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Characterization of Dabagi clay deposit for its ceramics potential

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A clay deposit in Gwandu Town of Kebbi State, Nigeria has been evaluated for its potential as industrial raw material. The chemical analysis was carried out using X-ray florescence spectrometery while physical property tests such as porosity, bulk density, linear shrinkage, thermal shock resistance, cold crushing strength and refractoriness were done using standard techniques. The result of chemical analysis indicated that the clay was composed of silica (SiO_2), 64.50%; alumina (Al_2O_3), 16.30%; iron oxide (Fe_2O_3), 14.20%; calcium oxide (CaO), 0.2%; potassium oxide (K_2O), 0.74%; titanium oxide (TiO_2), 1.71% and other oxides in traces. The chemical analysis suggests that the clay deposit is mainly made of kaolinite and free quartz. Result of the physical tests shows that the clay has an apparent porosity of 28.46%, bulk density of 1.81 g/cm^3, linear shrinkage of 6.80%, thermal shock resistance of seven cycles, loss on ignition test (L.O.I) of 4.46%, cold crushing strength of 14138 Nm^{-2} and estimated refractoriness of 1349°C.

Key words: Dabagi clay deposit, characterization, x-ray fluorescence and technological tests, Kaolinite, ceramic applications.

INTRODUCTION

Clay is a natural earthy, fine - grained material that acquires plasticity on being mixed with limited quantity of water (Velde, 1992; Idenyi and Nwajagu, 2003). From a chemical or mineralogical standpoint, clay is a complex aluminosilicate compounds containing attached water molecules, which have their origin in the chemical and mechanical disintegration of rocks, such as granites (Nwajagu, 2005). Clay occurs most abundantly in nature in solids, sediments, sedimentary rocks and hydro-thermal deposits (Velde, 1992). One basic property of or other polar ions into their structure. This is called the swelling property. Based on this property, Velde (1992) broadly classified all clays into swelling and non-swelling type. Swelling clays are called smectites. The important

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property according to Velde (1992) is the basic composition and structure of the clays; and this is used to further classify the clay minerals into: Kaolinite group ($Al_2Si_2O_{10}$ (OH_6)): this group has one silica and one alumina unit stacked in alternating fashion (1:1 lattice type). No ion or water molecules can enter the adjacent layers, and only the external surfaces determine their colloidal properties.

Owing to its relatively large particles and low specific surface, kaolinite exhibits less plasticity, cohesion and swelling as compared to other clay minerals. Kaolin is an important and widely used industrial mineral which is refined from kaolinite. It is a naturally occurring minerals of the clay family and may contain a number of impurities such as quartz, feldspar, tourmaline, limestone, zircon, etc. which were derived from the parent rock. It is a weathering product of silicate rocks which is whitish, earthy to dull with plastic touch.

The characteristics and chemical composition of a kaolin deposit usually determines its industrial utilization. Kaolin is one of the most valuable of the industrial clays which is used in most manufactured products. Prominent uses include paper filling and coating; paint, plastic, adhesive and ink pigment; rubber reinforcing agent, ceramic raw materials for porcelain, dinner ware, tiles and enamels, catalyst for petroleum cracking and auto exhaust emission catalytic control devices; cosmetics base; and digestive coating remedy (RMRDC, 2010); Bentonite: bentonite belongs to the group of clays whose technical properties are controlled by the proportion of montmorillonite, a sub-group within the smectitic clays. It is clay derived from deposits of weathered volcanic ash. Bentonites are hydrated aluminosilicates, which composed predominantly of the clay mineral montmorillonite. They are composed of a 3-tier structure with alumina silica sheets' sandwiched between tetrahedral silica units. A simplified formula for montmorillonte is Al_2O_3. $4SiO_2.H_2O$, the other minerals that could be found in bentonite in small content are chrystobalite, biotite, chalcedony, calcite, pyrite, dolomite and plagioclase. There are three principal types of bentonite namely: natural sodium bentonite or sodium montmorillonite, natural calcium bentonites or calcium montmorillonite; and sodium activated bentonites or sodium activated montmorillonites.

Natural sodium bentonite as the name suggests, occurs with sodium as the predominant exchange cation. They are characterized by high swelling, high liquid limit and high thermal durability. It is usually used for drilling mud. The vast majority of the montmorillonites occurring in abundance worldwide is of the calcium type and is referred to as calcium bentonite. Much lower swelling and liquid limit values compared to natural sodium bentonite, characterize them.

Calcium bentonite is used as a bleaching agent in cooking oil industries, bleaching agent in lubricant oil recycling, as a catalyst, absorber, filler, etc.

