A COMPARATIVE STUDY ON THE REFRACTORY PROPERTIES OF SELECTED CLAYS IN NORTH CENTRAL NIGERIA

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ABSTRACT

Niger is a resource rich country. Nevertheless, despite the relative abundance of local raw materials needed for the production of refractory materials for its process industries, Nigeria is heavily engaged in the importation of these materials. This study presents the results of comparative analysis and evaluation of the refractory properties of some selected clay deposits in Nigeria's North Central region with a view of determining their suitability for use as refractory materials. Characterization of Maikunkele, Tammah, Otaiko and Bukuru clays were carried out using an Atomic Absorption Spectrophotometer (AAS) and published data from previous studies were obtained for Tatiko, Beji and Nyikangbe clay. Result of analysis shows that the clay samples are high silicate clays with moderate alumina content, low ferrous oxide content and possess very low contents of other metal oxides. The low iron content gives the clays with the exception of Nyikangbe clay rather whitish appearances establishing their suitability for paint, chalk, and earthenware manufacturing. Maikunkele clay which had an impressive refractoriness value of 1710 ^oC making it the most excellent for ferrous metal handling and furnace wall lining with Tammah, Otaiko and Bukuru clays posting nearly 1700 ^oC. Tatiko, Beji and Nyikangbe clays had refractoriness below 1400 ^{o} C. Maikunkele clay's thermal shock resistance also outperformed the others at 28 heating and cooling cycles, with 22, 17, and 20 cycles for tammah, Otaiko, and Bukuru clays; against less than or equal to 10 cycles for Tatiko, Beji and Nyikangbe clays. More so the linear shrinkages of all the studies clays were within permissible limits for refractory clays at between 7-10 %.

Keywords: clay, Bukuru Clay, Otaiko Clay, Nyikangbe clay, Tatiko and Beji clays, refractory properties.

INTRODUCTION

Clay is a complex mixture, which varies in composition depending upon the geological location. It is a natural substance which occurs in great abundance (Apiam, 1985). The origin of clay may be traced to either of the two geological processes namely sedimentation and weathering (Apiam, 1985; Raymond, *et al*., 1990). According to Chester clay is a natural source of many industrial finished products. One of such products that have proved indispensable in the metallurgical industries is the refractory material (Ameh & Obasi, 2009).

In the last few years, there has been an increasing awareness on the scope, and the importance of refractory materials in the industrial development of Nigeria (Abolarin *et al.*, 2004). With the revamped development of the iron and steel industry via the rehabilitation of various inland rolling mills and the envisaged completion and commissioning of the multi-billion dollar Ajaokuta Steel complex to produce 1.3 million tonnes of liquid steel, there will be a great increase in consumption of

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refractory materials (Amuda *et al*., 2005). Ajaokuta is estimated to require 36,000 tonnes of refractory bricks worth over Sixty million naira just for furnace lining purposes only and more than 80 %of the refractory bricks to be required are fired clay (Ndanusa *et al*., 2005). The four refineries in Nigeria were recorded to have gulped about $850 million for their turn around maintenance (TAM) between 1997 and 2002. The critical unit in the TAM process is the Fluid Catalytic Cracking (FCC). This unit is lined with enormous quantity of various grades of refractory line (Borode *et al.,* 2002). Other demands for these products come from chemical, hardware, cement and glass industries. The refractory needs of these industries were well over 300,000 tonnes as the year 2000 (Ndaliman, 2007). These refractory materials are at present sourced by importation (Borode *et al.*, 2002).

Refractory materials are materials that are capable of withstanding high temperature both physically and chemically. High quality refractory materials resist high temperature fluctuations between 1000 ^{0}C and 1500 ^{0}C and are also good thermal and electrical insulators (Ameh and Obasi,2009). The metallurgical industries are the major consumers of refractory products. Refractories are specifically used to conserve heat within a system (Chester, 1973). These materials are usually used in the industries for furnace construction, smelting vessels for holding, transporting metal and slag, in furnace heating, and in the flues or stacks through hot gases are conducted (Waing *et al*., 2008).

The raw materials for the production of various refractory products include kaolinite ($Al_2O_3.2SiO_2.2H_2O$), chromite ($FeOCr_2O_3$), magnesite ($MgCO_3$) and various types of clays. Alumino-silicate and magnesite refractory products are the major types of refractories used in the Nigerian manufacturing industries (Omowumi, 2001). There are vast deposits of clay spread across every region in Nigeria, each differing from site to site on account of geological differences.

