EFFECT OF ALUMINA ADDITIONS ON THE REFRACTORINESS AND OTHER PROPERTIES OF SOME LOCAL FIRE-CLAYS FOR USE AS FURNACE LINING

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Abstract

This research was carried out on fire clay sample materials collected from two locations (in Ogun State), which were blended with alumina obtained from Aluminium Smelting Company of Nigeria, Ikot Abasi, Akwa-Ibom State *to determine their suitability as high refractory for use in furnace lining in foundry Industries. It was revealed that, blending the two fire clay samples (Onibode and Owode-Ketu) with alumina in various proportions such as; 60:40, 70:30, 80:20 and 90:10, respectively gave an improved refractory properties. The result of the analysis shows that these clay deposits can be used as high refractory lining in the foundry Industries. Onibode fire clay produced good refractory materials with the addition of alumina, with improved and acceptable service properties that give better results which can be used for lining of furnaces for melting of metals and its alloys compared to Owode-Ketu fire clay. The refractoriness of Onibode material is above 1600°C, while that of Owode-Ketu is 1580°C with the blended alumina. The crushing strengths of Onibode and Owode-Ketu clays are 16.3 MPa and 22.7MPa, respectively. With the addition of alumina the crushing strengths of the mixtures for the various proportions as shown in Table 3 are :* 21.3, 16.3, 18.2, 12.8, 19.2, 25.6, 19.2 and 18.1 MPa, respectively, which are also within the acceptable standard. *The result of the analysis shows that these clay samples can be used as refractory lining in the Foundry Industries.*

1.0 Introduction

The use of refractory materials, particularly for lining of kilns, furnaces, reactors, boilers and other pre-heating equipment is very important in foundry and allied industries.

Some of the equipment mentioned above operate at a very high temperature, which required high refractory bricks (1770°C and above). Abrupt failures of the lining materials in operation may result in great loss of time, equipment, energy and products. Most of the refractory materials which are being used in lining furnaces and other equipment using refractory are imported into the country at exorbitant prices. This practice is not acceptable and unnecessary as the materials for the production of source items are available in abundance in the country. The RMRDC report on Techno-Economic survey of non metallic minerals (2003), indicates that a number of these minerals are available in many states of the Nigeria, which can be tapped for these purpose. The cost of importing these refractory materials into the country has been put at N2.27 billion Naira per annum by Nnuka, etal (1999). The Naira (local currency) has witnessed unstable exchange rate against foreign currencies and its value has considerably depreciated in the recent time. Continuous importation of these products would be a great loss to the Nigerian economy. It has been estimated by Adondua (1989) that about 61.4×10^3 tons refractory materials are needed per annum by the Nigeria industries.

This work is aimed at studying fire - clays from Onibode and Owode-Ketu in order to identify which of the clays could be blended with alumina to give suitable refractoriness that will be suitable for furnace lining.

2.0 METHOD OF INVESTIGATION

2.1 Materials

The fire clay samples were collected from Onibode (ON) and Owode-Ketu (OW) in Ogun State, Nigeria. Alumina sample was obtained from Aluminium Smelting Company of Nigeria, Ikot Abasi, Akwa-Ibom State. The clay samples were crushed, soaked in water, air–dried and sieved through 63 microns. Test sample pieces were prepared in conformity with ASTM (1989), PA 19103-1187 standards for each test carried out. They were rammed into standard sizes, dried and fired. The samples were then tested for: permeability to air, cold crushing strength, fired linear shrinkage, bulk density, apparent porosity, thermal shock resistance, refractoriness and loss on ignition. The chemical analyses of the clay materials in conformity to British Standards (BS EN ISO 21587-3: 2007) were carried out using Atomic Absorption Spectrophotometer (PG990AFG) and in conformity to British Standards. The compositions of the various clays are recorded in Table 1, while Table 2 shows the physical analysis of the virgin clays, as well as those blended with alumina in different proportions (90:10; 80:20; 70:30 and 60:40%). The clay samples were used as the base for the analysis. The physico-thermal analysis of the samples was also carried out and the results are as shown in Table 3.

2.1.1 Permeability

Test samples from both locations were prepared to specification of 5.08cm diameter and 5.08cm height from a standard rammer.

The test pieces were air-dried for 24 hours and then dried at 110^0C for 12 hours in an oven (Genlab) of 250^oC capacity. About $2000cm^3$ of air was allowed to pass through the sample. The pressure difference between the surfaces was measured by a manometer. The time taken for $2000cm^3$ of air to pass through the test sample was recorded.

Permeability was calculated using the equation below:

$$P_A = \frac{VH}{APt} \quad (1)$$

where,

P_A is the Permeability number;

V is the Volume of air (cm^3);

H is the Height of specimen (cm);

A is the Cross sectional area of specimen (cm^2);

P is the Pressure of air in cm of water;

t is the Time (in minutes).

2.1.2 Cold Crushing Strength (CCS)

Test pieces of clay samples were prepared to a standard size of 76.2mm cube on a flat surface. The test pieces were fired in a furnace at 1100^0C for 6 hours and the samples were cooled to room temperature before removal. Each sample was placed on a compressive tester and load was applied axially by turning the hand wheel at a uniform rate till failure occurred. The barometer readings were recorded.

