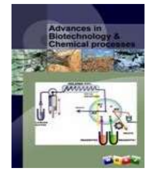
Advances in Biotechnology & Chemical processes 2 (2012) 1-5

Available at woaj

Advances in Biotechnology & Chemical processes

Journal homepage: www.woaj.org/JSA



A Comparative Study of the Refractory Properties of Selected Clays in Niger State, Nigeria

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ARTICLE INFO

Article history:
Accepted:
Available online: 6 December 2012

Keywords:

Tatiko clay,
Beji clay,
Maikunkele clay,
Nyikangbe clay,
Refractories,
alumina content,
silica content.

ABSTRACT

Nigeria as a nation has appreciable distribution of process industries engaged in the importation of refractory materials, despite the relative abundance of local raw materials needed for the production of these materials**.** This study present the results of comparative analysis and evaluation of the refractory properties of some selected clay deposits in Niger State, Nigeria with a view of determining its suitability for use as refractory material. Characterization of Maikunkele clay was 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 was high silicate clay with moderate alumina content, low ferrous oxide content and possesses very low contents of other metal oxides. The low iron content gives the clay rather whitish appearances establishing its suitability for paint, chalk, and earthenware manufacturing. All the clay samples had refractoriness below 1400 ^{o}C except for Maikunkele clay which had an impressive value of 1710 ^{o}C making it excellent for ferrous metal handling and furnace wall lining. Its thermal shock resistance also outperformed the others at 28 heating and cooling cycles against less than or equal for Tatiko, Beji and Nyikangbe clays. More so the linear shrinkages were within permissible limits for refractory clays at between 7-10 % even though the value was relatively high for the Maikunkele sample at 9.41%.

1. Introduction

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 refractory materials. Ajaokuta is estimated to

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require 36,000 tonnes per annum (Amuda *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 may be defined as materials that retain their physical and chemical identity when subjected to high operation temperatures. These materials are non-metallic compounds that can withstand temperatures above 1000 ^{o} F (538 ^{o}C). The ability to withstand exposure to heat above 538 ^{o}C is the critical distinction separating refractory from other ceramics, fibres and coating application at only lower temperature (Ndanusa *et al.,* 2004). Refractory materials are composed of either a single oxide such as alumina (Al_2O_3), silica (SiO_2), magnesia (MgO) or Zircon (ZrO_2) or combinations of these oxides (Abolarin *et al*.,2004). These metallurgical industries are the major consumers of refractory products. Fire clay bricks are by far the largest group of refractory's in use in these industries (Omowumi, 2000).

These materials are usually used in these 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). Abundant clay deposits have been reported across major geological belts in the country (Amuda *et al*., 2005). Each of these clays differs from site to site on account of geological difference (Onyeji, 2010).

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 need to meet the technological requirements of the country and to conserve much needed foreign exchange. Ndanusa *et al.,* 2005 in an earlier research showed that Lokogoma feldspar and Kankara clays can be used as acidic and basic refractory for heating and melting purposes. 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 Nyikangbe clay deposit reported by Onyeji, 2010, findings shows that clay could be used for production of ceramic, basic refractory, mortar lining, kilns and also for production of paints, chalks and raw materials for paper making industries.

Musa and Aliyu (2010) reported the investigation of the refractory properties of Tatiko and Beji clays and found that the clay are good for handling low melting temperature metals, paint, chalk and earthenware production. This work is aimed at a comparative studies and evaluation of various clay deposits in Minna, Nigeria to ascertain its suitability as a refractory material and for relevant application in Nigerian manufacturing industries.

2. Methodology

The clay samples used in this study was collected from Maikunkele area of 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 the moulded into bricks properly compacted with a hydraulic press. The bricks were air dried for a period of 24 hours and then oven dried at a temperature of 1100 ^{o} C for 12 hours. An electric muffle furnace was used to slowly fire the dried bricks to a temperature of 1100 ^{o} 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. Refractory properties that were determined in order to characterise the clay samples are: linear shrinkage, refractoriness, thermal shock resistance, porosity, bulk density and specific gravity. These properties have standard test procedures and are as described in BS 1902: Part 1 A (Chester, 1983; Ndaliman, 2007).

