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INFLUENCE OF COCONUT SHELL ASH ADDITIVE ON THE PROPERTIES OF LOCAL REFRACTORY BRICKS

*[1]Nenuwa O. B., [2]Owoyemi H. T., & [3]Aluko A. O.
[1,2,3]Department of Mineral & Petroleum Resources Engineering Technology
Federal Polytechnic Ado-Ekiti, Ekiti state, Nigeria
*Corresponding author: solanenuwa@gmail.com

ABSTRACT
Despite the extensive clay deposits that can be found in various parts of the country, Nigeria still depends on the importation of refractory materials to meet the need of her industries. This work examined the effect of the addition of different proportions of Coconut Shell Ash (CSA) to termite hill clay on the properties of fire-clay refractory. Physical tests were conducted on local bricks produced using termite hill clay and coconut shell ash as additive. The chemical composition of the material was consistent with clay obtained from other locations. The result of the physical tests carried out revealed that the apparent porosity (19.52 - 32.10%) of the refractory brick with additive increases as the percentage of coconut shell ash increases; the higher the additive the lower the bulk density which ranged from 1.40g/cm^3 – 1.77g/cm^3. There was also a reduction in the refractoriness (710^{o}C – 800^{o}C) and thermal shock resistance (4 – 5 cycles) of the clay as the proportion of additive increases. The loss on ignition (13.77 – 23.18%) increases with increase in additive while the linear shrinkage of blended refractory had a relatively stable value of 11.43%. The addition of coconut shell ash to termite hill clay enhanced the porosity, bulk density and linear shrinkage although the refractoriness of the material was reduced. Refractory bricks produced using termite hill clay and coconut shell additive will be suitable for lining pit furnaces which can be used for firing non-ferrous metals where the working temperature is less than 700^{o}C.

KEYWORDS: Clay; Coconut shell ash; Furnaces; Linear shrinkage; Refractory

INTRODUCTION

Refractories are inorganic, non-metallic and heterogeneous materials composed of thermally stable mineral aggregates, a binder phase and additives. They have enormous heat capacities and can withstand high temperatures, as well as other strains exerted on them such as abrasion, impact, thermal shock, chemical attack and high level loads at elevated temperatures. Refractories are commonly used for producing refractory bricks for furnace linings and other processing units; they are also used in tubes for electric furnaces, crucibles, thermocouple sheaths, refractory cements, among others (Chesti, 1986; Gerhard, 1989). Over 80% of the total refractory materials are being consumed by the metallurgical industries for the construction and maintenance of furnaces, kilns, reactor vessels and boilers. The remaining 20% are being used in the non-metallurgical industries as cement, glass and hard ware (Aderibigbe & Chukwuogo, 1984).

Nigeria has appreciable distribution of metal and process industries where high temperatures are generated and as such have considerable needs for Refractories. Present economic realities dictate the need for internal sourcing of raw materials to be used in the production of engineering materials (Yami, 2006). Refractory materials play useful and very crucial roles in the industrial development of any nation. Aderibigbe, (1989) reported that virtually all the refractory requirements in all the metallurgical industries in Nigeria are imported. The Nigerian metallurgical industries are struggling today because of many factors which include short supply of refractory materials. Adondua (1988), reported that Ajaokuta Steel Complex requires about 43,503 tonnes per year of fireclay refractories for its operations; and these refractories are sourced abroad. Despite having extensive clay mineral deposits in Nigeria, Nigeria continues to depend on the importation of refractory materials for many of her industries. Nigeria imported about 27 million metric tonnes of refractory materials in 1987 (Obadinma, 2003).

Most metallurgical processes are heat generating systems. Such systems require materials that can withstand not only the high temperature generated but equally must be able to withstand both physical and chemical action of molten metal, slag and gases without deteriorating. Engineering materials that possess these attributes are refractory materials. The base material for refractory production is clay. Clays are naturally occurring sediments produced by chemical actions resulting from weathering of rocks (Nnuka & Agbo, 2000). It is an earthly fine-grained material, which develops plasticity when mixed with water; clay has silica (SiO_2), alumina (Al_2O_3) and water as primary constituents. Other constituents are iron, alkaline, and alkaline earth metals (Abdul, 2005).

