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Thermal Conductivity of Barkin-ladi Fireclay Brick as Refractory Lining

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Abstract: *The study concentrated on the thermal performances of Barkin-ladi fireclay for its appropriateness as refractory lining. The Barkin-ladi clay brick has thermal conductivity of 0.03 K (W/m.k). The clay needs 0.7 J/g °C to raise its specific heat capacity at the minimum temperature of 93.33 °C. The specific heat capacity of the clay showed that as temperature increases the heat capacity changes with phase changes. The energy absorption of Barkin-ladi clay as shown in the DSC result indicated a glass transition at mid-point of 554.74 °C with exothermic reaction at 510 °C which signified energy being released and then crystallized. The clay sample was subjected to TG+DTA analysis. The TGA result had shown there were material weight losses of 0.19 mg, 0.43 mg and 0.80 mg at temperatures of 78.38 °C, 452.62 °C and 578.15 °C respectively. The DTA showed there were reactions of exothermic at 105.88 °C, and 450 °C then followed by endothermic reaction at the temperature of 1200 °C with indication of absorption of energy.*
Keywords: *Material degradation, Material reactions, Temperature, Thermal property*

I. Introduction

Refractory linings are brick materials that can withstand heat above 530 °C and are alumino-silicates that contained $Al_2O_3.SiO_2.H_2O$ [1] and are often used for reactors, ladles, ovens and furnace as thermal storage facilities in order to prevent escape of heat or heat losses to the surrounding environment [2]. Furnace is the thermal equipment used for melting iron and other heat treatment in metallurgy [3]. Losses of heat through thermal heat storage facilities can pose a critical problem to refractory industry that utilized them for their production process. It has become necessary to explore an alternative material and means of averting heat losses. The modern refractory materials includes; ceramic coating, ceramic fiber glass, insulating castables, calcium silicate, and very recently, refractories with high porosity of 60-80 % for insulating refractory material and porosity of 20-30 % for refractory fireclay bricks and [4, 21b]. The searching and being incisive for alternative materials that are available, cheaper and health friendly with abundant benefit for resolving the highlighted challenges. Naturally clay is an occurring substance that contained fine grained natural resources that become plastic when tempered with water and when fired it becomes rigid [5]. Clay that contains alumina and silica is referred to as alumino-silicate fireclay and can be a better option as proposed in this study. This can be replacement to glass fiber that posed a threat and health challenge to the fabricators and end users. The use of fireclay refractory bricks round thermal storage facilities can conserve high temperature inside the thermal facilities and inhibit heat losses to the atmospheres [6]. The understanding of thermal conductivity, specific heat capacity and energy absorption of these refractory materials is essential and precarious to solving the challenges of heat loss. Thermal conductivity is the quantity of heat conducted in a unit time over a unit area normal to the heat flow direction [7]. Heat flow via solids is due to vibration of atoms or due to transfer of energy by free electrons [8]. Specific heat capacity is the quantity of heat (energy) required to raise a major quantity of a material K and also measured in J/g°C [9]. Fireclay refractory bricks have higher thermal conductivity values compared to insulating refractory materials which have low thermal conductivity values as a result of its high porosity. Fireclay refractory bricks are used in the construction of furnaces as refractory lining. Thermal conductivity of any substance depends completely on the lattice vibration of atoms and molecules [10]. Nigeria is blessed as a country with profitable solid minerals, vast land with rich and plentiful clays. The raw material for production of refractories is clay and available in commercial quantity but it remained unexploited and under-utilized in the country [11, 21b]. Nearly all the refractories employed in the metallurgical and other manufacturing industry in Nigeria are imported [12]. Researchers in their previous work have shown concerned for the country's incapability to utilize the richness of these raw materials. It was observed that investigations carried out in this area, were most of the time on chemical and physical properties with almost nothing done through empirical research methods on their thermal properties like the thermal conductivity, energy absorption, specific heat capacity and TG+DTA. Previous researches have shown that the data collated on the previous work were not thorough enough as the usage of the international standard tests requirement for refractories and fireclay bricks inclusive [13]. Therefore, the objective of this research was to investigate the Barkin-ladi fireclay and ascertain its suitability for the production of fireclay refractory brick as furnace linings.

