COMPARATIVE EFFECT OF WOODFLOUR AND GRANULATED RICE HUSK ON THE THERMAL INSULATION OF TERMITE HILL CLAY

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Received 16 June 2023
Accepted 08 July 2024
DOI: 10.59957/jctm.v59.i5.2024.11

ABSTRACT

This research work covered the comparative effect of wood flour (saw dust) and granulated rice husk on the thermal insulation of termite hill clay. The raw clay samples were mined from the Federal University of Technology Akure Campus and processed. Likewise, the saw dust and rice husk were also processed and grinded. The clay samples and the additives were sieved to obtain 300 microns and were mixed in predetermined proportions of 0, 2, 4, 6, 8 and 10 wt. %. Cylindrical samples were developed from the mixtures which were compacted and then air dried before oven dried and finally fired. The fired samples were subjected to selected tests to determine their insulation and refractory properties. These tests include porosity, linear shrinkage, volumetric shrinkage, bulk density, thermal conductivity, thermal shock resistance and cold crushing tests. It was discovered that the saw dust samples meet the ASTM standard for insulating bricks while the rice husk samples did not. Saw dust samples with 2 and 8 wt. % were ones with optimum properties.

Keywords: termite clay, rice husk, wood flour, thermal insulation test.

INTRODUCTION

Thermal insulation retards heat transfer by acting as a barrier in the path of heat flow, playing a major role in the design and production of energy-efficient processes, devices, and systems. Insulators are materials that provide a high level of resistance to the flow of heat or electricity. They are used in most industrial operations where high temperature applications are required since they tend to reduce heat flow. As a result, such materials are referred to as refractory when they can endure high temperatures. Nigeria, as a developing country, has a plethora of sectors that rely heavily on refractory materials. Metallurgical industries, for instance, demand materials that can tolerate high temperatures. Most insulation materials are made of fiberglass, mineral wool, polyethylene, saw dust, rice husk or calcium silicate [1, 2].

For centuries, industrial furnaces have formed the backbone of metallurgical businesses. These furnaces are used in day-to-day processing of various metals by the metallurgical industry. The furnaces employ externally provided heat energy to turn metallic ores into a variety of valuable products at high temperatures.

However, these furnaces' efficiency is not at their peak due to shortfall in energy loss from the furnaces. Several experts are investigating ways to boost the efficiency of various components that make up these furnaces [3]. The major raw material in the production of refractory or insulating materials is clay which is utilized massively in kiln design and construction industries.

Clays are abundant fine earthly powders which are produced by the weathering and breakdown of granite and feldspathic rocks. They are anhydrous complex compounds of alumina (Al_2O_3) and silica (SiO_2) that occur in various proportions and comprise of varied amounts of impurities of iron, organic matters and residual minerals. These clay-based constituents occur both in the plain and riverine areas. Although clay usually contains phyllosilicates, it may contain other materials that could impart plasticity when wet and harden when fired. However, accompanying phases in clay may include organic matter and materials that do not impart plasticity [4, 5]. Scientists are looking on ways to improve the qualities of refractory bricks by exploiting various natural clay deposits. Ant hill/termite clay is one of such natural clay deposits. They are mounds of soil formed by ants or termites during the process of digging or building their nest. Ants are known to transport huge quantities of materials from within the soil and depositing it on the surface. Some of the Ant mould hills are about 5 m tall and 7 m in diameter. However, clay which forms the major composition of Ant hills is a naturally occurring material which composed primarily of fine-grained materials. These materials show plasticity when the required amount of water content is added and hardened when dried or fired. Hence, researchers have reported that Ant hills have a favourable combination of thermal and mechanical qualities for prospective refractories manufacturing [3, 6]. Several research works on the use of additives in termite hill clay to enhance the clay's refractory characteristics are ongoing [6 -13]. Some of the additives currently been used to enhance termite clay's refractoriness include graphite and asbestos [7], bentonite and pulverized glass waste [6], high aluminum cement [8], saw dust [9, 10,12], rice husk ash [8,12], corn husk [12], grapevine[11], cassava peel[2], waste glass[10], chicken droppings, melon shell and palm kernel shell[13]. Sawdust and rice husk are pore inducing additives, which implies that when integrated into products, they generate pores, and this helps to make the materials porous to satisfy the necessary insulating property. Refractory characteristics, for example, linear shrinkage, apparent porosity, and thermal shock resistance have all been enhanced by adding such additives [9, 14].