Great use has been made of Nigerian clay as a potter material for ages (Amuda *et al.,* 2005). However, in the last few years, there has been tremendous research effort geared towards the sustainable development of refractory products from local clay deposits with a view of determining their suitability for adoption as refractory materials for different metallurgical and process industries. This development is justified by the present situation of the nation’s economy, the need to meet the technological requirements of the country and to conserve much needed foreign exchange.

Nnuka and Agbo (2000) studied the characteristics of Nigerian clays and discovered that the Otukpo clay has refractories of 1710 ^{0}C which compares well with imported refractories.

Amuda *et al.* (2005) in an earlier research on the characterization and evaluation of refractory properties of some clay deposits in southwest Nigeria reported that the clay displayed reasonable refractory properties that compared favourably with standard values and recommended a blend of these clays for furnace lining.

Abolarin *et al.* (2005) studied the characteristics of Nigerian clays and discovered that the Barkin Ladi and Alkaleri clay sample were suitable for construction of furnaces and furnace lining.

In the report of analysis and characterisation of some selected North West clay deposit reported by Kure (2011), findings shows that the clays could be used for production of ceramic, basic refractory, mortar lining, and kilns and also as refractory bricks for furnace lining.

This work is aimed at characterization and evaluation of refractory properties of some selected clay deposits in North Central, Nigeria to ascertain its suitability as a refractory material and for relevant application in Nigerian manufacturing industries.

METHODOLOGY

The clay samples used in this study were collected from Tammah, Otaiko, Bukuru, and Maikunkele areas of Nassarawa, Kogi, Plateau and Niger States respectively all in North Central Nigeria; otherwise known as Nigeria’s Middle Belt. Their properties were compared to that obtained in previous studies (Musa & Aliyu, 2011; Onyeji, 2010) on Tatiko, Beji, and Nyikangbe clays all in Niger State. The samples were air dried, finely crushed and sieved with a mesh size of 1.13 mm. They were then mixed into a thick paste with water and then moulded into bricks and properly compacted with a hydraulic press. The bricks were air-dried for 24 hours and then oven dried at a temperature of

110 °C for 12 hours. An electric muffle furnace was used to slowly fire the dried bricks to a temperature of 1100 °C after which slow cooling was done to room temperature.

An Atomic Absorption Spectrophotometer (AAS) was used for the analysis of the chemical composition of the clay samples. Refractory properties that were determined so as to characterise the clay samples are: linear shrinkage, refractoriness, thermal shock resistance, porosity, bulk density and specific gravity. Chester (1983) and Ndaliman (2007) described these in detail as standard test procedures presented in BS 1902: Part 1 A.

RESULTS AND DISCUSSION

Colour

The colours of the dried clay samples at room temperature were determined using a colour chart. Tammah, Bukuru and Maikunkele clay samples possess a whitish appearance clearly due to having no trace of iron oxides that would have introduced a tinge of brown or reddishness. While the presence of iron oxides in Tatiko and Beji clays were reportedly responsible for their brownish appearances (Musa & Aliyu, 2011) with Onyeji (2010) reporting an especially yellowish brown colour for Nyikangbe (Table 1). This is corroborated by the relatively high percentage of ferrous oxide at almost 12%.

Chemical Composition

The chemical composition of the clay samples was determined non-destructively using an Atomic Absorption Spectrophotometer apparatus. These were compared with that of Nyikangbe (Onyeji, 2010), Tatiko and Beji (Musa & Aliyu, 2011) clays as shown in Table 1 together with standard industry values as suggested by Odo (2009).

Table 1: Chemical composition of the clay samples (%)

Location	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO
Tammah	56.43	27.48	0.000	0.106	0.003
Otaiko	54.20	22.31	0.042	0.158	0.013
Bukuru	47.80	26.83	0.000	0.025	0.009
Maikunkele	51.71	30.24	0.000	0.130	0.000
[1]Nyikangbe	54.03	21.80	11.93	-	1.330
[2]Tatiko	54.40	20.28	1.340	0.410	0.001
[2]Beji	52.23	22.83	0.870	0.450	0.020
[3]Refractory Bricks	51.70	25-44	0.5-2.4	0.450	0.1-0.2

Sources: [1]Onyeji (2010), [2]Musa & Aliyu (2011), [3]Odo (2009)

Results in Table 1 show that clay samples found in North Central Nigeria are high silicate clays. These values fall within the standard range of 46-62 % that is required for the production of good refractory materials as reported by Yami and Umaru (2007). Therefore, they can find applications as lining for heat treatment furnaces, melting furnaces for low melting temperature metals, aluminium ladle moulds and portions of blast furnaces.