II. Materials And Methods

2.1 Materials

The Barkin-ladi clay used in the study was collected from Pleteau state in the North central Nigeria. The clay sample deposit was collected according to standard method of collection and transportation of soil ASTM D4220/D4220M-14 [14].

2.2 Methods

2.2.1 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. The specimen powder was compacted in a mould into pallets using the caver hydraulic press machine. A force of 5KN was applied with a holding time of 60 seconds.

2.2.2 Energy absorption

Differential scanning calorimetry (DSC) equipment was loaded with 5µm of the Barkin-ladi clay sample and was placed alongside with the reference crucible in the DSC equipment with the heating rate of 5 °C per min. The energy absorption equipment has maximum temperature of 600 °C.

2.2.3 Thermal analysis (TG+DTA)

A quantity of 60 mg was measured into the alumina crucible from the parent sample Barkin-ladi clay. The crucible was located inside the specimen chamber. The differential crucible was also place in the same row with the crucible containing the specimen.

2.2.4 Thermal shock resistance

In the thermal shock resistance test sample of size 10 mm x 50 mm x 100 mm was produced. The fireclay brick was placed in the furnace and fired at 1200 °C with the heating rate of 2.5 °C per min. It was withdrawn out from the furnace and held for 10 minutes and taken back in to the furnace. The process was repeated until a crack was noticed on the clay sample of the refractory fireclay brick surface. The last number of cycles at which the clay sample cracks was recorded as the complete cycles required for producing visible cracks in the specimen and hence, the thermal shock resistance of the fireclay brick. The determination of the thermal shock resistance was done according to ASTM C1100-88 [15].

2.2.5 Refractoriness

The refractoriness of the fireclay brick was investigated using the pyrometric cone equivalent (PCE) to determine the temperature of softening in order to assist in the refractory material selection that will fit the temperature of working environment. The clay sample was formed into a conical shape. The standard pyrometric cones of known softening temperatures were arranged on a standard circular shaped plaque with the aid of a suitable bonding material that will not react with the cones and thereby reducing the fusibility. The Segar cone was fixed on plaque at an angle of 82^0 to the horizontal. It was then placed in the heating chamber of the refractoriness testing equipment. The temperature of the equipment was raised from room temperature of 27 °C-1700 °C. Located at the top of the refractoriness testing equipment is a built in mirror that enables one to view when the clay sample bends with the corresponding Segar cone bend in the firing chamber. The moment either of these cones in the chamber bends is then the refractoriness of the fireclay brick. The experimental procedure was according to ASTM C24-89 [16].

2.2.6 Thermal conductivity

The thermal conductivity of the fireclay brick was determined using hot guided plate method as presented in Fig.1. Test sample was prepared of circular shape of size 4 mm thick with a surface diameter of 25 mm. It was then transferred to the thermal conductivity apparatus for thermal conductivity measurement at room temperature. In the hot guided plate apparatus, the clay sample was placed in between two iron rods. Thermocouple sensors were inserted below and above the surfaces of the clay sample to observe the temperature at the lower and the upper surfaces respectively as the heat flows through the clay sample. The thermocouple was connected to the data logger; it records the temperature with respect to time. The thermal conductivity test was conducted according to ASTM C202-86 [17].

Figure 1: Hot guided plate apparatus with clay sample (steady state)

III. Results And Discussion

3.1 Thermal shock resistance

The thermal shock resistance of the Barkin-ladi fireclay was 24 cycles before it's fractured. The clay sample thermal shock resistance value fell within the standard values of 20-30 cycles for fireclay refractory bricks [12, 15]. The fireclay fractured was as a result of temperature change caused by the interplay between the thermal expansion and thermal conductivity of the fireclay brick.

