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Effects of Rice Husk Ash Addition on the Refractory Properties of Owo Clay

T. M. Onyia, N. E. Idenyi

Abstract: ***This research investigates the effect of rice husk ash (RHA) addition on the refractory properties of Owo clay. The clay is blended with RHA in increments of 5% for each experimental run. The blended material undergoes exposure to temperatures ranging from normal crucible liner conditions to 1200° C, followed by characterization for shrinkage, porosity, density, water absorption, and modulus of rupture. Results indicate that total shrinkage increases with RHA content throughout the experimental phase but stability was observed at 10% RHA. Porosity decreases with increasing RHA content, with the 10% RHA blend showing the most consistent decrease. RHA enhances compressive strength, reaching a peak of 24 N/mm² for 5% RHA at 1200°C, and a minimum of 10 N/mm² for 5% RHA at 900°C. Bulk density increases with decreasing porosity as temperature rises. Overall, the 90%-10% Owo clay-RHA Clay blend demonstrates the most suitable properties for industrial applications.***

Keywords: ***Chemical Composition, Owo Clay, Physical Properties, Refractoriness, Rice Husk Ash (RHA).***

I. INTRODUCTION

Clay is a type of soil that makes up the earth's surface; specifically, it is a soil that comprises complex minerals with the essential chemical formula of aluminium silicate of hydration ($2A1_2O_3$ $SiO_3.2H_2O$) [1]. Clay is a natural raw material for many industrial products such as refractories, ceramic wares, and electrical porcelain insulators. The use of clay for furnace lining, bricks making is common in many manufacturing industries. This is because of its ability to retain heat within a system, excellent plasticity, low thermal conductivity [2].

Several authors have tried to modify the properties of clay to achieve certain desired properties by adding groundnut shell [3] rice husk ash [4], and sugarcane bagasse [5]. These additives do not only modify the properties but can also improve the conventional properties making the resultant clay more versatile and durable [6].

Comprehensive review of RHA's potential uses, showing that its amorphous silica content makes it valuable for diverse industrial applications.

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[5] investigated the mechanical and durability characteristics of clay bricks made from waste materials like rice husk ash and sugarcane bagasse ash. The authors claim that the addition of not more than 5% husk ash and sugarcane bagasse resulted to lesser weight leading to lighter weight structures. A similar investigation was carried out by [7], the properties of interest were the linear shrinkage, compressive strength, porosity, water absorption, and bulk density. All other properties increased as the percentage of RHA increases apart for compressive strength which showed a decline as the percentage of RHA. [8] Investigated the effect of rice husk ash (RHA) addition to Ibaji clay and compared the properties with the non-reinforced RHA sample. The authors varied the RHA blends from 2 to 10%, and testing for atterberg limits, specific gravity, compressive strength, water absorption, X-ray diffraction and geochemical analyses. Their result showed that the addition of 2% RHA improved the water absorption and compressive strength characteristics, compressive strength and water absorption compared to the non -reinforced samples. They concluded that both RHA reinforced and non-reinforced sampled could be used for brick production. However, the addition of 2% RHA resulted in better properties and thus, recommended for optimum performance of the bricks. [9] discovered that samples with higher percentages of rice husk and lower percentages of groundnut shell exhibited the best modulus of rupture, indicating that strength increases with higher rice husk content. This analysis showed a higher percentage of silica and low percentage of lignin, indicates the potential usefulness of the blend as refractory lining. [2] Research assessed the physical properties of alkaleri clay mixed with rice husk ash (RHA) using Design Expert 7.1.6 Central Composite Design (CCD). Properties evaluated included bulk density, apparent porosity, linear shrinkage, cold compressive strength, thermal shock resistance, loss on ignition, and refractoriness. The refractory properties observed from this analysis meet the ASTM standards for refractory materials used in ferrous casting. [10] in their study, claimed that waste RHA added to clay improves compressive strength by 32.7% while reducing water absorption to 19% at 4% RHA. In addition, bricks with 4% RHA reduce indoor temperatures by 6°C and noise by 10 dB when compared to regular burnt clay bricks. Overall, bricks constructed from waste RHA have superior structural, thermal, and acoustic properties while successfully managing RHA waste, which is a significant environmental and ecological achievement [11]. they claimed that adding rice husk and rice husk ash to clay bricks improves porosity and water absorption while decreasing bulk density.