Bentonite has a wide range of industrial uses. The physical and chemical properties of bentonite make it an important industrial mineral, which has widespread application in various industrial sectors such as foundry sand bond in iron and steel foundries and in iron ore pelletizing in metallurgy; this is probably the largest use for bentonite, as insulator in civil engineering as an efficient materials for drilling mud (because the gel-like suspension it forms in water), as bleaching clay in oil refining, clarifying and decolourising, filtering agent for clarifying wine, beer and treating waste water, Ingredient in cosmetics, animals feeds and pharmaceutical (RMRDC, 2010).

Glass sand/quartz: silica sand/quartz constitutes one of the most readily available geological materials used in industries and factories such as glass manufacturing companies. Silica sand/quartz are said to consist of high optimal percentage of silicon oxide (SiO_2) which is a very good chemically stable element and it remains almost the same no matter the series of cycles it may have gone through, either in transportation or re-deposition. Quartz is silica occurring alone in pure state. Silica/glass sand on the other hand are products of weathering, erosion and transportation by rivers or/and the sea. Naturally occurring silica sands may contain some undesirable impurities like accessory haematite, rutile and dolomite etc. The glass sand is used in the production of various glass products: which include sheet glasses, for windows, bottles, mirrors, optical instruments, chemical apparatus, electrical insulation and condensers, pipe, doors, crucibles, automobile and aircraft bodies, filters and building blocks. They are also used for making abrasives and for gravel parking in the petroleum industries (Nwoye, 2009).

Clay products are versatile industrial material that have amazing variety of uses and applications in ceramics porcelain, dinner wares, glasses, refractory bricks, burnt bricks and architectural tiles and ceramic (Akudinobi, 2006). Important uses have also been found for clays in the rubber industry where its reinforcing potential has been exploited since the early part of 21^{th} century, particularly those with tolerable presence of silica (which serve as reinforcing component in rubber compounding) (Akudinobi, 2006).

The important properties of clay are plasticity, colour, strength, drying and firing shrinkages. The percentage of the minerals oxide (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) indicates their suitability for ceramic products Nnuka and Agbo (2000).

Nigeria has appreciable distribution of industries engaged in metal production and other process industries, and hence, there is need for raw - material to

Table 1. Chemical composition of Dabagi clay compared with standard clay for industrial applications: Chester (1973) and Grimshow (1971).

Composition	Dabagi clay	Ceramics	Refractory brick	High melting clay	Glass	paper	Paint
SiO_2	64.50	60.50	51.70	53-73	80-95	45.0-45.8	45.3-47.9
Al_2O_3	16.30	26.50	25-44	16-29	12-17	33.5-36.1	37.9-38.4
Fe_2O_3	14.26	0.5-1.2	0.5-2.4	1-9	2-3	0.3-0.6	13.4-13.7
CaO	0.26	0.18-3	0.10-20	0.5-2.6	4-5	0.03-0.60	0.03-0.60
K_2O	0.74	-	-	-	-	-	-
TiO_2	0.17	-	-	-	-	-	-
CuO	0.03	-	-	-	-	-	-
V_2O	0.08	-	-	-	-	-	-
LOI	4.46.	8.18	8-18	5-14	-	-	-

support their growth. Clay products such as ceramic wares, burnt bricks and floor tiles are cheaper and more durable building materials than cement particularly in Nigeria.

There are vast deposits of clay spread across every region in Nigeria, though their properties differ from one site to another on account of geological differences. The present economic state imposes the need for sourcing of local material to meet the increasing demands. This study therefore is to ascertain the chemical composition and mechanical/physical properties of Dabagi clay deposit in Gwandu town of Kebbi State of Nigeria so as to highlight its ceramic value, economic potential and encourage its immediate industrial application/ uses.

MATERIALS AND METHODS

Sample preparation

Stratified random sampling was used. 10 m sample area was divided into ten smaller units and from each unit three samples were collected randomly at a depth of 10 cm, mixed and homogenized. Cone and quartered method was employed until a required (representative) sample was obtained. The coning and quartering means pouring of the clay sample on a flat surface such that it formed a cone which was divided into four equal parts by using a straight edge.

The two alternate quarters are mixed again for further quartering. The representative fractions for the sample was later crushed and grounded to produce 60 mesh (BS). The crushed sample was used for analysis.

Chemical analysis

The chemical composition of the clay was determined using X-ray florescent (XRF). 1 g of clay sample was added to 10 g of anhydrous lithium tetra borate ($Li_2B_4O_7$) acting as a fluxing agent. The constituent were mixed inside a cleansed crucible and heated up to 500°C for 8 min and allowed to cool at room temperature to obtain the fused sample which was used for the analysis. The chemical composition of the sample is presented in Table 1.

