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Industrial Potentials of Ebiaji Clay from Ezza North Area of Ebonyi State, Nigeria

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ABSTRACT

Ebiaji clay deposits in Ezza North local government area of Ebonyi State, Nigeria were characterized for its chemical composition and refractory properties. The chemical composition was carried out using Atomic Absorption Spectrophotometer (AAS) procedure, whereas the physical property were carried using American Society for Testing and Material (ASTM) standards at the department of Ceramics Research and Production Projects Research and Development Institute, Enugu State, Nigeria. The physical property analysed were as follows: Plasticity Index, Swelling Index, Linear Shrinkage, Refractoriness, Loss on Ignition, Water of Absorption, Bulk density, Apparent density and Chemical composition analysis. Results obtained showed that Ebiaji clay is abundant in oxides of silica (SiO_2), Alumina (Al_2O_3) and Iron (Fe_2O_3) with other oxides in minute quantity. The chemical analysis carried out indicates that the clay deposit is of the aluminosilicate refractories that are under the class of kaolinitic fireclay having high values of refractory properties similar to standards. In line with physicochemical characteristics of kaolinitic fireclay deposit, this study shows that Ebiaji clay can be harnessed for use in paper industry, ceramics, refractory bricks, tiles and color vase but requires additive to help obtain the desired properties.

Keywords: Ebiaji clay, Physicochemical characterization, Ceramics, Industrial potentials.

INTRODUCTION

Clays are high temperature material that are non-metallic in nature possessing the capacity to withstand high temperature and pressure applied on them which include thermal shock impact, high load of elevated temperature and chemical attack [1]. Clay consist of Silica (SiO_2), Alumina (Al_2O_3) and water (H_2O) together with moderate concentration of oxides of Iron, alkali and alkaline earth metals In addition it comprises of crystalline substances called clay minerals which include quartz, feldspar and mica [2]. Some clay deposit can contain some oxide impurities in a minute amount which can give rise to properties in clay that are of technical values [3]. Clay refractories are mostly produced from clay with alumina and silica content between 18-44% and 50-70% respectively [4]. Clays are much diversified in origin and it is very unlikely that clays from different deposits would be identical in composition and properties. Clay from the same deposit may vary in refractoriness, plasticity, chemical composition and other properties depending on the depth of occurrence [5].

Clays are immersed geological, industrial and agricultural importance [6]. The mineral components of clay enable understanding and management of erosion and flood related problems [7] and in the construction of tunnels, road cuts, fills and dams [8]. Depending on physical and chemical characteristics, clay may find application in a number of industries such as paint, ceramic, plastic, catalyst, pharmaceutical and fibre glass among others [9].

History has shown that research has been carried towards the conversion of clays for industrial uses and application. According to the findings of Omowumi [10], the characteristics of refractories obtained from Onibode, Ara-Ekiti, Ibamajo and Ijoko Clay samples were similar to imported fire clay refractories. Hassan et al. [11] discovered that Onibode refractory clays are appropriate for the manufacture of refractory bricks for furnace building.

Omotoyingbo and Oluwole [12] studied the properties of some Ekiti clay deposits and discovered mixing Ara clay 2 with a combination oftwo different Ara clays in equal proportion were appropriate for the production of crucible and furnace lining for non-ferrous metals processing such as aluminium, lead and bronze.

The refractory properties of clay deposit from Kuru, Alkaleri, Barkin-ladi and Bauchi were studied and it was found that clay samples from Alkaleri and Barkin-ladi are suitable for furnace construction as a result of presence of the following physical properties: high thermal shock resistance, crushing strength, bulk density and refractoriness value [13]. Refractory bricks from Onibode near Abeokuta had refractoriness of about 1750°C [14].

Appreciable physical and chemical requirement suitable for refractory purposes were found in some Kogi clay deposit in Northern part of Nigeria [15]. Irrespective of these findings, the Nigerian ceramics industry is still lacking behind.

Metal production and other process industries are widely distributed in Nigeria, therefore increasing the need of raw materials to support their growth. Clay products such as ceramic wares, burnt bricks and floor tiles are economical and long lasting building materials than cement especially in Nigeria [16,17]. There are large deposits of clay spread across every region in Nigeria, though their property varies from one side to another as a result of geological differences. The present economic condition highlights the need for looking out for more local materials to meet the increasing demand. This study therefore is to ascertain the chemical composition and physical properties of Ebiaji clay deposit from Ezza North area of Ebonyi State Nigeria in other to highlight its ceramic value, economic potential and encourage its immediate industrial application/uses.

