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Production and Characterization of Porous Insulating Fired Bricks from Ifon Clay with Varied Sawdust Admixture

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ABSTRACT

The effect of compositions of saw dust admixture on thermal conductivity and other mechanical/refractory properties of Ifon Clay was investigated. The raw clay gotten from Ifon in Ondo state was first processed to very fine particles and characterized using SEM/EDX, XRD and XRF. Sawdust from mahogany tree procured from a saw mill in Akure the State capital of Ondo State was also dried to remove moisture present. A composite mixture of this dried saw dust with the processed clay was made at various proportions of the saw dust, with a little addition of water for plasticity. Samples of cylindrical dimensions were then produced from the mounting press by the process of compaction with a very high pressure. The samples were dried and then finally fired in the furnace at 1000˚C for a final curing. Properties which include thermal shock resistance, bulk density, cold crushing strength, thermal conductivity and porosity were obtained by the appropriate standard test methods. The microstructures of the fired samples were also characterized with SEM using back scattered secondary imaging. The results show that the amount of sawdust admixture affects the properties variously; porosity increases with percentage increase in sawdust admixture while the thermal conductivity and other properties of the sample reduce with percentage increase in sawdust admixture. It was concluded that for structural insulating bricks where compressive strength is important the sawdust admixture should not exceed 10 to 15 percent.

Keywords: Thermal Conductivity; Porosity; Insulating Brick; Ceramic

1. Introduction

Pores have traditionally been avoided in ceramic products to increase the crack resistance, but in the last decades an increasing number of applications that require porous ceramics have emerged. Porous ceramic materials have applications in many industrial areas, such as catalyst supports for heterogeneous chemical reactions, filters, membranes, thermal insulators, and bioceramics.

These applications require an optimal pore-size distribution, the porous microstructure, and other important properties such as chemical inertia, and resistance to thermal and/or mechanical shock [1]. The presence of pores (holes) in a material can render itself all sorts of useful properties that the corresponding bulk material would not have [2]. Generally porous materials have porosity (volume ratio of pore space to the total volume of the material) between 0.2 - 0.95 [3]. Pores are classified into two types: open pores which connect to the surface of the material, and closed pores which are isolated from the outside.

A thermal insulator is a poor conductor of heat and has a low thermal conductivity. Insulation is used in buildings and in manufacturing processes to prevent heat loss or heat gain. Although its primary purpose is an economic one, it also provides more accurate control of process temperatures and protection of personnel. It prevents condensation on cold surfaces and the resulting corrosion. Such materials are porous, containing large number of dormant air cells.

This endeavour is focused on the production of efficient thermal insulating bricks from local available clay deposit.

2. Materials and Methods

The materials used for this study include; dried saw dust, Ifon clay as mined, water, wooden sieve, beaker, conical flask and thermometer. The equipment used for this study include; a furnace, mounting press, grinding mill, pulverizer, seive shaker and set of sieves, and compression strength tester. Dried saw dust from mahogany tree acquired from a saw mill in Akure was sun dried further to remove moisture present. Clay acquired from

Ifon, also in Ondo State was soaked in water for three days to dissolve the clay and at the same time to form a slurry. The resulting slurry was then sieved to remove dirt and other foreign substances using a sieve. More water was thereafter poured into the clay to form a slurry once again. This is then allowed to settle down for seven days. The floating clear liquid was decanted after the seventh day. The settled fine clay was then poured into a P.O.P mould and left undisturbed for three days in other to allow the liquid still present to drain out completely. The resulting clay was then sun dried for two days. This was followed by grinding in a grinding mill to reduce the particle sizes. A pulverizer was then used to reduce the sizes of the clay particles further into still finer particles. A final sieving of the pulverized sample was then carried out. A sieve analysis of the clay and saw dust used in this project is as stated: Clay; <850 µm, Saw dust; <1700 µm. A mixture of clay and saw dust was made with the saw dust in various proportions of 5%, 10%, 15%, 20%, 25%, 30% and 35%. Each mixture was made thoroughly with a little addition of water to induce some plasticity and homogeneity of both the clay and saw dusts. The resulting mixtures (for each proportions of saw dust), were then compacted in a mounting press to obtain cylindrical shaped samples. These samples were then placed in the furnace and fired at 1000˚C (held at the temperature for 1 hour) such that the saw dust burns off leaving some ash and pores. Series of tests were then performed on the fired samples. These tests include; cold crushing strength, bulk density, porosity, thermal shock resistance, permeability and thermal conductivity.