Termites transport large quantities of materials from within the soil, depositing it on the surface. Some of the termites mould hills are about 5 meters tall and 7 meters in diameter. The clay from the termite mound is capable of maintaining a permanent shape after moulding because of its plasticity. It is also less prone to crack when compared with ordinary clay. In addition, it has low thermal conductivity and expectedly reduced solar heat flow and temperature fluctuation within an enclosure (Ndaliman, 2006). In an earlier paper of Akinbode, (1996) it was shown that the behavior of termite hill materials when subjected to refractory tests were in good comparison with the firebricks obtained elsewhere. It was then suggested that further improvement may be obtained when additives or other forms of rectification could be made. It was also shown by Ndaliman (2001) that termite hills can be used to produce insulating refractory when 25% of additives (Corn Husk, Saw Dust) were used. However, low values of refractoriness were recorded for these cases. The application would require a compromise between insulation and operating temperature. In yet another investigation, which sought to increase the refractoriness, Ndaliman (2000) used 25% each of graphite powder and asbestos with termite hill materials.

The increase in agricultural processes generates large quantities of waste which are disposed off in landfill and open burning. Coconut shell is an agricultural waste; according to some investigators the accumulation of improperly managed wastes has raised significant environmental and health concerns (Demir, 2006; Turgut & Yesilata, 2008). An on-going effort to counter this vicious cycle is to recycle and incorporate these disposable wastes in the construction and metallurgical industry, especially in the production of furnace lining. Coconut is produced in 92 countries worldwide on about more than ten million hectares. Indonesia, Philippines, and India account for almost 75% of world coconut production with Indonesia being the world’s largest coconut producer. The coconut fruit yield 40% coconut husk which contains 30% fiber, with dust making up the rest. The chemical components of coconut husk are of cellulose, lignin, pyroligneous acid, gas, charcoal, tar, tannin, and potassium. Coconut husk has higher lignin and cellulose content (Yerima & Grema, 2018). The use of coconut shell particulates to enhance the insulating refractory properties of Ukpor, Osiele and Kankara fireclays in Nigeria was studied and the results indicated that clays with 25 wt% - 30 wt% coconut shell and grain sizes of 212 - 300µm fired at 1150˚C - 1200˚C possess enhanced mechanical, physical and insulating (thermal) properties (Obidiegwu et al., 2015).

Since Nigeria has abundance of termite hill clay and large quantity of coconut shell which could be exploited for economic and industrial purposes, this work therefore evaluates the influence of coconut shell ash (CSA) on the physical properties of fired termite clay bricks for the purpose of lining furnaces. This will serve as a good alternative to the imported refractory bricks.

MATERIALS AND METHODS

Materials

The termite hill clay samples used for the experimental work were obtained from Aba Erinfun, Federal Polytechnic Road, Ado-Ekiti, Ekiti state and the coconut shell ash (CSA) was obtained from Itaogbolu, Akure North LGA, Ondo state. The chemical analysis of the termite hill clay was done using Atomic Absorption spectrometer (AAS) for the determination of major oxides present.

Sample Preparation

Five test samples (A, B, C, D and E) were prepared by mixing freshly sieved termite hill clay with 0%, 5%, 10%, 15% and 20% coconut shell ash respectively using 200g as the basis for each mixture. Sample A is the control sample which is 100% termite hill clay without the addition of coconut shell ash. The clay mixture was found to be plastic at 15-17% water content; allowed to hardened for 24 hrs that is to achieve a workable mix, and then manually packed into a cylindrical mould of dimension 3cm x 1.5cm and pressed using ram and peg to enhance homogeneity and surface smoothness. The mould bricks were oven dried for four days, (6hours each day) at a temperature range of 100 – 130^{o}C. The samples were thereafter fired in a furnace at a temperature of 1100^{o}C until constant weight is obtained, these samples were then presented for laboratory tests.

Physical Properties Tests

The fired bricks were tested for apparent porosity, bulk density, thermal shock resistance, linear shrinkage on firing, compressive strength and refractoriness following standard procedures (Hassan & Aigbodion, 2014).

Apparent porosity test

The samples were oven dried at 110^{o}C until a constant weight (W_D) is obtained. The dried specimen was suspended in 5000ml beaker containing distilled water and boiled for two hours, in this position. It was later allowed to cool down to room temperature and its new weight determined (W_S). The specimen was removed from water, and again reweighed in air to obtain (W_W). The Apparent Porosity (P) was determined using Equation 1:

$$P = \frac{Ww - WD}{Ww - Ws} \times 100 \qquad (1)$$

Where W_D = Weight of fired specimen, W_S = Weight of fired specimen in water,

W_W = Weight of soaked specimen suspended in air

Bulk density

The fired test samples were air dried for 24 hours and then dried at 110^{o}C, cooled in a desiccators and weighed, this is the dried weight (D) after which the specimens were transferred to a beaker and heated for 30 minutes to assist in releasing the trapped air. The specimens were cooled and the soaked weight (W) taken. The specimens were then suspended in water using beaker placed on a balance. The suspended weight (S) was taken. The bulk density was calculated using Equation 2:

$$Bulk\ Density = \frac{D.\rho w}{W - S} \quad (2)$$

Where D = Dried weight, ρ_w = Density of water, W = Soaked weight, S = Suspended weight

