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Performance Assessment of Physico-Mechanical Properties of Aloji Fireclay Brick

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Abstract: This research evaluated the physical and mechanical properties of Aloji fireclay brick's suitability for production of refractory fireclay brick as furnace linings. At the optimum sintering temperature of 1200 ^{0}C, the Aloji fireclay brick had apparent porosity value of 23.62 %, bulk density was 1.76 g/cm^3, firing shrinkage value of 8.62 %, water absorption of 7.77 % and CCS was 15.8 MPa. It was observed that, as the sintering temperatures increased the porosity, bulk density, firing shrinkage and the CCS were linearly increased. It can be concluded that various sintering temperatures have significant influence on the physical and mechanical properties of the Aloji fireclay brick.

Keywords: Mechanical strength, Sintering temperature, Production, Fireclay brick.

1. Introduction

Refractories are materials that can withstand heat at high temperature and contained alumina (Al_2O_3) and silica (SiO_2) to form a group of alumino-silicate fireclay bricks; this chemical composition serves as a basic for classification of refractories [1]. Refractories are non-metallic, heterogeneous, porous and inorganic materials composed of additives, thermally stable mineral combinations and a binder phase [2]. The clay raw material used for the production of refractory fireclay have the characteristic of making a coherent, sticky mass when tempered with water can be moldable and rigid when dried [3]. Fireclay bricks provide refractory brick linings used in furnaces of high temperature, reactors, kilns and ladles [4]. The physical characteristic of refractory is one of the major and essential properties that must be considered in material assortment for the production of refractories [5]. Consequently, refractories with particular set of properties are prudently chosen for a precise purpose to meet the exact service conditions and other special requirements. The cost effectiveness of refractories considerably influences cost of refractory product. Therefore, proper selection of refractory materials is extremely essential to ensure low production costs and durability of refractory product. The combination of these properties was to maintain reliability and standards of refractories in the thermal industry. The physical properties includes: apparent porosity, bulk density, firing shrinkage, water absorption [6]. The strength of most refractory fireclay brick is determined by the measure of its cold crushing strength (CCS) and modulus of rupture (MOR) [5]. Either of these methods can be used to express its mechanical strength without comparism of both results because CCS is compressive in nature and MOR is tensile in nature. These properties are regularly amongst those which are used in the quality control process during production of refractory fireclay bricks [7]. The chemical, physical and mechanical properties are further influenced by several other factors which include particle sizes, clay raw materials, fireclay brick size, fusion temperature, firing time, cooling rate and manufacturing methods like the hand moulded or the pressure press. Raw clay material can be found in abundance in Nigeria but remained under-utilized [8].

2. Materials and Methods

2.1 Materials

The Aloji clay was collected from Kogi state of Nigeria. Sample clay was collected according to standard practice for preserving soil sample collection and transportation of soil [9].

2.2 Test samples preparation

Clay sample collected was sun dried for three days and the impurities were all removed. The sample clay collected was air and sun dried for three days. The clay was crushed in the ball-mill. The ASTM standard sieve mash size of 63 µm was used to sieve the clay before being transferred for particle size analysis test using the Analysette 22 equipment. The clay sample of 63 µm was further sieved using 50 µm sieve mesh to obtain the particle size of 50 µm that was used in the preparations for test samples and production of fireclay bricks for furnace lining. The specimen powder was compacted into pallets using the caver hydraulic press machine. A force of 5000 KN was applied with a

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holding time of 60 seconds. The clay sample was subjected to varied sintering temperatures of 900 °C, 1000 °C, 1100 °C and 1200 °C for 8 hours with a soaking time of 2 hours and heating rate of 2.5 °C per min [10]. The chemical composition was determined using *Oxford Supreme 8000* bench top X-ray fluorescence (XRF) spectrometer. The fireclay brick was investigated for porosity, bulk density, firing shrinkage, thermal shock resistance and cold crushing strength (CCS) were determined according to standard terminology relating to refractories [11].

Apparent porosity of the clay sample was determined using a prepared test sample of size 20 mm × 20 mm × 20 mm. The dry clay test sample was weighed and recorded as D. The clay sample was suspended in distilled water and weighed in air as W. The sample was removed from water; the water on the surface of the specimen was cleaned off using filter paper. The weight was measured and recorded as S. The apparent porosity test procedure was performed according to ASTM C20-00 [12]. Bulk density of the clay sample was determined using a prepared test sample of size 20 mm × 20 mm × 20 mm. The dried clay sample was placed on the digital balance and weight was taken W. The clay sample was lowered and on to the surface of the mercury in the beaker and weight was taken as V_1 (g). A thread was used to tie the clay sample at the upper arm of the densometer and suspended the clay sample above the mercury. The pointer attached to the densometer pushes the suspended specimen to be submerged and soaked 5 minutes in the mercury by displacing the mercury and weight was taken as V_2 (g). The bulk density procedure was done according to [12].

