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Suitability of Birnin Gwari and Maraban Rido Clays as Refracory Materials

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Abstract: - Most of the industries in Nigeria depend heavily on the use of refractory materials. For instance the iron and steel industries, cement, glass, refineries, bakeries and ceramic industries. However, almost all the refractory materials used by these industries are imported. Consequently, it leads to the draining of Nigeria's foreign reserve and this in turn negatively affects the economy of the Country. Therefore, there is the need to increase the local production of the refractory materials in order to reduce their importation and thereby boost the economy Nigeria. Hence this researched work was carried out to investigate and see if the Birnin Gwari and Maraban Rido clays in Kaduna state, Nigeria can serve as refractory materials. The clay samples were obtained from the mining sites and processed to produce fireclay brick test specimens which were fired between 250^{o}C and 1400 ^{o}C. The fired bricks were then tested for refractory properties such as: the linear shrinkage, bulk density, apparent porosity, cold crushing strength, thermal shock resistance and refractoriness (Pyrometric Cone Equivalent) using ASTM standards. The obtained results were as follows: The Linear shrinkage was 10% and 8.0%; apparent porosity 24.65% and 21.55%; bulk density 1.75 g/cm^3 and 1.96 g/cm^3, cold crushing strength 165.0 Kg/cm^2 and 216.9 Kg/cm^2 , refractoriness 1300 ^{o}C and 1400 ^{o}C and thermal shock resistance 16.67 and 32 cycles for Maraban Rido and Birnin Gwari clays respectively. The results as compared with the standard refractory bricks, showed that both clays are suitable for fire clay refractory materials while bricks produced from Birnin Gwari clay are also suitable for batch furnace applications. Both clays can be used for lining of non-metallic melting furnaces.

Keywords: - *Birnin Gwari, Maraban Rido, Clay, Refractory Material, Bricks*

I. INTRODUCTION

According to Aigbodion V.S. (2008), Aigbodion V.S., et al (2007), a refractory material is one which has the ability to withstand high temperature, physical and chemical actions of molten metal slag and gases without deformation failure or change in the chemical composition under their own weight. It is said in Akingbode E.O (1996) and Hassan S.B. (2000) works that refractory materials are used for furnace linings and construction of tubes for electric furnaces, crucibles pots, thermocouple sheaths, refractory cements, among others. These properties are extremely very useful at enhancing both the process control and product quality according to Chesti A.R. (1986) et al.

i) Reinhard S.J. (1982) in his work said Refractories are considered as inorganic materials, which are mainly mixtures of oxides, obtained from naturally occurring minerals, which are capable of withstanding very high temperature condition, without any undue deformation, softening, change in composition. They include silica, magnetite, chrome, carbon, dolomite and alumino-silicates. From Okeugo C.O. and Nwabineli (2012) and Irabor P.S.A., (2002) works, we know that most industries dealing with the treatment of ores and other materials for the manufacture of metallurgical, chemical and ceramic products operates at a very high temperature condition, so the equipment used for the treatment of this materials must sustain the operating temperatures and other working condition such as erosive and local conditions. The industries in Nigeria such as the Iron and Steel, Cement, Glass, Refineries, Bakeries and Ceramic industries etc depend heavily on the use of refractories and their demand are presently met, to a large extent by the importation of theses refractories. Therefore, it has become imperative to produce these refactories locally. Nigeria is endowed with large quantity of clay deposits all over the country, which has not yet been fully explored. Such areas are Birnin Gwari and maraban rido clay deposits. Thus, the study covers the investigation of refractory properties of Birnin Gwari and Maraban Rido clay deposits. The success of the research will bring about a reduction in importation of the refractory bricks thereby preserving our much needed foreign reserve, creation of more jobs, add economic value to the abundant Birnin Gwari and Maraban Rido clays in Nigeria, the production of Cheaper Refractory. Consequently, with locally sourced raw materials, it is expected that both the cost of materials and production will be low hence the refractory materials will be cheaper.