Loss on ignition test (L.O.I)

This is the quantity of chemically combined H_2O (and sometimes organic matter content) in inorganic materials (Udochukwu, 2007). Fifty grams of the clay sample was dried in an oven at 110°C and cooled in the desiccator. A porcelain crucible was cleaned, dried and weighed (M_1) to nearest 0.001 g. The dried sample was introduced into the crucible and crucible together with the clay sample ions weighed (M_2) to an accuracy of 0.001 g. The crucible containing the sample was placed in a muffle furnace and heated to a temperature of 900°C for 3 h, were cooled in a desiccator and then weighed (M_3). The loss on ignition was calculated from Equation 1):

$$LOI = \frac{M2-M1}{M2-M3} \quad (1)$$

Apparent porosity test

Apparent porosity is the ability of the clay materials to be impervious to gasses and liquids. Pores are formed as water and gasses are given off during firing process (Nwajagu, 2005). Specimen measuring 5 x 5 x 4 cm was prepared from a conveniently made clay brick; it was dried in an oven at 110°C and fired in a furnace at interval of 100°C for every 10 min till the temperature of 900°C was attained. The fired specimen was cooled and then transferred into a desiccator and dried weight (D) was recorded. The specimen was then transferred into a 250 ml beaker; water was then introduced into the beaker until the tested specimen was completely immersed in the water. The specimen was allowed to soak in boiled water for 30 min being agitated from time to time to assist to release trapped air bubbles. The specimen was then transferred into empty desiccator to cool. The soaked weight (W) was recorded. The specimen was weighed suspended in water using beaker place on balance. This gave suspended weights (S). The apparent porosity was calculated using Equation 2:

$$\text{Apparent porosity} = \frac{W-D}{W-S} \times 100\% \quad (2)$$

Bulk density test

Bulk density is the mass per unit volume of the clay ignoring the

Table 2. Physical properties of Dabagi Clay compared with standard clay for industrial applications (Omowumi, 2000).

Sample description	Apparent porosity (%)	Bulk density (g/cm^3)	Thermal shock - resistance (cycles)	Cold crushing strength (KN/M^2)	Refractoriness (°C)	Linear shrinkage (%)
Dabagi clay	28.46	1.81	7	14138	1349	6.80
Fire clay	20-30	2.30	20-30	15000	1500-1700	4-10
Siliceous fire clay	23.7	2.0	1	15000	1500-1600	7-10
Ceramics	10-30	2.30	20-30	15000	1430-1717	-
Refractory brick	10-30	2.-30	20-30	15000	1430-1717	-

volume occupied by pores (Idenyi and Nwajagu, 2003). The molded brick of the specimen measuring 5 x5 x4 cm was also prepared and dried for 24 h and then dried in an oven at 110°C cooled in a desiccator and weighed (dried weight) after which the specimen was transferred to a beaker containing water and heated for 30 min to assist in releasing air. The specimen was cooled and soaked weight (W) taken. The specimen was then suspended in water using beaker place on balance. The suspended weight (S) was taken. The bulk density was calculated from Equation 3:

$$\text{Bulk Density} = \frac{\rho W}{W - S} \qquad (3)$$

Where, ρ*w* = Density of water.

Thermal shock resistance test

Thermal shock resistance is the ability of the clay materials to withstand heating and cooling several times before a deep crack appears (Lawal, 2005). The test piece of brick was air dried for 24 h and oven at 110°C for 3 h. The specimen was then fired in the furnace at 900°C for 3 h and allowed to cool. The prepared specimen was then inserted in a furnace which has been maintained at 900°C.

The specimen was removed from the furnace with a pair of tongs and allowed cool for 10 min on firebricks. The specimen was returned to the furnace for further 10 min. The process was continued until the test piece was cracked. The number of cycles of heating and cooling before cracking of the specimen was recorded as its thermal shock resistance.

Linear shrinkage test

Linear shrinkage is a property of the clay which makes it to undergo least structural changes and disintegration while being heated (Lawal, 2005). The clay was moistened with water to the point of wedging (which implies that the moistened clay materials remain packed into a ball in hand until intentionally vibration causes the mixture to flow). The wedge sample was cast into fabricated wood box.

The clay bar was prepared and the original/initial length was marked on the sample. The bar was fired at temperature of 900°C for 3 h. The final length after the clay had been fired was recorded. The linear shrinkage was then calculated using the Equation 4:

$$\text{Linear shrinkage} = \frac{A - B}{A} \times 100\% \qquad (4)$$

Where, A = Initial or original length; B = Final length.