2.1. Apparent Porosity

Test samples from each clay/saw dust blend (for varying proportions) were dried for 12 hours at 110˚C. The dry weight of each fired sample was taken and recorded as *D*. Each sample was immersed in water for 6 hrs to soak and weighed while been suspended in air. The weight was recorded as *W*. Finally, the specimen was weighed when immersed in water. This was recorded as *S*. The apparent porosity was then calculated from the expression:

$$p = \frac{(w-D)}{(W-S)} \times 100\%$$

2.2. Cold Compression Strength

Cold compression strength test is to determine the compression strength to failure of each sample, an indication of its probable performance under load. The shaped samples of clay blends with saw dust were dried in an oven at a temperature of 110˚C, allowed to cool and then placed between two plates of the compression strength tester. This was followed by the application of a uniform load to it. The load at which a crack appears on the sample was noted and the cold compression strength (*CCS*) is calculated from the equation:

$$CCS = \frac{\text{Load to Fracture}}{\text{Surface Area of Sample}} \text{KG} \cdot \text{cm}^{-2}$$

2.3. Thermal Shock Resistance

Each sample of the clay/saw dust blend was placed in an electrically heated furnace to attain the test temperature of 1000˚C for over 3 hours. Each sample was then withdrawn from the furnace and held for 10 minutes. The procedure was repeated until an appearance of a crack was visible. The number of cycles necessary to cause a crack was recorded for each of the samples and taken as a measure of its thermal shock resistance.

2.4. Bulk Density

The test specimens were dried at 110˚C for 12 hours to ensure total water loss. Their dry weights were measured and recorded. They were allowed to cool and then immersed in a beaker of water. Bubbles were observed as the pores in the specimens were filled with water. Their soaked weights were measured and recorded. They were then suspended in a beaker one after the other using a sling and their respective suspended weights were measured and recorded. Bulk densities of the samples were calculated using the formula:

$$\text{bulk density} = \frac{D}{\left((W-S)\right)\left(\frac{\text{g}}{\text{cm}^3}\right)}$$

where: *D* = Weight of dried specimen, *S* = Weight of dried specimen suspended in water, and *W* = Weight of soaked specimen suspended in air

2.5. Thermal Conductivity Test (Using Ibrahim's Thermal Conductivity Apparatus; the Steam Method)

Test specimens of area 0.002 m^2 and thickness of 0.01 m were cut from their respective mother bricks. The test specimens were tested one after the other. Each specimen was fixed between two copper discs provided within the equipment. A conical flask containing 50 ml of water was placed directly above and in contact with the specimen. A cork having a thermometer passing through it was used to cork the mouth of the conical flask. The thermometer reads the temperature changes of the water in the flask. The test section was then closed and the initial water temperature was noted. A second thermometer with the aid of a cork was inserted into the steam outlet pipe offset to monitor the steam temperature so as to ensure a constant base temperature of 100˚C.

The boiler water outlet valve was closed while 5 litres of water was measured and poured into the boiler. The steam inlet valve, outlet valve, and condensate outlet valve were all closed. With the boiler cover remaining opened, the boiler was switched on. Immediately the water started boiling, the boiler cover was closed, while the steam inlet valve was fully opened with all the remaining valves closed. Timing commenced with the aid of a stopwatch immediately the steam inlet valve was opened. The testing was timed in each case for 10 minutes and final temperature of the water in the beaker was noted at the end of time. Each specimen was tested (experimented) twice and a mean temperature value was obtained. At the end of each experiment, the steam outlet valve was opened to release steam. The water in the boiler was refilled to maintain 5 litres and the experiment was repeated as stated above for other specimens. The value of the thermal conductivity, K for each of the specimen was determined using the formula [4,5];

$$\frac{K = 2.303\frac{MCL}{A}\left[\log\left(\frac{\theta_1}{\theta_2}\right)\right]}{\tau}$$

where, K = thermal conductivity of the specimen, T_1 = temperature of steam k, T_i = Initial temperature of water in conical flask, T_4 = Final temperature of water in conical flask, τ = Time (s), A = Specimen area, (m^2), M = mass of water in conical flask k (kg), C = specific heat capacity of water in conical flask (J/kgk), L = thickness of specimen (m), $\theta_1 = T_1 - T_i$, $\theta_2 = T_1 - T_4$.