3.2 Refractoriness

The refractoriness of the fireclay brick of the Barkin-ladi clay sample was 1665 °C which corresponded with Segar cone 30 (PCE). The clay refractoriness fall within the standard values of 1500-1700 °C for fireclay refractory bricks [11, 16, 20a].

3.3 Thermal conductivity

The thermal conductivity was 0.03 W/m.K and fell within the standard value of 0.01-1.1 K (W/m.K) for fireclay refractory bricks [7, 8, 9, 20a]. The thermal conductivity was obtained as a result of the atomic and lattice vibration which is impeded via structural disorder using the steady state method.

Temperature gradient determines the direction of heat flow:

$$q = -K.A.\frac{dt}{dx}$$

Hence, thermal conductivity will drop with increase in temperature for fireclay refractory brick.

3.4 Energy absorption

Differential scanning calorimetry (DSC) was used to investigate the difference in the quantity of heat necessary to increase the temperature of a specimen and reference is measured as a function of temperature. The Barkin-ladi clay showed that as the temperature increases the clay sample developed phase change with sizable energy absorption. The differential scanning calorimetry equipment had maximum heat capacity of 600 J/ °C (DSC). The Barkin-ladi clay as presented in Table 1 showed a glass transition at mid-point of 555.39 °C with exothermic reaction at 538.36 °C which signified that energy being released and then crystallization occurred [18, 20a].

Table 1: DSC result indicating the glass transition, reaction and specific heat capacity

Barkin-ladi fireclay Enthalpy (°C)	Jg-1	C_P J/g (°C)	Glass transition mid-point (°C)	Onset (°C)	Observation
29.98	0	0	555.39	538.36	Exothermic reaction
93.33	65.91	0.706204			
156.67	115	0.734027			
220.02	146.84	0.667394			
283.36	166.74	0.588439			
346.7	180.29	0.520017			
410.05	191.21	0.466309			
473.39	188.01	0.397157			
536.74	252.54	0.470507			
600.08	189.4	0.315625			

3.5 Specific heat capacity

Specific heat capacity of Barkin-ladi fireclay brick as presented in Table 1 and Fig. 2 indicated that the Barkin-ladi clay will require 0.07 J/g °C to raise its body temperature at the minimum temperature of 93.33 °C. The effect of specific heat capacity was on the internal energy of the brick which caused the molecules to be in constant motion and make its particles vibrate faster, collide more violently thereby increasing the bulk density of the refractory brick. The result showed that the effect of specific heat capacity was on the thermal conductivity of the clay particles, porosity and on the removal of moisture content from the fireclay brick. The specific heat capacity of the clay showed that as temperature increases the heat capacity changes [8, 9, 20a].

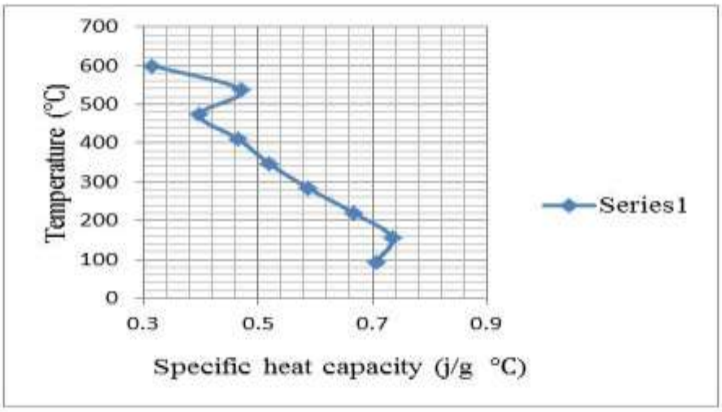

Figure 2: Specific heat capacity of Barkin-ladi clay

3.6 Thermogravimetric analysis

In the thermogravimetric (TGA), the Barkin-ladi fireclay as graphically presented in Fig. 3 showed that at temperature of 78.38 °C the clay sample experienced material reduction of 0.19 mg representing 0.32 %. This signified the evaporation of water in the material. At the temperature of 452.69 °C the material exhibited further reduction of 0.43 mg representing 0.41 %. This showed that the molecular structure of the clay was affected by the temperatures above 300-350 °C and carbonaceous material in the clay has decomposed and as such caused material reduction. At the temperature of 578.15 °C there was material reduction of 0.80 mg which represented 0.61 % [18, 19, 20a].