3. Results and Discussion

Colour

The colours of the dried clay samples at room temperature were determined using a colour chart. Maikunkele and Beji clay sample shows a whitish colour obviously because it has no trace of iron oxides that would have introduced a tinge of brown or reddishness. While the presence of iron oxides in Tatiko and Nyikangbe clay sample is responsible for the brownish colour (Table 1).These two clay samples 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.

Chemical Composition

The chemical composition of Maikunkele clay was determined non-destructively using an AAS apparatus. This is compared with that of Nyikangbe (Onyeji, 2010), Tatiko and Beji (Musa & Aliyu, 2011) clays as shown in Table 1.

Table 1: *Chemical Composition of the clay samples (%)*

Location	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO
Maikunkele	51.71	30.24	0.00	0.13	0.000
[1]Nyikangbe	54.03	21.80	11.93	-	1.330
[2]Tatiko	54.40	20.28	1.34	0.41	0.001
[2]Beji	52.23	22.83	0.87	0.45	0.020
[3]Refractory Bricks	51.70	25-44	0.5-2.4	0.45	0.1-0.2

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

Results in Table 1 show that all four clay samples found in the locality are high silicate clays with content of 49.01, 54.03, 54.4 and 52.23 % respectively. These values fall within the standard range of 46-62 % that is required for the production of good refractory

The selected clay samples can be described as moderate Alumina clays and shows appreciable consistency with the value of 13-30 % reported by Waing *et al.,* (2008) for typical refractory materials. The iron content of Maikunkele, Tatiko, Beji and Nyikangbe clay were 1.34 %, 0.87 %, 11.39 % and 0 % respectively. Onyeji (2010) reported that clays with appreciable amounts of iron cannot be used as sources of aluminium as the presence of these iron tends to have deleterious effects on the extraction process., Maikunkele, Tatiko, Beji clays can however serve as a source of aluminium. Nyikangbe clay is however not suitable for this purpose.

The presences of other oxides in Maikunkele clay were in minor quantities. This simply implies that the application for pottery purposes is not suitable for this clay, However Tatiko and Beji clays; are rather fit for use for the production of earthen wares, paints and chalks (Onyeji, 2010). It is important to add that appreciable amount of iron (11.93%) in the Nyikangbe clay is chiefly responsible for its yellowish appearance.

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.

Bulk Density

With an average bulk density of 2.19 g/cm^3, Maikunkele clay has the lowest value of the four selected clays from the locality 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)

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	Refractoriness, ^oC	Loss on Ignition
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)

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). 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 are more likely to shrink with the reported low bulk density.

Apparent Porosity

Tatiko and Beji clays have high apparent porosity. For both samples the value at 110 ^oC 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 $\frac{1}{3}$ 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. 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 four 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 requires adequate firing to ensure its suitability for transportation of slag's and fluxes. Maikunkele clay exhibit the poorest cold crushing strength at a value of 13.445 MN/m^2 rendering it 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. This value bests 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.

4. Conclusion

In Nigeria, a large number of naturally occurring raw materials have been found for the production of refractory materials. Despite this fact; 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 nations economy and the uncertainty facing the petrochemical and metallurgical industries has necessitate the need to source for local raw materials to support the growth of these industries by producing high quality refractory commercially thereby substituting for importation and saving the much needed foreign exchange. The refractory properties of four clay samples in Niger State, Nigeria were studied. They are clays from 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 that of the Tatiko, Beji and Nyikangbe posting impressive figures at 28 cycles and 1710 ^{o} C respectively. 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 Niger state 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 State as a whole.

Acknowledgements

The authors acknowledge the support of Sambo Bashir for bringing energy into the laboratory work.

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