At 10% addition, rice husk achieves 1.20 g/cm³ bulk density and 4.6 MPa compressive strength, while rice husk ash achieves 1.18 g/cm³ bulk density and 5.97 MPa compressive strength, meeting industrial lightweight brick standards [12]. in their research that by adding rice husk ash to clay bricks, ranging from 0 to 5% by weight, enhances porosity, with 3% producing the highest mechanical properties: 13.50 MPa compressive strength, 1.69 g/cm³ density, and 11.50% water absorption [13].

Research has shown great refractory property improvement with rice husk ash to improve mechanical and thermal properties of clay used as refractory material. Currently, most industries requiring refractory materials import them at a very high cost, leading to exorbitant prices for their products [15]. Despite significant research on utilizing local clays for industrial purposes, much work remains to harness the abundant clay deposits spread across Nigeria [16].

However, research has not yet been conducted on Owo clay and the potential improvements in its refractory properties with the addition of RHA [17]. Owo clay, which is abundant and readily available in Owo town, Enugu State, was therefore chosen for this study [18]. The combination of Owo clay and RHA is expected to produce an excellent refractory material [19].

II. MATERIALS AND METHODS

A. Sample Preparation

The clay for this work was sourced from Owo town, while the rice husk was gotten from a rice mill at Ugboka both in Nkanu East local government area in Enugu State. The collected samples of rice husk ash and Owo clay were weighed using a Metra TI.300 model electronic weighing balance. The clay samples were fired at various temperatures after shaping.

B. Physical and Chemical Test Analysis of Owo Clay and Rice Husk Ash

The physical properties were analysed using the American Society for Testing and Materials International standard. Chemical analysis of clay samples was performed using the X-Ray Diffraction (XRD). Table 1 and 2 shows the properties of the rice husk ash while Table 3 and 4 the properties of fire clay.

Table 1: Physical Properties of Rice Husk Ash

S/N	Particulars	Properties
1	Colour	Grey
2	Shape Texture	Irregular
3	Mineralogy	Non-Crystalline
4	Particle Size	<45 microns
5	Specific gravity	2.3 g/cm^3
6	Appearance	Very fine grains

Table 2: Chemical Composition of Rice Husk

S/N	Particulars	Proportions (%)
1	Silicon dioxide (SiO_2)	86.94
2	Aluminium oxide (Al_2O_3)	0.2
3	Iron oxide (Fe_2O_3)	0.1
4	Calcium oxide (CaO)	0.3-2.2
5	Magnesium oxide (MgO)	0.2-0.6
6	Sodium oxide (Na_2O)	0.1-0.8
7	Potassium oxide (K_2O)	2.15-2.30

Table 3: Physical Properties of Fire Clay

Constituent	Fire Clay
Linear Shrinkage (%)	7-10%
Apparent Porosity	20-30 %
Bulk Density	1.71-2.1g/cm^3
Cold Crushing Strength	1500kg/cm^3 (22.9-59N/mm^2)
Thermal Shock Resistance Cycle	25-30 Cycles
Refractoriness	1500-1700°C

Table 4: Chemical Composition of the Owo Clay Sample

Metal Oxide	Conc. (mg/L)	% Composition
SiO_2	343.76	42.97
Al_2O_3	186.72	23.34
Fe_2O_3	39.6	4.95
Na_2O	16.32	2.04
K_2O	29.36	3.67
MgO	23.44	2.93
CaO	27.84	3.48
MnO	7.76	0.97

C. Experimental Method

Rice husk ash and Owo clay in varying ratios as shown in Table 5 (experimental array) were used in this experiment. After thorough mixing and weighing, water was added to each sample, followed by settling for 24 hours. The procedure was repeated for consistency. The mixture was forced into wooden mould (7.00 cm long, 5.00 cm wide, 1.00 cm high) using gravitational force after which the samples were allowed to air-dry for a week, and then oven-dried at 100°C for 6 hours. Burning off carbon from the rice husk ash was achieved by firing it inside a gas kiln.

Table 5: Experimental Array

Samples	Owo Clay		Rice Husk Ash		Water	Firing Temp.
	Wt. %	Wt.(g)	Wt. %	Wt.(g)	Vol (cm)	°C
A	95	2850	5	150	400	900,1000,1100,1200
B	90	2700	10	300	400	900,1000,1100,1200
C	85	2550	15	450	400	900,1000,1100,1200
D	80	2400	20	600	400	900,1000,1100,1200
E	75	2250	25	750	400	900,1000,1100,1200

III. RESULTS AND DISCUSSION

The results of the experiment were judged by the resultant linear shrinkage, bulk density, porosity, water absorption, refractoriness test, spalling count test, and compressive strength test following the American Society for Testing and Materials International standard.

