Nigerian Research Journal of Engineering and Environmental Sciences 6(2) 2021 pp. 495-502
p ISSN: 2635-3342; e ISSN: 2635-3350

Nigerian Research Journal of Engineering and Environmental Sciences
Journal homepage: www.rjees.com

Original Research Article

A Study of Insulating Properties of Refractory Bricks Produced from the Blend of Fireclay and Periwinkle Shell

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http://doi.org/ 10.5281/zenodo.5805093

ARTICLE INFORMATION

Article history:
Received 27 Jun, 2021
Revised 16 Sep, 2021
Accepted 20 Sep, 2021
Available online 30 Dec, 2021

Keywords:
Insulation
Refractory brick
Periwinkle shell
Fireclay
Porosity

ABSTRACT

This paper studied the insulating properties of refractory bricks produced from a blend of fire clay and periwinkle shells to assess the possibility of developing a new material for lining furnaces with improved efficiency. Various samples were produced from 75 to 100 wt.% of clays with particle sizes of 300 µm, blended with 0-25 wt.% periwinkle shells of 150 µm. The samples were fired at temperatures ranging from 950 °C-1100 °C for 3 hours at the rate of 2.5 °C/minutes using an electric furnace. The chemical compositions of the clays and periwinkle shell were analysed using atomic absorption spectrometer (AAS). ASTM standard test methods were used to determine apparent porosity, bulk density, thermal conductivity, linear shrinkage and cold crushing strength (CCS) of the samples. The AAS result shows that calcium oxide and combustible material were the predominant compound in the periwinkle shells. Porosity increased with increase in periwinkle shell amount, the highest porosity being 40.2% at 950 °C and 25wt.% of periwinkle shell. There was a decrease in thermal conductivity from 0.32 W/mk to 0.088 W/mK with increase in the addition of periwinkle shell. Also, bulk density decreased from 5.2 to 1.57 g/cm^3 at 1100 °C. As the firing temperature increases, the CCS increased from 2066 to 3250 kN/m^2 and linear shrinkage increased from 5.2 to 9.4%. It was deduced from the results that bricks with 20 – 25 wt.% of periwinkle shells fired at 1100 °C possessed enhanced insulating properties.

1. INTRODUCTION

Refractory brick is a block of refractory ceramics material used in lining furnaces, kilns and fireboxes (Esezobor et al., 2015). They are used in building cooking chambers in wood-fired ovens, fire boxes and for creating fireplaces. The main raw material for making refractory bricks is clay. Clay is an earthy mineral and it can form plastic mud pie when mixed with water and maintain the shape after drying. It has rock-like hardness after being fired at high temperature. Additionally, clay contains a certain amount of impurities such as quartz, mica, pyrite, feldspar and organic substances.

Insulating refractory bricks must be light weight, possess low thermal conductivity which enables it prevent heat from moving through them. The thermal conductivity of insulating materials depends on their total porosity, pore sizes, shapes, chemical and mineralogical composition (Wu et al, 2013). Porosity is most often created by mixing combustible material with the clay. During firing, the combustible material burns out and a large fraction of pores are created within the material (Sadik et al, 2013).

In Nigeria, most of the refractory bricks are imported and this adversely affects foreign exchange. Recently, local researchers have come up with the production of insulating refractory bricks with different combustible materials obtained locally in order to establish the right proportion to meet up with international standards for insulating bricks. Obidiegwu et al. (2015) investigated the use of coconut shell particulate to enhance the insulating refractory properties of Ukpor, Osiele and Kankara fireclays in Nigeria. The results indicate that clays with 25-30% coconut shell and grain sizes of 212-300μm fired at 1150ºC-1200ºC possessed enhanced physical, mechanical and insulating properties. Hassan and Aigbodion (2019) investigated the effects of coal ash on some refractory properties of Kankara clay, as earlier works carried out showed that it has a low refractoriness, thermal resistance and high apparent porosity which are not satisfactory in refractory application. Medium duty fireclay brick capable of possessing good thermal shock resistance was made with 25wt% coal-ash as all the value obtained were within the recommended values for fireclay bricks. Osarenmwinda and Abel (2014) studied the performance evaluation of refractory bricks produced from some local clay deposits in Delta State, Nigeria. The clay samples after being processed were tested for shrinkage, bulk density, cold compression strength and thermal shock resistance. The results show that kaolin deposit at Oghara was found to be the best material suitable for the lining of walls of most high thermally operated equipment as its fusion temperature is above the operating temperature of 1200ºC. Mgbemere et. al. (2020) Investigated the effect of sawdust and rice husk blended with kaolin and ball clay used to produce insulation bricks through the solid state synthesis method and also the effect of sintering temperature on the refractory properties. It was found that as the amounts of kaolin used in preparing the samples decreased, the bulk density, modulus of rupture and cold crushing strength of the bricks decreased while the water absorption capacity, linear shrinkage increased. The temperature of sintering had a slight effect on the physical and mechanical properties of the insulation bricks. The samples that were sintered at 1200ºC had slightly better properties compared to those sintered at 1100ºC. Obidiegwu et. al. (2020) investigated the effect of addition gmelina seed shell particulates on the thermal and mechanical properties of insulating bricks produced with Osiele clay. This research discovered a new refractory material (Gmelina seed shells which are in abundance in Nigeria). This can enhance the physical, thermal and mechanical characteristics of a refractory brick.