Refractoriness test

This is the measure of the fusibility of a material and it indicates the temperature at which the material softens. The refractoriness of a clay sample is directly related to its softening temperature and is expressed as its Pyrometric Cone Equivalent (PCE). Pyrometric cone equivalent is the number which represents the softening temperature of a refractory specimen of standard dimension (38 mm vertical height and 19mm triangular base) and composition. Refractory clays are classified into different grades in respect of their softening temperatures, typified by the number of the standard pyrometric cone which deform under heat treatment. Test cones were prepared from the refractory clay samples, having the same dimensions with segar cones (standard cones). Then the test cone is placed in an electric furnace along with segar cones, and heated. The furnace is heated at a rate of 10^{o}C per minute during which softening of segar cone occur along with the specimen test cone. The temperature at which the apex of the cone touches the base is the softening temperature. The test cones are then compared with the standard cones and the test material is said to have the pyrometirc cone equivalent (PCE) of the standard cone that it resembled most in bending behaviour.

Thermal Shock Resistance Test

The test sample was placed in a muffle furnace preset at 700℃ for 10 minutes. It was then cooled outside the furnace for another 10 minutes and observed for cracks. The heating and cooling cycles are repeated until cracks were observed on the specimen. The number of these cycles undergone before cracking was recorded and this constitutes the thermal shock resistance of the material.

Loss on ignition

The loss on ignition (LOI) is the weight reduction on the total weight of the prepared clay samples, in percentage. Hence, the loss in weight by each clay sample was determined to be the difference in their weights before and after firing and consequently, the loss on ignition at that temperature was determined using Equation 3:

$$LOI = \frac{W1 - W2}{W1} \times 100 \quad (3)$$

Where: W_1 = Initial Weight of clay sample before firing, W_2 = Final Weight of clay sample after firing

Linear shrinkage test

A line was marked along the length of the cylindrical test sample. The distance between the two ends of the sample was measured using a vernier caliper. The sample was air-dried for 24 hours and oven-dried at 110℃ for another 24 hours. It was then fired at 700℃ for 6 hours. The test piece was cooled to room temperature and another set of measurement taken. The linear shrinkage was calculated using the relation in Equation 4:

$$Linear\ Shrinkage\ (\%) = \frac{L2 - L1}{L1} \times 100 \quad (4)$$

Where: L_1 = Initial length of clay sample before firing, L_2 = Final length of clay sample after firing.

RESULTS AND DISCUSSION

Chemical composition of Aba Erinfun Termite Hill Clay

The result of the chemical analysis of the termite hill clay is presented on Table 1. From Table 1, the termite hill clay sample has high silica content of 56.38%, this value falls within the standard range of 46 – 62% that is required for the production of good refractory materials (Yami & Umaru, 2007). Therefore, they can find application as lining for furnaces. The alumina content in the sample is low (21.24%) while the iron oxide, Fe_2O_3 (7.65%) is quite high; this will lead to low refractoriness of the refractories produced from this type of clay in addition to the iron oxides present in the coconut shell ash (Apeh et al., 2011). Therefore, the clay will require the removal of iron oxides through beneficiation. The other associated oxides present in the clay sample are: TiO_2 (1.04%), CaO (3.45%), P_2O_5 (0.04%), K_2O (0.94%), MnO (0.02%), MgO (1.46%) and Na_2O (1.28%).

Results of Physical Properties Tests

Table 2 is the results of the physical tests carried out to determine the refractory properties of samples A, B, C, D and E.

Apparent Porosity

The value of the porosity of the clay samples in percentages was also determined as shown on Table 2. Porosity determines the resistance of the material to penetration of molten slags, metals and flue gases. The apparent porosity of the termite hill clay refractory (sample A) is 11.05%. The porosity of refractories produced from termite hill clay with additives increases with the increasing percentages of coconut shell ash (CSA). The value of the porosity for the refractory with additives ranges from 19.52% to 32.10%. Sample C, D, and E have apparent porosity values above the indicated minimum limit of 20% for suitability of samples use as refractory material. The porosity of refractory clay material is directly related to the air pockets contained in it, the higher the porosity of the clay material, the higher its insulating properties (Iyasara, 2016). High porosity in refractory materials translates to increased air pockets and improved thermal insulation. This suggests that, termite hill clay with 10 – 20% weight of additives has better capability to minimize thermal losses in the furnace compared to others.

