by pressure to the corresponding volume of the mass of the test piece. The reading on the volumenometer was then recorded. Bulk density was then calculated, which is the ratio of the mass to the volume. $P_R = M/V_R$ in g/cm^3 or Mgm^{-3}.

(iv) **Apparent Porosity (AP)**

The prepared sample was weighed, the dry weight (W_1) was recorded. The sample was then placed in a dissector, and evacuated by air using water from the tap for 35 minutes. Water was connected to the evacuated dessicator bearing the sample, and allowed to submerge the sample just above their heights. The dessicator was again degassed. Bubbles were observed as the pores in the specimen were filled with water. After about 35 minutes, the sample was removed, cleaned and weighed, the weight W_2 was recorded. The porosity was then calculated

$$\text{as} \quad \frac{W_2 - W_1}{W_1} \times 100 \text{ in percentage.}$$

(v) **Shrinkage/Growth**

The dimensions of the test samples were taken at the green state. The dimensions of the dried specimens were also taken (at 100°C). The dimensions of the samples were also taken after firing. The shrinkage/growth of the samples was calculated both at dried state and fired state.

$$\text{Shrinkage/growth} = \frac{\text{Change in length}}{\text{Original length}} \times 100\%$$

$$\text{Linear shrinkage/Growth} = \frac{l_f - l_o}{Lo} \times 100\%$$

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Where L_f is the length after firing

L_o is the original length before firing.

(vi) **Thermal Shock Resistance**

The test bricks were placed in the electric muffle furnace preheated at 1200°C, and were allowed to soak for 10 minutes. The samples were then cooled outside the furnace for 10 minutes and observed for cracks. This process was repeated until cracks appeared on the specimens. The number of heating and cooling (cycles) before cracking occurred, was recorded and this was the thermal shock resistance for the sample.

RESULTS AND DISCUSSION

Table 2 contains the results of the studies of the physical properties of the clays samples from six sites in the equatorial and arid zones of Nigeria.

SHUWARI CLAY (SAMPLE A.)

Table 2, shows that the sticking and sintering temperatures of the Shuwari clay (Sample A) are high (1200°C and 1300°C respectively) and its Alumina, which is a determinant factor for the refractoriness of clays, was found to be 36% (Inegbenebor et al 2000). This gives Shuwari clay the high sintering temperature of 1300°C, which corresponds to between Seger cones 8 and 10 while the estimated refractoriness of 1500°C, corresponds to seger-cones of 16-18, (Delta Steel Company, 1982). The firing temperature and the flux content affect the strength of clay, (Chesters, 1974). The liquid phase upon firing, imparts strength, due to the amount of fusible matter or bond produced by the liquid phase at the firing temperatures. The cold crushing strength (C.C.S) is 7.75 MPa which is moderate.

Table 2: Summary of the results of the determined physical properties of the clays from equatorial and arid zones of Nigeria.

S/N	The Properties Parameter	Sample A Shuwari in Borno State	Sample A Pulka in Born State	Sample C Ijetu in Edo State	Sample D Ubulu-Uku in Delta State	Sample E Ngala in Borno State	Sample F Eruemukohwarien Delta State
1.	Sticking Point (°C)	1200	1300	1350	1600	1150	1300
2.	Sintering Temp. (°C)	1300	1250	1450	1700	1200	1400
3.	Cold Crushing Strength (MPa)	7.75	9.95	17.21	12.78	-	7.74
4.	Bulk density Mgm^{-3}	1.88	1.61	1.74	1.76	1.75	1.78
5.	Apparent porosity (%)	14.02	15.87	15.70	17	-	16.77
6.	Shrinkage/Growth (%)	1.52	2.12	2.65	0.30	5.72	5.04
7.	Thermal Shock	6 cycles	1 cycles	12 cycles	14 cycles	-	12 cycles

The bulk density, porosity and shrinkage/growth are properties which depend on the pore distribution in the clay. The bulk density of Shuwari clay is high at 1.88mgm^{-3} as a result of the low apparent porosity (14.02%) and high growth of 1.52%. The growth exhibited by this clay is an indication of the presence of expanding clay minerals with high coefficient of thermal expansion. Thermal shock resistance is moderate at six cycles. Based on the chemical analysis (Inegbenebor et al, 2000) and the physical properties of this clay, it can be grouped under the kaolinitic siliceous fireclays (Smithels and Brandes, 1978), of high-melting, medium-duty clay types (Brady and Clauser, 1991; Skestoperov, 1983). It should find application in structural engineering works as building or burnt bricks, general purpose brick used in the construction of re-heating furnaces and ladle linings.