MATERIALS AND METHODS

Sample preparation and moulding

The clay samples were collected from Ezza North LGA, Ebonyi state, Nigeria. The clay sample were collected from different locations at a depth of 1.55 m and blended properly to obtain a homogenous mixture. To obtain a representative sample, cone and quartered method as described by Abubakar et al. [17] was carried out. The mixture was agitated in water and shaken for proper dissolution. The dissolved clay particles were then filtered through a 0.425 mm mesh sieve to remove unwanted particles and plant materials. The filtrate was allowed to settle, and the excess water decanted off. The clay was dried under the sun and oven dried at $100^{\circ}C$ for 3 h, ground and passed through a mesh sieve of size 0.18 mm. 2.1 kg of the clay was weighed and agitated with suitable amount of water to make it workable for the moulding process.
The clay was then molded as described by Etukudoh et al. [3]. This was done by moulding the clay samples into three types of shapes by making use of metallic moulds and lubricants which were applied to the surface of the moulds to avoid the test pieces from sticking to the surface. The shapes of the molded clay are described by Etukudoh et al. [3].

Physical analysis

The physical properties analysis which include: moisture content, relative plasticity, modulus of rupture, linear and fired shrinkage, water of absorption, apparent density, apparent porosity, bulk density, loss on ignition and swelling index were carried out following standard procedures as described by Etukudoh et al. [3].

Chemical analysis

The weight of the clay (0.2 g) was taken and placed in a beaker and digested with 10 ml of aqua regia ($HCl + HNO_3$ in the ratio 3: 1 respectively) with a hot plate placed in a fume cupboard. Followed by addition of 10 ml of Hydrofluoric acid to aid the digestion process. The digested clay was further mixed with 30 ml of de-ionized water and filtered into a 250 ml volumetric flask using a filter paper and made up to mark with de-ionized water. The elemental composition analysis of the resulting sample was carried out using Atomic Absorption Spectrophotometer (Buck scientific model 210 VGP). The concentration of metal oxide in the clay was expressed in mg/l. The percentage composition of the elements in the clay was calculated from the equation:

$$\% \text{ Composition} = 100 \text{ CV/M}$$

Where C (mg/l) is the elemental composition obtained from the AAS, V (l) is the volume of the volumetric flask in which the digested solution was diluted and M (mg) is the mass of sample diluted [18].

Table 1: Chemical composition of Ebiaji clay compared with standard clay for industrial applications: Chester [19] and Grimshow [20]

Composition	Ebiaji clay	Ceramics	Refractory brick	High melting clay	Glass	Paper	Paint
SiO_2	44.32	60.5	51.7	53-73	80-95	45.0-45.8	45.3-47.9
Al_2O_3	28.7	26.5	25-44	16-29	Dec-17	33.5-36.1	37.9-38.4
Fe_2O_3	5.91	0.5-1.2	0.5-2.4	01-Sep	02-Mar	0.3-0.6	13.4-13.7
CaO	1.01	0.18-3	0.10-20	0.5-2.6	04-May	0.03-0.60	0.03-0.60
K_2O	1.68	-	-	-	-	-	-
Na_2O	1.73	-	-	-	-	-	-
MgO	0.77	-	-	-	-	-	-
MnO	0.37	-	-	-	-	-	-
LOI at 1200°C	14.94	8.18	-	-		-	-

