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Performance Assessment Of The Physical Properties Of Kadna, Tagwai And Gbakoita Clay Deposits As Refractory For Furnace Lining

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ABSTRACT

An experimental study on the physical properties of Kadna, Tagwai and Gbakoita clay deposits located in Bosso (Lat 9^0 39^I 12^{II} North, Long 6^0 30^I 58^{II} East) Niger state, Nigeria was carried out to examine their suitability for use as furnace lining material. The results shows that Kadna clay has a bulk density of 2.7 g/cm^3, apparent porosity of 29.6 %, linear shrinkage of 9.21%, thermal shock resistance of 17 cycles, cold crushing strength of 310.7 kg/cm^2 and estimated refractoriness of 1600^0C. Tagwai clay has a bulk density of 1.7 g/cm^3, apparent porosity of 24.7%, linear shrinkage of 6.9%, thermal shock resistance of 11 cycles, cold crushing strength of 151.34 kg/cm^2 and estimated refractoriness of 1300^0C. Gbakoita clay has a bulk density of 1.8 g/cm^3, apparent porosity of 21%, linear shrinkage of 2.8%, thermal shock resistance of 9 cycles, cold crushing strength of 156.11 kg/cm^2 and estimated refractoriness of 1000^0C. The results obtained from the analysis indicated that only Kadna clay satisfied almost all the physical parameters for fireclay refractory and furnace lining material.

Keywords: *Kadna Clay, Tagwai Clay, Gbakoita Clay, Physical Properties, Furnace Lining*

1. Introduction

An experimental study was carried out on the physical properties of three selected clay deposits to examine their suitability for furnace lining production. Furnace lining is a protective and insulating layer of heat resistant material attached to the inside of the shell, hearth and top holes of a furnace, which protect the furnace parts from the high temperature that occurred during smelting operation process [1]. Furnace lining materials are selected purposely for their ability to defy prolong exposure to high temperatures. Some of the important characteristics of a furnace lining materials are resistance to mechanical shock, abrasion and chemical reactions within the molten metals, while the most commonly used furnace lining materials are ceramic compounds and metal/ceramic combination [1]. Ceramic lining materials are made from variety of raw materials each with its own particular strength, the most common among them are aluminum oxide, magnesite, silicon carbide and dolomite [2]. A lot of studies have been carried out in Nigeria on the refractory properties of clay deposits within the country [2], [11], but more needs to be done to establish clays which can be employed in the construction of furnace lining in order to meet up with the country's industrial development. Clay is a mixture of silica (SiO_2), alumina (Al_20_3) and water (H_2O) with considerable amount of oxides of iron, alkali, alkaline earth, and contains group of crystalline minerals (quartz, feldspar and mica) [3]. Generally clay occurs in three principal forms, all of which have similar chemical compositions with different physical properties. For instance surface clays; may be the up thrusts of older deposits of more recent sedimentary formation, which are found near the surface of the earth. Shale clays; are clays that have been subjected to high pressures until they have nearly hardened into slate. Fire clays; are usually mined at deeper levels than other clays and have refractory qualities [4]. Fireclay is hydrated aluminum silicates that occur naturally. They are sufficiently pure to serve as raw materials for refractory. The principal mineral in fire clay is kaolinite, while other clay minerals may be present, the formula Al_2O_3. $2SiO_2$. $2H_2O$ can usually represents the clay fraction, but as kaolinite is subjected to high temperature in the process of making refractories it loses its water; theoretically, 45.9% alumina and 54.1% silica remain [5]. Refractory materials are needed in Nigerian iron and steel industry, for instance, Ajaokuta steel complex on completion will required about 36,000 tonnes of refractory bricks for furnace lining activities alone [6]. The quality of a refractory and it's suitability for a particular application primarily depends on its physical, chemical and mineralogical properties. It may be possible to assess the quality of a refractory on the basis of a single property or a group of properties and the most common properties which are considered in selecting the optimum refractory lining are; apparent porosity, bulk density, linear shrinkage, cold crushing strength, modulus of rapture, pyrometric cone equivalent, thermal expansion and conductivity [5]. Thus, this research is aimed at verification of some of these mentioned properties such as; apparent porosity, bulk density, linear shrinkage, refractoriness, thermal shock resistance, loss on ignition and cold crushing strength on Kadna, Tagwai and Gbakoita clay deposits to determine their suitability for use as refractory for furnace lining production in Nigeria.