3. Results and Discussion

Figures 1 and **2** respectively shows the XRD result the SEM/EDX analysis of the raw clay sample. **Tables 1** and **2** also respectively shows the XRD and XRF analysis results of the raw clay sample. These show the various phases present in the raw clay sample. It can be seen from **Table 1** that the overall feldspar contents of the raw clay samples is high (35.2% microcline and 12.07% Plagioclase Albite). It has been noted that feldspars favour liquid phase formation and densification at low temperature [6-11], this will disqualify the utilization of the clay in refractory (high temperature) applications except if subjected to serious purification process to reduce or eliminate the feldspar content.

It is also observed from **Figure 3** that the thermal conductivity of the samples decreases with increased sawdust admixture. This should be expected; as the samples were fire, the sawdust admixture got burnt off, leaving pores (compare with **Figure 4**) which are empty spaces within the solid-bodied samples. This is supported by **Figure 8** (compared with **Figure 9**) which show the SEM micrographs of the various samples with different percentages sawdust admixture.

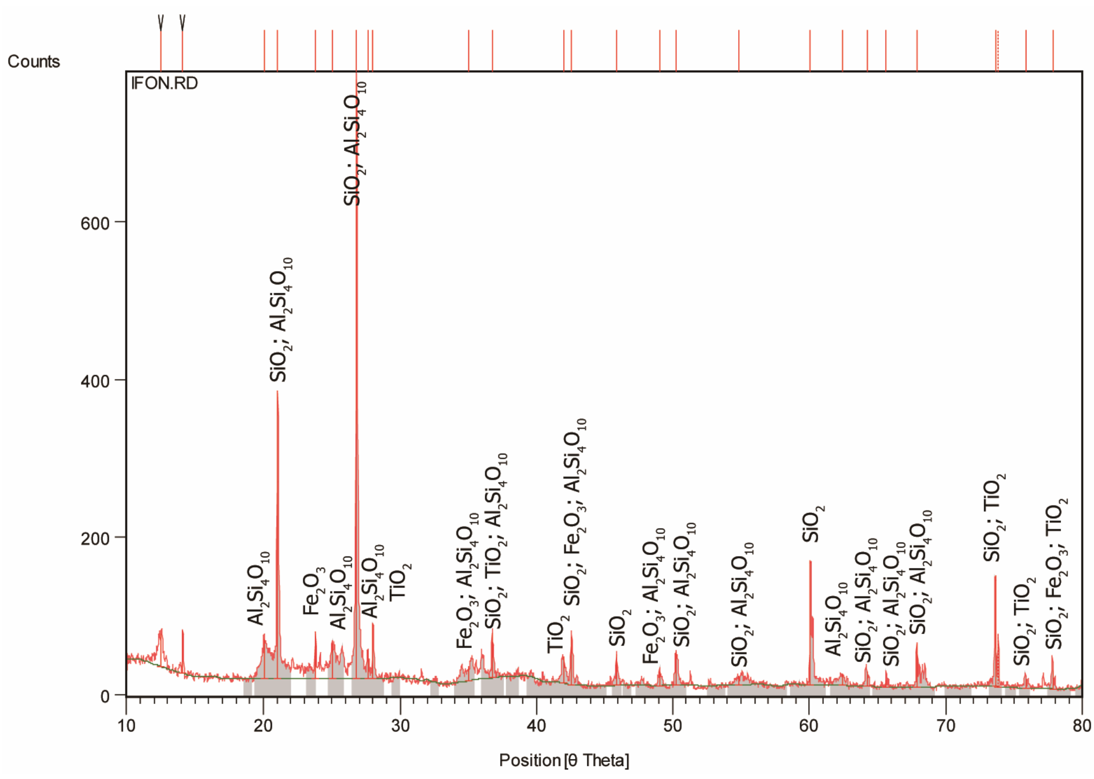
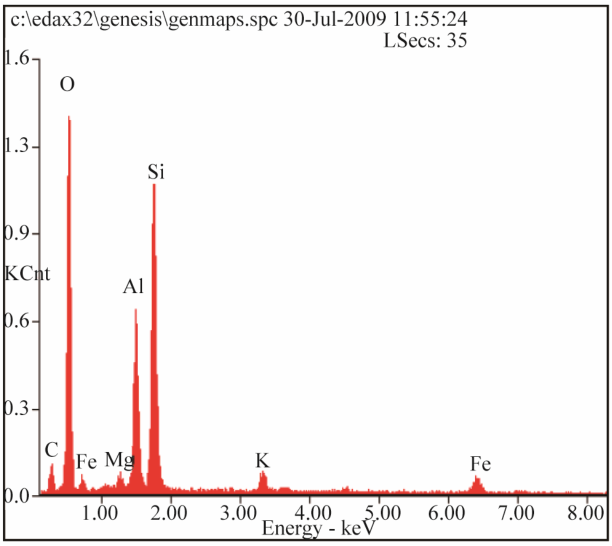


Figure 1. X-ray diffraction pattern (phase analysis) of the ifon clay sample.