The need for insulating refractory bricks in high temperature applications cannot be overemphasized and the local alternative materials for its production are in abundance in the country. Therefore, this research work used periwinkle shells particulates blended with indigenous fire clay to produce insulating refractory bricks. This will improve furnace efficiency, thereby improving the rate of production. It will also reduce importation and the cost of final product. The aim of this study is to produce high quality insulating refractory bricks using Nigerian clay and periwinkle shell.

2. MATERIALS AND METHODS

2.1. Material Collection and Preparation of Samples

The clay used was sourced from Osiele local government in Ogun State, Nigeria and was used both as the principal material and binder. Periwinkle shell, a waste material obtained from consumption of small marine animal called periwinkle served as the pore former and was obtained from Bariga market in Lagos State, Nigeria. The clays and periwinkle shells were washed, sun dried, crushed with a jaw crusher and ground to finer particles using ball milling machine at the Federal Institute of Industrial Research, Oshodi (FIIRO), Lagos State, Nigeria. The pulverized clay was sieved using sieve aperture of 300µm. Periwinkle shells were also sieved to 150 µm.


Figure 1: Pulverized periwinkle shells


Figure 2: Sample of clay

Various samples comprising 75 wt% - 100 wt% clays and 0 - 25 wt% of periwinkle shells were mixed thoroughly with 50 ml of water to attain some level of particle cohesion for a ball-in-hand consistency, indicative of adequate moisture content in order to induce some plasticity and homogeneity of both the clay and periwinkle shell. The brick samples were produced using mild steel moulds. Engine oil was used as a lubricant for easy removal of the bricks from the moulds. After moulding, the weight of the bricks was measured. The samples obtained were then sundried for 24 hrs after which the weight was measured again. The samples were then dried in the oven for another 24 hrs at 110 ºC at the metallurgy laboratory, Department of Metallurgical and Materials Engineering, University of Lagos, Nigeria. Lastly, the samples were then fired using electric resistance furnace at the Metallurgical department in Yaba College of Technology Lagos, Nigeria at temperature ranging from 950 ˚C to 1100 ˚C.

2.2. Chemical Analysis

The chemical analysis of the clay and periwinkle shell was carried out on the Atomic Absorption Spectrometric (AAS) machine, Perkin Elmer Analyst 200, at Chemistry Department, University of Lagos, Nigeria. This technique was used to identify the presence of elements in a sample. It also measures the concentration of the elements present in solids, powdered and liquid samples. The elemental concentrations present in the samples were calculated and displayed after applying automatic statistics to the results from the AAS machine.

2.3. Bulk Density

The bulk density is the weight per unit volume of the refractory material. Bulk density and apparent porosity were determined in accordance with ASTM C20-00 (2015) standard. The dried weights (D) of the fired brick samples were measured. The bricks were then soaked in hot water for 3 hours, and the soaked weight (W) was measured. The bricks were suspended in water thereafter and the weights (S) were measured. The bulk density of the bricks was calculated using Equation (1).

$$\text{Bulk density} = \frac{\rho \times (D)}{(W)-(S)} \tag{1}$$

2.4. Porosity

Porosity is the percentage relationship between the volume of the pore spaces on a refractory material and the total volume of the material. Porosity can be apparent or true. Apparent porosity is the percentage relationship between the volume of the open pores and the total volume of the material. This was determined in accordance with ASTM C20-00 (2015) standard the same method for bulk density. The value of the porosity was calculated using the formula given in Equation 2.