Bulk Density

The result showed that the control sample had the highest bulk density of 1.83g/cm^3. The values for the refractory with CSA additive ranged from 1.40 - 1.77g/cm^3; the higher the percentage of additives, the lower the bulk density. This indicates positive influence on the bricks as it will become lighter and this is important in the transportation or handling of a refractory material. The obtained bulk density for sample E which is 1.40g/cm^3 is lower than the recommended threshold values of 1.70 – 2.10g/cm^3 for dense fire bricks.

Refractoriness

The refractory without additive had the highest temperature as it can withstand the temperature of about 1090^{o}C before deformation, the temperature of the refractory with CSA additive ranges from 710 – 800^{o}C. Such a value is indicative of low sintering temperature which in turn is an indication of poor refractoriness. The introduction of the additives tends to lower the refractory of the clay samples. The low refractoriness value is likely due to low alumina (Al_2O_3) content of the termite hill clay. However, the furnace lining produced with CSA additive should be limited to a working temperature less than 700^{o}C. This type of furnaces is used for melting non-ferrous metals such as aluminium, zinc, lead that have melting point of 660^{o}C, 416^{o}C and 326^{o}C respectively.

Thermal Shock Resistance

The result showed that the dense pure termite hill clay resist spalling cycle up to 6 cycles. However, the sample with additive showed that thermal shock resistance (TSR) reduces from 4 – 5 cycles. The result obtained generally indicated that the spalling resistance of the materials reduces with increasing percentage of additive. All the samples showed poor thermal shock resistance as acceptable thermal shock resistance in practice is of values greater than 10cycles. Sudden changes in the temperature can cause fine cracks in refractory bricks which lead to spalling. The occurrence of spalling can be minimized by slow cooling. The use of these materials should be restricted to lining of ladles, slag pots and small furnaces which are mended at short intervals.

Loss on Ignition

The LOI of termite hill clay was determined as the percentage of moisture loss to ignition on firing the prepared clay samples. This value is highest at 20% additives with LOI of 23.18%, but lowest for the sample without additive showing value of 9.76%. This represent the amount of moisture the clay materials could hold or percentage weight reduction of samples which may probably be a reflection of their grain structures and fineness i.e. the higher the percentage, the higher the amount of loss on ignition, which indicates that it contains element of combustible material.

Linear Shrinkage

The linear shrinkage for sample without additive is 20%, on addition of 5%, 10% and 20% coconut shell ash, there was a uniform linear shrinkage value of 11.43%. The linear shrinkage of sample D with additive of 15% was higher compared to others. The samples with CSA additive showed better thermal stability than the sample without additive, these samples after drying and firing generally have lower linear shrinkage values with the variations falling within a narrow range. The shrinkage values obtained showed that the clay could be processed for use as low refractory furnace linings.

CONCLUSIONS AND RECOMMENDATIONS

The results showed that the termite hill clay can be used to produce local refractory bricks when blended with coconut shell ash additive. Although, the presence of the CSA additive influenced some of the properties like refractoriness, loss on ignition, thermal shock resistance adversely in regard to dense refractory bricks, the positive effects provided by the coconut shell ash were observed in the improvement of the refractory properties like apparent porosity, bulk density and linear shrinkage. It was also observed that the termite hill clay blended with coconut shell ash will be suitable for the lining of ladles, slag pots and small furnaces that will operate at a working temperature less than 700^{o}C; in addition, they will exhibit good insulating property. This type of furnaces is used for melting non-ferrous metals such as aluminium, zinc and lead. Furnaces lined with refractory produced from termite hill clay and coconut shell ash blend should be fired steadily and cooled slowly in order to increase its cycle time. The percentage of coconut shell ash should be limited to an optimum value of 10% weight in order to guarantee good service performance of the refractory lining. Further works should be directed towards investigating the service performance of other type of local clay blends utilized in producing refractory materials.

REFERENCES

Abdul J. M. (2005). Effects of some selected chemical additives on shrinkage and compressive strength of ball clay in Ikotun. *Journal of Mechanical Engineering, University of Ado-Ekiti. 3*(1), 7 - 15.

Aderibigbe A., & Chukwuogo, B. (1984). Potentials of some Nigerian clay deposits as refractory material for steel industry. *Proceeding of Nigerian Society of Engineers*, 132-138.