2. Materials and Methods

The clay samples were obtained from three different locations of Bosso local government area of Niger state Nigeria, which include Kadna, Tagwai and Gbakoita. The samples were each collected at a depth of between one to two meters and analysed. The specimens were dried, crushed, milled and sieved. The apparatus used in course of the experiment are: Electrical weighing scale, electric furnace and ovens, lab mortars and pestles, hydraulic press, desiccator, vibrating sieve, venier caliper, beaker and measuring cylinder.

2.1 Bulk density

The bulk density test was carried out for each sample by using boiling method [7]. A moulded brick was made from the specimen with dimension 60mm × 60mm × 40mm, the brick was air dried and oven dried at 110^0C, which was weight (D) after cooling. The specimen was put inside a beaker of water and heated for 2 hours in which the treed air was removed. It was cooled and soaked weight (w) taken, and the specimen was suspended in water using beaker placed on a balance. The suspended weight (S) was observed. The bulk density was calculated using the equation below.

$$\text{Bulk density} = \frac{D}{W-S} \text{ X } \rho W$$

Where, D = dried weight

W = soaked weight

S = suspended weight

ρW = density of water

2.2 Apparent porosity

The apparent porosity test for the clay samples was determined using boiling method [7]. A moulded brick was made from each specimen with dimension 60mm × 60mm × 40mm, and dried inside oven at 100^0C to a constant weight, which was measured 'D'. The dry specimen was suspended inside water and boiled for 2 hours which was later allowed to cool at room temperature and soaked weight (W) was taken. The specimen was weighed and suspended in water with a beaker placed on a balance, which give the suspended weight (S). The apparent porosity was calculated using the equation below.

$$\text{Apparent porosity} = \frac{W-D}{W-S} \times 100$$

Where, W = soaked weight

D = Dried weight

S = Suspended weight

2.3 Linear shrinkage

The linear shrinkage test of the clay samples was determined. A standard rectangular brick mould was used to produce the test piece. The length of the brick was taken (Di), using a venier caliper. The piece was air dried and oven dried at 110^0C for 6 hours [6]. It was later cooled at room temperature and fired for 2 hours 30 minutes at 900^0C, then the new length was measured (Fi) after cooling in a dessicator [7]. The shrinkage of the sample was calculated both at the dried and fired state using the equation below.

Linear shrinkage = $\frac{Di-Fi}{Di} \times 100$

Where, Di = dried length

Fi = fired length

2.4 Cold crushing strength

The cold crushing strength test was carried out in accordance with ASTM [8]. A cube was made from the fired brick as a specimen and fired at 1200^{0}C for 5 hours inside a furnace and allowed to cool before it was transferred into a compressive tester in which the load was applied axially on it, until the test piece failed to support the load bearing. The load at which the specimen experience a crack was observed and stand as the load required to determined cold crushing strength of the specimen. The cold crushing strength (CCS) was determined using the equation below.

CCS = $\frac{maximum\ load\ (KN)}{cross\ sectional\ area\ (M2)}$

2.5 Thermal shock resistance

The ability of clay material to defy heating and cooling frequently before a crack was observed is known as thermal shock resistance [9]. The test piece made from the specimen was air dry exhaustively and oven dried at 110^{0}C for 2 hours. The specimen was fired in the furnace at 900^{0}C for 3 hours and removed to cool for 10 minutes [7]. The process was repeated for another 10 minutes with the same temperature until fracture was observed in the sample. The number of cycles of the heating and cooling before fracture occurred was observed as its thermal shock resistance.

2.6 Refractoriness

Pyrometric Cone Equivalent (PCE) was used to determine the refractoriness of the clay samples [10]. A test cone of a standard dimension was prepared from the refractory clay which has the same dimension of the standard cone. The sample was put into a muffle furnace and fired at 900^{0}C together with the Orton standard pyrometric cone designed to perform based on ASTM standard. The temperature was raised to 10^{0}C/min until the test cone bend over its weight and the heating was halt, which was later compared after cooling with the standards cones. The conduct of the test piece that corresponds with the standard cone will be used as pyrometric cone equivalent (PCE) of the test samples.