II. METHODOLOGY

2.1 Materials and Equipment

The materials used were Birnin Gwari and Maraban Rido clays (Kaduna State)

The major equipment used were: X-ray Flouresence (XRF) Machine, Carbolite furnace, Standard Pyrometric cone and roll crusher, Paul Weber hydraulic press, Densometer Electric Water Heater, Electrical Resistance Furnace

2.2 Experimental Procedures

- **Winning:**

The process of collecting clay material is called winning. The available basic winning methods for obtaining clay are mechanical winning and hand digging. Hand digging was employed in this work based on the ease of the process and the low cost involved**.**

- **Crushing and grinding**

The collected clay samples were in wet lump. The samples were dried (dehydrated) in sun for a day for easy crushing to smaller particles before further processing. The crushing and grinding of clay were done by mechanical means using pulverizing machine. The dried clay was crushed and ground into powder form. The ground clays were then sieved with a sieve of 300µm aperture according to ASTM C1054-03 (2008)

- **Chemical Analysis*:***

The elemental composition of the two clays was determined through the X-Ray Fluorescence (XRF) analysis in accordance with American Society of Testing of Materials (ASTM) C25-06. (2010) The results are presented in table 3.1

- **Samples/Brick Production**:

Preparation of the test samples involved mixing of the freshly sieved clay with water. The clay mixture was found to be plastic at 15% water content level. The mixed blend was packed into a metal moulding box and pressed using hydraulic press. A pressure of $10kg/cm^2$ was applied to enhance homogeneity and surface smoothness of the samples.

- The moulds used for forming the sample bricks was made from mild steel with internal cross section of 50mm X 50mm and lengths of 40mm, 50mm and 60mm.

Fig 3.1 : Hydraulic Press for Moulding

• The moulded bricks were dried in open air for three days, followed by drying in oven for 12 hours at 110^{O}C to expel any moisture left in them and to avoid crack during firing. Firing was carried out in electric heating furnace pre set at heating rate of 7^{o}C/minute. The firing procedure used involved heating and soaking the samples at various temperatures using ASTM-C16-03 (2009), as shown below:

- a) 250^{O}C for 6 hours
- b) 650 ^{O}C hours for 4 hours
- c) 950 ^{O}C for 3 hours
- d) 1100 ^{O}C hours for 8 hours
- e) 1400 ^{O}C hours for 8hours

• The bricks were then allowed to cool in the furnace at a cooling rate of 1^{o}C /minute immediately after firing to avoid sudden cracks according to ASTM-C16-03 (2009). The cooling rate was achieved with a digital pre-set furnace and this was done to avoid sudden cooling that may result to cracking of the bricks after firing.

1.3.1. TEST PROCEDURE:

The refractory properties of the fired bricks were tested, which includes: linear shrinkage, apparent porosity, bulk density, cold crushing strength, Refractoriness and thermal shock resistance, in accordance to the recommended standard.

a. Measurement of Linear Shrinkage:

The green and fired dimensions of the bricks were measured. The linear shrinkage was then calculated as a percentage of the original wet length as shown below

Percentage of fired shrinkage = $\frac{l_{b-}l_{c}}{l_{b}} x100\,(\%)$ …………………………..(1)

l_b-- dimension of green bricks
l_c--- dimension of fired bricks

b. Apparent Porosity and Bulk Density

The fired brick of 50mm x 50mm x 40mm size was kept in the oven at 110^{O}C for 3 hours to obtained constant weight D, the brick was then suspended in distilled water and boiled on a hot plate for 30 minutes, after boiling, while still in hot water, the water was now displaced with cold water and the weight W was measured on a spring balance hinged on the a tripod stand. The test samples were removed from the water and extra water wiped off from the surface by lightly blotting the sample with wet towel and the weight S in air was measured, the apparent porosity (P_a) of the bricks was determined from the relationship below in accordance with ASTM - C20–80 (2011):

$P_a = \frac{W-D}{W-S} x100(\%)$ …………………..……………………………..(2)

