

PHYSICO-MECHANICAL AND THERMAL PROPERTIES OF INSULATING REFRACTORY BRICKS DEVELOPED FROM IKORODU AND OSIELE FIRECLAYS AND AGROFORESTRY WASTES

¹Obidiegwu, E. O., ²Esezobor, D.E., ³Bodude, M.A. and ⁴Lawal, G. I.

^{1, 2, 3, 4}Metallurgical and Materials Engineering Department, University of Lagos

E-mail: eugenia_obidi@yahoo.com, esezobordave@yahoo.com, mbodude@unilag.edu.ng and glawal@unilag.edu.ng

ABSTRACT

This paper studies the physico-mechanical and thermal properties of insulating refractory bricks developed from selected Nigerian fireclays and agroforestry wastes. The as-received clays and agroforestry wastes were air dried, crushed and ground. Refractory bricks were produced with various weight percentage (60 - 95 %) of clay and (5 - 40 %) of agroforestry wastes and fired at temperature ranging from (950 – 1200°C). The bricks were characterized in accordance with ASTM standards to determine their chemical constituents, physical, mechanical and thermal properties. The microstructural examination of the bricks was carried out using Scanning Electron Microscope. The cost benefit analysis was also conducted. The results of the chemical analysis revealed that the major chemical constituent in the clays were silica (>45%) and alumina (>36%). The sawdust is more carbonaceous in nature with Loss on ignition (L.O.I 97.15) than both rice husk (43.30) and coconut shell (93.47). The porosity of the insulating brick increases from 26.51 - 84.6% as the volume of waste increases from 0 - 35%. The larger the pores (26.51 - 84.6%), the lower the strength (10,000 – 2,239.06kN/m²). The high degree of porosity enhanced the thermal insulating property (0.046 W/mK) of the refractory bricks. The cost benefit analysis carried out revealed that the price of the developed bricks (N261-265) are far lower than the cost of imported bricks. The economic savings is approximately 57 % per unit brick.

Keywords: High temperature, manufacturing, porosity, strength

Introduction

High-temperature processes such as manufacturing and processing industries require a considerable amount of materials and heat energy. Often the heat energy consumption for high-temperature processes is used only partially for the actual technical process and 30 to 40% heat energy escapes through the walls into the atmosphere resulting to thermal inefficiency and high fuel consumption. Unfortunately, the cost of energy to generate heat

has been on the increase in the recent times. To optimize the heat energy used and to prevent its escape into the ambience, special materials are necessary. Hence the refractory products in form of bricks are used in metallurgical, chemical, glass and petrochemical industries in furnace construction and maintenance.

In Nigeria, most of the manufacturing and processing industries depend mainly on imported insulating refractory bricks for their furnaces, kilns, boilers, ovens, etc. in order to improve energy efficiency and reduce the loss of heat energy despite the abundant resources of fireclays in the country. This is as a result of the absence of high quality indigenous refractory bricks in commercial quantities. This has contributed to the high cost of the final products. Therefore, the need to develop insulating refractory bricks in the sector has become more prominence.

In search of refractory materials, the prominent early researchers on characterization of the properties and suitability of different fireclay deposits for refractory materials, include Aniyi and Adewara, (1986), Hassan and Adewara, (1993) and Lori *et al.*, (2007), These prominent researchers found out that these clays could be suitable for furnace construction with respect to their thermal shock resistance, crushing strength and bulk density typical for dense refractory bricks.

Some researchers studied the potentials and suitability of some metallurgical wastes such as tin tailings and steel slag for refractories (Aigbodion *et al.*, 2010; Obidiegwu *et al.*, 2014) respectively. Investigation on the “effect of coal ash on some refractory properties of alumina-silicate (Kankara) clay was also carried out; it is found that the linear shrinkage and apparent porosity of the bricks produced from Kankara clay blended with coal ash decrease with increasing percentage of coal ash addition (Hassan and Aigbodion, 2014). These reports serve as a guide in the investigation of raw materials for dense refractory bricks, however none of these reports relates to the specific needs of insulating refractory.