The selected clay samples can be described as moderate Alumina clays and show appreciable consistency within the value of 13-30 % reported by Waing *et al.*, (2008) for typical refractory materials. There were no traces of iron in Tammah, Bukuru, and Maikunkele clays but 0.042% of Otaiko clay is iron as is 11.39 % of Nyikangbe clay. Onyeji (2010) reported that clays with appreciable amounts of iron cannot be used as sources of aluminium as the presence of iron tends to have deleterious effects on the extraction process. Tammah, Otaiko, Bukuru, Maikunkele, Tatiko and Beji clays can however serve as a source of aluminium but Nyikangbe clay is however not suitable for this purpose. Also, it may not find much use as a refractory material for the internal furnace linings of furnace due to its relative large iron content which is beyond the recommended range of 0.5-2.4% (Odo, 2009).

In addition, with the exception of Nyikangbe clay which was not determined all the selected clay samples contain between 0.1 and 0.45 % of magnesium oxide. They can be used for insulators in industrial cables and as basic refractory materials for laboratory crucibles and also as principal fireproofing ingredient in construction materials. Other mineral oxides in the clay samples were in minor quantities. However Tammah, Bukuru, Maikunkele, Tatiko and Beji clays due to their negligible iron content, hence whitish appearances, are rather fit for the production of earthen wares, paints and chalks (Onyeji, 2010).

Linear Shrinkage

This is an indicator of the firing efficiency of the clay samples. The values reported by Musa & Aliyu (2011) for Tatiko and Beji clays were 1.41 % and 1.20 %, Omowumi (2001) quoted a recommended range of 4-10% for fireclays and Abolarin *et al* (2004) pointed out that lower values were more desirable as this means the clay is less susceptible to volume change. Maikunkele clay however has a comparatively high linear shrinkage value (9.41%) but falls within the range for normal kaolin ($Al_2O_3.2SiO_2.2H_2O$) which is between 7 and 10 %. This means that Maikunkele clay must be processed so as to dry slowly in order to minimise any deformation or damage to finished articles. Chester (1973) recommended a linear shrinkage range of 7-10 % for refractory clays; therefore, the selected Niger clays can be classed, based on this range, as refractory clays.

Table 2: Physical Properties of Test Samples

Location	Bulk density g/cm^3	Apparent porosity, %	Linear shrinkage, %	Thermal shock resistance, cycles	Cold crushing strength, MN/M^2	Refractorines, °C	Loss on Ignition
Tammah	3.10	30.69	7.41	22	11.215	1696	4.75
Otaiko	1.96	30.75	4.37	17	16.014	1662	7.85
Bukuru	1.98	15.32	7.76	20	13.726	1694	2.37
Maikunkele	2.19	ND	9.41	28	13.445	1710	3.07
Nyikangbe[1]	2.35	6.34	ND	8	18.065	1400	ND
Tatiko[2]	4.00	23.05	1.41	10	15.805	1300	12.05
Beji[2]	4.04	21.30	1.20	9	16.620	1350	11.75

ND: Not determined. Sources: [1]Onyeji (2010), [2]Musa & Aliyu (2011). All values are average of 3 readings.

Bulk Density

With average bulk densities of 1.96 and 1.98 g/cm^3, Otaiko and Bukuru clays have the lowest values of the selected clays from the region while Beji clays has the highest of 4.04 g/cm^3 . For the most part, bulk density varies with the volume concentration of the open and close pore space. To a certain extent however, it is also related to the mineral composition of the bricks. Mazen (2009) observed that the specific gravity of bricks varies indirectly with Al_2O_3 content in the raw materials. This is evidenced by the values in Tables 1 and 2. Maikunkele clay with the highest alumina content in Table 1 has the lowest bulk density. In comparison to clays from other regions of Nigeria, these are quite dense when compared with values obtained for Gur and Yamarkumi clays (2.06-2.11 g/cm^3), Plateau and Bauchi clays (1.94-2.04 g/cm^3) as respectively reported by Yami & Umaru (2007) and Abolarin *et al* (2004). As Bukuru clay is Plateau clay, this is in agreement with the value obtained in the present study. Onyeji (2010) noted the correlation between bulk density, linear shrinkage and apparent porosity and stated that the denser clays are less porous and less likely to shrink. Maikunkele clay as a result is more likely to shrink with the reported low bulk density.

