Analysis Of Mubi Clay Deposit As A Furnace Lining

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Abstract: Mubi clay was investigated to examine if the deposit can be used as a furnace lining material. The result shows that the clay has a bulk density of 2.3g/cm^3, apparent porosity of 13.70%, firing shrinkage of 9.6%, thermal shock resistance of 8 cycles, cold crushing strength of 253 kg/cm^2, loss on ignition of 4% and refractoriness of 1,300 ^{0}C. The percentage composition of impurities is generally below 2.0% while iron II oxide account for 5.986%. The chemical analysis shows that the percentage composition of Aluminium oxide (Al_2O_3) is 18.1% while the Silica (SiO_2) content is 67.7%. The results obtained from Mubi clay showed that the clay can be used for lining of heat treatment furnace, melting furnaces for low melting point metals, liquid metal ladles and portions of blast furnaces.

Index terms: Furnace lining, Clay, Composi

INTRODUCTION

Furnace lining is a protective and insulating layer of heat resistant material attached to the inside of the shell, hearth, and tap holes of a furnace. This layer serves to protect the furnace parts from the extreme heat developed during smelting operations. It also prevents excessive heat loss from the external furnace surfaces making the process more efficient. Furnace lining materials are typically ceramics or combination of metal/ceramics that have ability to withstand protracted extreme temperatures. Furnace materials also known as refractory materials must able to resist mechanical shocks abrasion; and chemical reactions within the molten metal; have low thermal conductivity and low coefficient of expansion [1], is typically anhydrous complex compounds of Alumina and silical, that is in various proportion and contain varied amount of impurities of iron, organic matters and residual minerals [2].Clays used for furnace linings in metallurgical industries are classified as refractory clays [3]. However, the degree of refractoriness and plasticity of any clay material is often influenced by the amount of impurities contained in them.

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The percentage of the minerals (Fe_2O_3, MgO, CaO, Na_2O, etc) in the clay ultimately determine the areas of application of the clay such as in bricks, floor, tiles and that metal oxides (Na_2O, K_2O, CaO, etc) indicate their suitability for making ceramic products [4]. The ability of any refractory clay to withstand high temperature and resist physical and chemical reactions determines the suitability of such clay for use as furnace lining. Nuhu and Abdullahi [5], explained that the selected refractory clay will have to be beneficiated with refractory clay material from other, sites and be properly blended with other additives to improve their physical, thermal, and chemical properties of the final product. Most developing nations that are consumers of refractory materials, for instance Nigeria, have to spend their hard earn foreign currencies on the importation of these materials to meet their needs [6]. Nigeria has appreciable distribution of industries engage in metal and process industries but lack adequate raw materials to support their growth. In the light of this situation there has been a continuous upsurge of interest in the area of the development of good refractories from vast deposits of clay spread across every region in Nigeria in the last two decades. However, some local clay deposits have been investigated with good result in Benue State and Ikere Ekiti to meet local needs [3][7]. Yanu, Hassan, and Umaru [8], also reported that clays from chanchanga, Bida, Suleja; and Zungeru all in Niger State have better refractory and physical properties compared with imported ones. The aim of this work therefore, is to investigate the physical and chemical properties of clay deposit found in Mubi Adamawa State Nigeria to know whether it will be suitable as a furnace lining material.

MATERIAL AND METHODS

Potter's Clay sample was collected from Mubi town in Adamawa State, Nigeria. The Clay sample was later on sent to "National Metallurgical Development centre, (NMDC)" Jos, Plateau State; where thermal and chemical analyses of the sample carried out on an Energy dispersive (ED), X-ray Fluorescence spectrometer (XRFS). The physical properties and refractoriness of the clay sample was also determined.

Chemical Analysis of the Refractory Clay

The chemical analysis of the clay sample from Mubi was carried out on Mini Pal Energy dispersive X-ray spectrometer designed for the elemental analysis of a wide range of samples. The system is controlled by a PC running the dedicated Mini Pal analytical software. The Mini Pal 4 version in use is PW 4030 X-ray spectrometer, which is an energy dispersive microprocessor controlled analytical instrument designed for the detection and measurement of elements in a sample (Solid, powders and liquids, from sodium to uranium). The sample for analysis is weighed and grounded in an agate mortar and a binder (PVC dissolved in Toluene) is added to the sample, carefully mixed and pressed in a hydraulic press into a pellet. The pellet is loaded in the sample chamber of the spectrometer and voltage (30KV maximum) and a current (1mA maximum) is applied to produce the X-rays to excite the sample for a preset time (10mins in this case). The spectrum from the sample is now analysed to determine the concentration of the elements as presented in Table 1.

Physical Properties and Refractoriness of the Clay Sample

The Physical Properties of the clay sample was determined with respects to apparent porosity, cold compression strength, bulk density, refractoriness, loss of ignition, thermal shock resistance and permanent linear Change.

