American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-6, Issue-12, pp-74-77
www.ajer.org
Research Paper Open Access

Characterization of Obe Clay Deposits for Refractory Production

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ABSTRACT: A clay deposit in Obe Town of Enugu State, Nigeria has been studied for its potential as industrial raw material. The chemical analysis was determined using atomic absorption spectrophotometer (AAS). The physical properties like bulk density, porosity, linear shrinkage, cold crushing strength, refractoriness and thermal shock resistance were done using standard techniques. The clay composition was silica (SiO_2) 51.32%, alumina (Al_2O_3) 27.9%, iron oxide (Fe_2O_3) 3.08%, sodium oxide (Na_2O) 2.09%, potassium oxide 1.18%, calcium oxide (CaO) 1.12%, magnesia (MgO) 0.64%, manganese oxide (MaO) 0.26% and Titanium oxide (TiO_2) 0.03%and loss on ignition test (L.O.I) 14.32%. Physical tests results at 1300 ^oC show that the clay has bulk density 1.83g/am^3, apparent porosity 20.12%, linear shrinkage 7.5%, cold crushing strength 327.85kg/cm^2, refractoriness 1650^{o}C, thermal shock resistance 28 cycles, water absorption 11.01%, modulus of rupture 31.54kg/cm^3. At 900^{o}C the modulus of rupture is 6.65kg/cm^3, modulus of plasticity is 3.513 while the permeability is 52.15

Keywords: Characterization, Clay Deposits, Refractory Production

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Date of Submission: 09-11-2017 Date of acceptance: 11-12-2017

I. Introduction

Clay minerals are minerals of the earth near the surface which form in soils and sediments and by digenetic and hydrothermal alteration of rocks. They are mostly non-metallic materials having enormous heat capacity that can withstand high temperatures and pressure exerted on them such as thermal shock, impact, chemical attack and high load at elevated temperature [1]. Clay minerals are fine-grain materials that acquire plasticity on being mixed with limited quantity of water. They geologically occur as particles with a phyllosilicate or sheet structure with diameters ranging from few microns to a few hundreds of microns. Clay occurs mostly in nature in solids, sediments, sedimentary rocks, hydrothermal deposits, and are abundantly in every part of Nigeria. Velde, [2], used the swelling property of clay to broadly classify all clays into swelling and non-swelling type.

Clay is a natural raw material for many industrial finished products [3] such as refractories, ceramic wares, electrical porcelain insulators etc. Refractories are specifically used to conserve heat within a system [3]. These refractory materials are employed in constructing furnaces for smelting ores, holding of molten metals and slags, heat treatment operations, kilns for cement production, rotary furnaces for iron ore reduction, cast iron and non-ferrous metals production, glass melting, heat exchangers etc. The production of various refractory products utilizes raw materials such as kaolinite ($Al_2O_3.2SiO_2.2H_2O$), magnesite ($MgCO_3$), chromite ($FeOCr_2O_3$). The major type of refractories found in Nigeria's manufacturing industries is mainly aluminosilicate and magnesite refractory products [4].

Many local researchers have worked towards evaluation and development of Nigerian clays deposits as suitable raw material for refractories production [4,5,6,7,8]. Though Nigerian's metallurgical industries where refractories are heavily required are still developing, some other functional industries demand enormous quantity of refractors. Fluid catalytic cracking (FCC) units in refineries require various grades of refractory lining while glass, thermal turbines, cement, chemical industries also use vessels lined with different refractories [9]. These should encourage researchers to do more work on evaluating our clay deposits for refractory production.

II. Experimental Technique

2.1 *Materials preparation*

The clay sample used in this work was collected from Obe in Nkanu-West Local Government area, Enugu State, Nigeria. Stratified random sampling was used whereby within $100m^2$ area, ten locations were located and samples collected at a depth of 100cm. The samples were mixed together and crushed in hammer mill whereby 50kg was obtained. This is further ground and mixed in a laboratory mixer to obtain homogeneity.

2.2 Chemical analysis

A representative sample from the mixed clay was obtained and subjected to chemical analysis using atomic absorption spectrophotometer. The chemical composition of the sample is presented in Table 3.1.

2.3 Physical analysis

Samples were taken from the mixed clay for various physical and mechanical tests analysis. The tests conducted were wet-dry shrinkage, dry-fired shrinkage, total shrinkage, apparent porosity, apparent density, bulk density, water absorption, modulus of rupture, modulus of plasticity, green strength, permeability, thermal shock resistance, moisture content, sintering point, refractoriness. These tests were conducted using standard test procedures presented in BS 1902: part 1A as described by chester [3]

III. Results And Discussion

3.1 Colour

The dried clay sample at room temperature possessed light tinge of brown colour, which changed white brown to dark brown during firing due to presence of iron oxides. This was determined using a colour chart.

3.2 Chemical composition

The chemical composition of the clay was determined using AAS and is shown below

Table 3.1: Chemical composition of the clay samples (%)

Constituent	percentage
SiO_2	51.32
Al_2O_3	27.9
Fe_2O_3	3.08
Na_2O_3	2.09
K_2O	1.18
Cao	1.12
MgO	0.64
MnO	0.26
TiO_2	0.03
LOI	12.32

Table 3.2: Chemical composition of refractory clays by international standard [10]

Constituent	Fired clay (%)	Refractory 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
K_2O	<2.0	
MgO	< 2.0	
LI0	12-15	

Table 3.1 depicts the chemical composition of Obe clay deposit. The clay has 51.32% Si, 27.9% Al_2O_3, 3.08% Fe_2O_3, 2.09% Na_2O_3, 1.18% K_2O, 1.12% CaO, 0.64% MgO, 0.26% MnO, 0.03% TiO_2, and 12.32% LI0 as its constituents. From the chemical content of the clay as shown in Table 3.1, the silica and aluminum percentages of 51.32 and 27.9 respectively meet the standard for refractory bricks as shown in Table 3.2. The alumina content in clay has direct relationship to its refractoriness such that the higher the alumina in clay the higher the refractoriness. Also high values of silica, iron oxide, Na_2O_3, K_2O lower the refractoriness of clays. These oxides fall within the range for refractory bricks and fired clay [10].