3. Results and Discussion

Table 1. Physical properties of the test samples

Sample location	Bulk density (g/cm^3)	Apparent porosity (%)	Linear shrinkage (%)	Thermal shock resistance (cycles)	Cold crushing strength (kg/cm^2)	Refractoriness (^{0}C)
Kadna clay	2.7	29.6	9.21	17	310.70	1600
Tagwai clay	1.7	24.7	6.9	11	151.34	1300
Gbakoita clay	1.8	21	2.8	9	156.11	1000

The experimental test results for Kadna and Tagwai clay indicate that the clay has a linear shrinkage of 9.21 and 6.9% respectively, which is in line with the standard value for fire clay [11], while Gbakoita clay fall below standard with linear shrinkage of 2.8%. Kadna clay also satisfied the standard value for siliceous fire clay (7-10%), among the three samples [11]. The apparent porosity test of 29.6% for Kadna clay and 24.7% for Tagwai clay indicate that the clay fall within the standard range for fire clay at 20-30% and above the standard range of a siliceous fire clay at 23.7% [11]. Gbakoita clay fall below standard for both fire and siliceous clay with an apparent porosity of 18.3% [11], which is an indication that combustible materials during firing did not combust or burn off. The bulk density test of 1.8 g/cm^3 for Gbakoita clay and 1.7 g/cm^3 for Tagwai clay samples fall below the standard range for fire clay at 1.98 g/cm^3 and siliceous fire clay at 2.0% [14]. Kadna clay, with bulk density of 2.7 g/cm^3, has exceeded the standard range for fire clay at 2.3 g/cm^3 and siliceous fire clay at 2.0 g/cm^3 [11]. The thermal shock resistance of 11 and 9 cycles, exhibited by Tagwai and Gbakoita clays respectively are poor, due to the high thermal coefficient of expansion and fine particle size, though it cannot be used as a fire clay because it is below the minimum standard of 20 cycles [12], but it can find its application in lining of cable slag pots [13], while Kadna clay with 17 cycles, is fairly acceptable to use as fireclay [12]. With Kadna cay having the highest cold crushing strength of 310.70 kg/cm^2, followed by Gbakoita clay, 156.11 kg/cm^2, and Tagwai at 151.34 kg/cm^2, indicating that they all fall above the minimum standard for fire clay refractory at 150 Kg/cm^2, [11]. The high refractoriness exhibited by Kadna clay can be due to high alumina contents and low amounts of impurities (oxides) such as alkali metals which usually lower its fusion temperature, and with estimated refractoriness of 1600^{0}C Kadna clay fall within the recommended standard for fire clay at 1500-1700^{0}C and siliceous fire clay at 1500-1600^{0}C [11]. However Tagwai and Gbakoita clays have a refractoriness of 1300 and 1000^{0}C respectively, which is below the recommended standard for fireclay [14.]

4. Conclusion

After the assessment of the physical properties of Kadna, Tagwai and Gbakoita clay deposits, the following conclusions were made; Kadna clay satisfied most of the standard test on the physical properties requirements for both fire and siliceous fire clay. It possesses a good refractoriness, apparent porosity, bulk density, linear shrinkage, thermal shock resistance and cold crushing strength which qualifies it to be used in furnace lining and refractory applications. Tagwai clay can be employed for furnace lining of test kiln and ovens that are not subjected to more than 1200^{0}C during firing operation process, due to its low refractoriness, thermal shock resistance and bulk density which it exhibited poorly during the experiment. Though, it has a good linear shrinkage, apparent porosity and cold crushing strength that are within the standard range for fire clay. Gbakoita clay exhibited very poorly to be used as a refractory clay material for furnace lining, the properties observed such as linear shrinkage, bulk density, cold crushing strength and refractoriness fall below the standard specifications with exception of apparent porosity and cold crushing strength which falls within the standard range for fire clay.

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