Apparent Porosity

Tammah and Otaiko clays are highly porous clays with porosities in excess of 30% while Tatiko and Beji clays are moderately porous at 110 °C were found to be within internationally defined standard of 15-25% (Mazen, 2009). These make the soils suitable for usage as fire bricks for insulation (see Table 2). In contrast however, Nyikangbe clay is far less porous at 6.34 % which is less than $^1/_3$ of the values for either Tatiko or Beji clays.

Thermal Shock Resistance

This property determines a material's ability to withstand heating and cooling cycles. While Maikunkele clay withstood an impressive 28 cycles, Tammah, Otaiko and Bukuru clays posted 22, 17 and 20 cycles. This makes them excellent for long time refractory use as these cycles measure their longevity which in turn could result to cost savings due to minimal replacement. Tatiko Beji and Nyikangbe clays only managed 10, 9 and 8 cycles of heating (at 1000 ^oC) and cooling respectively which are poor for refractories. The value obtained for these 3 clay samples was lower than the values reported by Mazen, 2009, Ndaliman, 2007, who reported above 20 cycles, and up to 18 cycles respectively. But maikunkele clay shows appreciable consistency with the 29 cycles by Abolarin *et al* (2004).

Cold Crushing Strength

Cold crushing strength is a measure of the ability of clays to withstand abrasion and loading. Values for properly fired High Duty Silica Bricks are above 18 MN/m^2. Of the clays investigated, only Nyikangbe had an average value in excess of 18 MN/m^2 at 18.065 MN/m^2, which still falls short of the 26.5 MN/m^2 reported by Ameh and Obasi (2009) for Nsu clay. For Beji clay, the value obtained was 16.62 MN/m^2 while Tatiko clay produced a value of 15.81 MN/m^2. These clays require adequate firing to ensure suitability for transportation of slags and fluxes. Tammah clay exhibits the poorest cold crushing strength at a value of 11.215 MN/m^2 rendering it completely unsuitable for slag and flux transportation.

Refractoriness

Refractoriness refers to a material's ability to withstand high firing temperatures without deterioration of their physical and mechanical properties. Maikunkele clay withstood up to 1710 ^oC thereby exhibiting exceptional refractoriness and the best among the investigated clays. Also impressive are Tammah, Otaiko and Bukuru clays in terms of refractoriness with magnitudes of 1696, 1662, and 1694 ^oC respectively. These values best that of the celebrated Nsu clay whose refractoriness was theoretically determined to be 1683 ^oC by Ameh & Obasi (2009) using Shuen's formula. For Tatiko and Beji clays, Musa & Aliyu (2011) reported values of 1300 and 1350 ^oC respectively. These are much lower than the recommended range of 1500-1700 ^oC for fire clay refractories as quoted by Yami & Umaru (2007) who went further to attribute the low values to high silica content and as such, their use is restricted to non ferrous metals processing with melting points below 1400 ^oC.

CONCLUSIONS

Huge amounts of naturally occurring raw materials have long been discovered for the production of refractory materials in Nigeria. Despite this, there are no refractory industries in the country. Hence the refractory needs of the nation process industries are met by importation. The present down turn in the nation's economy and the uncertainty facing the petrochemical and metallurgical industries has necessitated the need to source for local raw materials to support the growth of these industries by producing high quality refractories commercially thereby substituting for importation and saving the much needed foreign exchange. The refractory properties of seven North Central Nigerian clay samples were studied. They are clays from Tammah, Otaiko, Bukuru, Maikunkele, Nyikangbe, Beji and Tatiko areas. Results show that they are high silicate clays with moderate alumina content, low ferrous oxide content and possess very low contents of other metal oxides. The low iron content give them rather whitish appearances making them good candidates for paint, chalk, and earthenware manufacturing. They are generally refractory clays as their acceptable values of linear shrinkage and bulk density show. However, on the issue of thermal shock resistance and refractoriness, the clay sample from Maikunkele area bested the others at an impressive 28 cycles and 1710 ^oC respectively. Not far behind are the Tammah, Otaiko and Bukuru clays which bested that of that of Tatiko, Beji and Nyikangbe. It is therefore recommended that a geological survey of the sampled areas should be carried out to determine the extent of the deposits so as to form basis of building a refractory clay material economy for North Central Nigeria that has the capacity to create jobs, save much needed foreign exchange going by the huge reported amounts expended yearly in importing similar materials, and transform the fortunes of the region as a whole. These can go a long way in providing high quality refractories needed at the massive Ajaokuta Steel Complex in Kogi State (also in North Central Nigeria), Aladja Steel complex and the Aluminium Smelter Company Ikot Abasi, all in the South.

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