Compressive strength was calculated from the equation,

$$CCS = \frac{\text{Maximum load (KN)}}{\text{Cross-Sectional area } (m^2)} \quad (2)$$

The results are shown in Tables 2 and 3, in MPa.

2.1.3 Fired Linear Shrinkage

Test samples were made into slabs of dimension 95x45x12mm and placed 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 (0-25cm) and later air-dried for 24 hours before being oven dried at 110^{0}C for 6 hours. The test pieces were cooled to room temperature and the fired length measurements were taking. The fired linear shrinkage was calculated from the relation given below:

Fired Shrinkage =(DL – FL) x 100% (3)

where,

DL is the Dried Length;

FL is the Fired Length.

2.1.4 Bulk Density

Test samples of 60mm x 60mm x 15mm each were prepared from each clay materials. The samples were air-dried for 24 hours and oven dried at 110^{0}C. The samples were cooled and weighed to an accuracy of 0.0018g. The weighed samples were later heated for 30 minutes to evacuate the trapped air. Second readings of the weight of the samples (w) were taken after cooling and soaking in the water. Similarly, the suspended weights of the samples were recorded. The bulk density was evaluated using equation 4.

$$\text{Bulk Density} = \frac{D \cdot \rho_w}{W - S} \ (g/cm^3) \quad (4)$$

where,

D is the dried weight;

W is the soaked weight;

S is the suspended weight;

ρ_w is the density of water.

2.1.5 Apparent Porosity

Test samples of dimension 20mm x 30mm diameter each were prepared and air-dried for 24 hours. They were oven dried at 110^{0}C and cooled to analytical temperature (25^{o}C). The weights of the samples were measured to the nearest 0.01g in desiccators.

The samples were later transferred into a 25ml beaker in an empty vacuum desiccators. Water was introduced into the beaker until the test samples were completely immersed. The samples were allowed to soak in boiled water for 30 minutes and agitated from time to assist to release trapped air bubbles. They were cooled in vacuum desiccators and weighed (W). After which, the sample was weighed suspended in water using beaker placed on balance to give suspended weight(s). The apparent porosity was calculated using the equation 5 below:

$$\text{Apparent porosity} = \frac{W-D}{W-S} X100 \qquad (5)$$

where,

W is the soaked weight;

D is the dried weight;

S is the suspended weight.

2.1.6 Thermal Shock Resistance

Three test samples with diameter 50mm x 75mm each were placed in a furnace, at temperature of 900^0C for 10 minutes. The samples were further cooled for 10 minutes in the air. The samples were returned to the furnace for duration of 10 minutes. The process was repeated until the test samples crack. The number of heating and cooling cycles for each sample was recorded as shown in Tables 2 and 3.

2.1.7 Refractoriness

The test pieces mounted on a refractory plague along with a standard cone whose melting point is slightly above or slightly below that expected of the test cone were placed in a muffle furnace. The temperature of the furnace was raised at a rate of 100^0C per minute until the tip of the test cone bent over level with the base. At the end of the experiment, the final temperature was recorded. The result of the test is presented in Tables 2 and 3.

2.1.8 Moisture Content

The specimen for the determination of moisture content was weighed (G) and then placed in an electrical furnace at a constant temperature of 104 °C - 110°C. The sample was taken out, cooled and re-weighed (G_1).

The loss in weight gives the amount of moisture content (W), which can be expressed as a percentage of the initial sand sample. The following expression can be used:

$$W = \frac{G - G_1}{G} X\ 100\% \qquad (6)$$

Where,

W is the moisture content, %; G is the weight of the sample before drying, g;

G_1 is the weight of the sample after drying, g.

The moisture content results of the sand are shown in Tables 2 and 3.

2.1.9 Loss on Ignition (LOI)

50g of the sample was dried at 110^{0}C and cooled. The sample in a clean and dried porcelain crucible was heated in a muffle furnace to a temperature of 900^{0}C for 3 hours. The loss on ignition (LOI) was calculated from equation 7.

$$LOI = \frac{m_2 - m3}{m2 - m_1} X\ 100\% \quad (7)$$

where,

m_1 is the weight of the crucible;

m_2 is the weight of clay and the crucible;

m_3 is the weight of dried clay and the crucible.

3.0 RESULTS AND DISCUSSION

From the analysis on the clay materials, the thermal shock resistance of Onibode clay falls within the accepted value of 25-30 cycles as reported by De Bussy (1972), while that of Owode Ketu falls below the standard but with addition of alumina to it, the result improved to 20 cycles as shown in Table 3. It was observed from the analysis that the refractoriness of Onibode clay which is 1550°C for the control is within the standard, 1500-1750°C for fireclays, according to Grimshaw (1971), while that of Owode-Ketu is 1350°C. The blended mixture of Onibode with alumina also gave great improvement on the refractoriness of the materials (> 1600^{0}C with 40% alumina), the results is as shown in Table 3. There was also an improvement when alumina was added to Owode-Ketu clay, as shown in Table 3. It was observed that the linear shrinkage of both clays were within the accepted value, Chester (1973), which were 2% and 3.2%, respectively.