Rice husk (RH) is an agricultural waste that accounts for 20 % of the 649.7 million tons of rice produced each year worldwide. The produced partially burnt husk from the milling plants when used as a fuel also contributes to pollution. Thus, efforts are being made to overcome this environmental challenge by applying the material as a supplementary cementing material [15, 16].

Wood flour is the material obtained after sawing of wood. It has many applications in the manufacturing of chip boards, furniture additives in clay, and many more. To keep the cost of production low, the waste agricultural material to be used in inducing insulation in the clay body should be readily available, locally soured, and of low cost [2].

Several high temperature operations are still ongoing, which emphasizes the need for insulating bricks. Approximately, 30 - 40 % of the energy supplied for this operation escapes through the walls into the atmosphere, resulting in thermal inefficiency and high fuel consumption. Despite their high thermal resistance, insulating firebricks will inevitably begin to fail and breakdown over time if not properly developed to meet these requirements [18]. Such problems can be overcome by the utilization of excellent insulating materials to enhance its thermal insulating properties which and, this form part of the reasons for this research. Comparative effect of wood flour and rice husk on the thermal insulation potentials of termite hill clay was investigated in this research.

EXPERIMENTAL

Materials

The materials employed in this study were sourced exclusively from Nigeria. The termite clay, functioning as the matrix, was obtained from the urban area of the Federal University of Technology Akure, located in Ondo state. Meanwhile, the wood flour was acquired from a sawmill in Akure city, also situated in Ondo state, Nigeria. This sawmill processes wood into various sizes, resulting in the generation of wood particles, known as wood flour, which are typically considered as byproducts. Furthermore, the rice husks were procured from the Rice Mill of Nigeria, positioned at Plot 25, Block 42 Adebayo Unuigbe Close, Alagbala, Akure 340106, Ondo state, Nigeria. Both the rice husks and wood flour were utilized as additives in the matrix to fabricate a ceramic-based composite specifically designed for refractory applications.

Methodology

The clay extracted from a termite mound was immersed in clean water for 72 h to facilitate the removal of harmful substances, which were then separated from the mixture. Following the elimination of undesired elements, the slurry was combined with fresh water for an additional 48 h, allowing the clay particles to settle beneath the water surface. Subsequently, the water was decanted, and the residue was filtered through a thick cloth to drain excess water, a process lasting 24 h. The resulting clay was air-dried for a week, resulting in the formation of clumpy clay aggregates. These aggregates were subsequently crushed into smaller particles using a mortar and pestle, followed by oven-drying at 110°C for 4 h to eliminate residual moisture. The dried clay was then pulverized using a laboratory machine to further reduce particle size, and subsequently processed in a ball mill for 1 hour, with grinding occurring at 15 min intervals. The ground clay was then gathered and sifted through a sieve shaker with a 300 µm aperture size, in accordance with the methodology outlined by Folorunso et al. [19].

In the preparation of the additives, after the acquisition of these materials, both substances were immersed in water for a duration of 48 h, followed by a sieving process, and the resulting filtrate was subjected to air drying for 72 h to eliminate any residual moisture content. Following the air-drying phase, they underwent oven drying at a temperature of 50°C to further eradicate any remaining moisture. After the drying procedures, the substances were introduced into the ball mill and permitted to undergo grinding for a period of 3 h, with grinding intervals occurring every 20 - 25 min. Upon completion of the grinding process, the additives were sifted using a sieve of identical aperture size as that of the clay.