Aderibigbe, D. A. (1989). Local sourcing of raw materials and consumables for the iron and steel industries in Nigeria-Challenges for the future. *Raw Materials Research and Development Council of Nigeria (RMRDC)*, 55.

Adondua, S. (1988). Indigenous refractory raw materials base for Nigeria steel industries". *Journal of the Nigerian Society of Chemical Engineers (NSCHE),7*(2), 322.

Akinbode F.O. (1996). An investigation on the properties of Termite hill refractory material for furnace lining, *India Foundry Journal*, *5*(3), 10-13.

Apeh F. I., Esezobor, D. E., & Lawal, G. I. (2011). Characterization of Onibode and Owode - Ketu clays for use as refractory materials in foundry industry. *Journal of Engineering Research, 16,* 69-77.

Chesti A.R. (1986). *Refractories: Manufacture, Properties and Applications*. New Delhi., India: Prentice-Hall.

Demir, I. (2006). An investigation on the production of construction brick with processed waste tea, *Building and Environment*, *41*(9), 1274 - 1278.

Gerhard, M. (1989). *Basic Know-how for the making of burnt brick and tiles*. Misereor, Aachen, Federal Republic of Germany.

Hassan, S. B. and Aigbodion, V. S. (2014). Effect of coal ash on some refractory properties of alumino-silicate (Kankara) clay for furnace lining. *Egyptian Journal of Basic and Applied Sciences*,*1*(2), 107-114.

Iyasara, A. C., Stan, E. C., Geoffrey, O., Joseph, M., Patrick, N. N., & Benjamin, N. (2016). Influence of Grog size on the performance of NSU Clay-based dense refractory bricks. *American Journal of Materials Science and Engineering*, *4*(1) 7-12.

Ndaliman, M. B. (2000). Effect of certain additives on refractory properties of Termite hill for furnace lining. *Proceeding of the 2nd Annual Engineering Conference, Federal University of Technology, Minna* 4th-6th September, 139-144.

Ndaliman, M. B. (2001). Some studies in Refractory properties of Termite Hills in Nigeria. *Nigeria Journal of Education and Technology*, *2(*1&2), 44 - 46.

Ndaliman, M. B. (2006). Refractory properties of termite hills under varied proportions of additives. *Leonardo Electronic Journal of Practices and Technologies.* 9, 161 - 166.

Nnuka, E. E., & Agbo, U. J. E. (2000). Evaluation of the refractory characteristics of Otukpo Clay deposit. *NSE Technical Transaction 35*(1), 34 - 41.

Obadinma, E.O. (2003). Development of refractory bricks for heat treatment facilities. *Journal of Science and Technology Research 2*(2), 13 - 17.

Obidiegwu, E.O., Esezobor, D.E., Agunsoye, J.O. and Lawal, G.I. (2015). Enhancement of insulating refractory properties of selected Nigeria fire-Clays using coconut shell. *Journal of Minerals and Materials Characterization and Engineering, 3*, 458 – 468.

Turgut, P., & Yesilata, B. (2008). Physico-mechanical and thermal performances of newly developed rubber-added bricks. *Energy and Buildings 40*(5), 679 - 688.

Yami, A. M. (2006). *Investigation of the properties of selected Clay Deposits in Mangada and Hawul local government areas of Borno state for the production of refractory bricks*. Unpublished M. Eng thesis. Production Engineering, Bayero University, Kano.

Yami, A. M., & Umaru, S. (2007). Characterization of some Nigerian clays as refractory materials for furnace lining. *Continental Journal of Engineering Sciences*, 30 - 35.

Yerima, I., & Grema, M. Z. (2018). The potential of Coconut Shell as biofuel. *The Journal of Middle East and North Africa Sciences*, 4(8), 11-15.

Table 1: Chemical composition (Wt. %) of Aba Erinfun termite hill clay

Oxides	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	P_2O_5	K_2O	MnO	MgO	Na_2O
Composition %	56.38	21.24	7.65	1.04	3.45	0.04	0.94	0.02	1.46	1.28

Table 2: Physical properties of the test refractory samples

Samples	**A 0% CSA**	**B 5% CSA**	**C 10% CSA**	**D 15% CSA**	**E 20% CSA**
Porosity (%)	11.05	19.52	24.94	25.88	32.10
Bulk Density (g/cm^3)	1.83	1.77	1.69	1.68	1.40
Refractoriness (^{o}C)	1090	800	790	745	710
Thermal Shock Resistance (Cycle)	6	5	4	5	4
Loss on Ignition (%)	9.76	13.77	15.91	19.41	23.18
Linear Shrinkage (%)	20.00	11.43	11.43	14.29	11.43