This paper therefore studies the physico-mechanical and thermal properties of insulating refractory bricks developed from Ikorodu and Osiele fireclays blended with agroforestry wastes (sawdust, coconut shell and rice husk) as pore formers in order to provide an alternative to imported insulating refractory bricks and conventional pore formers that are very expensive and scarce for the production of insulating bricks.

Materials and Method

The fireclays used in this research were obtained from Osiele Abeokutain Ogun State and Ibeshe-Ikorodu of Igbogbo Local Government Council in Lagos State.

The agroforestry wastes used were rice husk (*oryzasativa*) from Otuns Rice in Abakaliki, Ebonyi State with generating capacity of 146.0 tons of rice husk annually under constant operation and coconut shell (*cocosnucifera*) from both Sebasia Coconut Oil and Ceno Coconut Oil Producing Factories at Aradagun Badagry with a capacity of 300-360 tons of coconut shell each annually and sawdust from Oyingbo saw mill, Lagos State. The as-received clays and agroforestry wastes were air dried, crushed with a jaw crusher and ground in a ball mill. The pulverized materials were classified with various sieves (212 – 600 μm). Pre-tests were done on the various sizes to determine the appropriate size for the experiment. Formulation mix was determined by sampling of the materials of various mixtures using the fabricated 76.2mmx76.2mmx76.2mm, 60x60x15mm, 50x75mm, 95x45x12mm and 220mmx100mmx60mm standard metallic moulds. Productions of bricks of various sizes were done with respect to the mould sizes.

The materials were characterized in accordance with ASTM C 456-13 standards using Atomic Absorption Spectrometer (AAS) to determine their chemical constituents, while the physical properties of the materials were determined in accordance with ASTM C373-88 (2006) standard for test methods for bulk density, apparent porosity and water absorption of refractory bricks. The mechanical property (cold crushing strength, C.C.S) test of the bricks was done using universal testing machine (Testometric M-500-25kN) in accordance with ASTM C133-97(2008) standard. The thermal characterization of the refractory bricks, subjected to different firing temperatures in a resistance furnace was determined using Eq. (1) in accordance with ASTM C356-19 standard.

$$\begin{aligned} \text{Total Linear Shrinkage} \\ = \frac{(L_0 - L_1)}{L_0} \times 100 \% \end{aligned} \quad (1)$$

The thermal conductivity of the test specimens were measured using KD2 Pro-Thermal Properties Analyzer.

The micro structural examination of the refractory bricks was carried out using ASPEX 3020 variable pressure Scanning Electron Microscope (SEM)/ Energy Dispersive X-ray (EDX) at the Materials Laboratory, College of Engineering and Techonology, Kwara State University, Malete, Nigeria.

where, L_0 is the Original Length of the green specimen, W/m^0C and L_1 is the fired Length of the specimen.

Results and Discussion

The results of the chemical analysis of agroforestry wastes and clays and physical properties of refractory bricks are shown in Table 1 and Figs. 1 and 2

The results of the spectro-chemical tests on the agroforestry wastes (in Table 1) indicate that the sawdust is more carbonaceous in nature due to high loss on ignition(L.O.I) (97.15 wt, %) than both rice husk (43.30 wt, %) and coconut shell (93.47 wt, %). However, the values of the alkali metals in the sawdust (1.37 %) and rice husk (1.45 %) are higher than in the coconut shell (0.33 %). The characterization of the agroforestry wastes indicates that the materials can be utilized in the manufacturing of insulating refractory bricks (Obidiegwu *et al.*, 2015).

