Characterization of Ibamajo, Moye and Nkwo-Alaike Fireclays for Use as Refractory Materials in Foundry Industry

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Abstract
This work is directed towards harnessing local potential in refractory sourcing for use in foundry industries. Fireclay deposits from Ibamajo, Mowe in Ogun State and Nkwo-Alaike in Imo State were characterized for refractory properties and from the results; it was revealed that, the clay sample from Mowe has the required refractory properties compared to that of Ibamajo and Nkwo-Alaike clays. The samples collected are of the compound of aluminosilicate and are acidic in nature. The refractoriness of Mowe clay is 1,700°C while those of Ibamajo and Nkwo-Alaike are 1,630°C and 1,660°C respectively. They all fell within the standard value range of 1,500-1,700°C. The percentage of impurities Fe_2O_3 in Nkwo-Alaike is higher than that of Mowe and Ibamajo. Thermal shock resistances of the materials were +30 cycles for both Mowe and Ibamajo clays, while that of Nkwo-Alaike was 26 cycles, The compressive strength of Ibamajo, Mowe and Nkwo-Alaike clays are 14.68, 28.61, 27.60MPa respectively. The compressive strength of Ibamajo clay is lower than the minimum value of 22.9MPa, while that of Mowe and Nkwo-Alaike are superior to standard. The results of these analyses show that the materials from Ibamajo and Nkwo-Alaike can be used for refractory bricks production for various purposes in the foundry industries (lining of preheating furnaces and other furnaces operating below 1630°C), while that of Mowe can be used for linings of melting furnaces for ferrous metal and its alloys.
Keywords: aluminosilicate, compressive strength, fireclay, foundry, furnace, refractory.

1.0 Introduction

ASTM C71 defines refractories as "non-metallic materials having those chemical and physical properties that make them applicable for structures or as components of systems that are exposed to environments above 1000°F or 538°C". Refractory materials have the ability retain its strength at high temperatures. Refractories are used in lining of furnaces, kiln, incinerators and reactors and are also used to make crucibles. They must be chemically and physically stable at high temperatures; have resistance to thermal shock and be chemically inert, have specific ranges of thermal conductivity and thermal expansion.

The oxides of aluminum, silicon and magnesium are the most important materials used in the manufacturing of refractories. Fire clays are also widely used in the manufacture of refractories. These materials are very expensive and their sudden failure in service may result in economic losses and life. The refractoriness of refractory materials is determined by pyrometric conic equivalent (PCE), which indicates that the tip of a test cone of a material understudy is heated at a given rate in accordance with ASTM C 24 –79, touches the supporting plague simultaneously with a standard cone (ASTM 1989).

A lot of research works have been carried out to determine the potential of local refractory materials across the geopolitical zones of Nigeria, which needed to be properly used to guide for exploration and application of these materials. Refractories are usually classified in terms of the ranges of temperature at which they are used. Thus, low refractory are those below 1770°C; medium refractory 1770-2000°C and high refractory above 2000°C (Kachiev, 1993).Similarly, in terms of their chemistry, there are three types of refractory materials, acidic, basic and neutral refractories (Gupta, 2008). Appropriate materials selection is required for the production of refractory materials of specified property.

The refractories need of Nigeria is potentially enormous. It was estimated that the Ajaokuta Steel Company and Delta Steel Company will at full capacity, respectively require 43,503 and 25,000 tons/year of refractories for their activities. These products are sourced from abroad (Adondua, 1988). Onyemaobi (2002) noted that small-scale industries in Nnewi and in some parts of the country have recently embarked on the fabrication of spare parts that needed the application of refractory materials. These spare parts are fabricated using high temperature furnaces that require linings. Obadinma (2003) reported that in 1987 alone, Nigeria imported 27 million metric tons of refractories. A lot of foreign exchange is spent on the importation of refractory materials into the country. Therefore, there is need to develop the local refractory materials for their application in the required industries. Thus, this work studies the physical, chemical and thermal properties of Ibamajo, Mowe and Nkwo-Alaike clays to determine their suitability for refractory bricks production.