Pa=apparent porosity

The bulk density (B_d) was also calculated from the relationship as:

Bd = $\frac{D}{W-S}$ (g\cm^3) ……………………..……………………….(3)

Bd=bulk density, D = Dried weight, W = Soaked weight, S = Suspended weight

c. Cold Crushing Strength

The fired bricks with 50mm wide and 50mm high were tested for crushing strength, using hydraulic machine. The load was applied axially by turning the hand wheel at a uniform rate until fracture occurs. The crushing strength was then calculated using the relationship below in accordance with ASTM C133-97 (2010):

Cold Crushing strength = $\frac{load(KN)}{Area(m^2)}$ ……................................... (4)

d. Thermal Shock Resistance

The fired bricks of 50mmx50mmx60mm were used. The thermal shock was carried out using the test rig according with ASTM-C16-03 (2009) [Standard Test Method for Load Testing Refractory Shapes at High Temperatures]. The test rig consists of a sample holding table which is designed so that the heat transfer due to conduction is reduced to its minimum value. Stainless steel sheathed K-type insulated junction thermocouples of

0.5 mm in diameter; 150 mm long were used to measure the surface and the centre temperatures. These thermocouples can measure temperatures ranging from 0 to 1100°C. The sample was placed in the test rig and maintained at about 1100°C and soaked for 15 minutes, after which, it was air cooled and observed for any cracks. If none were observed, it was returned to the furnace and the same process repeated until the sample cracked. The result of the number of cycles of the samples is presented in Table 3.7.

e. Refractoriness

The clay samples were made into sample cones of 1.27cm base side and a perpendicular vertical length of 3.81cm, this size is the recommended shape for refractoriness test by ASTM-C24-79 (2002). The cones were mounted on refractory base along with several other standard compositions. The cones were heated at a rate of 5^0C/min in an oxidizing atmosphere in the furnace until the test cone squatted was compared with the standard cones, the test material is said to have the pyrometric cone equivalence of the standard cone whose behavior most resembled the test cone. The refractoriness or softening point was determined using the method of pyrometric cone equivalence (PCE) in accordance with ASTM C24 – 79 (2002). The refractoriness for each test cone is the number of 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. The result of the refractoriness of the samples is presented in Table 3.8.

III. RESULTS AND DISCUSSION

3.1 Chemical Composition

The average values of the elemental composition analysis of raw samples of Maraban Rido and Birnin Gwari clays were done using X-ray fluorescence (XRF) machine and are presented in Table 3.1.

Table 3.1: Elemental (XRF) Analysis of Raw Clay samples

Composition	Maraban Rido %	Birnin Gwari %
Al_2O_3	33.42	35.67
SiO_2	45.94	44.59
Fe_2O_3	0.70	0.23
CaO	1.30	0.08
MgO	0.04	0.06
K_2O	0.36	0.52
Na_2O	0.36	0.14
TiO_2	1.28	1.10
Cr_2O_3	2.23	1.85
MnO	0.36	0.43
Moisture	13.93	15.23
LOI	0.08	0.10

The chemical composition of both clay samples tested showed that the alumina (Al_2O_3) content for Maraban Rido was 33.42% while that for Birnin Gwari was 35.67%. Both of them were found to qualify as high melting clays. This is because the values of their alumina content lie within the recommended range for high melting clays (ASTM, 1982). Also the silica (SiO_2) content of Maraban Rido was 45.94% while that for Birnin Gwari was 44.59% and both meet the standard for fireclay refractory. (ASTM, 1982). This means that these clays can be used for lining of heat treatment furnaces and portions of blast furnaces in accordance with the Annual Book of ASTM Standards, 1982.

The iron oxide content of both clay samples is low and these levels of oxide will not impart a reddish colour to the clay when fired. The iron oxide of Maraban Rido was 0.70% and the Birnin Gwari was 0.23% which meets the iron oxide requirement for both refractory clays and high melting clays. According to the Annual Book of ASTM Standards (1982), the maximum amount of iron oxide for fireclay must not exceed 2%.