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

Where W = Soaked weight, D = Dried weight and S = Suspended weight

2.5. Cold Crushing Strength (CCS)

CCS is the amount of load that the clay or refractory material can withstand after it has been fired to a temperature of 1200 ^{o}C. Refractories must be able to withstand the structural load coming over the dense and fine-grained refractories which generally possess good crushing strength whereas porous and coarse-grained refractories have poor crushing strength. The formula is given in Equation 3 (ASTM C133-97 2015).

$$\text{Cold crushing strength} = \frac{Maximum\ load}{Cross-sectional\ area} \quad (3)$$

2.6. Linear Shrinkage

Shrinkages are more commonly expressed in linear form. In expressing drying linear shrinkages, dimension of both unfired and fired samples using a digital vernier calipers are made. The formula for linear shrinkage is given in Equation 4 (ASTM C356-17 2017).

$$\text{Total linear shrinkage} = \frac{(lo-l1)}{lo} \times 100 \quad (4)$$

Where, l_o and l_1 are the original and final length in (mm) of the samples before and after sintering respectively.

2.7. Thermal Conductivity

Thermal conductivity of the test samples was evaluated using Equations 5a, 5b, and 5c after measuring the parameters in accordance with ASTM C201-93 (2013) standard.

$$K = \frac{2.303MC\delta(\log(\frac{\theta_1}{\theta_2})}{A\times t} \quad (5a)$$

$$\theta_1 = Ts - T_1 \quad (5b)$$

$$\theta_2 = Ts - T_2 \quad (5c)$$

K represents the thermal conductivity of the specimen, (W/m˚C). Ts is temperature of steam (˚C), T_1 is the initial temperature of water (˚C), T_2 is the final temperature of water (˚C), t is time (s), A is the area of the specimen in (m^2), M is the mass of water (kg), C is specific heat capacity of water (J/kg˚C) and δ is thickness of specimen (m),

3. RESULTS AND DISCUSSION

3.1. Chemical Analysis

The results of the chemical analysis of the periwinkle shell and Osiele clay which was carried out with AAS is shown in Table 1. From the result, it was observed that the major constituents of Osiele clay are silica (46.24%) and Alumina (37.10%) this is in conformity with the research carried out by (Apeh et al., 2011).

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Therefore, the clay belongs to Aluminosilicate family (Chesti, 1986). The high alumina content indicates that the clay is a good refractory clay that can withstand high temperature. It was also observed that periwinkle shells mainly contain calcium oxide (42.11%), silica (20.3%), combustible materials (LOI 20.2%) and alumina (14.54%). The combustible materials present made the periwinkle shells suitable to serve as a pore former.

Table 1: AAS results for the periwinkle shell and Osiele clay

Materials	Components (%)									
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	H_2O	LOI
Osiele clay	46.24	37.10	1.33	0.06	0.86	0.50	1.04	0.04	0.05	1.24
Periwinkle shell	20.3	14.54	0.09	42.11	1.82	0.60	0.48	0.007	0.001	20.02

Note: LOI means loss on ignition

3.2. Bulk Density

The results in Figure 3 shows that the trend of periwinkle shell content with bulk density is an inverse relationship. This means that as periwinkle shell additive increased, bulk density reduced. The density decreased from 5.2g/cm^3 with 0% periwinkle shell composition to 1.7g/cm^3 with 25% composition. This was possibly due to the portion of the periwinkle shell that burnt off during firing and created pores which was occupied by air (Gupta, 2004). The air is less dense than periwinkle shell. The trend is in agreement with the research earlier conducted by Aramide, (2012). In Figure 3, it was also observed that increase in temperature resulted to decrease in bulk density of the refractory brick. This was as a result of escape of volatile organic matter and moisture at higher temperature thereby resulting to decrease in bulk density. The trend observed in the result is also in conformity with the research conducted by (Aramide, 2012).

