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RESEARCH ARTICLE

THERMAL CHARACTERIZATION AND LAGGING APPLICATION OF FIRECLAY DEVELOPED FROM ABEOKUTA IN OGUN STATE, NIGERIA

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ABSTRACT

The enormous loss of heat from high temperature equipment like boilers, furnaces, kilns and incinerators necessitates the use of fireclay as lagging material for minimizing the heat transfer from these systems to the surrounding. This paper presents the thermal characterization and application of fireclay samples developed from Abeokuta North Local Government Area of Ogun state in Nigeria. The clay samples were excavated from two clay deposit sites namely; Idi-Ori (sample A) and Eruku (sample B), they were processed into powdered form and pressed into shape to determine their chemical composition and thermal properties vis-a-viz refractoriness, thermal shock resistance, thermal conductivity and specific heat capacity. The chemical composition reveals 30% and 33.2% alumina for sample A and B respectively. The result of thermal shock resistance was over 25 cycles for both samples. Also the determination of the refractoriness (melting temperature) reveals 1512^oC for sample A and 1550^oC for sample B, the specific heat capacity of sample A is 1,315.4 J/kg^oK while that of sample B is 819.77 J/kg^oK. Finally, the thermal conductivity of 0.1272 (W/mK) and 0.1441 (W/mK) were determined for sample A and B respectively. The Performance test of the refractory bricks developed from the clay was carried out using an incinerator operating at 706^oC, heat minimization of 654^oC (from 706^oC to 52^oC) was recorded from the test compared to fibre glass that produced 640^oC (from 706^oC to 66^oC)

KEYWORDS: Fireclay, Lagging material, Refractoriness,Refractory bricks, Thermal conductivity, Thermal shock resistance and Specific heat capacity

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INTRODUCTION

Fireclay used for lagging application is known as a refractory brick. Refractory bricks are used for insulating high temperature systems and they are important elements in heat engineering plants since the 1960s, where they were effectively used to improve performance and energy efficiency. According to the American Society of Testing and Materials (ASTM) C71 "refractories are 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 538°C. Refractory materials are used for the internal lining of furnaces, kilns, boilers, incinerators and reactors as well as being used for making crucibles. It was estimated that the Ajaokuta Steel Company and Delta Steel Company in Nigeria will at full capacity, require 43,503 and 25,000 tons/year of refractories respectively for their activities, these products are sourced from abroad (Adondua, 1988). Onyemaobi (2002) reported that small scale industries in Nnewi and in some parts of the country have recently embarked on the fabrication of spare parts using high temperature furnaces that require refractory linings. 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, yet vast amount of fireclay deposits abound in the country, which can be developed to meet our local needs (Obadinma, 2003).

About seventeen years ago, over 90% of the refractories used by Nigerian industries were imported from America, Asia and Europe, the estimated cost of these materials is put at 2.27 billion naira per annum (Nnuka and Adekwu, 1999). Huge savings could be obtained if the available local clay materials are properly exploited and harnessed for the production of refractory bricks.

The combustion of solid waste in a mass burn incinerator occurs at a temperature range of $850^oC - 1100^oC$; pyrolysis and gasification take place at temperature ranges of $500^oC - 800^oC$ and $800^oC - 1000^oC$ respectively (Walter, 2002). Also in the metallurgical industry the melting of scrap ferrous metal takes place in an electric furnace that operates at a temperature above 1530^oC. Similarly, the smelting process of extraction of iron metal from its ore in a blast furnace occurs at about the same temperature. The efficiencies of all these processes requires that as much heat as possible is conserve within the system, only minimal heat should be lost to the surrounding and this implies that the system should be well lagged with a refractory material.

In this work, fireclay samples were excavated from Idi- Ori and Eruku clay deposit sites in the Abeokuta North Local Government Area of Ogun State in Nigeria. The samples were crushed, milled and pressed into shape, various test were carried out on them in order to develop a lagging material suitable for lining high temperature equipment.

MATERIALS AND METHODS

The fireclay samples used in this work were characterized in terms of chemical composition and thermal properties vis-a viz, refractoriness (softening or melting point), thermal shock resistance, specific heat capacity and thermal conductivity.

Sample preparation

The clay samples were collected from two chosen clay sites in Ogun State, Nigeria:
1. Idi-Ori deposit, Abeokuta North LGA; located on latitude 7.0667 (74'0.012''N), longitude 2.9000 (253'60.000''E) and altitude of 47m above sea level.

2. Eruku deposit, Abeokuta North LGA; located on latitude 8.1500 (89'0.000''N), longitude 5.4167 (525'0.012''E) and altitude 78m above sea level (http://www.tiptopglobe.com/city?i=1610511&n=Eruku. Last visited, June 2015).