Element	wt%
O	42.45
Mg	00.85
Al	11.03
Si	21.82
K	02.44
Fe	08.22

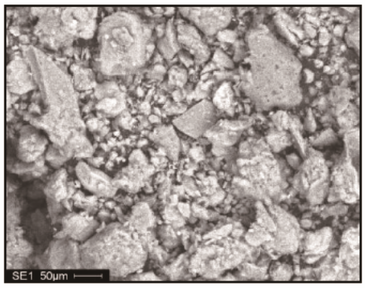


Figure 2. Typical SEM/EDX of ifon clay sample; showing the morphology of the minerals and its chemical composition.

Table 1. XRD result of the ifon clay sample showing the quantity of different phases.

Phases identified	Weight%
Kaolinite	10.21
Microcline	35.2
Muscovite/illite	4.7
Plagioclase albite	12.07
Quartz	37.78

Table 2. XRF Semi-quantitative analysis of the elements of Ifon clay sample (weight %).

Phases	A
Al_2O_3	22.42
SiO_2	63.35
Fe_2O_3	6.109
K_2O	2.878
MgO	1.351
Ba	0.092
CaO	0.689
Cl	-
Co	-
Cr_2O_3	0.046
Cu	0.021
MnO	0.117
Na_2O	0.789
Ni	0.064
P_2O_5	0.109
SO_3	0.047
Sr	0.019
TiO_2	0.923
Zr	0.045
Total	99.1

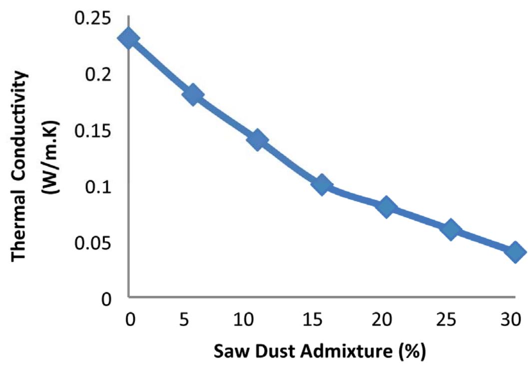


Figure 3. Effect of percentage saw dust admixture on the thermal conductivity of the sample.

It could be noticed that the pores in the micrographs increases with sawdust admixture. These empty spaces or voids (though may contain air) insulate the thermal flow hence, the reduction in thermal conductivity of the samples as the percentage sawdust admixture increases. The same explanation is applicable to **Figure 4**, where the porosity of the samples increases with increased percentage sawdust admixture. When the samples were fired, the sawdust admixture got burnt off, leaving pores. As the percentage sawdust admixture increased it leads to increased percentage pores when the samples were fired [12,13].

The influence of texture and porosity may be considered together because; the principal effect on the thermal conductivity is the relation between the amount of solid and of air which the heat has to transverse in passing through the material. Since air is a much better insulator than any solid material, the larger the proportion of air the greater will be the thermal insulation power of the material. Hence, a fine grained, closed-

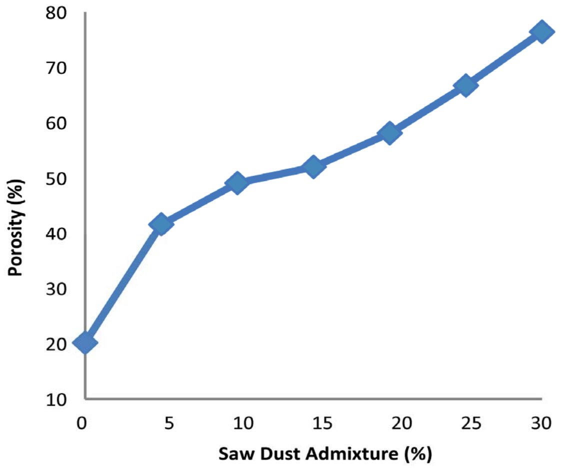


Figure 4. Effect of percentage saw dust admixture on the porosity of the sample.

textured material has a much greater thermal conductivity than one with a coarser open texture. The relation between insulation power and texture or porosity cannot, however be expressed in very simple terms. The thermal conductivity of ceramic materials will, in fact, not only depend on the total void space but also the size and the nature of the voids *i.e.* to whether the voids are closed or interlinked.