2.0 Experimental Method

2.1 Materials and Equipment

The clay samples used in this work were collected from Ibamajo (IB), Mowe (MO) South-West of Nigeria, while the Nkwo-Alaike (NA) sample was taken from South-East of Nigeria for their characterization. The clay samples were collected at a depth of 1.5 meter using digger and shovel. The samples were crushed, soaked, air-dried and sieved through 1.8mm mesh and rammed into standard sizes of (5.08cm x 5.08cm) and (2.5cm x 2.5cm) using (Standard Laboratory Rammer. Ridsdale & Co., Ser. No.891. Test sample pieces were prepared dried and fired in accordance with ASTM (1989).The samples were then tested for Apparent Porosity, Fired Linear Shrinkage, Compressive Strength, Thermal Shock Resistance (using muffle furnace), Water Absorption, Moisture Content, Refractoriness (using muffle furnace), Loss on Ignition (using oven), Moisture Content and Bulk Density. The chemical composition was carried out using Atomic Absorption Spectrophotometer (AAS, PG990AFG). The result of the chemical analysis is shown in Table 1, while Table 2 shows the result of the physical analysis. The mineralogical analysis was carried out using X-ray diffraction. The following were analyzed during the studies:

2.1.1Fired Linear Shrinkage

Test pieces were made into standard slabs; the test pieces were marked along a line in order to maintain the same position after heat treatment. The distance between the two ends of the slabs was measured with Vernier Caliper. The samples were air dried for 24 hours and then fired at 110^{o}C for 6 hours in the oven. The test pieces were cooled to room temperature and measurements were taken. The fired linear shrinkage was calculated using equation (1).

$$F.S = \frac{(D_l - F_l)}{D_l} * 100 \quad \ldots\ldots (1)$$

Where,
D_l is the dried length
F_l is fired length

2.1.2 Apparent Porosity

Representative pieces of test bricks were prepared and air-dried for 24 hours. The pieces were then oven dried at 100^{o}C for 24hours. The pieces were fired at a temperature of 110^{o}C, cooled and then transferred into Desiccators and weighed to nearest 0.01g (dried weight). The specimens were then transferred into 250ml beaker in empty Vacuum Desiccators. Water was then introduced into the beaker until the test pieces were completely immersed. The specimens were allowed to soak in boiled water for 30 minutes being agitated from time to time to assist to release of trapped air bubbles. The specimens were transferred into empty Vacuum Desiccators to cool. The soaked weight (W) was recorded. The specimens were then weighed suspended in water, using beaker placed on balance. This gave suspended weight(s); the apparent porosity was calculated using equation (2):

$$A.P = \frac{(W - D)}{(W - S)} * 100 \quad \ldots\ldots (2)$$

Where,
W = Soaked weight
D = Dried weight
S = Suspended weight

2.1.3 Bulk Density

Three samples of each clay bricks measuring 60mm x 60mm x 15mm were prepared. The specimens were air dried for 24hours and then oven dried at 110^{o}C, cooled in Desiccators and weighed to the accuracy of 0.0018g (Dried weight), after which the specimen was transferred to a beaker and heat for 30 minutes to assist in realizing the trapped air. The specimens were cooled and the soaked weight (W) was taken. The specimens were then suspended in water using beaker placed on a balance. The suspended weight (S) was taken and the bulk density was calculated from equation (3):

$$B.D = \frac{D_{pw}}{(W - S)} g/cm^3 \quad \ldots\ldots (3)$$

Where,
D= Dried weight
W= Soaked weight
S=Density of water

2.1.4 Compressive Strength

Test pieces of clay samples were prepared to a standard size of 76.2mm^{3}on a flat surface. The test pieces were fired in a furnace at 110^{o}C and the temperature maintained for 6 hours. The samples were then cooled to room temperature. The specimens were placed on a compressive tester and load was applied axially by turning the land wheel at a uniform rate till failure occurs. The manometer readings were recorded. Comprehensive Strength (CS) was calculated from equation (4):

$$C.S = \frac{Max.Load(KN)}{C.A(m^2)} \quad \text{.......} (4)$$

2.1.5 Thermal Shock Resistance

Test pieces measuring 50mm by 75mm were prepared. The pieces were inserted in a furnace (Nabertherm, 1999), which was maintained for 10 minutes at 900^{o}C. The specimens were removed with a pair of tongs from the furnace one after the other and then cooled for 10 minutes. The process was continued until test pieces were readily pulled apart in the hands. The numbers of heating and cooling cycles for each specimen was recorded.

2.1.6 Refractoriness

The test pieces were mounted on a refractory plaque along with some standard one whose melting point is slightly above slightly below that expected of the test cone. The plaque was then put inside the furnace (Nabertherm, 1999) and the temperature was raised at a rate of 100^{o}C per minute. The test was continued until the tip of the test cone had bent over level with the base.