3.3. Porosity

In Figure 5, it was discovered that the porosity increased with an increase in the periwinkle shell composition. The increase is from 26.4% to 40.2%. This is within ASTM C20-00 (2015) standard which recommends porosity between 20 – 75% for insulating refractory bricks. This increase was possibly as a result of periwinkle shell that was used as a pore former which burnt off during sintering thereby creating pores. The trend observed in the result is in conformity with the research carried out by Esezobor et al. (2014). The results in Figure 5 also indicates that increase in the firing temperature leads to decrease in the apparent porosity. The reduction of porosity is due to the vitrification process that occurred at high temperature, which results to the fusion of the particles into a coherent body with an amorphous or glassy phase. As the firing temperature increases, moisture within the brick changes into vapor and diffuse out of the brick, thereby creating vacant sites within the clay. (Nwoye et. al. 2014). During this process, the pores tend to shrink.

3.4. Cold Crushing Strength

Figure 5 shows the variation of CCS with firing temperature at different periwinkle shell content. There was an increase in the CCS as the firing temperature increased. This increase in CCS could be attributed to the formation of bonds between particles of the clay, which occur at high temperatures (Obidiegwu et al., 2015). There was also a reduction in strength as the percentage composition of periwinkle shells increased. This trend could be attributed to high porosity due to voids created by periwinkle shell which burnt off at elevated temperature, leading to reduced CCS (Aramide, 2012). Nevertheless, it was noted that the CCS of the samples were still within the ASTM standard of >1000 kN/m^2.

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3.5 Thermal Conductivity

The results of thermal conductivity tests in Figure 6 show that the thermal conductivity decreases from 0.32 W/mK at 0% composition to 0.088 W/mK at 25% composition with increase in the percentage composition of the periwinkle shell as temperature increases from 950 – 1100 ^{o}C. This also could be attributed to the increase in the formation of pores that hinder heat transfer from one particle to another. During firing, periwinkle shells burnt out creating empty spaces or pores. The empty spaces or voids created after combustion of periwinkle shells insulate the thermal flow. The air trapped in the pore acts as insulator, (Bwayo and Obwoya, 2014). Most of the results obtained were within the range of 0.023 - 0.25 W/mK adopted by ASTM C 182-88 (2013) standard.

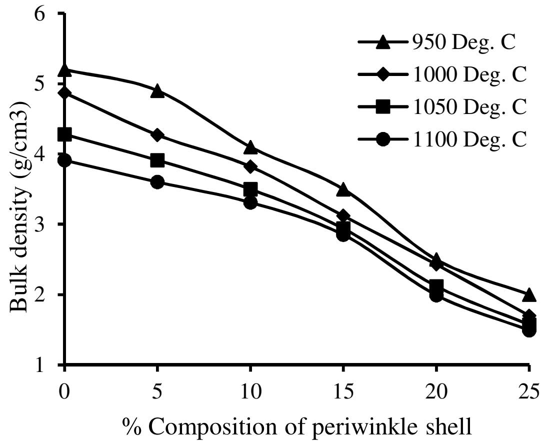

Figure 3: Effect of composition of periwinkle shell and temperature on the bulk density

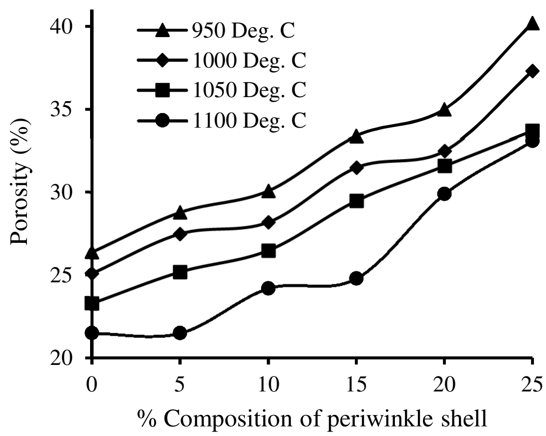

Figure 4: Effect of composition of periwinkle shell and temperature on porosity

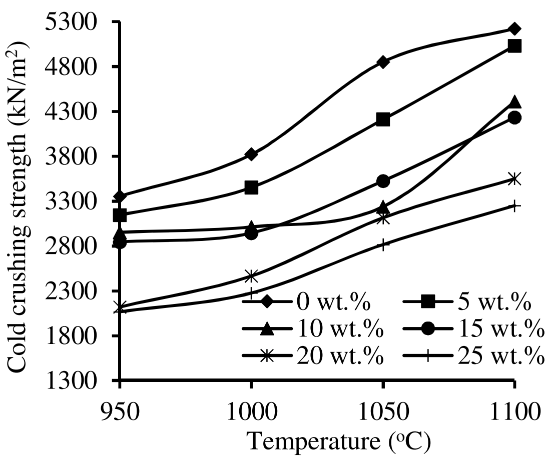

Figure 5: Effect composition of periwinkle shell and temperature on cold crushing strength