The samples were prepared by crushing (using a crusher) and air-dried for 24 hours, this was followed by milling into powdered form and sieved using sieve aperture size of 710 *microns*. At this point the samples were tested for physical properties. Water was added and the mixture was thoroughly worked into a plastic state, then rammed (using Buehler Hydraulic Press) into a mould of 32*mm* (diameter) x 200*mm* (thickness) under a pressure of *2MPa*. After pressing, a suitable wooden plunger was used to extrude out the green brick from the mould. The extruded green brick was cut into required sizes of 50*mm* thickness. The sample was oven dried at 110°*C* for six hours and fired in a muffle furnace to 1200°*C* for six hours and finally tested for thermal properties.

The following tests were carried out on the two samples for analysis.

Chemical Analyses

The representative samples of the clays were analyzed to determine their chemical composition (% SiO_2, Al_2O_3, etc). The analysis was done using an X-ray fluorescence spectroscopy at the National Steel and Raw Material Exploration Agency in Kaduna. The machine fires a beam of X-ray radiation on the sample, this process causes an excitation of the electrons of the sample resulting in the release of energy in the form of X-ray fluorescence (XRF), this can be detected and the amplified signal is processed and read out.

Determination of refractoriness

The refractoriness of a fireclay is the temperature at which the material softens and hence it is a measure of fusibility of the material. The refractoriness of the clay samples was determined using the method of pyrometric cone equivalence test (PCE). This method involved using some standard cones (pyrometric cones) having cone numbers – 15, 16, 17, 18, 19 and 20 designed to deform at 1430°*C*, 1491°*C*, 1512°*C*, 1522°*C*,1541°*C* and 1564°*C* respectively- along with the molded cones of the clay samples. Both the standard and the molded test cones were mounted on a refractory plaque and placed in PCE furnace with a temperature rise of 100°*C* per minute. The heating was discontinued when the test cone bent over and leveled with the base of the plague. The refractoriness for each test cone is the number on the standard pyrometric cone that has bent over to a similar extent as the test cone. The temperature corresponding to the cone number was read off from the ASTM Orton Series. For sample A the number is 17 and for sample B the number is 19 corresponding to 1512^oC and 1550^oC respectively.

Thermal shock resistance
The two fired brick samples were heated in a muffle furnace at about 1000℃ for 10 minutes, thereafter they were removed and dipped into water at room temperature for about 60 seconds. They were later air-cooled for 10 minutes and returned into the furnace at about 1000℃ for another 10 minutes before plunging into water again. This cycle was repeated 25 times.

Determination of thermal conductivity: The test specimens measuring $29mm$ diameter and $4mm$ thickness were used for this test. The Lee's apparatus was used for the test in which a constant heat source (heating element) is sandwiched between two identical metal cylinders (heating disc). Thereafter the test specimen was placed over the surface of one of the disc and a third identical heating disc was in turn placed over the specimen so that they were all concentrically aligned. The thermal conductivity of the test specimen is then determined from the steady-state temperatures of the three blocks, the exposed surface areas of the blocks and the thickness of the test specimen.

The thermal conductivity of the specimen can be determined from equation 1

$$KA\frac{\theta_y + \theta_x}{d} = \frac{1}{2}ea_x\frac{\theta_y + \theta_x}{2} + ea_x\theta_x \quad (1)$$

Determination of Specific Heat Capacity
The specific heat capacity of the test specimens were determined experimentally using the method of heat transfer or method of mixture. This method of mixtures makes use of the principles that when two bodies at different temperatures exchange heat, the quantity of heat lost by the warmer body is equal to the heat gained by the cooler body, and some intermediate equilibrium temperature is finally reached. In this experiment, the test specimen of known mass and temperature was dropped in a calorimeter containing known mass of cold water. The equilibrium temperature was then measured. The magnitude of the heat lost by the solid must be equal to the magnitude of the heat gained by the water, and calorimeter with stirrer this is given in equation 2.

Equating heat lost to heat gained:
Heat lost by the solid = Heat gained by water + (calorimeter &stirrer)

$mC(T_3 – T_1) = m_2C_2 (T_3 – T_2) + m_1C_1(T_3 – T_2)$…………………………………………..(2)

This equation is used to compute the unknown specific heat, C, of the specimen.

Performance Test of the Lagging Material

The lagging material (sample A) developed was lined between the inner and the outer shells of an incinerator to evaluate its performance for minimizing heat loss and reducing temperature across the shells. The temperature inside the combustion chamber was taken with a thermocouple while a thermometer was used to take readings on the outer shell.

