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Thermal Assessment of Kpata Fireclay for Refractory Applications

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ABSTRACT. This study focused on the thermal propertiesof the Kpata fireclay in order to look into its refractoriness. Thermogravimetry (TGA), differential thermal analysis (DTA) and thermal conductivity tests were carried out to analyse the fireclay's thermal properties. The fireclay was also compacted and fired at various firing temperatures. The TGA result indicated that there was material weight loss at 0.26 mg, 0.56 mg and 1.74 mg at temperatures of 90.53 °C, 425.12 °C and 578.87 °C respectively. The DTA revealed that there were exothermic and endothermic material reactions.The Kpata fireclay also had a thermal conductivity of 0.33 K (W/m.k). Apparent porosity of fired fireclay showed that the porosity was reduced as firing temperature increased. These conditions indicated that Kpata fireclay has the possibility in refractory and insulating applications.

Keywords: *Thermal property, Fireclay, Refractory;*

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1. INTRODUCTION

The rapidly witnessed request for an efficient and effective thermal insulation system through the use of earths naturally endowed clays used as fireclay refractories can never be over emphasized thermal industries. Fireclay refractories are insulating materials used as thermal barriers to store heat and conserve energy [1].

Furnaces as a thermal system are used for heat generation, melting, heat treatment that required extreme conservation in order to reduce heat losses for efficient and maximum heat efficiencies [2]. This will promote the least consumption of fuel as well as maximum production as an effort to maintaining maximum working temperatures [3]. Energy cost has increased and more importantly because of the role played by refractories in ceramic, glass and metallurgical industry cannot be over emphasized [4].

In recent time cost of energy has become high and the emergence of a new wide range of refractory materials with high temperature insulation technology that are proficient to restrain the leakage of heat at a higher temperature [5]. Fireclay refractory brick are materials that can withstand heat above 538 ° contained $Al_2O_3.SiO_2.H_2O$ as alumino-silicate. It is frequently used as thermal storage materials in form of bricks for furnace lining [6]. The insulating materials used today includes; ceramic coating, ceramic fiber glass, calcium silicate, insulating castables [7]. Very lately, refractory materials with porosity up to 10-30 % [8] are used as refractory bricks with high thermal conductivity suitable for the outer layers of furnace as refractory linings [9]. Refractory materials with 70-80 % of porosity [8] are used as insulating materials with a low thermal conductivity and suitable for the inner walls of furnaces [10]. The knowledge of thermal conductivity, energy

absorption and heat capacity of these refractory materials is very necessary and critical to solving heat losses challenge. Thermal conductivity is the amount of heat conducted in a unit time through a unit area normal to the direction of heat flow [11]. Heat flow through solids is due to elastic vibration of atoms or due to transfer of energy by free electrons [12]. Heat capacity is the quantity of heat (energy) necessary to raise a major quantity of a material C_P and is measured in J/g°C [13]. Thermal conductivities depend entirely on the lattice vibration of atoms and molecules [14]. There exists a relationship between the thermal conductivity of refractory insulating materials with other thermal analysis methods in order to have total comprehensive understanding of the materials thermal behaviour through the techniques of thermogravimetry analysis (TGA) and the differential thermal analysis (DTA)[15]. The formal deals with material weight losses while the later deals with material reaction in the thermal environment that can result to either exothermic or endothermic and may involve both reactions depending on the type and nature of the refractory material [16]. Clay of alumino-silicate group can be a better preference as specified in this study. It can replace the glass fiber that usually posed a health challenge to the producers and end users.

Nigerian clays are not only abundant but health friendly, cheaper and of unlimited advantage in resolving the problems highlighted. The motivation for this study therefore, was to investigate the measurement and analysis of thermal conductivity of the Kpata clay for its suitability as refractory and insulating materials.

2. MATERIALS AND METHODS

The collection of the clay sample was from Kpata clay deposit in Kogi state of the North central geo-political zone of Nigeria. The packaging and handling of the clay sample was performed according to the standard method of collection and transportation of soil [17].

2.1 Test samples preparation. The Kpataclay was crushed using the ball-mill. The sieve shaking machine was vibrated for 10 min. The amplitude was 0.5 maximum with the arrangement for 50 µm was obtained according to these order of sieves, 63µm, 50 µm followed by pan at the bottom. The sieve analysis was conducted according to ASTM E11-500 [18].

2.2 Thermal analysis. The sample Kpata clay of 60 g was measured as required quantity and poured into the alumina crucible and then situated inside the sample chamber. The thermogravimetry thermal analysis (TGA) and the differential thermal analysis (DTA) test were performed simultaneously using the technique of simultaneous thermal analysis (STA) thermal-balance apparatus (*Linseis STA*).

2.3 Thermal conductivity. The determination of thermal conductivityof Kpata clay was by hot guided plate steady state technique as presented in Fig. 1.