Preparation of samples

Mixtures comprising clay and sawdust, or rice husk particles were prepared with various proportions of sawdust and rice husk, ranging from 0, 2, 4, 6, 8 and 10 wt. %. Each specific mixture underwent thorough mixing with a 10 wt. % addition of water to enhance plasticity and achieve a uniform blend of both rice husk and clay, as well as sawdust and clay. The resulting homogenous mixture, presenting as a plastic paste, was molded into cylindrical samples measuring 50mm in height and diameter, utilizing a cold compression-moulding machine. These dimensions conformed to the standards set by the American Foundrymen Society (AFS), as detailed in the work of Folorunso et al. [19]. Subsequently, the cylindrical samples fabricated by the cold compression moulding machine were air-dried for 48 h, followed by further drying in an oven at 110ºC for 2 h. Post the 110ºC drying process, the samples were subjected to firing in a furnace at 900ºC, employing a preset temperature profile consisting of a heating rate of approximately 100°C h^{-1}, a dwelling time of 2 h, and a cooling rate of around 70°C h^{-1}, in alignment with the methodology established by Folorunso et al. [20]. The fired samples were subsequently tested in accordance with the American Standard for Testing and Materials for the following properties.

Apparent porosity

Using boiling process, a moulded fired brick sample was prepared. The brick was air dried for 24 h before being oven dried to a consistent weight (D) at 110°C. After that, it was transferred to a beaker and cooked for 30 min with distilled water to aid released trapped air. After soaking, the saturated weight (W) free of surplus water was calculated. After suspending the specimen in water in a beaker, the suspended weight (S) was obtained and the apparent porosity was determined using the following Eq. 1 [20, 21].

$$\text{Apparent porosity} = \frac{W-D}{W-S} \times 100 \qquad (1)$$

where: W is soaked or saturated weight, D is dried weight, S is suspended weight.

Bulk density

The boiling method was also employed to determine the bulk density of the refractory sample. A sample of moulded burned brick was made. The brick was air dried for 24 hours before being oven dried to a consistent weight at 110°C (D). After that, it was transferred to a beaker and cooked for 30 min with distilled water to help release trapped air. After that, it was allowed to soak, and the saturated weight (W) was recorded. After suspending the specimen in water in a beaker, the suspended weight (S) was obtained [20]. The bulk density was then estimated using Eq. 2 which followed ASTM C373-14a procedure [21].

$$\text{Bulk density} = \frac{D}{W-S}\rho_W \qquad (2)$$

where: D is dried weight, W is saturated weight, S is suspended weight, ρ_w is density of water.

Linear change

The linear shrinkage, in accordance with ASTM C67 [22], was measured to assess the dimensional stability of the refractory clay samples at elevated temperatures. Cylindrical samples (50 mm x 50 mm) were prepared for this purpose. The linear shrinkage was determined by comparing the green (unfired) and fired dimensions of the samples, with precise measurements taken using a Vernier caliper. The height of each sample was recorded before and after firing, and the linear shrinkage was calculated as a percentage of the original green length, as detailed in Eq. 3.

$$\text{Linear shrinkage (\%)} = \frac{L_{dried} - L_{fired}}{L_{dried}} \text{ X } 100\ \% \qquad (3)$$

where: L_{dried} is length of the oven dried sample, mm, L_{fired} is length of the fired sample, mm.

Compression test

The specimen bricks produced using termite clay and rice husk/saw dust particles were prepared to standard cylindrical size of the same dimensions (50mm x 50mm). Each specimen was subjected to a hydraulic compression testing machine, where an axial load was applied until the onset of cracking. The load at which the specimen cracked was recorded, representing the load required to determine the compression strength also called cold crushing strength of the test specimen. The compression strength or cold crushing strength was then determined using Equation 4 [5, 20].

$$\text{C.C.S} = \frac{Maximum\ Load\ P\ (KN)}{Cross\ Sectional\ Area\ A\ (cm^2)} \qquad (4)$$

where: C.C.S is cold crushing strength, P is applied Load. A is area of the load applied.