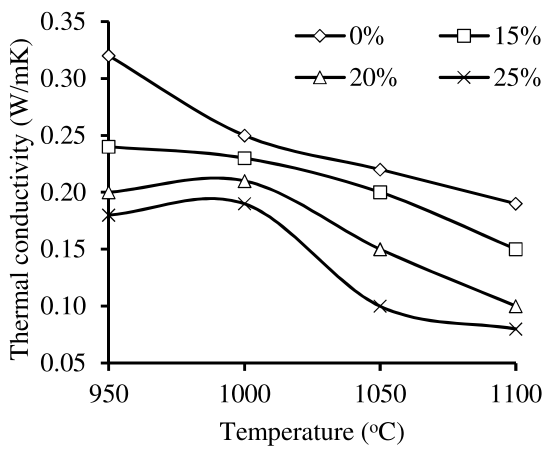

Figure 6: Effect of composition of periwinkle shell and sintering temperature on thermal conductivity

3.6 Linear Shrinkage

In Figure 7, it can be deduced that the linear shrinkage increased with increase in firing temperature. This could be as a result of the bonding between particles at high temperature with the decline in inter-particle separation (Nwoye et. al., 2014). The sample fired at 950°C had lowest shrinkage of 5.2%, while the sample fired at 1100 °C had the highest shrinkage of 9.4%. Also, the increase of composition of the periwinkle shells led to higher shrinkage which is as a result of periwinkle shells being burnt off. However, the samples were within linear shrinkage ASTM C356-17 (2017) standard for clays and in conformity with the range of (2 - 10%) and (8 - 13%) for dense and insulating refractory bricks respectively.

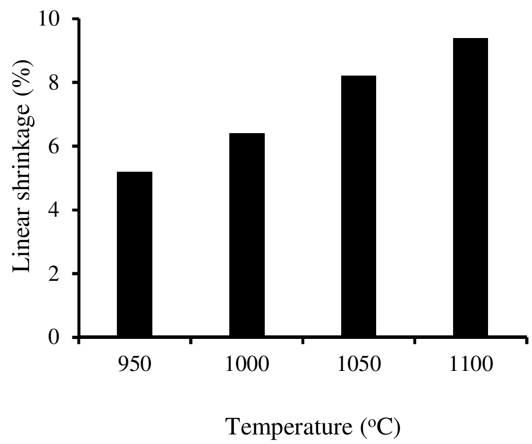

Figure 7: Effect of sintering temperature on the linear shrinkage of refractory bricks with 20% composition of periwinkle shells

4. CONCLUSION

From the above results, the following conclusions were drawn:

- Bricks with 20 and 25 wt% of periwinkle shell possessed the enhanced cold crushing strength for medium insulating bricks which is above 1000 kN/m^2 for ASTM Standard.
- Thermal conductivity of 0.08 to 0.32 W/mK were comparable with the results obtained by other researchers and also within the range recommended by ASTM 182-88 (2013) standard.
- Periwinkle shells produced high amount of pores in the bricks which in turn improves the insulating and refractory properties.
- The study has provided an alternative utilization of this waste for insulating refractory bricks production.
- The product can be used as backup in lining furnaces, in cement, metallurgical, glass, petroleum industries and kilns for ceramics industries at temperature between 1000 °C – 1100 °C.

5. ACKNOWLEDGMENT

The authors wish to acknowledge the assistance and contributions of the laboratory staff of Department of Metallurgical and Materials Engineering and Department of Chemistry, University of Lagos, Akoka Lagos, Department of Metallurgical Engineering Yaba College of Technology, Yaba Lagos, Nigeria, towards the success of this work.

6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work..

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