3.3 Physical Properties

The physical and mechanical properties of this clay as determined were shown in Tables 3.3 and 3.4.

Table 3.3: Physical properties of Obe clay

Property	Temperature ^oC				
	900	1000	1100	1200	1300
Wet-dry shrinkage (%)	3.7	3.8	3.8	4.0	4.2
Dry-fried shrinkage (%)	1.14	1.46	2.39	2.23	3.31
Total shrinkage (%)	4.8	5.2	6.1	7.2	7.5
Apparent porosity (%)	29.14	28.09	26.91	22.51	20.12
Apparent density (%)	2.52	2.43	2.37	2.29	2.11
Bulk density (g/cm^3)	1.66	1.70	1.73	1.78	1.83
Water absorption (%)	20.58	17.71	15.55	12.88	11.01
Modulus of rupture	21.38	23.45	26.14	28.23	31.54
Cold crushing strength (kg/cm^2)	210.15	222.54	244.68	276.15	327.85
Firing colour	White Brown	White Brown	White Brown	Yellow Brown	Dark Brown
Crack formation	No crack	No crack	No crack	No crack	Slight crack at one side

Table 3.4: Other physical properties of Obe clay

Property	Value
Modulus of plasticity	3.51
Thermal shock resistance (cycles)	28
Green strength (kgf/cm^2)	27.32
Moisture content	4.01
Permeability number	52.15
Sintering point (^oC)	>1400^oC
Refractoriness	1650^oC

Table 3.5: Physical and Thermal properties international standard [3]

Properties	Value
Fried linear shrinkage (%)	2-10
Permeability to air	25-90
Apparent porosity (%)	20-30
Bulk density (g/cm^3)	2.2-2.80
Cold Crushing strength, MPa	15.0 minimum
Thermal shock Resistance, cycles	20-30
Refractoriness, ^oC	1500-1750
Moisture content, %	1-13

3.3.1 Shrinkage

This is an indicator of the firing efficiency of the clay samples. Omowumi in his work, [5] quoted a recommended value of range of 4-10%. Abolarin et al, [9] in their work advice that lower values were more desirable in order that the clay will be less susceptible to volume change. Obe clay shrinkage falls within the two recommendations. Chester, [3] also recommended linear shrinkage range of 7-10% for refractory clays; therefore, Obe clay can be classified, based on this range, as refractory clay.

3.3.2 Apparent porosity

The apparent porosity is a measure of the effective open pores spaces in a refractory into which molten metal, slag, fluxes, vapours etc can penetrate and thus contribute to the structure's degradation. According to Chester, [3] the standard values range for porosity is 20-30%. Gupta in his book [10] noted that low percentage of apparent porosity enhances gas entrapment in the refractory which adversely affects its life span when in operation. The porosity level in Obe clay meets these observations, table 3.3.

3.3.3 Bulky Density
In general, the bulk density is considered in conjunction with apparent porosity. It is a measure of the weight of a given volume of refractory and provides a general indication of the product quality. Table 5 showed the standard for bulk density of refractory clay and Obe clay falls within it, table 3.3.

3.3.4 Modulus of Rupture (MOR)
The modulus of rupture is the flexural breaking strength (in kg/cm^2) of a refractory, measured at room temperature. Obe clay has high modulus of rupture, which is $31.54 kg/cm^2$ for sample fired at 1300^oC

3.3.5 Cold crushing strength
Cold crushing strength is the capacity of a refractory to provide resistance to a compressive load at room temperature which is the load in kg/cm^2 at which the refractory breaks. The minimum cold crushing strength according to Chester, (3), is 15 Mpa and Obe clay offers strength much higher than this.

3.3.6 Thermal shock resistance
Obe clay has good thermal shock resistance of 28 cycles which is well within the acceptable standard of 20-30 cycles, table 3.5

3.3.7 Refractoriness.
It was observed from this study that the refractoriness of Obe clay is 1650^0C. This falls within the standard value ($1500 - 1750^oC$), for refractory, table 3.5. This high refractoriness results from its high alumina content of 27.9%, table 3.1. Impurities like Fe_20_3 in aluminosilicate refractory lowers the refractoriness and service limits of the bricks. Based on its refractoriness Obe clay belongs to the group of medium duty fireclay (pyrometric cone equivalent-PCE – 29-31), [10].

IV. Conclusion
The investigation conducted on the Obe clay deposit sample showed that its service properties have favourable results in comparison to standard fireclay refractory materials. The result of the chemical analysis conducted using Atomic Absorption Spectrophotometer (AAS) showed that from the various constituents' percentage composition, silica and alumina are the major ones; hence the clay belongs to the family of aluminosilicate, table 3.1. The physical analysis depict the clay has properties within the acceptable range for international standard for refractory production, tables 3.3 and 3.4. It is therefore recommended that a geological survey of the sampled area should be carried out to determine the extent of the deposit.

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J.c ugwuoke. "Characterization of Obe Clay Deposits for Refractory Production." American Journal of Engineering Research (AJER), vol. 6, no. 12, 2017, pp. 74-77.