Thermal conductivity

Thermal conductivity of the newly developed ceramic based composite material was evaluated using the Lee's Disk method according to ASTM E1530-19 standard [23]. This technique assesses the thermal diffusivity of both the composite and control samples. The experimental setup involved positioning the sample disc between two well-defined temperature-controlled metal discs (maintained at temperature T). Heat flux was established through the sample from the hot disc to the cooler one. The temperature profile across the sample was monitored by strategically placed thermocouples embedded within the metal discs. The temperature evolution on the cooler disc was continuously recorded at defined time intervals until steady-state thermal equilibrium was achieved. The thermal conductivity was calculated using Eq. 5 which was also utilized in Folorunso et al. [19, 20] and Oladele et al. [24].

$$K = \frac{m\ Cp(\theta 1 - \theta 2)\, 4x}{\pi D2\,(T_1 - T_2)\,t} \qquad (5)$$

where: m is mass of the disk, 0.0078 kg, C_p is specific heat capacity of the disk, 910 kJ $kg^{-1}K^{-1}$, θ_1, θ_2 are initial and final temperature of disk B, respectively, D is diameter of the sample,mm, T_1 and T_2 = temperatures of disk A and disk B, K, x = thickness of the sample, t = final time taken to reach a steady temperature, s.

Thermal shock resistance

The thermal shock resistance of the developed composite materials, defined as the ability to withstand rapid temperature changes without failure, was investigated. Green-state samples underwent a standardized thermal shock resistance test. This involved gradual heating in a furnace to a homogenizing temperature of 900°C for 30 min. Subsequently, each sample was extracted using tongs and allowed to cool naturally in ambient air for 10 min. This heating, holding, and cooling cycle was repeated until visible surface cracks (fractures) appeared on both the reinforced and control composite specimens. The number of thermal cycles endured before cracking was the metric for each sample's thermal shock resistance.

Clay characterization

Analyses of the clay were carried out using XRF according to the standard procedure [10, 16]. The results are presented in Table 1.

Table 1. XRF of termite hill clay.

Element	Content, %	Fireclay*
SiO_2	61.41	55-75
Al_2O_3	19.13	25-45
Fe_2O_3	1.86	0.5-2.0
CaO	1.08	--
K_2O	1.24	<2.0
MgO	0.85	<2.0
Na_2O	1.11	--
TiO_2	1.13	--
MnO	0.95	--
LOI	11.24	12-15
Total	100.00	

Stereomicroscopic microstructure analysis

Micromorphological analysis of the clay brick was performed using reflected light microscopy with a stereomicroscope (model SMDM-1030, 50x magnification). Prior to imaging, sample surfaces were prepared by sequential polishing with emery paper of decreasing grit size (starting at 120 grit and finishing with 600 grit) to ensure optimal image quality. The results are presented in Fig. 7 - 9.

RESULTS AND DISCUSSION

X-ray fluorescence clay characterization

X-ray fluorescence (XRF) analysis was employed to characterize the elemental composition of the termite clay matrix and compare it to the standard fire clay composition reported by Folorunso et al. [19]. Table 1 reveals that the developed refractory brick falls outside the classification range for fired clay bricks as defined by ASTM C27-98 [25]. This is primarily due to the alumina content (19.13 %), which deviates from the recommended range of 25 - 45 % for fire clay as outlined by Folorunso et al. [19, 20]. This deviation in alumina content is expected to have a significant impact on the refractoriness of the brick as observed in Folorunso et al. [19]. Although as regard the silica composition the developed refractory brick was in range (61.41 %) when compared to the fire clay (55 - 75 %).

The relatively low iron content (1.86 %) observed in the termite clay is considered beneficial. As reported by Ojukwu et al., a lower iron content translates to lower thermal conductivity, thereby enhancing the thermal insulation capacity of the clay [13]. The presence of other elements in minor quantities is not anticipated to significantly influence the thermal, physical, or mechanical properties of the fired clay brick. [17, 20].

Apparent porosity

Fig. 1 presents the apparent porosity of the samples. The apparent porosity increased as the percentage of both sawdust and rice husk increased because the additives burnt off at the elevated temperature of 900ºC. The more the additives added, the more the pores created. Despite this trend, there was a slight reduction for 4 wt. % saw dust and 8 wt. % rice husk the reduction may be attributable to improper mixing of the clay and additives during the sample preparation. However, the results showed that