A. Linear Shrinkage

After drying and firing, the changes in the length of the marks were measured to calculate total shrinkage of the samples. The length of the sample after drying (dry length) and after firing (fired length) were both obtained for each experimental array. To obtain the wet length, the samples were immersed in water of 25^{0}C for 2 hours which after the length measurement were taken.

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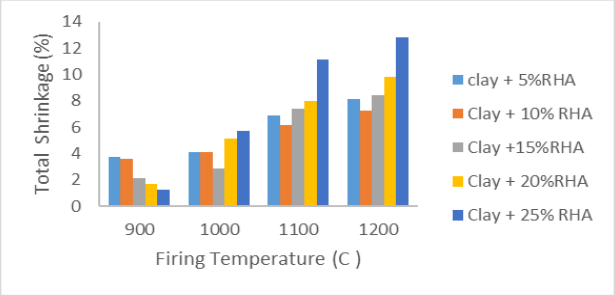
$$\%\text{Total shrinkage} = \frac{\text{Wet length} - \text{Fired length}}{\text{Wet length}} \times \frac{100}{1} \quad \text{Equation 1}$$



[Fig.1: Graph of Total Shrinkage Against Firing Temperature]

The total shrinkage graph above shows that at a firing temperature of 900^0C, the total shrinkage decreased as the rice husk ash increased, which can be attributed to the RHA's inability to burn-off at that temperature. It is also worth noting that as the firing temperature increased, so did the total shrinkage. Furthermore, at firing temperatures of 1000^0C, 1100^0C, and 1200^0C, total shrinkage increased with increase in rice husk ash. The higher the temperature at which the mixture is fired, the more it loses the rice husk ash and constitutional water, causing shrinkage and reducing porosity; additionally, the more a clay body shrinks, the less porous it becomes and thus the denser.

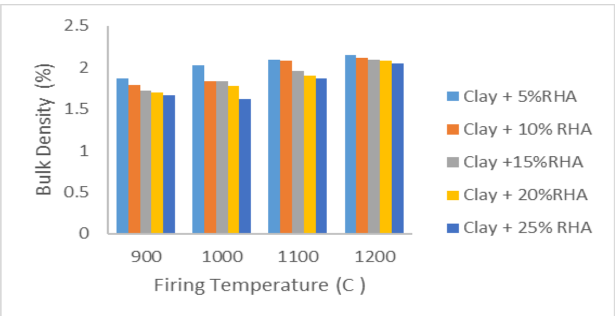
B. Bulk Density

The samples' length, breadth, and height were measured and recorded in centimetres. In preparation for the test, the samples were fired to the required temperatures. An electronic weighing balance was used to determine the dry weight in air. The obtained results were used to calculate the sample's bulk volume and, consequently the bulk density (g/cm^3) was obtained.

Bulk Volume of Brick = $(L \times B \times H)\ cm^3 = LBHcm^3$

Let weight of Bulk (Brick) = W_g

Therefore, Bulk Density = $\frac{W_g}{LBH(cm^3)}$



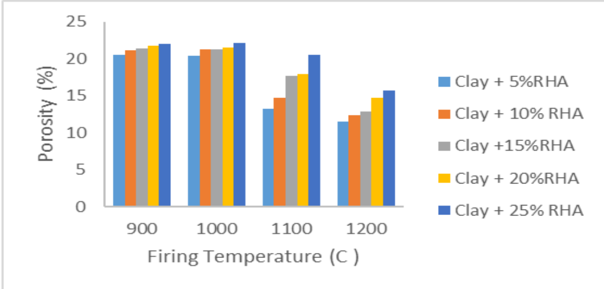
[Fig.2: Graph of Bulk Density Against Firing Temperature]

From the bulk density graph in Figure 2, it was observed that the bulk densities of the clay mixtures at different temperatures decreased with an increase in the rice husk ash content. At all temperatures, the value obtained for clay + 25wt% RHA falls within the range of 1.62g/cm^3 – 2.05 g/cm^3 which is within the standard range of 1.71-2.1g/cm^3 as shown in Table 3. Thus, the blend clay satisfied the condition for fire bricks. This increase in bulk density at 1200°C can be attributed to a slight reduction in porosity at 1100°C and 1200°C, as well as an increase in linear shrinkage.

