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PRODUCTION OF REFRACTORY BRICKS FROM TERMITE MOUNDS

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ABSTRACT: Refractory bricks employed for their exceptional heat insulation properties are typically categorized into porous and non-porous, with porous bricks possessing lighter weight and better insulation. Porosity is usually achieved through the introduction of combustible components to the raw material mixture. This study examined the feasibility of utilizing Abeokuta termite mound for producing refractory bricks with rice husk as pore former. The termite mound was ground, crushed, sieved, and characterized to find its mineralogy and chemical compositions. Bricks were produced from the termite mound and rice husk in different proportions, and dried. The physical properties of the bricks evaluated were specific gravity (SG), apparent porosity (AP), water absorption (WA), bulk density (BD), thermal shock resistance (TSR), linear shrinkage (LS), compressive strength (CS) and refractoriness (R). The values of SG, CS, AP, BD, WA and LS were in the range of 1.97 and 1.73, 4.75 and 4.56N/mm^2, 33 and 57.5%, 1.781 and 0.8 g/cm^3, 16 and 24.7%, 4.0 and 6.0 for 0 and 16% rice husk respectively. Apparent porosity, water absorption and refractoriness all increased with rice husk; while specific gravity, bulk density and thermal shock resistance decreased with an increase in rice husk. The TSR reduced from 24 to 16 cycles with increased rice husk. The values obtained for all the parameters tested agreed with literature. Abeokuta termite mounds are suitable for refractory bricks production.

Keywords: Termite mound, Refractory bricks, Clay-based materials, Rice Husk, Agriculture waste materials.

1.0 Introduction

Refractory materials possess remarkably high melting points and the ability to retain their structural integrity under extreme temperatures. These materials are inorganic and non-metallic, consisting of porous and heterogeneous compounds, including thermally stable mineral aggregates, a binding phase, and additives. When combined with water, they form a cohesive, adhesive mass, allowing for easy molding while wet, and the ability to maintain their shape once dried. Refractories are utilized to line high-temperature furnaces and other processing units, providing crucial resistance to physical wear, elevated temperatures (exceeding 538°C), and corrosion caused by chemical agents (Kaczmarek, 2021).

Refractory is defined technically as an inorganic, non-metallic material that is useful in manufacturing equipment with an extremely elevated temperature like crucibles, kilns and furnaces. They are selected for such construction because of their inherent ability to withstand extremely elevated temperatures (Ahmed, 2014).

Refractories are typically categorized into two groups based on porosity, namely: dense and porous refractories. These materials come into direct contact with hot gases and liquid metals. Porous refractory bricks form a significant subset widely employed in industrial settings for their exceptional heat insulation properties (Gupta, 2008). They are lightweight, offering notably lower thermal conductivity and heat capacity compared to other refractories (Gupta, 2008). The porosity is usually achieved by introducing combustible components to the raw material mixture. The material burns off during the firing and leaves a significant volume of pores within the finished product. Various pore-forming agents such as sawdust, rice husk, organic foams, or granular materials are commonly incorporated to reduce the density or create porous density or create porous structures in insulation materials (Folorunso, 2015).

Termite mound is a form of clay with improved plasticity because of termite secretion. It is better than ordinary clay in the production of laterite bricks (Mijinyawa *et al.*, 2007). According to Parker (1998) and as reported by Mijinyawa *et al.* (2007) heat treated termite mound clay units are resistant to wear, abrasion and penetration by liquids. Adeniran *et al.* (2014) investigated termite mound as a replacement for clay in construction. Some mechanical properties measured showed that termite mound can serve as a good replacement for clay in brick production.

Ndaliman (2006) investigated the production of insulating refractory materials from Minna termite hills by incorporating 25% additives, such as corn husk and sawdust with 1,200ºC refractoriness obtained, which improved to 1,600 and 1,700 ºC when 25% of graphite powder and asbestos were added to termite mound as pore formers in a subsequent investigation. This work investigated the production of refractory bricks from Abeokuta termite mounds.