Table 1: Chemical analysis of clays and agroforestry wastes

Materials	Parameters (%)									
	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	MnO	H ₂ O	L.O.I
Osielle Clay	46.24	37.10	1.33	0.06	0.86	0.50	1.04	0.04	0.05	1.24
Ikorodu Clay	45.31	36.32	0.12	0.16	0.52	0.05	0.04	0.01	0.002	0.003
Coconut Shell	2.46	1.92	0.24	0.15	0.11	0.20	0.13	0.03	0.001	93.47
Rice husk	22.82	0.12	0.17	0.86	0.12	0.03	1.42	0.02	0.008	43.30
Sawdust	0.022	0.063	0.007	0.214	0.030	0.831	0.542	0.005	0.003	97.15

Table 1 revealed that the major chemical constituent in the clay are silica and alumina. Therefore the clays belong to alumino-silicate family. The clays have the required composition for the production of refractory bricks.

It is observed that as from 25 to 30 weight percent of waste (Fig. 1), there is a sharp increase (6%) in the degree of porosity compared to its decline at 35 percent waste content. This indicates saturation point of agroforestry wastes. The results obtained show that as the percentage of the waste increases from (0 to 30 %), the porosity of the bricks increases (26.51 to 81.15 %) for coconut shell, (27.8 to 82.8 %) for rice husk and (28.2 to 84.6 %) for sawdust.

The porosity of the insulating brick increases as the volume of waste increases (Fig. 2) but decreases as the firing temperature increases. This is because, increase in admixture of combustible waste leads to increase in the amount of organic matter present, which leaves air spaces (pores) after firing.

The results of the mechanical and thermal properties tests are presented in Figs. 3 – 4. The high degree of porosity degrades the mechanical strength of the material (Fig. 3). However, the values of strength of the bricks obtained from Ikorodu (2,246-11,195

kN/m²) clays are higher than the Osiele clays (2,239-10,000kN/m²) due to increase in pore condensation in the solid, particularly the alkali metals.

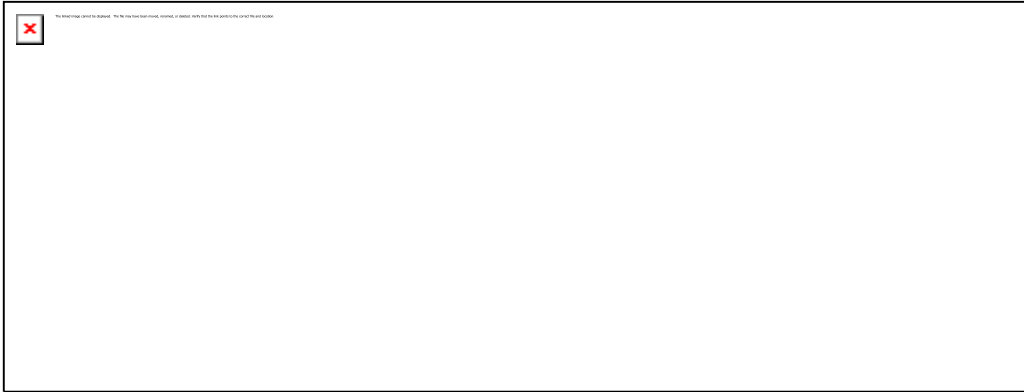


Fig. 1: Variation of porosity of the bricks with different of agroforestry wastes