2.1.7Moisture Content of the Clay Samples

The air dried sample was weighed (W) and then placed in a furnace (Nabertherm, 1999) and heated to a constant temperature of 110^{o}C for 24hrs. The sample was taken out cooled in Desiccators and re-weighed (W_1). The loss in weight gives the amount of moisture content (M.C) which can be expressed as percentage of initial sand sample. The following expression in equation (5) was used:

$$M.C = \frac{W - W_1}{W} \times 100 \quad \text{.......} (5)$$

Where,
M.C is the moisture content (%);
W is the weight of the sample before drying (gm);
W_1 is the weight of the sample after drying (gm)

2.1.8 Loss on Ignition

The Test sample was dried at 110^{o}C and cooled. The sample in a clean and dried porcelain crucible was heated in a muffle furnace to a temperature of 900^{o}C for 3hours. The loss on ignition (LOI) was calculated using equation (6).

$$LOI = \frac{m_2 - m_3}{m_2 - m_1} \times 100\% \quad \text{.......} (6)$$

Where,
m_1 is the weight of the crucible (gm);
m_2 is the weight of clay and crucible (gm);
m_3 is the weight of the dried clay and crucible (gm).
The results of the physical and thermal properties of the various materials used are shown in Table 2

3.0 Results and Discussion

The chemical composition of the clay deposits is shown in Table 1. From the Table, it is seen that the alumina content of Ibamajo, Mowe and Nkwo-Alaike are 22.80%, 26.93%, 26.55% respectively. The results show that the alumina content of Mowe and Nkwo-Alaike are within the standard value range of 25-45%, while that of Ibamajo fell below the standard. This explains why the Ibamajo clay has the lowest refractoriness value compared to Mowe and Nkwo-Alaike clays Chester (1973).The silica content is high in all the clay samples investigated. Silica content above 46.5% (Ryan, 1978) indicates free silica. This showed that the clay samples are richer in silica and this has contributed to a high compressive strength for Nkwo-Alaike and Mowe clays. The presence of high value of impurities in aluminosilicate refractory, such as, Fe_2O_3, lowers the refractoriness and service limit of the bricks. Figures 1(a – b) show the charts for the chemical compositions of the clay samples and the standard value. The major phases of the materials collected are aluminosilicate and it is acidic in nature based on Chester (1986).

Table 1: Chemical Analysis of Clay Materials collected

Sample Location	**Chemical Analysis, (%)**								
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	TiO_2	L.O.I
Ibamajo	54.40	22.80	1.0	0.30	0.20	0.30	1.0	0.86	16.73
Mowe	56.0	26.93	1.5	0.16	0.50	1.10	0.65	1.09	10.21
Nkwo-Alaike	56.57	26.55	1.76	0.30	0.20	0.85	0.08	1.68	9.76
***Standard (Devon)**	57.0	26.70	1.60	0.20	0.70	2.0	0.10	1.10	12.15

The moisture content of the fireclays collected from Mowe, Ibamajo and Nkwo-Alaike were 10, 8.6 and 9.5%. This implies that Ibamajo will require more water for proper mixing of the material. The apparent porosity of Nkwo-Alaike clay which is 27.77 falls within the standard value of 20-30% according to Chester (1986), while that of Ibamajo and Mowe fall below the standard. The low percentage of apparent porosity enhances the entrapping of gases in the material during operation. This will adversely affect the life span of the refractory material when in operation (Gupta, 2008).The values may be increased with addition of fine grain of additives, such as, saw dust or rice husk.

The thermal shock resistances of the three clay samples are within the acceptance values of 26-30 cycles (Allen, 1986). The refractoriness value obtained for Ibamajo, Mowe and Nkwo-Alaike clay samples are within the range of 1,500– 1,700^{o}C for the fireclay according to De Bussy (1972) (see Table 2).The average Fired Linear Shrinkage for the three clay samples is within the recommended values of 4–6% (Chester, 1986). With this value, the materials will have a better interlock of grains, which will consequently enhance the strength of refractory when in operation.

The cold crushing strength (compressive strength) of the materials collected from Mowe and Nkwo-Akaike are within the standard value of 22.9 – 59N/mm^2 (Allen, 1986). However, Ibamajo clay sample has a value that is below the recommended standard value. Thus, the Ibamajo clay has less resistance to load, tension and shear stresses than Mowe and Nkwo-Alaike samples. The average bulk density of the clay samples is as shown in Table 2 and within the recommended value of 1.7 – 2.1g/cm^3(De Bussy, 1972).