2.0 Materials and Method

2.1 Materials

The materials used for this study were termite mound which served as the base materials, Rice husk as the pore former, water and lubricating oil used to lubricate the mold for ease of removal of formed bricks. Equipment used were a blunger, where the soaked soil sample was washed, disintegrated, dispersed and sieved; a jaw crusher; kerosene-fired kiln; muffle furnace; salters spring balance (ML 25) for suspended weighing of bricks; weighing balance for high precision measurement; hydraulic press machine for compaction of bricks; vernier calipers; and tongs for holding hot samples.

2.2 Sample Description

The Termite Mound was sourced during the rainy season. The color was pinkish brown. As it gets dried the color changes to a brighter brown and becomes dark brown and some turn black as it is being fired. Drying and firing of mound removes water and collapses the hydrated crystal structures within it. Carbonates and carbonaceous matter were also burnt. This process of firing induces a thermally activated, irreversible phase changes (Edomwonyi-otu *et al.*, 2010).

Physically, the termite mound was lumpy (4 - 8 cm) which was easily crushed under slight pressure from the fingers giving a smooth powdery form.

2.3 Chemical Composition

The oxides of elements were determined by X-ray fluorescence (XRF) spectrometer following the standard procedure. X-ray Fluorescence (XRF) analysis of the mound sample revealed the major and the minor oxides. The oxides were silica (SiO^2), Alumina (Al_2O_3), iron oxide (Fe_2O_3), alkaline and alkali earth oxides (Na_2O, K_2O, CaO etc).

2.3.1 Mineralogical Characterization

The mineralogical analysis of the clay sample was carried out by X-ray diffraction (XRD). X-ray diffraction is a non-destructive test method used to analyze the structure of crystalline materials. It identifies the crystalline phases present in the materials.

2.3.2 Scanning Electron Microscope (SEM)

Scanning electron microscopy was carried out on the raw materials, to show the three-dimensional representation of the raw materials.

2.4 Experimental Methods

A wooden mold of dimensions (100mm x 100mm x 100mm) was fabricated, and the termite mound was crushed, graded and ground using a ball mill grinder. Rice husk was also crushed, graded and grounded; the rice husk was added as a pore-former in the proportion of 0% to 16% contents, for the production of the bricks (this implies that 5kg of termite mound had rice husk contents of 0, 200, 400, 600 and 800 g). The bricks were air-dried under a shed to avoid cracking due to direct sunlight. A total of 105 bricks were produced and were oven-dried for six hours at 105˚C and then fired at 1000˚C. The physical properties of the bricks evaluated were specific gravity, apparent porosity, water absorption, bulk density, thermal shock resistance, linear shrinkage, compressive strength and refractoriness.

2.5 Determination of Physical Properties

2.5.1 Bulk Density

The fired bricks were cooled in a desiccator after which the bricks were transferred to a beaker, in order to get rid of the air trapped. The dried bricks were weighed to the accuracy of 0.008 grams (dried weight). The densities of the bricks were obtained by calculating their volume (length, breadth and height) using the beam balance. Equation (1) was used to obtain density.

$$\text{Density } \rho = \frac{\text{Weight of dry soil (g)}}{\text{Volume of dry soil (cm}^3\text{)}} \tag{1}$$

2.5.2 Water Absorption (Clay Sample)

The fired samples were soaked in water at room temperature for a period of 24 hours; their weights were taken before and after soaking in water. The water absorption was determined as the percentage of water absorbed by the samples using Equation (2).

$$\text{Water Absorption} = \frac{\text{Wet weight (Ww)} - \text{Dry Weight (Wd)}}{\text{Dry Weight (Wd)}} \text{ x } 100\% \tag{2}$$

Where, Wd is the dry weight before soaking and Ww is the wet weight after soaking