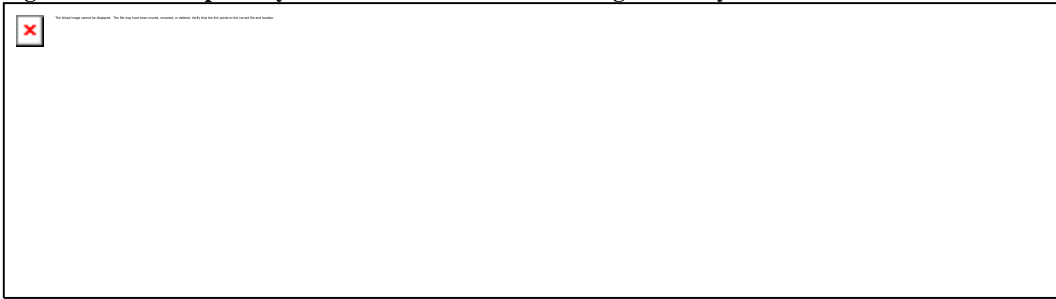


Fig. 2: Variation of porosity of the bricks with varied percentage of waste

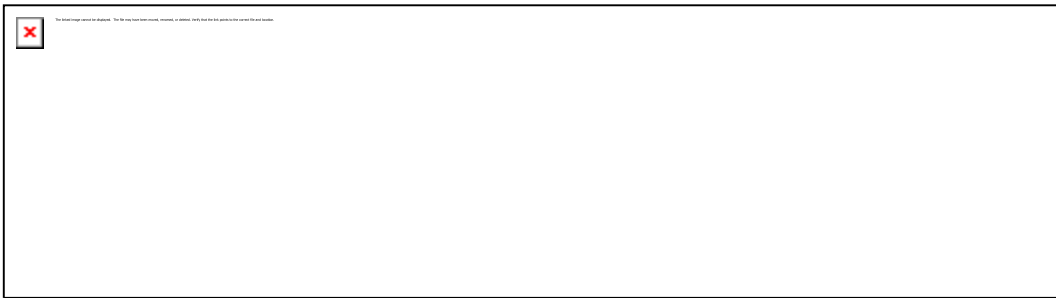


Fig. 3: Variation of CCS with weight percentage of waste

The cold crushing strength in longitudinal direction is higher than the transverse direction, because the particles were compressed in the longitudinal direction thereby increasing resistance to fracture in that direction. The high degree of porosity (as a result of rise in waste content) contributes to the decline in the value of the thermal conductivity of the refractory bricks (Fig. 4). The thermal conductivity of bricks produced with 30wt.% of waste is 0.046W/m^oK while that of imported is 0.049 W/m^oK. The presence of pores in the bricks improves the insulating property of the bricks. The pores hinder heat transfer from one particle to another. Since heat transfer in solids is mainly by conduction. Heat transfer by conduction occurs via the transfer of heat wave from one particle to another in a material. At an increase in porosity, entrapped air that comes between the particles inhibits the rate of heat transfer from one particle to another.