Similarly, the water absorption of the three clay samples fall within the recommended value of 2.6-2.7 % according to Chester (1973).The chart showing the comparative analysis of the physical properties of the fireclay samples are displayed in Figures 2(a – b).

Table 2: Physical and Thermal Properties of the Materials

Properties	**Sample Location**			
	Ibamajo	**Mowe**	**Nkwo-Alaike**	***Standard(Devon)**
Fired Linear Shrinkage, %	4	6	4	4-6
Apparent Porosity, %	16.11	16.11	27.77	30
Bulk Density, g/cm^2	1.76	1.72	1.72	2.3
Compressive Strength, N/NM^2	14.68	28.61	27.6	59
Thermal Shock Resistance, Cycles	30	30	26	30
Water Absorption, %	2.6	2.67	2.64	2.7
Moisture Content, %	8.6	10	9.5	8-12

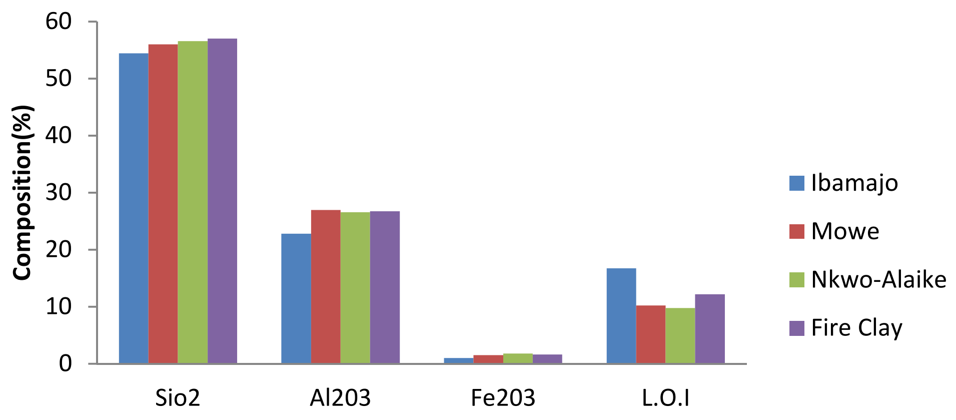

Figure 1a: Chart showing the comparison of chemical compounds of the Clay

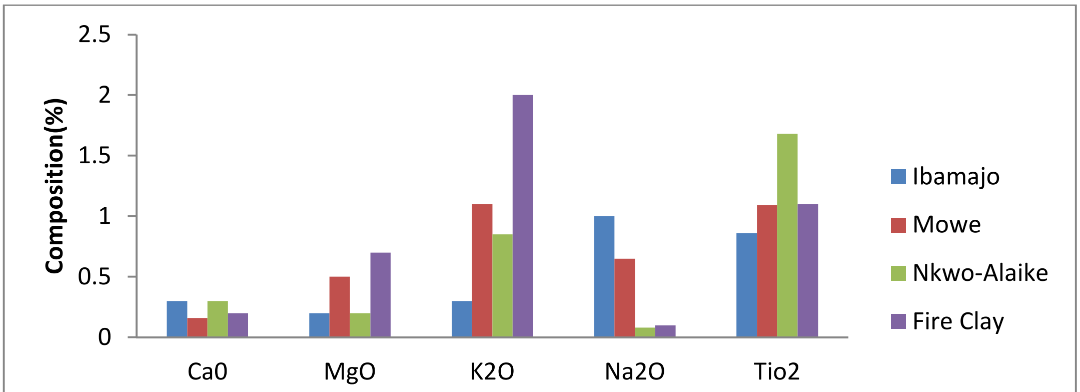

Figure 1b: Chart showing the comparison of the chemical compounds of the Clay samples