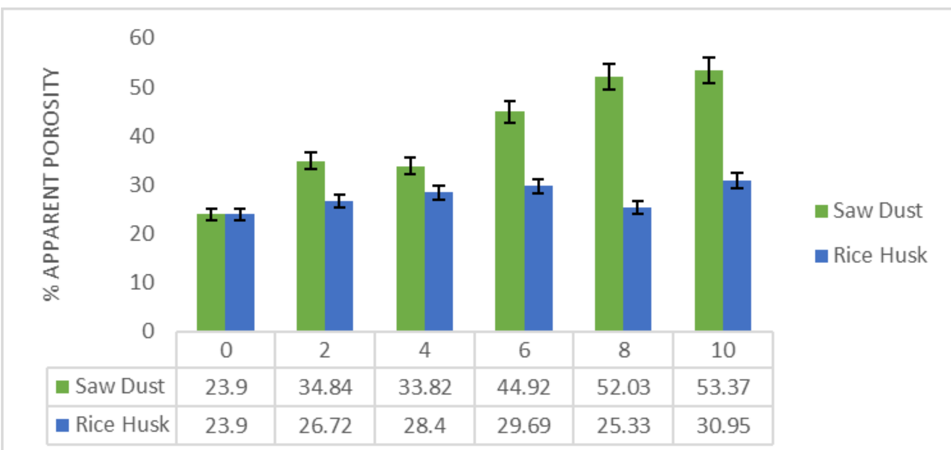

Fig. 1. Variation of apparent porosity with % rice husk and saw dust content.

the saw dust had higher porosity values compared to rice husk and this because, the saw dust burn off when fired at 900°C causing creating of pores while rice husk were majorly converted to ash when fired at that same temperature although some volatile content present in rice husk burnt off during firing. The results also show that 8 - 10 % sawdust exhibited the desired expectations ≥ 45 % porosity [2, 16]. High strength, however, is incompatible with high porosity because the larger and more numerous the pores, the thinner the enclosing wall of solid material and the lower the strength [16].

Bulk density

The result in Fig. 2 shows that the clay possessed good bulk densities. As is typical of high-quality insulating firebricks, the bulk density is anticipated to fall within the range of 1.6 to 2.0 g dm^{-3} [15]. For saw dust, samples with 0 % and 2 % sawdust addition falls within the range while samples with 4 %, 6 %, 8 % and 10 % are slightly closer to the range. Also, for rice husk, all the Samples falls within this range except for sample with 10 % rice husk composition that is slightly closer to the range. There is a decrease in the bulk densities with increase in the percentage addition of rice husk and saw dust although a slight increase was observed at both 8 wt. % of rice husk and saw-dust. The variation in the bulk densities was due to voids formation resulting from the burning off sawdust from the bricks during firing. These organic matters are usually not evenly distributed and hence the variation. Similar results were reported by previous researchers [12, 13].

Linear Shrinkage

The linear shrinkage showed the variation with sawdust and Rice husk addition according to Fig. 3. The sample with 0 % sawdust addition showed the highest linear shrinkage and sample with 10 % sawdust and rice husk showed the lowest linear shrinkage, although the samples with rice husk generally showed high linear shrinkage than that of saw dust. The linear shrinkages of the samples from both additives were slightly in decreasing order with increased percent sawdust and Rice husk addition with high degree of densification which were within the acceptable range < 10 % required for insulating materials [2]. Hence, the lower values were more desirable in order that the clay will be less susceptible to volume change [6, 26].

Cold crushing strength

Cold crushing strength is the resistance of the refractory to compressive force, which mostly happened during transport. It is used as one of the indicators of abrasion resistance of lining. CCS gives compressive stress required to cause failure. From Fig. 4 two different samples were investigated the saw dust and rice husk samples, the sample 2 % rice husk possesses the highest value of cold crushing strength of both samples containing additives, and it is the only sample that fall in range for thermal insulating clay according to [12], meanwhile the lowest value of CCS is noticed from sample 2 % of saw dust. It is noticed that saw dust samples generally possess lower CCS values compared to the rice husk samples in termite clay this is due to