Furthermore, from **Figure 5**, it is observed that the bulk density of the various samples reduced with increased percentage sawdust admixture. This is because firing the samples, burn off the sawdust admixtures leading to increased porosity while at the same time results in reduced matter contents of the samples. From **Figure 6**, it is also observed that the cold crushing strength of the samples reduced with increased percentage sawdust admixture [14]. This is because as explained above, the increased percentage sawdust admixture leads to reduced matter content of the sample; less matter are available to bear the applied load. A brick of high porosity will have lower load bearing capacity than one of the same material with lower porosity, since there is less material in the brick to carry the load in the former case. Porous bricks are lighter and therefore unlikely to carry heavy load [15].

Moreover, from Figure 7, it is observed that the thermal shock resistance of the samples reduces with increase in the percentage saw dust admixture; this could be attributed to increase in the amount of open porosity in the sample which acts as 'notch' which is a stress (both mechanical and thermal) concentrator. Also highly porous insulating materials have been noted show little stability due to their high porosity [16, 17]

4. Conclusions

From the discussion so far it can be concluded that;

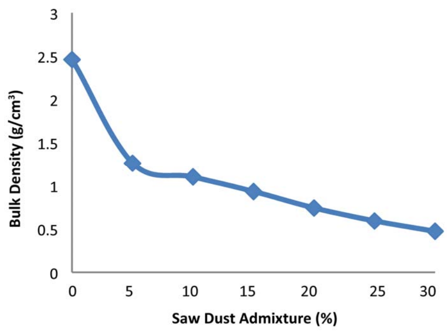


Figure 5. Effect of percentage saw dust admixture on the bulk density of the sample.

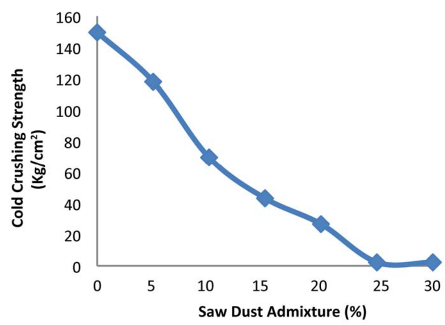


Figure 6. Effect of percentage saw dust admixture on the cold crushing strength of the sample

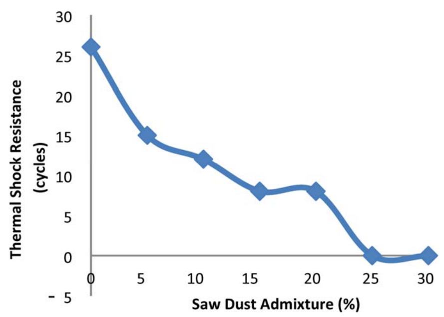


Figure 7. Effect of percentage saw dust admixture on the thermal shock resistance of the sample.

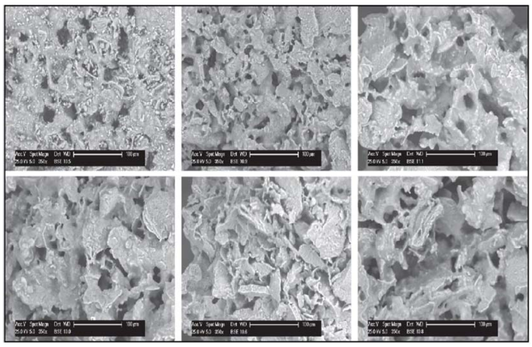


Figure 8. Scanning electron micrographs of the morphology of the various samples with sawdust admixture: Top, left to right; 5%, 10% and 15% sawdust; while Bottom left to right; 20%, 25% and 30% sawdust respectively.

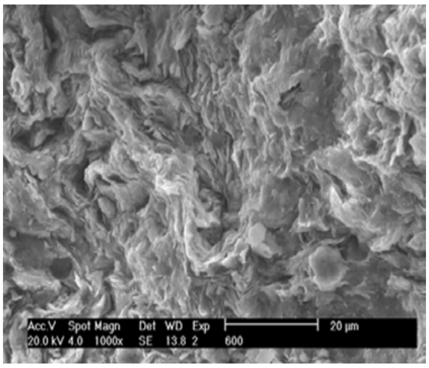


Figure 9. Scanning electron micrographs of the morphology of the samples with no sawdust admixture (0% sawdust).

- Porosity of the samples considered varies inversely as the thermal conductivity, cold crushing strength and bulk density of the samples
- The porosity of the sample could be controlled by varying the percentage sawdust admixture
- For structural insulating fired brick where the compressive strength is also important, the percentage sawdust admixture should not exceed 10 to 15 percent.

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