2.5.3 Apparent Porosity Test

The bricks were dried in the oven at 105℃ for 24 hours. They were then fired to a temperature of 1000℃, cooled and transferred into a desiccator and weighed to the nearest 0.01 g (Dried weight). The bricks were transferred into a 250 ml beaker in an empty vacuum desiccator. Water was then introduced into the beaker until the test piece was completely immersed. The bricks were soaked in boiled water for 30 minutes and agitated from time to time to assist in the release of trapped bubbles. The bricks were transferred into an empty vacuum desiccator to cool. The soaked weight (W) was recorded. The brick kept in a beaker suspended in water was weighed on a balance. This gave the suspended weight (S). The standard used was ASTM (ASTM C20-00 2015) as given in Equation (3).

$$\text{Apparent Porosity} = \%\text{Pa} = \frac{W-D}{W-S} \text{ x } 100 \tag{3}$$

where:

D = Constant Weight of the dry sample
S = Weight of the sample suspended in water.
W= Weight of sample in air including the moisture in its open pores.

2.5.4 Shrinkage Test

The bricks were placed under a hydraulic pressure of 350 kN/m^2. A slanted line of 10 cm was inserted diagonally on each brick and recorded as L1. The bricks were then placed inside the furnace and fired at 1000^{o}C for 6 hours and the line drawn across the diagonal axis of the pieces was measured to determine its final length L2 after firing.

2.5.5 Thermal Shock Resistance

The bricks were placed in a furnace and held at temperature of 1000℃ for 10 minutes. The bricks were removed from the furnace with a pair of tongs and allowed to cool for 10 minutes. The bricks were returned to the furnace for another 10 minutes. This process was repeated many times until the test piece cracked and shattered. The number of heating and cooling cycles for each brick was recorded.

2.5.6 Cold Crushing Strength

The bricks were fired in a furnace at 1000℃ and was held constant for 6 hours. The bricks were cooled to room temperature. The bricks were placed on a compressive tester and load was applied axially by turning the hand wheel at a uniform rate until failure occurred. Cold crushing strength was obtained using Equation (4)

$$\text{Cold Crushing Strength (CCS)} = \frac{Load\ Applied\ (kg)}{Area\ (cm^2)} \tag{4}$$

2.5.7 Specific Gravity

Equipment used for specific gravity determination included a pycnometer, weighing balance, vacuum pump, funnel and spoon. The specific gravity was evaluated using Equation (5)

$$\text{Specific Gravity} = \frac{Weight\ of\ \text{oven dry soil}}{Weight\ of\ \text{water}} = \frac{W_2-W_1}{W_3-W_2} = \frac{W_2-W_1}{W_4-W_1} \tag{5}$$

where, W_1 = Weight of empty bottle in gram; W_2 = Weight of empty bottle + dry soil, in gram; W_3 = Weight of empty bottle, in gram; W_4 = Weight of empty bottle + water only, in gram.

3. Results and Discussion

3.1 Chemical Composition of the Termite Mound

The chemical composition of Abeokuta termite mound as compared to the international standard is as shown in Table 1 X-ray Fluorescence (XRF) analysis of the mound sample revealed the major and the minor oxides. The oxides were silica (SiO_2), Alumina (Al_2O_3), iron oxide (Fe_2O_3), alkaline and alkali earth oxides (Na_2O, K_2O, CaO etc.).

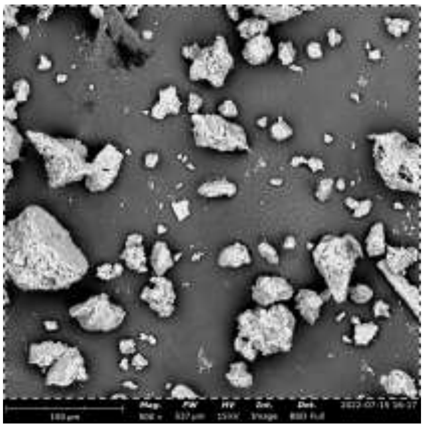
According to the study conducted by *Toure et al.* (2017), on the mechanical and thermal characterization of bricks, a combined percentage of SiO_2 and Al_2O_3 should be greater than 70% to be good for brick production. The chemical compositions of the termite mound samples given in (Table 1) had silica, SiO_2 is 65.77%. The alumina, Al_2O_3 is 18.48%. The sum of the SiO_2 and Al_2O_3 content is 84.25%, which conforms with the study by Toure. The combined percentage also meets the requirements of ASTM C-618 (ASTM C- 618 2010). The abundance of aluminium oxide in the Abeokuta termite mound improved its refractoriness.