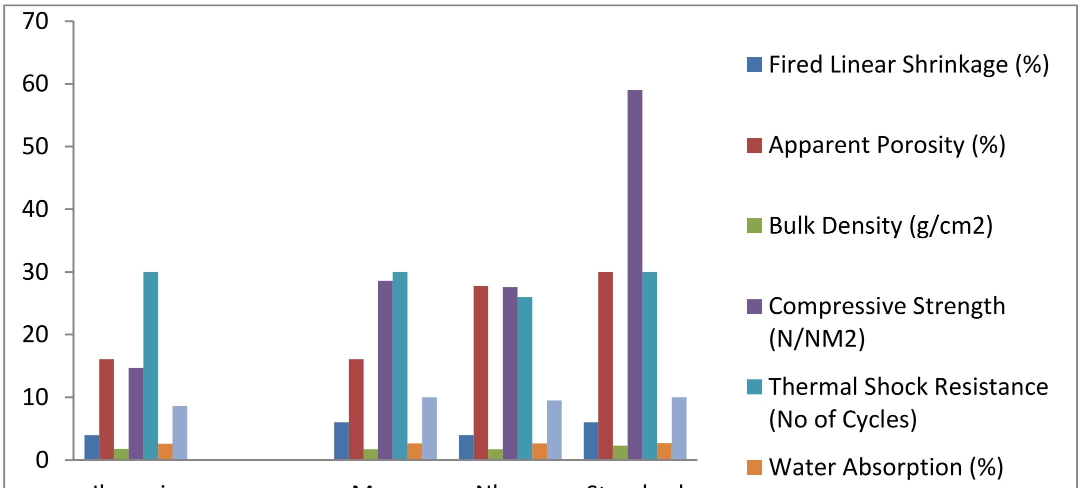

Figure 2a: Chart showing the comparison of the physical properties of the Clay

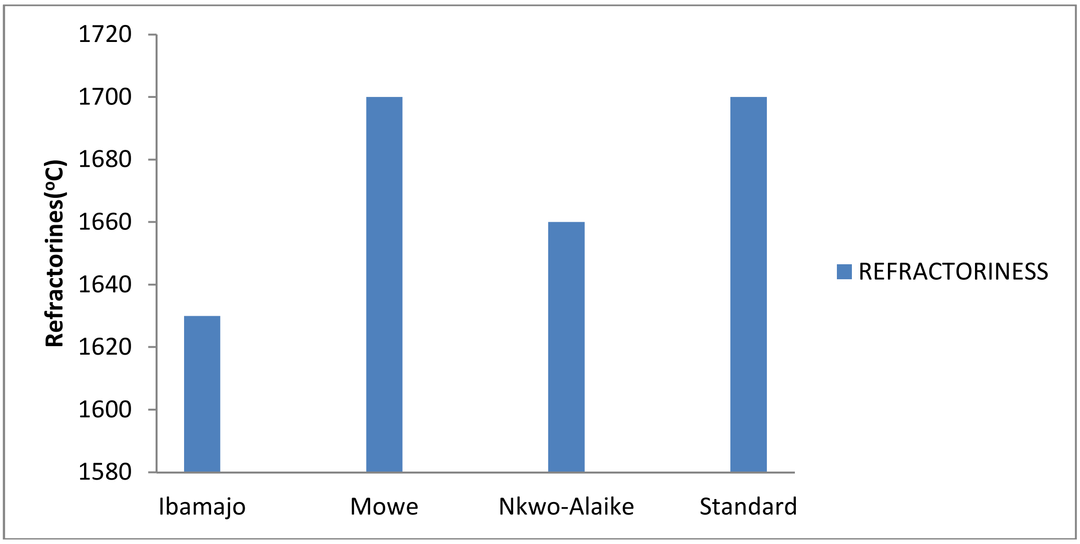

Figure 2b: Chart showing the comparison of the physical properties of the Clay

4. Conclusion

The investigation carried out on the three clay deposits; Ibamajo, Mowe and Nkwo-Alaike revealed that the service properties of Mowe as compared with Ibamajo and Nkwo-Alaike clays have favorable results that, when bricks are produced from these materials they can be used in the application industry. The chemical analysis of the clay materials which was carried out using Atomic Absorption Spectrophotometer (AAS, PG990AFG) shows the percentage composition of the various constituents with 54.40%,56.0% and 56.57% SiO_2 for Ibamajo, Mowe and Nkwo-Alaike, respectively.$Al_2O_3$for Ibamajo, Mowe and Nkwo-Alaike are22.80%, 26.93%and 26.55% respectively, which indicated that the materials are richer in silica than alumina. The high impurities, such as, Fe_2O_3, CaO, TiO_2 and Na_2O which are very much present in Nkwo-Alaike and Ibamajo clays have drastically affected the service properties of the clays. The water absorption of the three clay samples fall within the recommended value range of 2.6-2.7%.From the analyses, the clay samples exhibit refractory properties (especially, Mowe clay sample) such that, when they are processed into bricks they can be used for various applications in the foundry Industries.

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