Determination of Clay Refractoriness

The refractoriness of a clay sample is directly related to its softening temperature and is expressed as its pyrometric cone equivalent and is the number which represents the softening temperature of a refractory. Specimen of standard dimension (38mm vertical height and 19mm triangular base) and composition was prepared from the refractory clay, having the same dimensions with Segar cone (Standard cone). Then the test cone prepared from the specimen is placed in an electric furnace along with Segar cone, and heated. The furnace is heated at a standard heating rate of 10^0C per minute during which softening of Segar cone occur along with the specimen test cone. The temperature at which the apex of the cone touches the base is the softening temperature. The test cone is then compared with the standard cone and the test material is said to have the pyrometric cone equivalent of the standard cone as it resemble it most in bending behaviour. The minimum pyrometric cone equivalent for low, intermediate, high and super duty are 19, 29, 31/32 and 33 respectively which corresponds to the following fusing temperatures: $1{,}500^0$C, $1{,}650^0$C, $1{,}690^0$C and $1{,}750^0$C respectively.

Cold Crushing Strength of Refractory Clays

Cold Crushing Strength of the refractory Clay sample was determined by making cubical specimen from the clay sample. The dimensions of the test piece was taken before it was fired to the required temperature and allowed to cool to room temperature before the test was carried out. The test specimen is kept on a flat surface in between 5-6mm thick cardboard sheet or asbestos fiber. This is then flowed by application of a uniform load to it through a bearing block in a standard hydraulic press until the test piece failed to support the load. The maximum recorded load was taken as the crushing load which is computed using equation 1.

$$Cold\ crushing\ strength = \frac{Maximum\ load\ (KN)}{Cross\ sectional\ area\ (m^2)} \quad (1)$$

Thermal Shock Resistance

Test piece of refractory brick made from the specimen was thoroughly dried and placed in cold furnace and heated at the rate of 5^0C until the furnace temperature read 1200^0C.This temperature was maintained for 30 minutes after which the test piece was removed from the furnace and cooled for 10 minutes. The test piece was recharged again for another 10 minutes at $1{,}200^0$C and then cooled again for 10 minutes. Such cycles of heating and cooling was repeated till fracture was noticed in the test sample.

Determination of Apparent porosity of Refractory Clay

The refractory Clay was made into brick and cleaned from any dust of loose particles adhering to it surface. The specimen was dried in an oven at 1000C to a constant weight. This weight was recorded as D. The dried specimen was suspended in distilled water and boiled for two hours in this position. It was later allowed to cool down to room temperature and its new weight S is recorded. The specimen was removed from distilled water and extra water was used to wipe off its surface. The sample was then weighed in air and this weight was recorded as W. Apparent porosity is thus evaluated using equation 2.

$$Apparent\ porosity = \frac{W-D}{W-S} \times 100 \quad (2)$$

Bulk Density

A molded brick of the specimen with dimensions was prepared. The brick was air dried for 24 hours and then oven dried at 110^0C, cooled in desiccators and weighed as Wa, after which it was transferred to a beaker and heated for 30 minutes to remove trapped air. It was then cooled and then soaked in mercury and weighed as Wm. The bulk density is then evaluated using equation 3.

$$Bulk\ density = \frac{W_a}{W_m} \times density\ of\ mercury \quad (3)$$

Permanent Linear Change (Firing Shrinkage)

The test piece was made into a standard brick using the brick mould. The length was recorded as L_1 and the brick was air dried for 24 hours and oven dried at 110^0C for another 24 hours. The test piece was cooled to room temperature and measurement taken as L_2. The linear change of the dry brick is evaluated using equation 4.

$$Linear\ change = \frac{L_2 - L_1}{L_2} \times 100 \quad (4)$$

Loss on Ignition of Refractory Clay

Test piece was made into brick, cut and weighed as W_b. The brick was transferred into the furnace and fired up to temperature of 10000C for about 2 hours and it was allow to cool. The new weight was measured and recorded as W_f. The weight loss was evaluated using equation 5.

$$Loss\ on\ ignition = W_b - W_f \qquad (5)$$

RESULTS AND DISCUSSION

Table 1 Chemical Composition Analysis of Mubi Clay deposit

Constituent	**Percentage**
Al_2O_3	18.1
SiO_2	67.7
SO_3	0.20
K_2O	4.98
CaO	1.33
TiO_2	0.906
V_2O_5	0.043
Cr_2O_3	0.031
MnO	0.119
Fe_2O_3	5.986
NiO	0.069
CuO	0.010
ZnO	0.194
MoO_3	0.10
BaO	0.20

Table 2 Composition of the Chemical Properties of International Standards

Chemical constitu-ent	**Fire clay (%)**	**Refract-ory brick (%)**
SiO_2	55-75	51-70
Al_2O_3	25-45	25-40
Fe_2O_3	0.5-2.0	0.5-2.4
MgO	<2.0	-
K_2O	<2.0	-
L_2O	12-15	-

Source: [10][11]

Table 3 Physical properties of Mubi Clay Deposit

Properties	Values
Refractoriness	1300^0C
Bulk density	2.3g/cm^3
Apparent porosity	13.7%
Permanent linear change	9.6%
Thermal shock resistance	8 cycles
Cold crushing strength	253 kg/cm^3
Loss of ignition (L.O.I)	4%