Table 1: Chemical composition of Abeokuta Termite Mound

Oxide (%)	International Standard (ASTM)	Abeokuta Termite mound
SiO_2	63.00	65.77
Al_2O_3	17.59	18.48
Fe_2O	5.34	4.33
K_2O	1.14	1.65
MgO	3.00	0.60
CaO	3.60	4.85
TiO_2	1.79	1.22
Na_2O	4.00	2.40
MnO	0.03	0.04
SO_2	0.34	0.41
P_2O_5	0.04	0.05

3.2 Scanning Electron Microscope (SEM)

The Scanning Electron Microscope (SEM) result of the raw materials below shows the three-dimensional representation of the raw material as illustrated in Plate 1. From the SEM result, oxygen has a weight concentration of 62.85, followed by silicon at 13.45 and then aluminum at 12.31 and carbon at 10.08. The SEM analysis shows that the Abeokuta termite mound was rich in silicate and alumina, the sample has a homogenous microstructure with small grains. The edges of the flakes are irregular with flakes (thin fragment) surface dimension (~3µm). The aggregate shape is in principle like soot particles, but the surface of the catalysts was observed to be rough and there appears to be non-uniformity in the shapes and sizes due to clustering of particles. This report conforms to Madaki (2022).



Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
8	O	Oxygen	68.56	62.85
6	C	Carbon	14.64	10.08
14	Si	Silicon	8.36	13.45
13	Al	Aluminium	7.96	12.31

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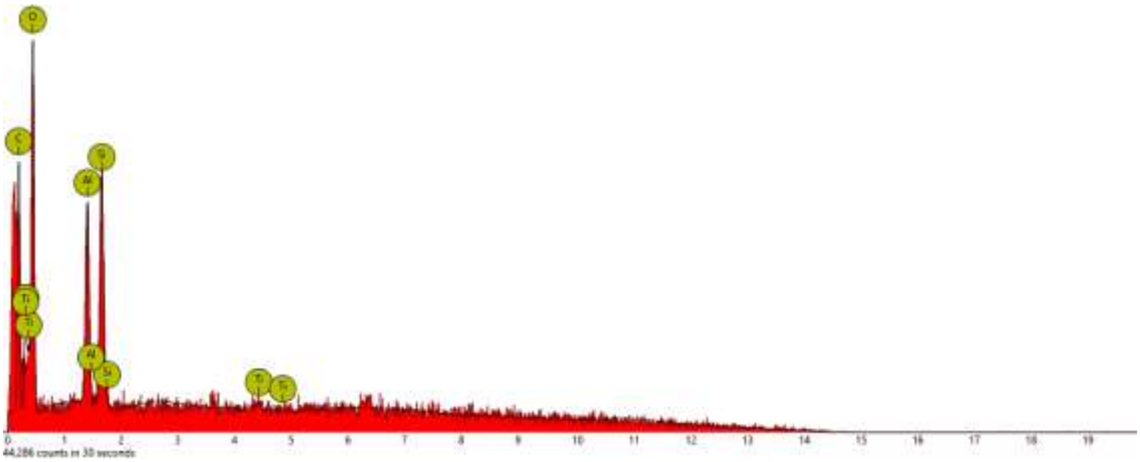

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Plate 1: Scanning Electron Microscope (SEM) result

3.3 Samples of Refractory Blocks Produced

The samples of refractory bricks produced are shown in Plate 2 and Plate 3

Plate 2: Picture showing the molded bricks

Plate 3: Picture showing the molded bricks inside the furnace

3.4 Sinterability of Termite Mound sample

The common shrinkage for the Termite mound bricks ranged within 7-9% at 1000^{o}C. This is within the international standard range of 7-9%. The color change observed after firing the bricks suggested the presence of trace-colored impurities especially iron oxide, carbonaceous matter and water of crystallization.