C. Porosity

The dry weight in air was measured with an electronic weighing balance and immersed in a boiling water vessel for 2 hours. For 4 hours, the samples were allowed to cool to room temperature in the water vessel. The samples were taken out of the water and weighed, the weight difference between the boiled and unboiled bricks was recorded as water porosity. This will be calculated as a percentage of the original weight.

$$\%\ \text{porosity} = \frac{\text{Wet weight} - \text{Dry weight}}{LBH(cm^3) \times \text{Dry weight ofthe sample}} \times \frac{100}{1}$$



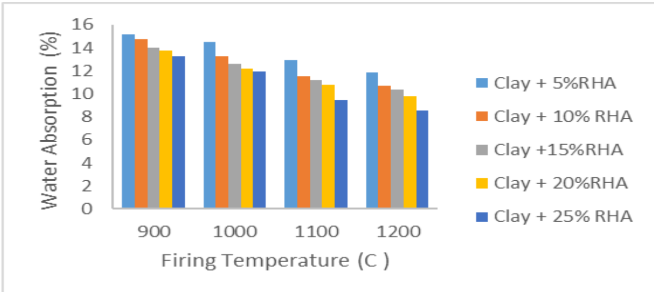
[Fig.3: Graph of Porosity Against Firing Temperature]

From figure 3, the percentage porosity at 900°C and 1000°C increased relatively with increasing rice husk ash content. The differential increase in percentage porosity at 1100^0C and 1200^0C was found to be greater than that at 900^0C and 1000^0C. The porosity of the mixture decreased at 1100°C and 1200°C; the decrease in porosity at 1100°C and 1200°C was caused by an increase in firing temperature from 1100°C to 1200°C. At temperatures ranging from 1100°C to 1200°C, the mixtures have lost their absorbed moisture and constitutional water, resulting in increased shrinkage and decreased porosity; additionally, the more a clay body shrinks, the less porous it becomes.

D. Water Absorption

Water absorption is a measure of the clay body's maturity. For this study, rectangular bars test pieces with dimensions of 7.00cm x 5.00cm x 1.00cm were used. The test samples were weighed after being fired at various temperatures. The fired samples were then boiled for two hours before cooling. The samples' surfaces were dried with a dry towel before being weighed again. The following equation was used to calculate the percentage of water absorption.

$$\text{percentage water absorption} = \frac{\text{saturated weight} - \text{dry weight}}{\text{dry weight}} \times \frac{100}{1}$$



[Fig.4: Graph of Water Absorption Against Firing Temperature]

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Water absorption capacities decreased with increasing rice husk ash content at different firing temperatures. It was also discovered that as the firing temperature increased, the clay mixture's water absorption capacity decreased.

E. Refractoriness Test

The shuen's formula for estimation of refractoriness is [14]

$\frac{360+AI203-RO}{0.228}$ = K here K = Refractoriness (°C)

$A1_2O_3$ = Alumina content in the clay (or materials)

RO = Sum of all other oxides beside SiO_2 in the clay (or materials) 360

and 0.228 are constant.

Owo clay.

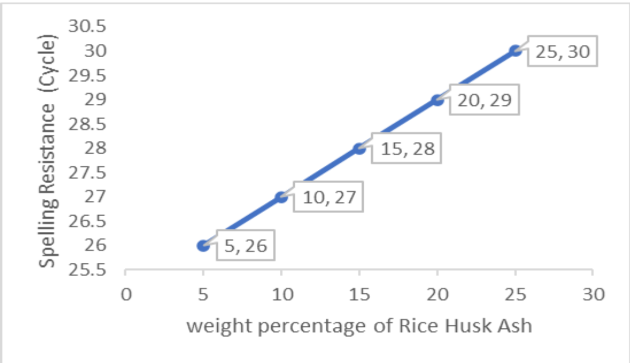
From the chemical composition. $A1_2O_3$ = 36.0% and RO = 6.009%

$$\frac{360 + 36.0 - 6.009}{0.228} = \frac{389.991}{0.2281}$$

Therefore, K= 1710°C

F. Spalling Count Test

The number of thermal cycles (heating and cooling) was used to calculate spalling resistance. Our insulating bricks should be able to withstand many cycles of heating and cooling without cracking, in addition to being refractory. The refractory brick test pieces were thoroughly dried before being placed in the cold furnace and heated at a rate of 5°C/minute until the furnace temperature reached 1000°C. The samples were then removed one after the other using a pair of tongs and cooled in air for 10 minutes, and then observed for cracks. In the absence of cracks, the bricks were put back into the furnace and reheated for a further period of 10 minutes and cooled for another 10 minutes. This process of heating, cooling and observing for cracks was repeated until cracks were observed.