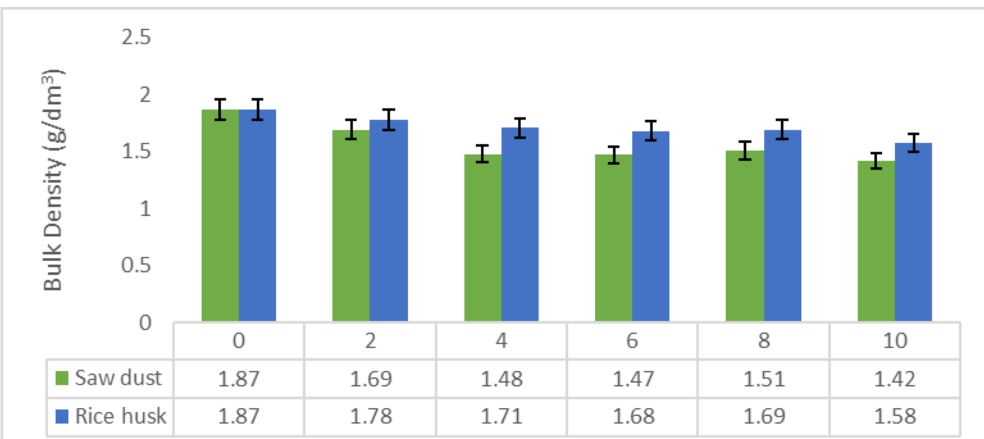

Fig. 2. Variation of bulk density with % rice husk and saw dust content.

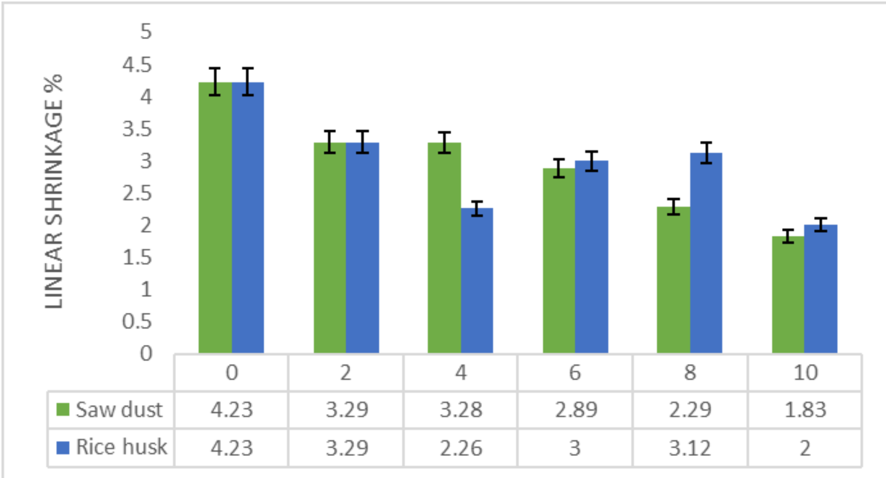

Fig. 3. Variation of linear shrinkage with % rice husk and saw dust content.

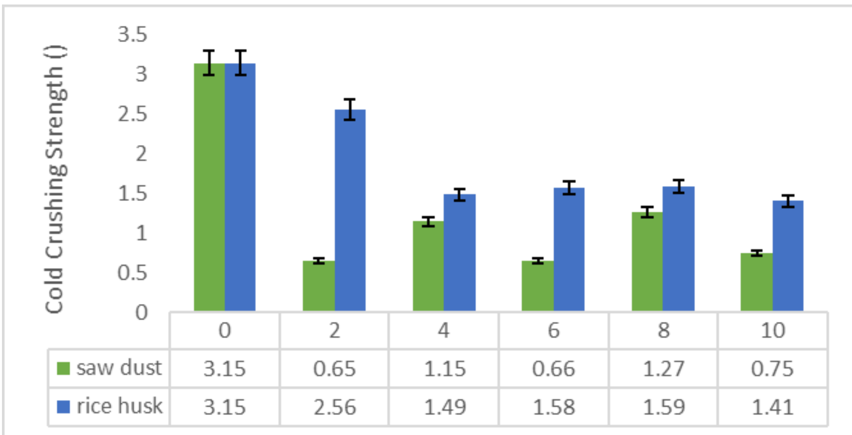

Fig. 4. Variation of cold crushing strength with % saw dust and rice husk content.

number of pores formed during firing as the saw dust tends to burn off during firing of the samples.