3.2 Surface Appearance

The physical appearance of the bricks after firing revealed that there was no crack in all the bricks after firing. This means that both clays bond very well during firing (see Table 3.2 and Photograph 3.1).

Table 3.2: The surface appearance the bricks

Samples	After Drying	After Firing	Colour Change
Maraba Rido clay	No crack	No crack	No colour change
Birni Gwari clay	No crack	No crack	No colour change

Photograph 3.1: Sample placed inside the Oven

3.3 Linear Shrinkage

The results of the linear shrinkage are show in Table 3.3.

Table 3.3: Firing Shrinkage of Bricks Samples

S/N	Sample Name	Initial Length (cm)	Final Length (cm)	Firing Shrinkage %
A	Maraban Rido	10.0	9.0	10.0
B	Birnin Gwari	10.0	9.2	8.0

The linear shrinkage of Maraban Rido clay was found to be 10.0%, while that of Birnin Gwari clay was 8.0% as reflected in Table 3.3. Both clays are within the recommended values of fireclay bricks which have values from 7.0-10.0 % (see Table 3.9). These values are satisfactory, because higher shrinkage values may result in warping and cracking of the brick and this may cause loss of heat in the furnace.

3.4 Apparent Porosity and Bulk Density

The results of the apparent porosity and bulk density of the two clays are shown in Table 3.4 - 3.5 respectively.

Table 3.4: Apparent Porosity of Brick Samples

S/N	Name	D (g)	S (g)	W (g)	% Porosity
A	Maraban Rido	11.54	6-19	13.39	25.70
		10.45	5.48	12.05	23.68
Average Porosity					**24.65**
B	Birnin Gwari	16.66	8.41	14.87	22.10
		13.66	6.94	15.45	21.00
Average Porosity					**21.55**

The **apparent porosity** values of the bricks were 24.65% and 21.55% for Maraban Rido and Birnin Gwari clays respectively. Hence the porosity of the clays fall within acceptable level as recommended for fireclay bricks of 15-25% as reflected in Table 3.9. Maraban Rido has a higher value of apparent porosity than Birnin Gwari clay, because Birnin Gwari clay underwent good vitrification during firing.

The **bulk density** values of the bricks were 1.75g/cm^3 and 1.96g/cm^3 for Maraban Rido and Birnin Gwari clays respectively as shown in Table 3.5. Bricks made from Birnin Gwari clay were within the recommended standard for fireclay which has value range of 1.9 – 2.3 g/cm^3 as presented in Table 3.9. The bulk density is a useful property of refractories, which is the amount of refractory material within a volume (g/cm^3). High bulk density observed for the Birnin Gwari clay bricks indicates an increase in heat capacity and resistance to slag penetration.

Table 3.5: Bulk Density of Brick Samples

S/N	Sample Name	W_1 (g)	W_2 (g)	Bulk D (g/cm^3)
A	Maraban Rido	14.18	109.16	1.75
		13.05	100.61	1.75
		Average		**1.75**
B	Birnin Gwari	16.99	120.48	1.907
		21.22	142.39	2.016
		Average		**1.96**

3.6 Cold Crushing Strength

The average cold crushing strength was 165.0 and 216.9kg/cm^2 for Maraban Rido and Birnin Gwari clays respectively as presented in Table 3.6. The two clays meet the standard of cold crushing strength of 150kg/cm^2 minimum for fireclay as presented in Table 3.9. But bricks made from Birnin Gwari clay have higher cold crushing strength which means it can withstand handling, transportation and abrasion more than bricks made from Maraban Rido clay.