The test sample was prepared into a circular size of 4 mm thick with diameter of 25 mm. It was positioned in the thermal apparatus for thermal conductivity measurement at room temperature. The clay sample was located in between two iron rods on the hot guided plate apparatus. Thermocouple sensors was inserted below and above the surfaces of the sample was viewed and observed the temperature at the upper and the lower surfaces respectively as the heat flows through the sample clay. The thermocouple was connected to the data logger; it records temperature with respect to time. The thermal conductivity measurement was accomplished according to [19].

$$q = -K.A\frac{dt}{dx} \quad (1)$$

Where q is steady state flow, k is thermal conductivity, A is the cross sectional area of the clay material, and dt/dx represents the temperature gradient.

2.4 Firing process. The powder specimen was compacted using a mould into pallets by use of the hydraulic press caver machine. The application of force of 5 kN was administer with a holding tim of 60 seconds. The sampleKpataclay was firedvaried Firing temperature of 900 °C, 1000 °C, 1100 °C and 1200 °C with a heating rate of 2.5 °C /min. and a soaking time of 2 hours.

2.5 Apparent porosity. The fired clay sample was weighed using digital balance and documented as dried weight D (g). The sample was positioned in the triple stand basket and immersed in water, then weight

taken and documented as suspended weight S (g). The soaked sample removed from water and weighed and documented as soaked weight W (g). Apparent porosity test was determined according to [20].

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

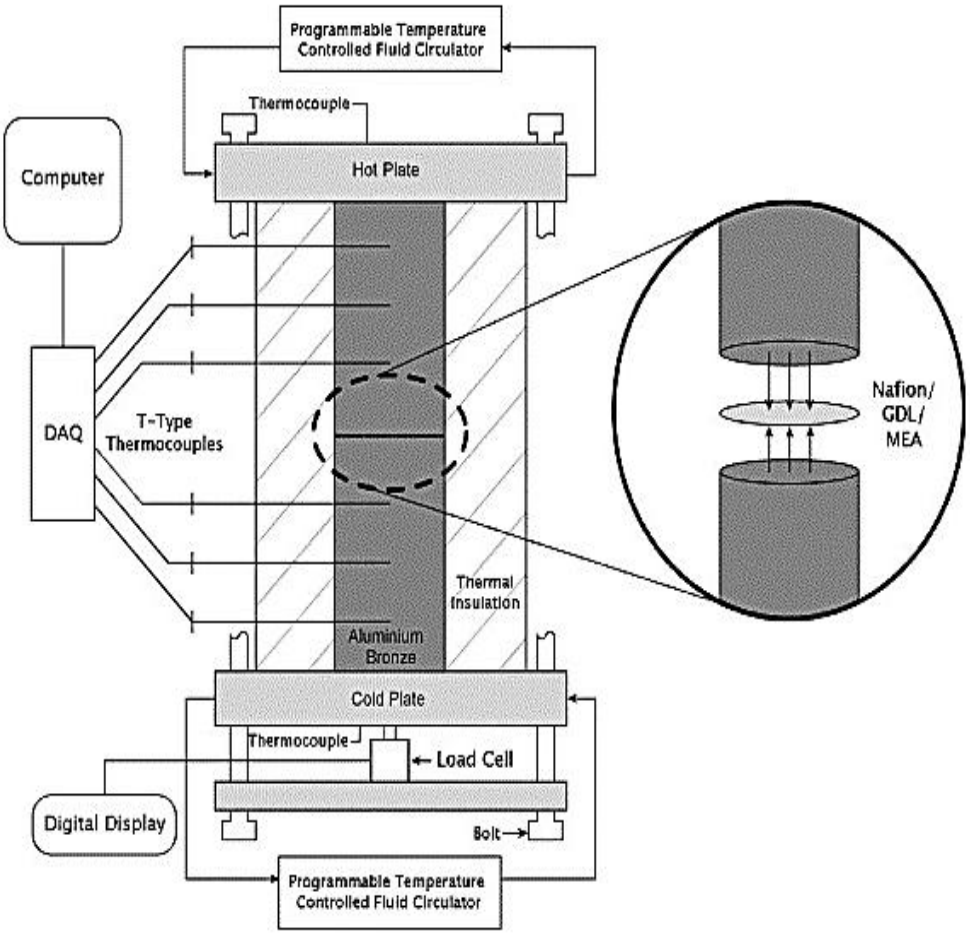

Fig. 1. Hot guided plate apparatus (steady state)

3. RESULTS AND DISCUSSION

3.1 Simultaneous ThermalAnalysis (STA). The TGA of Kpata clay as presented graphically in Fig.2 displayed at temperature of 90.53°C the sample clay encountered material weight loss of 0.26mg signifying 0.43%. This suggested the water being evaporated from the material clay. At temperature of 425.12°C the material clay sample demonstrated further weight loss of 0.56mg signifying 0.5%. This disclosed that the molecular structure of the clay sample was influenced by the temperatures above 300°C – 350ºC and carbonaceous material in the sample clay had decomposed and consequently caused material weight loss. At temperature of 578.87 °C there was another weight loss of 1.74 mg which signified 1.97%. The influence of TGA was seen to have caused weight loss in the clay. The dehydroxylation of the minerals in the sample clay as ensued at these temperatures. It implied the beginning of the initial phase in the oxidative degradation of the sample clay material. Flux compounds like P_2O_5, CaO and K_2O exhibited reaction from 900 °C which suggested the beginning of the Firing process, material crystallization and phase change [21,22].