3.5 Physical Properties of the Samples

3.5.1 Specific Gravity

The results of specific gravity versus rice husk are presented in Figure 1. The trend of Rice Husk content with specific gravity was inversely proportional. The results showed that, as rice husk additive increased, specific gravity reduced. The specific gravity obtained from Abeokuta termite mound bricks ranged from 1.73 to 1.97, this trend compared favorably with the results obtained by Ndaliman (2006) for Minna termite mound which ranged from 1.84 to 2.0, and lower than Nwakonobi (2013) results for Makurdi red and white termite mound that ranged from 2.77 to 2.44. Termite mound obtained from the three locations followed the same trend an increase in the rice husk resulted in a decrease in their respective specific gravities.

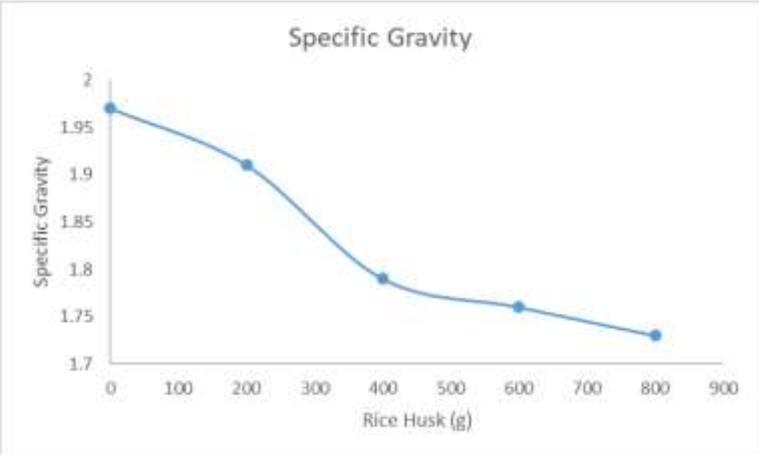

Figure 1: Graph of Rice Husk versus Specific Gravity

3.5.2 Bulk Density (g/cm^3)

The results of bulk density versus rice husk are shown in Figure 2. Bulk density in g/cm^3 ranged from 1.781 at 0 gram of rice husk to 0.8 at 800 grams of rice husk. The trend of Rice Husk content with bulk density was inversely proportional. The range of international standard of refractory materials for bulk density is 1.71g/cm^3 – 0.8g/cm^3 (Atterberg Limit Test, 2014). It also compared favorably with Minna termite mound insulating bricks whose average bulk density was 2.52g/cm^3 – 1.01g/cm^3 (Ndaliman, 2006).

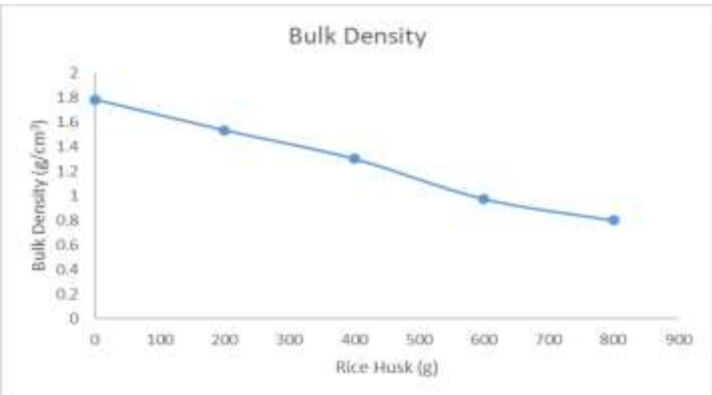

Figure 2: Graph of Rice Husk versus Bulk Density

3.5.3 Water Absorption

Figure 3 shows water absorption versus rice husk result, the values ranged from 16% to 24.7% for 0 gram of rice husk to 800 grams. The effect of Rice Husk additive on water absorption was directly proportional. As rice husk additive increased, the pores produced after firing the bricks increased. As porosity increased, the absorption capacity of the bricks also increased. Bricks from Abeokuta and Makurdi (red and white) termite mounds reacted to the increase in rice husk the same way. It can be deduced that water absorption increased in all three locations with an increase in the percentage of rice husk. The value of water absorption across the three locations ranged from 13.4% to 27.6%.