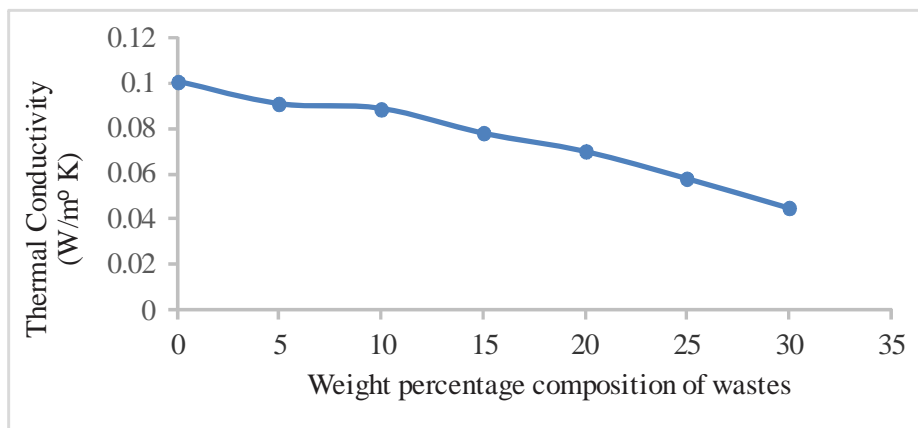


Fig. 4: Variation of thermal conductivity with percentage content of waste

Microstructural Analysis

The SEM/EDX images of the imported brick and the developed are displayed in Plates 1 – 3. As the temperature increases to 1150°C a crystal like shape is observed showing the formation of a highly crystalline compound known as mullite (Esezobor *et al.*, 2014). It is observed from Fig. 3 and supported by the SEM micrographs that the CCS of the samples reduces with increase in percentage of waste, while the percentage of porosity increases. This is because high strength is incompatible with high porosity – the larger and more numerous the pores, the thinner the enclosing walls of solid material and the lower the strength (Jonker, 2006; Esezobor *et al.*, 2014). Moreover, the thermal conductivity is lower when the volume of air space is larger, the thermal conductivity of a brick depends more on the uniformity of size and even distribution of these pores than on the size of pores.

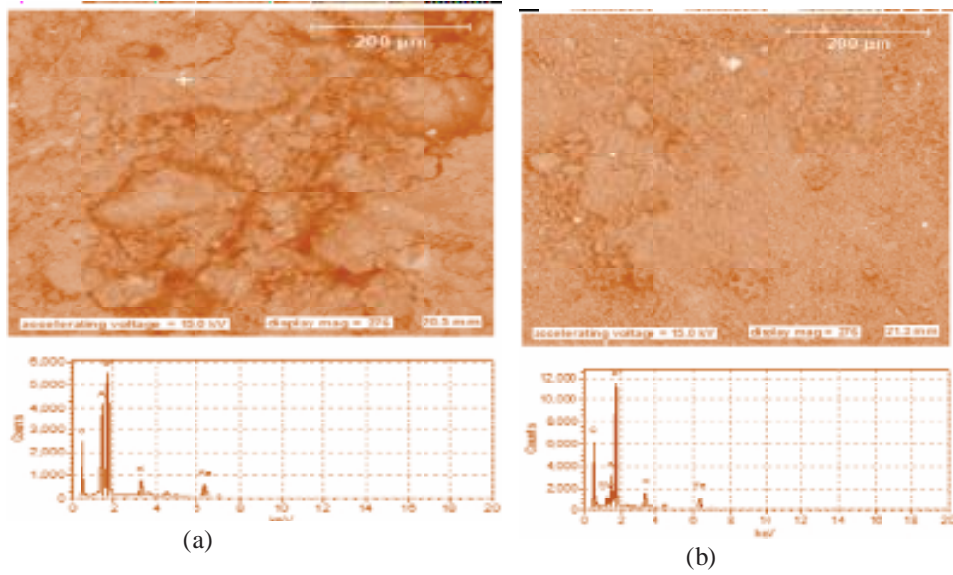


Plate 1: (a) SEM image/EDX of Imported Refractory brick (b) brick with 100% clay fired at 1050°C

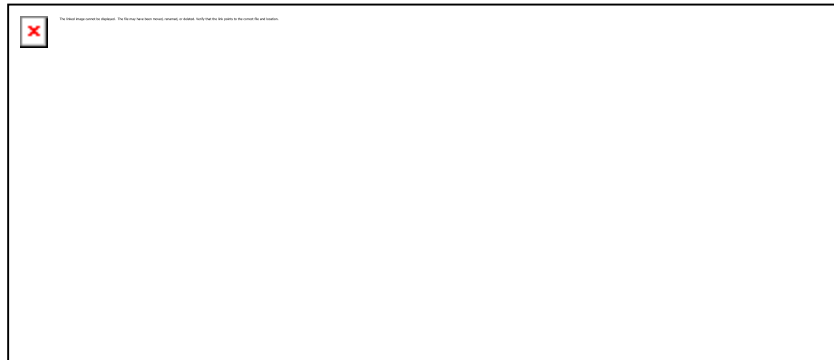


Plate 2: SEM images of Brick with 10%, (a) and 15 %, (b) waste content fired at 1000°C