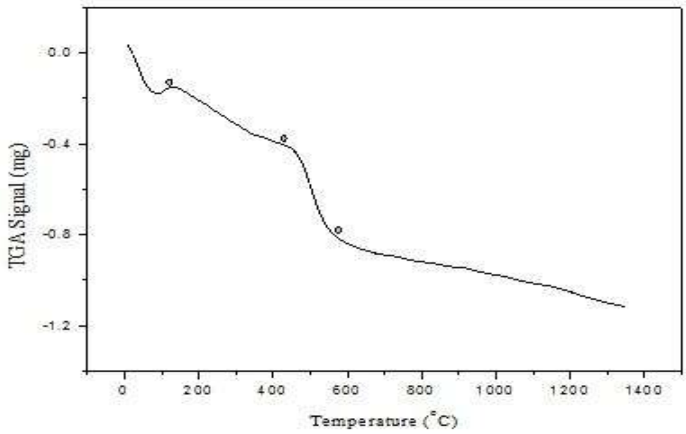

Figure 3: TGA curve of Barkin-ladi clay brick

3.7 Thermal shock

The differential thermal shock (DTA) result manifested material reactions of exothermic at 105.88 °C and 450 °C as presented in Fig. 4 showed evaporation of water molecules being rapid and the carbonaceous materials in the fireclay refractory brick sample start burning out at the second reaction which signified that heat energy was being released respectively. Endothermic reactions occurred at temperatures of 523.15 °C and 1200 °C this revealed a complete decomposition of carbonaceous materials and experienced heat absorption. The dehydroxylation of the minerals in the clay ensues at these temperatures signified the initial step in the oxidative degradation of the clay material. The flux compounds like P_2O_5, CaO and K_2O manifested reaction from 900 °C which signified the beginning of sintering process, material crystallization and phase change [18, 19, 20a].

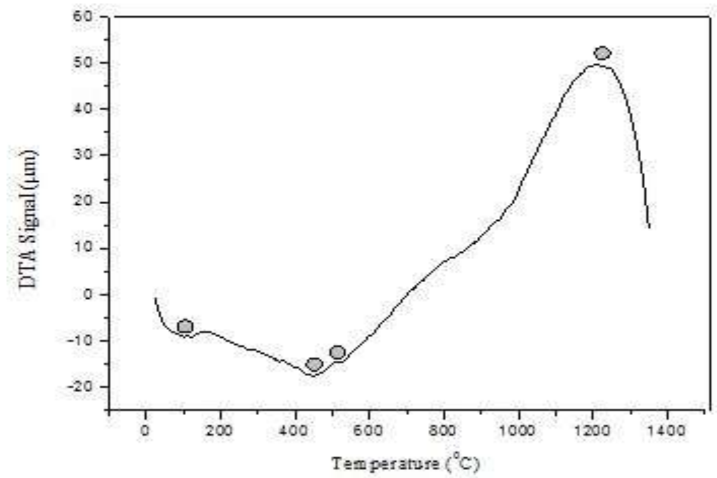

Figure 4: DTA graph of Barkin-ladi clay brick

IV. Conclusion

Based on the Barikin-ladi fireclay results of thermal conductivity value of 0.03 K (W/m.k), 0.07 J/g°C was needed to raised its the specific heat capacity, the refractoriness (PCE) was 1665 °C, thermal shock resistance was 24 cycles and were found to be within the standard values for refractory fireclay bricks respectively. DSC showed exothermic reaction at temperature of 510 °C with glass transition at mid-point of 555.39 °C, TGA and DTA were used for quality control during manufacture and the clay was therefore, suitable for production of refractory fireclay brick for furnace lining.

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