RESULTS AND DISCUSSION

Table 1 showed the result of the chemical composition of Ebiaji clay deposits indicating that the clay has 28.7% Al_2O_3, 44.32% SiO_2, 5.91% Fe_2O_3, 1.73% Na_2O, 1.68% K_2O, 0.77% MgO, 1.01% CaO, 0.37% MnO and 14.94 Loss on Ignition (LOI) as its constituent matter. The results showed that silica (SiO_2) and alumina (Al_2O_3) constitute the major components of the clay whereas the other metal oxides were found in negligible amounts. The alumina content of Ebiaji clay shown in Table 1 is 28.7% which fell within the range of 25-40% for refractory bricks and 25-45% required for fire clay but did not meet the requirement for manufacture of paper (33.5-36.1%), paint (37.9-38.4%) and glass (12-17%) [19,20]. Alumina content of clay determines its refractoriness [21] and the greater the percentage of alumina in clay, the higher the refractory property of the clay. The silica composition of Ebiaji clay deposit did not meet the requirement for the production of ceramics (>60.5%), refractory bricks (>51.7%), high melting clays (53-73%), glass (80-90%), paper (45.0-45.8%) and paint (45.3-47.9%) [19,20]. High value of silica content and other oxide such as Fe_2O_3 contribute to low refractoriness [22]. In this study, the relative increase in value of refractoriness of Ebiaji clay deposit can be as a result of increase in alumina contents of this sample. The Iron oxide (Fe_2O_3) content of Ebiaji clay was higher than the standard requirement for ceramics (0.5-1.2%), refractory bricks (0.5-2.4%), glass (2-3%) and paper (0.3-0.6%) [16]. but met the standard specification for the production of high melting clays which requires only 1-9% of Fe_2O_3 as reported by Grimshow [20]. In addition to that, increased amount of Iron oxide gives the clay body a red color when fired making it appropriate for making products such as flower vase that requires such coloration [16]. The reddish brown coloration acquired after firing of the clay body was as a result of presence of Fe_2O_3 (Table 1). The color of the clay makes it inappropriate for production of white ware products [23]. The existence of alkali metal oxides (CaO, K_2O and Na_2O) in Ebiaji clay are the main fluxing and ion exchange materials in clay. Thus the vitrification and ion exchange materials of these clays are expected to be low. This however is an added advantage for its use in brick making since a high level of CaO can cause undesirable expansion and subsequent cracking in structures [24]. The loss on ignition of Ebiaji clay is 14.94 (Table 1) which represents removal of water vapour from dehydroxylation reactions in the clay minerals, carbonate decomposition into CO_2 and oxides as well as burning out of organic matter or other impurities present in the clay [25]. It fell within the standard specification for the production of ceramics (>8.18), high melting clays (5-14%) and refractory bricks (8-18%) [20]. It also suggest that Ebiaji clay is of fine grain and compacted as high LOI implies higher porosity due to removal of LOI component during firing. The refractoriness or temperature reached for the sample was >1250°C. This is lower than the range of 1580-1750°C accepted internationally for refractory materials [26]. This may be as a result of low amount of Al_2O_3 and existence of alkali metal oxide fluxes in Ebiaji clay which reduced its refractoriness. The refractoriness of Ebiaji clay was close to that reported by Etukudoh et al. [3].

The physical test results of Ebiaji clay were shown in Table 2. The firing shrinkage of clay is a very useful and important property in the manufacture of refractory bricks. This is as a result of high shrinkage value giving rise to warping and cracking of clay that may lead to loss of heat and produce undesired finished product. The linear shrinkage of Ebiaji clay when fired at different temperature gives rise to the following observation. It is observed that a rise in the linear shrinkage of the clay from 2.17 to 9.33% with rise in the firing temperature from 900 to 1200°C was recorded. This increase may be as a result of expulsion of certain constituents in the clay body with rise in temperature giving rise to sintering and subsequently vitrification of the clay body. Therefore with rise in temperature the clay tends to be pressed together and may result in reduction in porosity. The linear shrinkage of Ebiaji clay at firing temperature of 1000°C (4.86%), 1100°C (7.07%) and 1200°C (9.33%) fell into the requirement range of 4-10% for fire clay [16]. Also the value met the standard for aluminosilicate and Kaolinites [27]. This might show that Ebiaji clay is from a kaolinite origin as deduced from the moderate amount of alumina present. The high shrinkage values show a reduced amount of non-fluxing impurities [26]. The total shrinkage of Ebiaji clay shows an increase from 5.4 to 12.7% with rise in firing temperature as shown in Table 2. Although the total shrinkage and wet-dry shrinkage are almost insignificant since there is variation of their values with moisture content during firing [26]. The moisture content of the Ebiaji clay is 21.74% which is high and accounts for the wet-dry and total shrinkage recorded due to loss of such water during drying. It is also higher than the range for standard according to Chester [19] which is within 2.6-2.7%. Table 2 shows the apparent porosity of Ebiaji clay with firing temperature. Reduction in porosity from 31.12 to 21.32% with increase in firing temperature was observed. This can be as a result of increased shrinkage with rise in temperature which gave rise to closer assembly and closure of pore of the clay sample. The values of apparent porosity fell within the range of 20-80% needed for manufacture of firebricks [28] but above the standard range of 20-30% and >23.7% for manufacture of fireclay and siliceous fireclay respectively [10]. Moreover the apparent porosity of 24.71% and 21.32% obtained at 1100°C and 1200°C respectively for Ebiaji clay fell within the range. The high porosity of the clay can be reduced by addition of glaze in the final product when a porous surface is not required for manufacture [3].