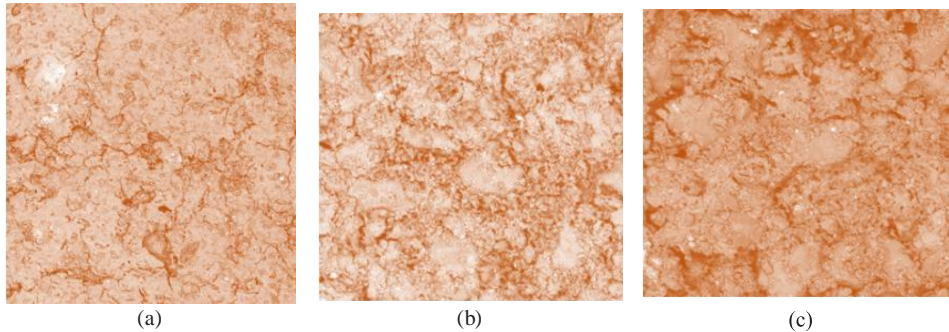


Plate 3: SEM images of Brick with 20% waste, (a) 25 % waste, (b) and 30 % waste, (c) content fired at 1000°C

The refractory bricks manufactured from Ikorodu and Osiele clays favourably compared with imported bricks in terms of pores distribution (Plates 1 – 3)

Cost-Benefit Analysis

The unit cost price and selling price of the brick in Table 2 were evaluated using Adeniyi’s method (Adeniyi, 2004).

Table 2: Estimates of the unit cost price and selling price of the bricks

Type	Days/yr	Machine Capacity	Quantity/ yrproduction	Cost(PC)	Other Nairaaddition f PC)	co:Total Cost (10%Naira	Cost/ Unit (Naira)	Handling Cost (Naira)	Selling Price (Naira)
OC	240	1,000	240,000	28,868	,886,800	31,754.8	132.31	132.31	265.00
OR	240	1,000	240,000	28,823	,882,300	31,705.3	132.11	132.11	264.00
OS	240	1,000	240,000	28,658	,865,800	31,523.8	131.35	131.35	263.00
KC	240	1,000	240,000	28,668	,866,800	31,534.8	131.40	131.40	263.00
KR	240	1,000	240,000	28,623	,862,300	31,485.3	131.20	131.20	262.00
KS	240	1,000	240,000	28,458	,845,800	31,303.8	130.40	130.40	261.00

O – Osiele clay; K – Ikorodu clay; S – sawdust; R – rice husk and C – coconut shell

Economic Comparative Analysis between Imported Bricks and Developed Bricks

The cost values of bricks produced from various sources evaluated are presented in Table 3.

Table 3: Economic values of locally produced refractory bricks(average cost of imported bricks taken as 600 Naira)

Types	Unit Cost of (22.6x11.2x6.5cm ³)Locally Produced Brick in Naira	Gain
OC	265.00	335.00
OR	264.00	336.00
OS	263.00	337.00
KC	263.00	337.00
KR	262.00	338.00
KS	261.00	339.00

Table 3 indicates that there are significant benefits of producing the insulating refractory bricks domestically. This includes among others the cost price of the domestically produced insulating refractory bricks (N261 – N265) is far lower than the cost of imported bricks (N600). The economic savings is (N335 – N339) per unit brick (22.6 x 11 x 6.5 cm) based on the 2014 buying price of the imported bricks.

Conclusion

It can be concluded that:

1. The studied clays belong to alumino-silicate family(Silica>45 % and alumina>36 %). The clays and the combustible agroforestry wastes have the required composition for the production of insulating refractory bricks with low (0.003 %) and high (97.15 %) loss on ignition (L.O.I) respectively. This positively affects the thermal property of the developed bricks, because with high L.I.O, the wastes will burn off during firing thereby creating pores which reduces thermal conductivity and improves insulation.
2. Furthermore, the average unit production and selling cost of the developed standard bricks is N130.5 and N261 respectively against N600 for imported bricks of the same size.
3. Finally, the domestically produced bricks mechanically and economically compared favourably with the imported bricks.

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