Firing shrinkage was done the initial preparation of test sample of dimension 10 mm × 50 mm × 100 mm from the clay sample was produced to standard brick size required for the test. The measurement was carried out using vainer caliper to measure the L_1 and L_2. Firing shrinkage was determined according to ASTM C20-00 [12]. The bricks was weighed W_1 and were immersed in water completely for 24 hours. At the expiration of 24 hours of immersion, the specimen from water was removed; the surface water was then wiped off using a damp cloth. The wet bricks were then weighed and recorded as weight W_2. Water absorption was conducted according to ASTM C20-00 [12]. The CCS was determined by preparing the experimental requirement of 5 pieces of test samples of size 20 mm × 20 mm × 20 mm. The specimen was tested for its mechanical strength by CCS using the hydraulic strength testing machine. The application of a uniform load on it was followed. The pressure load at which a crack showed on the clay sample was observed. The compressive strength failure of the specimen is usually an indication of its mechanical property and its performance probable under load. The CSS test procedure was performed according to ASTM C133-97 [13].

3. Results and Discussion

3.1 Chemical composition (XRF)

The dominate oxides in the XRF result as presented in Table 1 were SiO_2 and Al_2O_3 with weight values of 57.8 % and 38.8 % respectively and less than 5 % of impurities. The result significantly showed that the clay belong to alumino-silicate group of fireclay bricks [1] and can effectively be suitable for production of refractory fireclay bricks for refractory lining.

Table 1 Chemical composition of Aloji clay

Oxide	**%**
Al_2O_3	38.8
SiO_3	57.8
Fe_2O_3	0.54
TiO_3	1.61
MgO	0.28
K_2O	0.23
P_2O_5	0.25
SO_3	0.02

3.2 Apparent porosity

The apparent porosity result indicated that the Aloji fireclay at the lowest sintering temperature of 900 °C had the highest value of 46.25 % as compared to the lowest porosity value of 23.62 % at the maximum sintering temperature of 1200 °C. Its porosity was found to be within the standard value of 10-30 % for refractory fireclay bricks [10]. The effect of the sintering temperatures was seen here as sintering temperatures was increased the percentage porosity decreased [15].

3.3 Bulk density

The clay sample have the least bulk density of 1.7 g/cm^3 at the least sintering temperature of 900 °C as compared to the highest value of 1.76 g/cm^3 obtained at the maximum sintering temperature of 1200 °C. Its bulk density fell within the standard values of 1.7-2.3 % [13,14]. Bulk density plays a vital role in material transportation and material selection for refractory production.

3.4 Firing shrinkage

Firing shrinkage of the fireclay at the lowest sintering temperature of 900 °C was 7.78 % as compared to the highest value 8.62 % obtained at the maximum sintering temperature of 1200 °C. The firing shrinkage fell within the standard value of 7-10 % [10,12].

3.5 Water absorption

Water absorption test was used to determine the amount of water absorbed under specific conditions.

Factors affecting water absorption include temperature and length of heat exposure [10]. Water absorption of the Aloji fireclay at minimum sintering temperature of 900 °C was 13.02 % which was the highest as compared to the lowest value of 7.77 % at the maximum sintering temperature of 1200 °C.

3.6 Cold crushing strength

The Aloji fireclay brick had the maximum cold crushing strength of 15.8 MPa at the highest sintering temperature of 1200 °C as compared with the least cold crushing strength of 9.64 MPa at the minimum sintering temperature of 900 °C. The CCS fell within the standard values of 15-59 MPa for refractory fireclay bricks [10,13]. This signified that as the sintering temperatures increases CCS also increased [15]. The CCS of the fireclay brick can be attributed to the Al_2O_3 and the influence of the sintering temperatures, while SiO_2 content of 87.08 % in the chemical composition in Table 1 was responsible for the fireclay brick's vitrification.

4. Conclusion

Observation on the results of physical and mechanical properties have shown that the Aloji fireclay brick has porosity of 23.62 %, bulk density of 1.76 g/cm^3, firing shrinkage of 8.63 %, water absorption of 7.77 % and CCS of 15.8 MPa. There was a clear relationship between the varied sintering temperatures and the physico-mechanical properties of the Aloji fireclay brick [15]. The result of the physical and mechanical strength investigation proved that the Aloji fireclay brick have sufficient attributes and prospect to be used as refractory fireclay bricks.

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