RESULTS AND DISCUSSIONS

Table 1: Chemical composition of the fireclay samples

S/N	Elemental oxide	% Composition	
		Sample A (Idi Ori)	Sample B (Eruku)
1	SiO_2	41.41	44.40
2	Al_2O_3	30.00	33.20
3	Ti_2O	5.74	7.98
4	Fe_2O_3	6.63	5.89
5	P_2O_5	0.43	0.37
6	CaO	0.22	0.20
7	BaO	0.21	0.16
8	Nb_2O_5	0.11	0.16
9	MgO	0.10	0.07
10	V_2O_5	0.09	0.12
11	K_2O	0.06	0.03
12	NiO	0.02	0.03
13	Cr_2O_3	0.04	0.04
14	Na_2O	0.08	0.08
15	MoO_3	0.03	0.05
16	Ga_2O_3	ND	0.02
17	Sc_2O_3	0.01	ND
18	Eu_2O_3	ND	0.01
19	SO_2	ND	ND
20	MnO	ND	ND
21	LOI	14.84	7.19

ND – Not Detectable, LOI – Loss on Ignition

Chemical composition of the clay

The result of the XRF chemical analysis to determine the composition of the clay samples from Idi-Ori and Eruku were presented in Table 1. This shows that for Idi-Ori clay the alumina (Al_2O_3) content was 30.00 %, silica (SiO_2) 41.41 % and iron oxide (Fe_2O_3) content was 6.63 %. Similarly, for the Eruku clay sample the alumina (Al_2O_3) content was 33.20 %, silica (SiO_2) 44.40 % and iron oxide (Fe_2O_3) content was 5.89 %. Hence, this indicates that the samples belong to the aluminium-silicate group. The alumina in both clay samples were within the range of 25% − 45% (Chesti, 1986) required for fireclay refractories. The higher the alumina content in clay, the higher is the refractoriness, similarly the low values of the fluxing oxides such as CaO and MgO further confirmed that the clay could be used as a lagging material.

Thermal properties of the firebrick samples

The thermal properties of the samples were determined from different experiments and the results were presented in Table 2. It was observed from the PCE analysis that samples A and B have refractoriness of 1,512°C and 1,550°C respectively which are within the acceptable range reported by Appel *etal.* (2011) and Grimshaw (1971). The relatively high refractoriness can be attributed to high alumina content of the clay and the low amount of impurity oxides, as their presence in high amount usually have an adverse effect of lowering the refractoriness. Also, the thermal shock resistances analysis of the fired brick samples reveals that they fall within the acceptable values of 25-30 cycles as reported by De Bussy (1972). The thermal conductivity of sample A and B are 0.1272 W/mK and 0.1441 W/mK respectively, these values depict very low thermal conductivity required for a refractory brick and compares closely with the value 0.12 W/mK (Toru *et al.* 2013) of firebricks developed abroad. The low thermal conductivity implies that heat transferred to the surrounding is minimized thereby conserving more heat in the combustion chamber.

Table 2: Thermal properties of the fireclay samples

Properties	**Sample A**	**Sample B**
Refractoriness (°C)	1520	1550
Thermal shock resistance	› 25 cycles	› 25 cycles
Thermal conductivity(W/mK)	0.1272	0.1441
Specific heat capacity (J/kg °K)	1,315.4	819.77

Performance Testing for Lagging Application

Table 3 shows the results obtained from the performance testing of the lagging material developed (sample A with thermal conductivity of 0.1272 W/mK). The lagging material was lined between the inner and outer shells of an incinerator; the temperatures of the shells were recorded with a thermocouple (for the inner shell) and a thermometer (for the outer shell) during the combustion process. The results obtained from the performance test of the lagging material revealed a significant reduction in the temperature (392°*C*) across the inner and outer shells of the incinerator. This implies that a considerable amount of heat was conserved during the combustion process of the solid waste materials. A similar test was carried out on a section of the incinerator using fibre glass as the lagging material, this produced a temperature difference of (385.1°*C*). This suggests that the refractory bricks conserve more heat than the fibre glass when used as a lagging material.

Table 3: Results of the performance testing of the lagging material

Temperature of inner shell (°*C*)	Temperature of outer shell (°*C*)
437	45.1
432	44.3
431	44.3
430	44.1
426	43.8
406	43.2
401	43.0
392	42.8
389	42.1
386	42.0

CONCLUSION

In this study, clay samples from Idi-Ori and Eruku have been characterized to ascertain their potentials as lagging materials. They can be used to line high temperature equipment like kilns, furnaces incinerators and steam boilers. The results obtained show they meet the criteria for use as a lagging raw materials in most of the characteristics investigated, vis-a-viz: chemical composition, specific heat capacity, thermal conductivity and refractoriness. The results of the investigation will be very useful and serve as a data base for prospective investors and managers of metallurgical industries.

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