Table 2: Physical properties of Ebiaji clay at different temperatures

Parameter/Temperature	900°C	1000°C	1100°C	1200°C
Wet-Dry Shrinkage (%)	3.2	3.3	3.4	3.2
Dry-Fired Shrinkage (%)	2.17	4.86	7.07	9.33
Total Shrinkage (%)	5.4	8.2	11.3	12.7
Apparent Porosity (%)	31.12	28.01	24.71	21.32
Apparent Density (g/cm^3)	2.82	2.74	2.66	2.55
Bulk Density (g/cm^3)	1.72	1.75	1.77	1.79
Water Absorption (%)	17.44	14.81	11.58	9.98
Modulus of Rupture (Kg/cm^3)	15.42	18.24	24.81	29.52
Green Modulus of Rupture (Kg/cm^3)	7.97			
Modulus of Plasticity	1.376			
Making Moisture (%)	21.74			
Swelling Index (%)	39.1			
Colour before firing	Grey			
Colour after firing	Reddish brown			
Refractoriness	>1250°C			

As the firing temperature increased, there was an increase in the bulk density of Ebiaji clay from 1.72 to 1.79 g/cm^3 (Table 2). This property has been shown to be important in the transportation or handling of refractory materials and also contributes to the overall weight coming upon the foundation of a refractory structure in a furnace [29]. Factors known to affect this property include treatment during manufacturing, nature of materials in the clay sample and the proportion of the clay mixture with their size [12]. For the apparent density a decrease from 2.82 to 2.55 g/cm^3 was obtained with rise in firing temperature. This is obtainable in previous studies as apparent density shows an opposite trend to the bulk densities of fired clay bodies. The bulk density of Ebiaji clay fell within the internationally accepted standard of 1.7-2.1 g/cm^3 required for building and fireclay [30]. The apparent density of Ebiaji clay was also within the standard range of 2.3-3.5 g/cm^3 as reported by Ryan et al. [31]. A decrease in water of absorption with rise in firing temperature was observed in Ebiaji clay deposit (17.44 to 9.98%). Water of absorption followed a similar trend with apparent porosity due to dependence of water of absorption on the pores of the clay body and is also directly proportional to its apparent porosity. As a result of this relationship, decrease in water of absorption is as a result of decrease in porosity with rise in firing temperature since the pores are responsible for water uptake. As stated earlier addition of glaze to the clay body helps to decrease water of absorption due to reduction in porosity.

The relationship between Modulus of Rupture (MOR) and firing temperature of Ebiaji clay is shown in Table 2. It was observed that rise in MOR from 15.42 to 29.52 Kg/cm^3 with increase in firing temperature was obtained. This increase is as a result of increase in bulk density, sintering and vitrification of clay body as temperature increases. Furthermore the increase can also be attributed to formation of bond in the glassy state of the clay sample [32]. Also the strength of clay body increases on cooling due to formation of low temperature melting compounds by alkali metal oxide fluxes found in the clay body. The MOR of Ebiaji clay was within the standard acceptable range of 1.4 to 105 Kg/cm^2 for production of any clay product [26]. Additionally the relative plasticity of Ebiaji clay was 1.38 as shown in Table 2. This is lower than that reported for Ituku clay (1.57) [33], but greater than what was reported for Ishiagu clay (1.21) [34], adiabo clay (1.33) [26] and Ezzodo clay (1.35) [3]. The high value reported for Ebiaji clay show better and higher plasticity which is required as the clay can easily be moulded into shape and therefore has impressive workability. This property of Ebiaji clay makes it suitable for many industrial products though it faces some limitations in the manufacture of white wares due to increased amount of Fe_2O_3 and other oxides. However it can serve as an additive to enhance the workability of other clays. The swelling index test investigates the tendency to swell (hydrate) over a period of time [35]. The swelling index for Ebiaji clay was given as 39.1% which was low. This is lower than the standard requirement for use as drilling mud as found in most bentholithic clays but appropriate for other uses. Other test has to be carried out to ascertain if use as drilling mud will be considered. High swelling index indicates good moulding properties of a clay binder [26].

CONCLUSION

The above result obtained showed that:

1. The refractory property of Ebiaji clay is not suitable enough for manufacture of furnace lining and refractory.
2. The increased strength and moderate plasticity makes its suitable for use as an additive for short clays.
3. Its engineering properties make it suitable for application in ceramic production.
4. The clay is appropriate for manufacture of high melting clay, colored vase, tiles, bricks and clay pipes.

All these uses of Ebiaji clay mentioned above require the addition of additives to obtain the desired properties.

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