PULKA CLAY (SAMPLE B)

Table 2 also shows the physical properties of Pulka clay (Sample B). The sticking and sintering temperatures are low at 1200°C and 1250°C respectively. This low value is associated with the high alkali impurities (Inegbenebor et al, 2000). The sintering temperature of 1250°C corresponds to seger-cones between 4a-7, and the refractoriness is estimated to be a temperature of 1400°C which corresponds to seger-cones 13-15. The cold crushing strength is high at 9.25 MPa; the bulk density, moderate at 1.61 Mgm^{-3} ; the apparent porosity, low at 15.87% and the growth is high at 2.12% , probably due to its high silica content of 51%,which should logically raise its coefficient of thermal expansion. The thermal shock resistance of Pulka clay is very poor, that is one cycle. The clay after being fired to 1000°C showed initial cracking on the surface, therefore, it could not withstand the thermal stress that it was subjected to. The results of the physical analysis agreed with that of chemical properties (Inegbenebor et al, 2000) which grouped Pulka clay as a kaolinitic siliceous semi-acid fireclay, of the low-melting, medium-duty clay type.

Refractoriness does not alone determine the suitability of a refractory material other furnace elements contribute (Krivandin and Morkov, 1980). It was observed that Pulka clay is highly reactive, it deforms in shape and growth increases abnormally when fired above 1000°C for an extended period of time. For this reason, Pulka clay can only be used in refractory applications below 1000°C, that is, if it is necessary. The high cold crushing strength will make it very suitable for construction building materials (bricks), it can also be used in earth dams and water canals.

IJETU CLAY (SAMPLE C)

Table 2, further shows that the sticking and sintering temperatures for Ijetu Clay (Sample C) , are high being1350°C and 1450°C respectively and the refractoriness of 1700°C, corresponding to seger-cone of 31, is also high probably because of its high alumina and low lime contents (Inegbenebor et al, 2000). The cold crushing strength of 17.21 MPa gives this clay a high fracture strength at room temperatures, higher strength will be achieved at a temperature close to its sintering temperature. The bulk density of Ijetu clay is high at 1.74 Mgm^{-3}, porosity and shrinkage are both low at 15.70% and 2.65% respectively.

These results put the Ijetu clay in the high alumina clay category. Kaoliniic in nature, it falls under the heavy-duty, high refractory normal fireclay. Ijetu clay will perform excellently as a general purpose brick for use in reheating furnaces, open-hearth furnace, soaking pits, boilers, kilns etc. It can substitute for imported fire clay bricks.

UBULU-UKU CLAY (SAMPLE D)

The results of the physical properties of the Ubulu-Uku clay (Sample D) are also shown in Table 2. The sticking and sintering temperatures are 1600°C and 1700°C respectively. These high values are in agreement with the high alumina contents (Inegbenbor et al, 2000), the sintering temperature has a seger-cone 31 and the estimated refractoriness of 1900°C corresponding to seger-cone 42 is expected. The cold crushing strength is 12.78 MPa which can be improved upon by firing the clay close to the sintering temperature so as to enable fusion of the liquid phase and the clay materials form a higher bonding strength. The clay has a high bulk density of 1.76 Mgm^{-3} which will increase at higher firing temperature, and its apparent porosity is low at 17% while a linear growth of 0.30% is also very low, suggesting that thermal expansion is also low. It has an excellent thermal shock resistance of fourteen cycles, which should make its use very economical. Other economic advantages are good resistance to slag attack and erosion by grit laden gases.

From the results of chemical analysis (Inegbenebor et al, 2000), and physical properties of this clay, it can be grouped as a high-alumina kaolinitic clay. It is heavy-duty, neutral oxide highly refractory clay. It can be employed in any severe conditions in all types of combustion chambers. It is recommended that Ubulu-Uku clay be exploited for local production of refractory bricks in steel production.