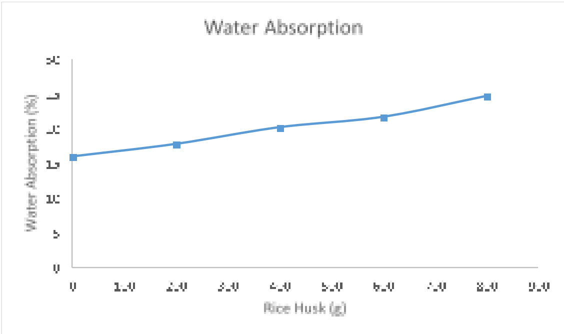

Figure 3: Graph of Rice Husk versus Water Absorption

3.5.4 Thermal Shock Resistance

The results indicated that the dense pure termite mound bricks resisted spalling up to 24 cycles. However, thermal shock resistance decreased from 24-16 cycles with increase in amount of rice husk added, from 200 g to 800 g. Figure 4 shows the result of thermal shock resistance versus rice husk. According to the standard international specification for refractory bricks, the minimum blow or shock for a good refractory brick is 15 cycles. The results obtained generally indicated that the resistance of the materials reduced with increased percentage of additives.

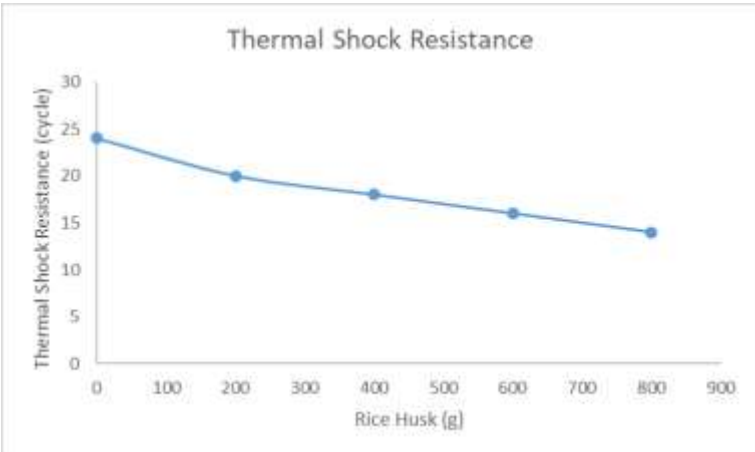

Figure 4: Graph of Rice Husk versus Thermal Shock Resistance

3.5.5 Compressive Strength (N/mm^2)

The results indicated that compressive strength rose from 4.75 N/mm^2 at 0 gram of rice husk to 5.32 N/mm^2 at 400 gram of rice husk then declined to 4.56 N/mm^2 at 800 grams of rice husk. This pattern compares favorably with Nwakonobi (2013) insulating bricks whose compressive strength value peaked at 5.08 N/mm^2 for 400 grams which rose from 4.58 N/mm^2

at 0 gram and declined thereafter. Figure 5 shows the compressive strength versus rice husk result