The differential thermal analysis (DTA) as presented graphically in Fig.3 showed an indication that the clay specimen experienced exothermic reactions at temperatures of 517.4 °C and 1150 ºC respectively. This means the clay material absorbed energy at these temperatures. Another reaction of endothermic was exhibited by the clay at the temperature of 989.9 ºC which signified the clay released energy at that particular temperature. The DTA caused exothermic reaction in the clay sample as energy being absorbed and the endothermic reaction in signifying energy being released [21,22].

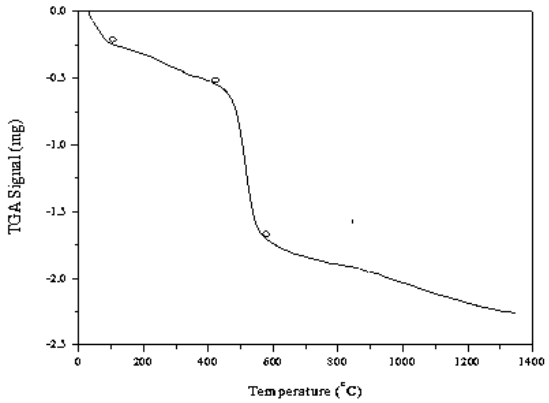

Fig. 2.TGA curve for Kpata fireclay brick

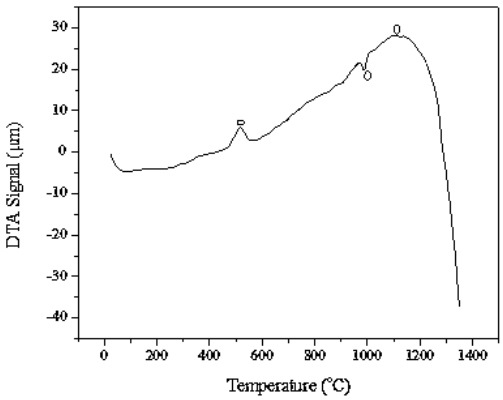

Fig. 3. DTA graph of Kpata fireclay brick

3.2 Apparent porosity **.**The highest apparent porosity value of the sample was 43.76 % at the least firing temperature of 900 ºC as compared with lowest porosity value of 21.58 % attained at the highestfiring temperature of 1200 °C. The porosity of the sample fell within the standard values of 20-30 % for refractory fireclay bricks [8]. It was revealed in Fig.4 that when the Firing temperature was increased, the volume of sample clay open pores decreased. This showed that the Firing temperatures have influenced the apparent porosity of the sample.

3.3 Thermal conductivity**.** The thermal conductivity of Kpata clay sample exhibited the value of 0.33 K (W/m.k) and fell within the standard values of 0.01 to 1.1 K (W/m.k) for refractory fireclay bricks [12-14]. Thermal conductivity of the clay sample was attained as a caused through the atomic and lattice vibration which is impeded via structural disorder by the heating. Consequently, thermal conductivity dropped with the increasing temperature. Temperature gradient determines the direction of heat flow.

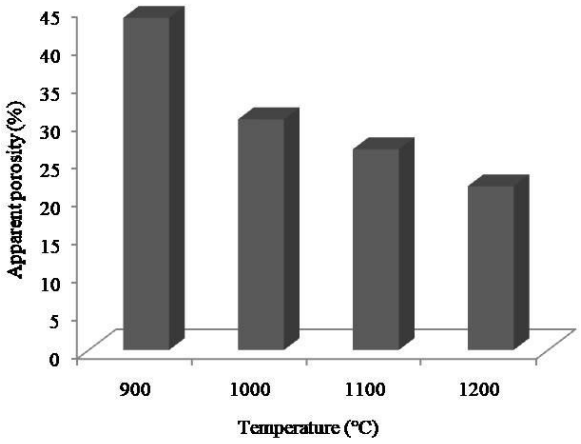

Fig. 4 Apparent porosity of Kpata fireclay brick at varied firing temperatures

4. SUMMARY

The results of the Kpata fireclay refractoriness were found to be within the standard values for refractory fireclay bricks. The thermal properties of the fireclay brick as investigated through thermal methods of TGA, DTA and thermal conductivity concluded that the Kpata fireclay brick was found to be potential candidate for refractory applications.

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