Table 4

Constituent	**Fire Clay**
Bulk density	1.71 – 2.1*
Apparent porosity	2.0 – 30*
Thermal shock resistance cycles	25 – 30**
Linear shrinkage %	7 – 10*
Cold crushing strength	15000**
Refractoriness	1500^0C– 1700^0C

Source: [10]* [12]**

Chemical Composition: Analysis

The result of the chemical composition analysis shows that the alumina (Al_2O_3) content of the sample shown in Table 1 is 18.1%, which is below the 20 – 40% for refractory bricks and 25 – 45% required for fire Clay as shown in Table 2. The alumina content in clay is a strong indicator of its refractoriness. The higher the amount of alumina in clay, the higher is the refractoriness of the clay. Silica (SiO_2) content as shown in Table 1 Is 67.7%, which satisfies both the ranges for fire clay and refractory bricks. This means that it can be used for lining of heat treatment furnace melting furnaces for low melting point metals, liquid metal ladles and portions of blast furnaces. The iron oxide (Fe_2O_3) content of 5.986% is higher than the standard of 0.5 – 24 for refractory bricks and that of fire clay. Such level of iron oxide usually imports a reddish color to clay when fired, so making it attractive as a ceramic raw material [7]. This high iron oxide content also effects the clay, such as the fire strength. This makes the clay in this category attractive and suitable for structural engineering works. The low percentage composition of impurities such as SO_2, CaO, TiO_2, V_2O_5, Cr_2O_3, MnO, N_2O, CuO, ZnO, MoO_3, and BaO as shown in Table 1 are generally below 2.0%. The result of this low percentage composition of impurities is low fusion temperature which makes the clay sample unsuitable for furnace lining but meet the requirement of fire clay.

Physical properties

Bulk Density:- The bulk density of Mubi clay is 2.3g/cm^2. When compare with the range of 1.71 – 2.1g/cm^2 [10], it can be seen that the result is a little higher and can be accepted that Mubi clay satisfies the condition for firebricks in Table 4.

Refractoriness:- The temperature obtained is 1,300^{0}C which indicates poor refractoriness. Fire clay refractory bricks should have refractoriness in the range of 1500 – 1700^{0}C (Table 4). This low value of refractoriness is as a result of the high silica content of the clay. The effect of this is that its use is restricted to the processing of materials which melting points do not exceed 1,300^{0}C.

Apparent Porosity:- The value obtained is 13.7% which is below the range indicated in Table 4. The effect of this is that at high temperature, thermal losses shall be experienced. It is established that thermal conductivity decreases in refractory materials as its porosity increases with the pores acting as non-heat conducting media.

Permanent Linear Change (Linear Shrinkage)
The Linear Shrinkage of Mubi Clay as obtained from the experiment is 9.6%, which falls within 7 – 10% as shown in Table 4. The controlling factors for thermal expansion are the particle size and chemical composition of the clay, as some compounds are known to expand readily than others at the same temperature. From the result, it can be seen that the sample has high alkali and seemingly coarse particles which gives rise to high coefficient of linear thermal expansion.

Thermal Shock Resistance
The result in Table 3 shows that the thermal shock resistance is 8 cycles which falls below 25 – 30 cycles in Table 4. The low thermal shock resistance is due to high thermal coefficient of expansion and fine particle size; and, thus the low resistance to sudden change in temperature. The implication of this is that it can be used to lining of ladles.

Cold Crushing Strength
The minimum requirement for refractory brick is 15,000kg/cm^2 while the value obtained for Mubi Clay sample is 253kg/cm^2 as shown in Table 4. This result shows the effect of firing on ceramic bound and this may be affected by firing sintering characteristics and pressing methods.

Loss on Ignition (L.O.I)
The result of the loss on ignition of the brick made from clay is presented in Tables 3. The result shows that loss on ignition for the clay sample brick is 4%; and it is below 12% minimum specification for refractory clay. This suggests that Mubi Clay is of coarse grain and less compacted.

Conclusion
Careful observation of the result confirmed that the clay at Mubi contain 18.1% Aluminum Oxide which is below the required standard for refractory bricks and fire clay. The silica (SiO_2), which satisfies both the ranges for fire clay and refractory bricks means that the clay can be used for lining of heat treatment furnaces, melting furnaces for low melting point metals, liquid metal ladles and portions of blast furnaces. The percentage composition of impurities is generally below 0.2% while iron II Oxide account for 5.986% which is too high compared to specification for a refractory clay. The refractoriness is 1,300^{0}C, which is below 1,500^{0}C minimum requirement. This shows that there is low refractoriness of the clay content, low percentage of Aluminum Oxide (Al_2O_3) and high percentage composition of iron II oxide impurities. Analysis of the result also shows that the apparent porosity, thermal shock resistance, cold crushing strength and loss on ignition fall below the specification with the exception of Bulk density which is a little higher than specification and linear shrinkage which falls within the specification for a refractory clay. For Mubi clay to be used as furnace lining material, the percentage composition of impurities such as iron II oxide (5.986%) has to be reduced to traces by magnetic sieve. The percentage composition of aluminium oxide 18.1% also need to be increased to specification by mixing it with other refractory clay with higher percentage composition of aluminium oxide.

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