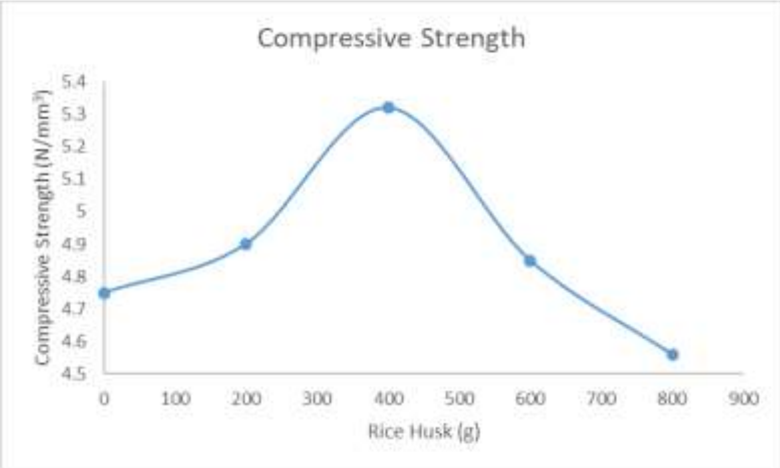

Figure 5: Graph of Rice Husk versus Compressive Strength

3.5.6 Apparent Porosity (%)

Result of apparent porosity versus rice husk is presented in Figure 6. The apparent porosity ranged from 33% at 0 gram of rice husk to 57.5% at 800 grams of rice husk respectively.

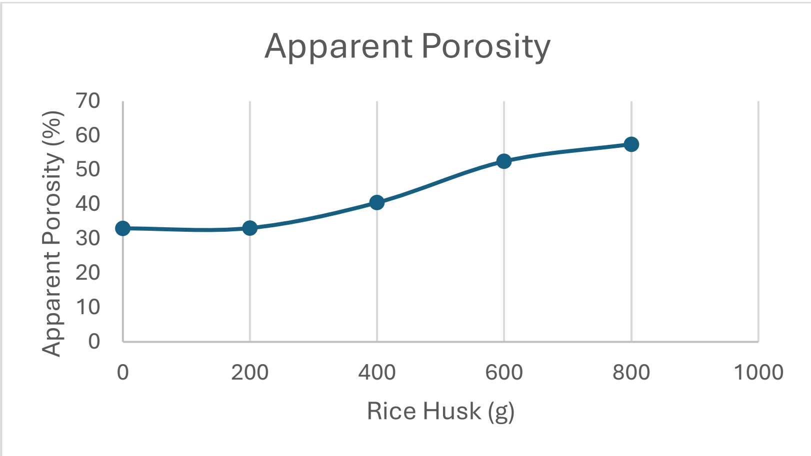

Figure 6: Graph of Rice Husk versus Apparent Porosity

3.5.7 Refractoriness

Figure 7 below shows refractoriness vs rice husk results. The results indicated that the refractoriness ranged from 1300℃ at 0 gram to 1520℃ at 800 grams.

Figure 7: Graph of Rice Husk versus Refractoriness

4. Conclusion

The project was designed to investigate the feasibility of producing insulating refractory bricks from termite mounds using rice husk as a pore former. The raw materials were sourced, beneficiated and characterized. The Refractory bricks were molded, dried in air and fired in the oven first at 105°C and then 1000°C. The refractoriness was determined, and other mechanical properties were tested. The termite mound was characterized and the XRF revealed that it had 65.77% of SiO_2, 18.48% of Al_2O_3. The refractory bricks had plasticity index of 18%, bulk density of 0.8 to 1.78g/cm^3, ISTM of 1.0 to 2.1%, and thermal shock resistance values from 14 to 24 cycles. Specific gravity ranged from 1.73 to 1.97. The average linear shrinkage of dried bricks varied from 4.0 to 6.0 while the average linear shrinkage after firing varied from 7.1 to 7.9. Water absorption ranged from 16% to 24.7% and the refractoriness of the fire bricks reached a maximum at 1530°C. The study concluded that based on the refractoriness of 1530°C, chemical compositions of 65.77% for SiO_2, 18.48 for Al_2O_3, average linear shrinkage of 4.0 to 6.0, thermal shock resistance of 24 to 14 cycles, specific gravity of 1.97 to 1.73, bulk density of 0.8 to 1.78 g/cm^3 and compressive strength of 4.75 to 5.32 N/mm^2, all falling within the international standards, termite mounds found near Federal University of Abeokuta, Ogun state could be used for refractory bricks production.

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