Table 3.6: Cold Crushing Strength of Brick Samples

S/N	Sample Name	L (cm)	B (cm)	Area (cm^2)	Force (KN)	Mass (kg)	C.CS (Kg/cm^2)
A	Maraban Rido	2.5	2.5	6.25	10	1000	160
		2.4	2.4	5.76	9.8	980	170
		Average					**165**
B	Birnin Gwari	2.4	2.4	5.76	13.5	1350	234.4
		2.7	2.6	7.02	14	1400	199.4
		Average					**216.9**

3.7 Thermal Shock Resistance

The thermal shock resistance values were 16.67 and 30 cycles for bricks made with Maraban Rido and Birnin Gwari clays respectively as presented in Table 3.7. Bricks produced from Birnin Gwari clay fall within the acceptable ranges of 20-30 cycles for fire clay as presented in Table 3.9. This might be due to the fact that no degree of fusion might have taken place that may have burn off the brick which would have resulted to low thermal shock resistance.

Table 3.7: Thermal Shock Resistance of Brick Samples

S/N	Sample Name	No of Circles	Average No. of Circles
A	Maraban Rido	16, 15, 19	**16.67**
B	Birnin Gwari	30, 29, 30	**30.0**

3.8 Refractoriness

The refractoriness values were 1300 and 1400^{o}C for bricks made with Maraban Rido and Birnin Gwari clays respectively as shown in Table 3.8. The bricks made with Birnin Gwari clay can withstand higher temperature than bricks made with Maraban Rido clay. These low values of refractoriness were as a result of the alkali content in the clays. Because of the limitation of furnace in temperature (i.e. maximum furnace temperature was 1400^{O}C), the refractoriness of Birnin Gwari clay could not be obtained above this temperature, and hence their refractoriness for ferrous metals cannot be ascertained. However, there were indications that the refractoriness of Birnin Gwari bricks can be higher than 1400^{O}C

Table 3.8: Refractoriness of Brick Samples

S/N	Name	Refractoriness
A	Maraban Rido	1300^o
B	Birnin Gwari	1400^o

Table 3.9: Summary and Comparison of Properties of the Clays with Standard Fireclay Brick

Refractory properties	Maraban Rido	Birnin Gwari	Fireclay (ASTM), 1982
Bulk Density (g/cm^3)	1.75	1.96	1.9 - 2.3
Apparent Porosity (%)	24.65	21.55	15 – 25
Linear Shrinkage (%)	10.0	8.0	7 – 10
Thermal Shock Resistance	16.67	30	20 – 30
Cold Crushing Strength (kg/m^2)	165	216.9	150 minimum
Refractoriness (^oC)	1300	1400	1500 - 1700

IV. CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

The present research was centered on the development and characterization of Maraban Rido and Birnin Gwari clays as refractory materials. From the forgoing results and discussions, the following conclusions were arrived at:

1) The investigated clays are high silicate clays with moderate alumina content, low ferrous oxide content and possess very low contents of other metal oxides.
2) Bricks produced from Birnin Gwari clay have higher refractoriness. This means that Birnin Gwari clays do not easily burn off or fused. This suggests there was an improved vitrification which improved bonding and the cold crushing strength of the bricks.
3) The cold crushing strengths of the two clays meet standard values of $150kg/cm^2$ minimum for fireclay. This means that high strength bricks can be made from this clay.
4) Bricks produced from Birnin Gwari clay have a thermal shock resistance of 30 cycles which makes them suitable for heat treatment furnaces application.
5) It can be seen that the physical properties of Birnin Gwari clays compare very favorably with those for international standard fire clay refractory bricks as presented in Table 4.9.

4.2 Recommendations

The research has yielded some important information on the suitability of Maraban Rido and Birnin Gwari clay deposits as refractory materials and thus, the following recommendations are made:

1. Birnin Gwari clay is recommended to be use as fireclay bricks
2. It is recommended that further investigation on the micro structural analysis of these bricks be carried out to be able to known the particles' spacing and interfacial bonding of the clay
3. Both Maraban Rido and Birnin Gwari clays are recommended to be used in casting non-ferrous materials only. However, further studies should carried out to investigate the properties of these clays by firing above 1400 ^{o}C in order to find the suitability of these clays for ferrous materials.
4. The geological survey of the Birnin Gwari and Maraban Rido Clay deposits should be carried out to determine the extent of the deposits so as to form the basis of establishing a refractory company there.

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