Cold crushing strengths test

Cold crushing strength is the ability of the clay to bear load (Udochukwu, 2007). A cube measuring 50 mm on a flat surface was made from the refractory brick the test piece was fired in a furnace at 900°C and the temperature maintained for 5 h. The sample was then cooled to room temperature. The specimen was placed on a compressive tester and the load was applied axially by turning the hand wheel at a uniform rate until failure occurred. The manometer readings were recorded. Cold crushing strength (CCS) was calculated from Equation 5:

$$\text{CCS} = \frac{Maximum\ \ load\ (KN)}{cross\ section\ \ area\ (M2)} \qquad (5)$$

Refractoriness test

This is the resistance of the clay to fusion and softening at high working temperatures. It is the maximum temperature clay can withstand with no load applied (Nnuka, 2003). The clay sample was formed into simple cones of 1.27 cm base diameter and height 3.81 cm. The cone was mounted on refractory base along with several other standard cones of the same dimensions and standard compositions, the cones were heated at a rate of 5°C/min in the furnace until the test cone bent over its own weight. After cooling, the test cone was compared with the standard cones. The test material was taken to have the pyrometric cone equivalent (PCE) of the standard cone whose behaviour most resembled that of the test cone.

RESULTS AND DISCUSSION

The results from the experimental work are given in Tables 1 to 2. The chemical results of Dabagi clay show high silica (SiO_2) content of 64.50% which satisfies the standard for the manufacture of refractory bricks, ceramics as well as high melting clay with values 51.70, 60.50 and 53-73% respectively but below the range for glass formulation. The alumina content (16.30%) of Dabagi clay is short of the standard required for ceramics (26.50%), refractory bricks (25-44%), paper (33.5-36.1%) and paint (37.9-38.4%) manufacturing industries as reported by

(Chester, 1973). However, it can still be used in the manufacture of high melting clay and alumino silicate and fibreglasses because they required only 16-29% and 12-17% of aluminum oxide respectively as reported by (Chester, 1973). The alumina content of clay is a strong indicator for its refractoriness. The higher the amount of alumina, the higher is the refractoriness of the clay. The iron oxide content of 14.26% is higher than the standard for refractory bricks (0.5-2.4%). Such level of iron oxide usually imparts reddish colour to clay when fired, so making it attractive as a ceramic raw material Nnuka and Agbo (2000). The high iron oxide content also affects the high temperature characteristics of the clay, such as fired strength. The loss on ignition of Dabagi clay is below the range of 8-18% for ceramic and refractory brick production as reported by Chester (1973) and 5-14% for high melting clay. Loss on ignition values are often required to be low (Omowumi, 2000). This is because of its effect on the porosity of material especially refractory bricks.

The physical tests results of Dabagi Clay show an apparent porosity of 28.46%, which is within the standard for the production of fire clay and siliceous fireclay with 20-30% and 23.7% respectively (Omowumi, 2000). The bulk density of 1.81 g/cm^3 is below the value required for the manufacture of fireclay and siliceous fireclay as reported by Omowumi (2000).

The linear shrinkage of the sample after drying and firing fall within the acceptable value of 4 - 10% for fireclay, High Shrinkage values may result in warping and cracking of the clay and this may cause loss of heat in the finished products.

The thermal shock of the clay sample is below the acceptable values of 20-30 cycles as compared in Table 2. The practical implication of this is that their use IS restricted to lining of cables slag pots.

The refractoriness or temperature reached for the sample was 1349°C. This is lower than the recommended range for the manufacture of fireclay, siliceous fireclay and ceramics industries and this may be due to the low amount of Al_2O_3 obtained for Dabagi Clay.

The cold crushing value obtained for Dabagi Clay was 14138 KN/M^2 which is below the specification for the manufacture of fireclay, siliceous fireclay and ceramics industries.

Conclusion

An experimental study was conducted to investigate the suitability of Dabagi clay as an industrial raw material in view of its chemical and physical properties. The result of the chemical analysis shows that Dabagi clay con-tains aluminum oxide (Al_2O_3) and silica (SiO_2) as major constituent. The apparent porosity and linear shrinkage of the clay are moderately high while the bulk density and cold crushing strength values are low.

The clay is therefore found to be a source of raw material for the production of refractory bricks, ceramics and high melting clay materials.

Recommendation

Dabagi clay deposit is one of the unidentified clay in Nigeria. This probably IS the first work on this clay deposit, thus, if this clay is exploited and harnessed, it will no doubt provide internal sourcing raw material used in ceramic, paper, high melting clay, refractory bricks etc. there is also the need for a geological survey to determine the extent of the deposit.

Some additives such as kaolin clay or limestone and rice husk ash should also be added so as to improve the properties of the clay.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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