Thermal conductivity

The results of thermal conductivity tests presented in Fig. 5 showed that there were irregular increase and decrease of the thermal conductivity which may be due to the variation of saw dust and rice husk addition during mixing of the clay but this values gotten were still very low and samples containing saw dust were seen to have a much more lower thermal conductivity compared to sample contain rice husk and this is due to the increased porosity present for saw dust sample. This also can be attributed to the increase in the formation of pores that hinder heat transfer from one particle to another, since heat transfer in solids is mainly by conduction. As evident in micrographs (see Fig. 8 and 9), when there is increase in porosity, entrapped air between the particles inhibits the rate of heat transfer [26]. These empty spaces or voids (though may contain air) insulate the thermal flow hence, reducing the thermal conductivity.

Thermal shock resistance

Fig. 6 shows the thermal shock resistance of the firebricks produced from the processed termite hill clay at different rice husk and saw dust contents. The results represent the outcome of the tests carried out as described in section above. They revealed that thermal shock resistance increased from 15 cycles at 0 % saw dust addition to 30 cycles at 8 % addition. While the

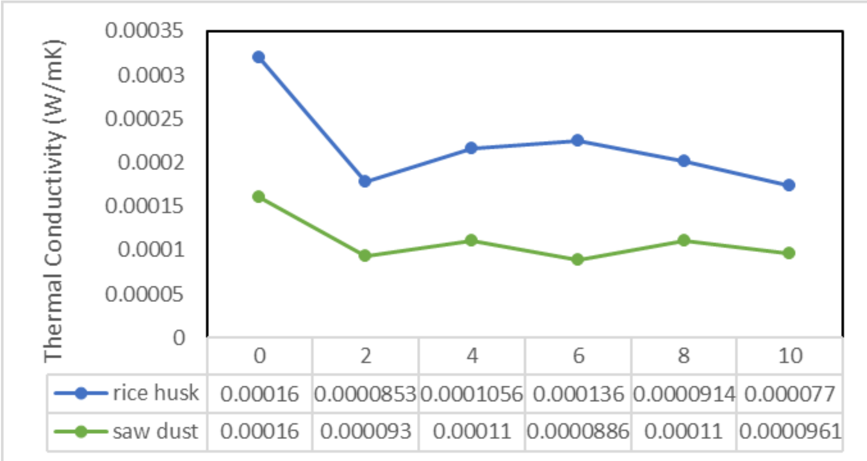

Fig. 5. Variation of thermal conductivities of % saw dust and rice husk content.

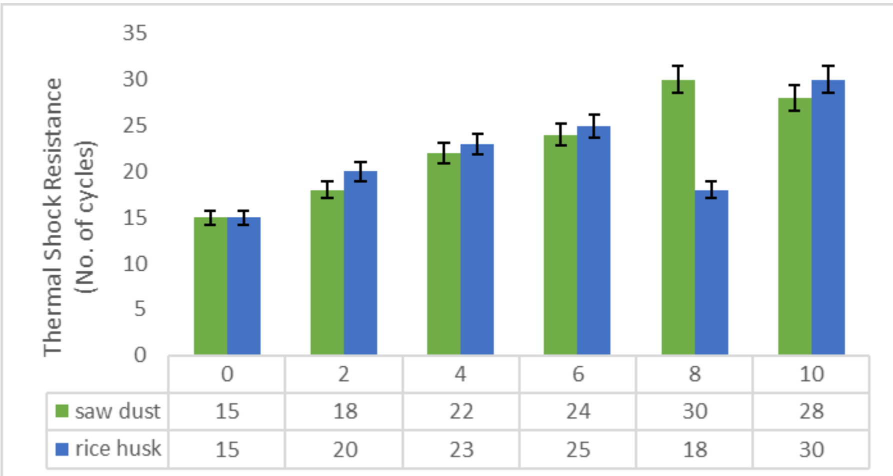

Fig. 6. Variation of thermal shock resistance of % saw dust and rice husk content.