NGALA CLAY (SAMPLE E)

The physical properties exhibited by Ngala clay are very poor for it to be considered for use as refractory material. Although it possesses some excellent chemical composition (Inegbenebor et al, 2000), its reaction upon firing concludes its unsuitability for most structural and refractory application. The results of the physical properties of Ngala clay shown in Table 2 include sticking and sintering temperatures of 1150°C and 1200°C respectively. Hence, the refractoriness is estimated to be less than 1400°C, with a corresponding seger-cones between 11 to 13. The cold crushing strength of Ngala clay could not be estimated from the compression-testing machine used. Readings on the measuring scale could not be obtained as the clay collapses the instance load was applied. This brittleness could be as a result of the fine grain structure and about 21% by weight of the clay consists essentially of organic matter. Upon firing, the organic materials and other alkali impurities are burnt off leaving a highly porous structure in the clay mass with the resultant brittleness. Ngala clay has a bulk density of 1.75 Mgm^{-3} and it is believed to be highly porous, although porosity test could not be carried out on the clay, as most of the test sample particles fell off from the brick before it was brought out from the dessicator. Shrinkage was very high at 5.72%. The reason of this high shrinkage could not be ascertain. Thermal shock resistance was not determined for the clay, since it shrinks, cracks and warps considerably even on drying at 110°C.

Ngala clay can be grouped as a ball clay, due to the high presence of impurities, thereby falling under the low-melting, low-duty fireclay. The high plasticity of this clay makes it useful as an additive to bodies deficient in plasticity to make them workable, it can also be used as binders in foundry sand, and as drilling mud.

ERUEMUKOHWARIEN CLAY (SAMPLE F)

The physical properties of the Eruemukohwarien clay (Sample F) clay are shown in Table 2 included the high sticking and sintering temperatures of 1300°C and 1400°C respectively. Its sintering temperature corresponds to seger-cone 14, and the estimated refractoriness was about 1650°C (Seger-cone 30). The cold crushing strength moderate at of 7.74 MPa. This clay has a high shrinkage value of 5.04%, with a measured bulk density of 1.78Mgm^{-3} and apparent porosity of 16.77%. Its thermal shock resistance of twelve cycle was excellent, indicating its ability to withstand sharp temperature variation without cracking. The clay can be grouped under the medium-duty semi-acid refractory fire clay. The clay will find application in reheating furnaces, open-hearth furnace doors and checkers, soaking pits, kilns, boilers etc. It can also be employed in structural building bricks.

In Summary, Table 3 shows the colour changes at temperature and possible of usage of the clays samples from different localities.

Table 3: Colour changes at temperature and possible of usage of the clay samples from different localities (Inegbenebor et al, 2000)

Sample	Colour Eummited	Temperature °C	Possible areas of use
A	Reddish	1200	Line regenerator laying the lower Course of the hearth, laddlelining cement factory; burnt bricks and other ceramic application
B	Reddish	1000	Earth dam, canals and building Bricks
C	Reddish brown	1000	As binders in foundry sand and as drilling muds
D	Reddish with grey patches	1200	Re-heating furnace, combustion chambers, open-hearth furnace, soaking its, boilers, kilns etc.
E	Reddish with grey Patches	1200	Re-heating furnace, combustion chambers, open-hearth furnace, soaking pits, boilers, kilns. Also in structural buildings bricks
F	Reddish	1200	Re-heating furnace, open-hearth furnace doors and checkers, soaking pits, kilns, boilers, also in structural building bricks.

CONCLUSION

The samples from Ubulu-Uku, Ijetu, Ememukohwarien and Shuwari can be employed in high temperature applications, and because of their high fusion points, they are classified as high refractory clays. The other physical properties parameters such as cold crushing strength, bulk density, apparent porosity, linear shrinkage and thermal shock resistance are good enough to make them suitable for fire clay refractory. They could be used in many thermal unit applications where refractory are necessary. The other two clays from Ngala and Pulka are grouped under the low-melting clay types, not suitable for refractory production.

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