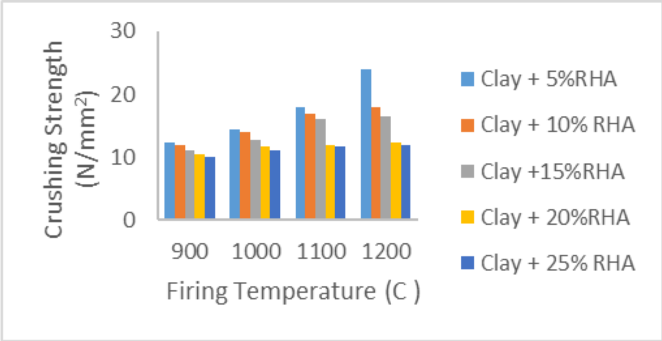


[Fig.5: Line Graph of Spalling Resistance Against Weight Percentage of Rice Husk Ash]

The thermal shock resistance test results showed that the material's thermal shock resistance increased slightly from 26 cycles to 30 cycles. The values, are within the acceptable range of 20 - 30 cycles, as recommended by some researchers [1].

G. Compressive Strength

A Schmidt hammer, also known as a rebound hammer, is a device which measures the elastic properties or strength of concrete or rock, mainly surface hardness and penetration resistance. The hammer measures the rebound of a spring-load mass impacting against the surface of the sample. The test hammer will hit the bricks at a defined energy. Its rebound is dependent on the hardness of the concrete and is measured by the test equipment. By reference to the conversion chart, the rebound value can be used to determine the compressive strength.



[Fig.6: Graph of Crushing Strength Against Firing Temperature]

From the Compressive Strength graph above the maximum values obtained at 900^{0C}, 1000^{0C}, 1100^{0C} were progressively approaching the International Standard value of 22.9-59N/mm^2. At 1200^{0C}, the value obtained were increasing and became matured at sample D with 24N/mm^2 that met the standard range of 22.9-59N/mm^2.

IV. CONCLUSION

In conclusion, our research investigated the refractory potentials of Owo clay when enhanced with rice husk ash (RHA) as an additive. Through a systematic analysis of various properties, we observed distinct trends influenced by both RHA content and firing temperature. Specifically, our findings reveal that firing shrinkage decreases with increasing RHA content, while total shrinkage increases. Moreover, the percentage porosity decreases with rising firing temperature but increases with higher RHA content. Additionally, bulk density decreases with increased RHA content but rises with higher firing temperatures. These trends in property evolution suggest a complex interplay between RHA composition, firing conditions, and resultant material characteristics.

Our results further indicate that the 90:10 blend of Owo clay-RHA emerges as the most suitable for industrial applications, demonstrating optimal performance across multiple properties. This finding underscores the potential of Owo clay-RHA admixtures as high-quality refractory materials with favourable mechanical and thermal attributes.

Looking ahead, our study sets the stage for future research endeavours aimed at refining the synthesis and performance optimization of Owo clay-RHA refractory materials. By delving deeper into the underlying mechanisms governing material behaviour and exploring additional parameters, such as particle size distribution and sintering conditions, researchers can further enhance the utility and applicability of these innovative materials in various industrial settings. Ultimately, the insights gleaned from our study contribute to

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the broader body of knowledge on clay characterization and additive-based material enhancement, paving the way for the development of advanced refractory solutions with enhanced performance and sustainability

V. RECOMMENDATION

The following recommendations were made;

- Rice rush ash is suitable for use as clay reinforcement for the production of refractory bricks.
- Eha-Ndiagu clay + 10 weight percentage of rice husk ash is suitable for production of refractory bricks.

DECLARATION STATEMENT

After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

- **Conflicts of Interest/ Competing Interests:** Based on my understanding, this article has no conflicts of interest.
- **Funding Support:** This article has not been sponsored or funded by any organization or agency. The independence of this research is a crucial factor in affirming its impartiality, as it has been conducted without any external sway.
- **Ethical Approval and Consent to Participate:** The data provided in this article is exempt from the requirement for ethical approval or participant consent.
- **Data Access Statement and Material Availability:** The adequate resources of this article are publicly accessible.
- **Authors Contributions:** The authorship of this article is contributed equally to all participating individuals.

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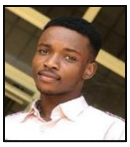

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