The fireclay collected from Onibode contained 1.90% moisture while that of Owode-Ketu was 4.90%. The mixture moisture content ranged from 2.2-12.4% for Onibode and 6.2-8.5% for Owode-Ketu, respectively. The apparent porosity of the clays were 28.18% and 13.39%, respectively. The value of Onibode clay which was 28.18% fell within the standard values of 20-30%, according to Chester (1973), while that of Owode-Ketu fell below the standard, but the addition of 40% alumina tended to improve the apparent porosity to standard value of 30%. The result is depicted in Table 3.

On the cold crushing strength (CCS), the value obtained for Onibode and Owode-Ketu are 16,3MPa and 22,7MPa and 21.3, 16.3, 18.2, 12.8, 19.2, 25.6, 19.2 and 18.1 MPa for the mixture, respectively. This value is within the standard as reported by De Bussy (1972) on fire clay materials. The average bulk density of the clay samples is as recorded in Table 2. The permeability of the analyzed clays is also recorded in Table 2 and is within the stipulated standard as reported by Chester (1973). The chemical composition of the materials collected is shown in Table 1. The CCS of the virgin material from Onibode was 16,3MPa while that of Owode-Ketu was 22,7MPa but the addition of 10% Alumina to both clay materials; the CCS of Onibode increases to 21,3MPa while that of Owode–Ketu decreases to 19.2MPa. The highest CCS of the mixture for Onibode was recorded with the addition of 10% Alumina and that of Owode-Ketu was with the addition of 20% alumina, respectively.

Table 1: Chemical Analysis of the Materials Collected

Sample Location	Chemical Analysis,%											
	Al_2O_3	SiO_2	Fe_2O_3	TiO_2	CaO	CuO	MnO	K_2O	Cr_2O_3	V_2O_5	ZrO_2	LOI
Onibode Clay (ON)	37.40	50.80	5.83	3.60	0.24	0.06	0.02	0.98	0.06	0.14	0.18	0.67
Owode-Ketu Clay OW)	21.00	57.30	13.70	3.37	1.28	0.08	0.24	1.96	0.06	0.13	0.35	0.88
Alumina (AL)	98.5	-	0.09	-	0.25	0.07	0.022	-	0.04	-	-	1.09
*Standard for fireclay (Devon)	34.00	48.00	1.00	0.90	0.20	-	0.03	1.60	-	-	-	13.80

Table 2: Physico-Thermal Properties of the Virgin Materials Used

Properties	Sample Location			
	Onibode Clay	Owode-Ketu Clay	Alumina (Ikot Abasi)	*Standard for Clay
Fired Linear Shrinkage,%	2.0	3.2	1.5	7-10
Permeability to Air	78	67	82	20-30
Apparent Porosity %	28.18	13.39	58.34	20-30
Bulk Density, g/cm³	1.92	2.15	1.32	2.2-2.80
Cold Crushing Strength, MPa	16.3	22.7	5.6	15 min.
Thermal Shock Resistance, Cycles	25	18	23	20-30
Refractoriness, °C	1550	1350	>1600	1500 – 1700
Moisture Content, %	1.90	4.90	4.70	7 – 12

Table 3: Physico-Thermal Properties of the Fire Clay with Alumina

Properties	Sample with Alumina							
	ON + AL				OW +AL			
	10%	20%	30%	40%	10%	20%	30%	40%
Fired Linear Shrinkage,%	2.0	1.5	1.0	2.0	5.0	1.0	1.5	4.0
Permeability to Air	69	70	76	80	68	69	72	75
Apparent Porosity %	29.87	32.70	38.70	43.44	24.43	29.95	35.24	56.32
Bulk Density, g/cm^3	1.95	1.9	1.83	1.7	2.15	2.02	1.92	1.82
Cold Crushing Strength, MPa	21.3	16.3	18.2	12.8	19.2	25.6	19.2	18.1
Thermal Shock Resistance, Cycles	25	23	24	21	18	20	20	18
Refractoriness, °C	>1600	>1600	>1600	>1600	1400	1450	1550	1580
Moisture Content, %	2.2	3.0	3.4	12.4	6.2	6.7	7.7	8.5

4.0 CONCLUSION

Blending of both fire clay materials with addition of 40% alumina as investigated showed a great improvement on refractoriness for both deposits (Onibode and Owode-Ketu), which were about 96.8% and 98.4%, respectively. It was reviewed that the service properties of Onibode clay as compared with Owode-Ketu clay with the blended alumina has favourably result which can be used as high refractory for furnace lining in foundry industries for melting of metal and its alloys. This material when processed as refractory bricks can be exported for commercial purpose. The Owode-Ketu clay can probably be used in lining of furnaces for melting of cast iron, glass production companies and other furnaces operating within 1350-1550°C.

This study shows that blending of Onibode clay with 10%, 20%, 30% and 40% alumina gives good result as shown above in Table 3.

The higher the percentage of alumina in the mixture, the higher the refractoriness obtained. The result also shows that Nigeria has the potential to produce refractory materials, which can be harness for commercial purposes.

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