thermal shock resistance increased from 15cycles at 0 % rice husk addition to 25 cycles at 6 % addition before a slight reduction at 8 % addition. Sample with 8 % saw dust and 10 % rice husk showed highest thermal shock resistance. Previous study [17] used the following principle to determine thermal shock resistance: TSR greater than 30 cycles was rated as "outstanding," 25 - 30 cycles as "good," 20 - 25 cycles as "fair," 15 - 20 cycles as "acceptable," 10 - 15 cycles as "poor," and less than 10 cycles as "extremely poor." As a result, it is concluded that the inclusion of saw dust (between 8 % and 10 %) and rice husks 6 and 10 % will generate a good lining material for refractory works that is acceptable. 4 - 6 % saw dust and 2 - 4 % rice husk are still fair, while 0 - 2 % saw dust and 0 and 8 % rice husk are acceptable.

Microstructural characterization

The micrograph image shown by the stereo microscope carried out on the samples with optimum properties (2 wt. % and 8 wt. %). The image shown in Fig. 7 indicated a homogeneous structure in the termite clay than in the structure that contained saw dust (2 wt. % and 8 wt. %) which contains more pore sizes (see Fig. 8 and 9). this is because of the complete burning off the saw dust additives leaving more pore spaces in the structure, however the sample 8 wt. % sawdust addition contains more pores. The increased pore sizes gave rise to increased apparent porosity observed in the result. This phase is responsible for good value of insulation and other related properties.

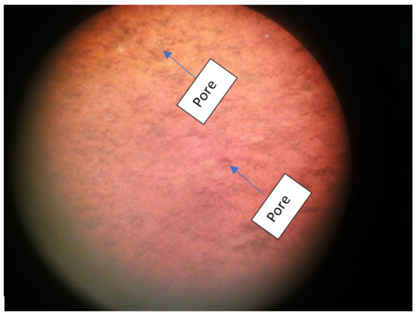

Fig. 7. Brick without additives fired at 900°C.

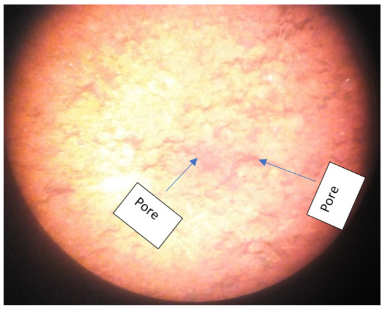

Fig. 8. Brick with 2 wt. % of sawdust fired at 900°C.

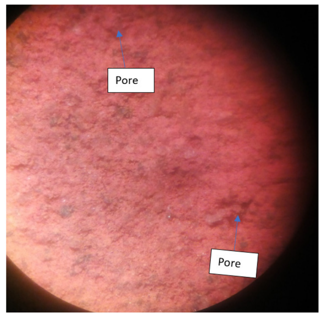

Fig. 9. Brick with 8 wt. % of sawdust fired at 900°C.

CONCLUSIONS

From the investigation and comparative analysis carried out in this research, it was concluded that saw dust and rice husk granules mixed with the termite hill clay used to produced insulating brick, have enhanced the insulating and refractory properties. However, saw dust reinforced termite hill clay exhibited better refractory properties when compared with rice husk samples.

- The apparent porosity of the saw dust samples produced have been able to meet more than 45 % requirement by ASTM C210 for insulating firebricks. Thus, only saw a dust additive is suitable for production of porous bricks which will give good thermal efficiency.
- Thermal conductivities result from, the admixture of saw dust and rice husk granules have improved the service and functional requirement of termite hill clay as insulating bricks due low values obtained while for thermal shock resistance, sample with 8 wt. % saw dust and sample with 10 wt. % rice husk reinforced termite hill clay have the highest cycles. Thus, the investigation has revealed the ratio of reinforcement to matrix materials for enhancing refractory property with wood dust and rice husk particles, respectively.
- Hence, the product can be used as thermal insulator in furnaces, cement, metallurgical, glass, petroleum industry and kilns.

Acknowledgements

The authors wish to express their gratitude to Dr. Omole S.O., Chief Technologist, The Federal University of Technology, Akure and Engr. Akinfolarin J.F., Senior Technologist, The Federal University of Technology, Akure for their continuous support and assistance throughout this work.

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