Effect of Groundnut Shell Addition on the Physical and Mechanical Properties of Kankia Clay for Sustainable Lightweight Refractory Applications

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ABSTRACT

This work focused on the effect of groundnut shell addition to some refractory properties of Kankia clay located in Nigeria. Kankia clay and groundnut shell were prepared, milled, sieved to particle size of 0.25 mm and mixed with additions of groundnut shell of 0, 5, 10, 15, 20 and 25 wt%. The raw materials were moulded under constant compaction pressure and then dried and fired at 1000°C for 6 h. The clay is an aluminosilicate material and the X-ray fluorescence analysis confirmed that the contents of SiO_2 and Al_2O_3 were 68.11 wt% and 17.545 wt%, respectively, which makes it suitable for refractory applications. The groundnut shell was found to have a high CaO content (30.2 wt %), while its organic fraction served as the primary pore-forming component through decomposition and burnout during firing. Results of the tests revealed that apparent porosity increased as groundnut shell content increases and alternatively, bulk density, particle density and cold compressive strength decreased as groundnut shell content increases. The control specimen produced the highest value of cold compressive strength (17.31 MPa), whereas the addition of groundnut shell enhanced the green compressive strength, with the optimum obtained at 5 wt% addition. The increase in porosity and decrease in density was explained on the basis of the thermal decomposition of the lignocellulosic components of the groundnut shell that created more pores in the structure. The results indicate that Kankia clay has good refractory characteristics and by incorporating controlled amount of groundnut shell, lightweight insulating refractory with desirable properties can be produced.

Keywords: Kankia Clay, Groundnut Shell, Refractory Properties, Agricultural Waste Utilization, Apparent Porosity, Lightweight Insulating Refractories.

INTRODUCTION

Refractory materials are materials that are capable of withstanding applications at high temperatures, such as furnace linings, due to their resistance to high-temperature exposure, thermal shock, and chemical deterioration (Oryina et al., 2025). The main constituents of these special materials are oxides of high melting points that include SiO_2, Al_2O_3, MgO, Cr_2O_3, and ZrO (Ibrahim et al., 2018). The most appropriate refractory material is mostly non-metallic mineral that has a unique heat capacity that involve very high melting point, thermal insulation, heat accumulation and resistance to thermal shock. Thus, refractories are commonly applied in the lining of furnaces (Obaje et al., 2013). They are suitable for use in metallurgical applications due to their excellent properties such as their ability to resist heat at elevated temperature (Dansarai et al., 2020). In Nigeria, clay is one of the many mineral resources available which has been of great importance since the prehistoric periods. Altough there are significant occurrences of clay deposits within several parts of the country, there is a low production of refractory materials locally (Oryina et al., 2025). The properties and oxide composition of the clays that are used in manufacturing refractory materials are important in the performance of refractories. The natural clays, however, may not satisfy the high demands of refractories applications unless suitable modifications are made (Keke et al., 2025).

Many indigenous Nigerian clays possess limitations such as high porosity, impurities, variation in composition, low mechanical strength and poor thermal shock resistance, which restrict their direct application as refractory materials (Folorunso et al., 2021; Balogun et al., 2021). These shortcomings necessitate the modification of local clays through the incorporation of suitable additives capable of improving their physical, chemical and thermo-mechanical properties while maintaining low production costs.

Previous studies have shown that the incorporation of additives such as alumina, bauxite, fly-ash and agricultural waste can to a large degree, improve the output of these clay-based refractories (Balogun et al., 2021; Hossain & Roy, 2019; Adediran et al., 2021; Keke et al., 2025). Therefore, to improve the physical, chemical and thermal properties of these clays, proper blending with good additives is important (Dansarai et al., 2020).

Despite these reported improvements, relatively few studies have investigated the suitability of Kankia clay reinforced with groundnut shell for the development of lightweight insulating refractory materials. Furthermore, limited information is available regarding the combined influence of using groundnut shell as reinforcement on the refractory properties of Kankia clay. Consequently, the potential of this abundant and sustainable agricultural waste as a pore-forming additive for refractory production has not been adequately established.

The outer covering or peels of groundnut seed is called groundnut shell. They are those easily attainable agro–industrial waste which are slow to decompose in nature. Groundnut shells are most often, buried or burnt which affect the natural environment. With the backdrop of pollution caused by this waste, the notion of researching to see how this waste can be converted into meaningful product emerged (Nathan, 2020).

Consequently, the objectives of this study are to:

i. Prepare the Kankia clay and the groundnut shell powder for refractory production.

ii. Use XRF to determine the oxides present in the raw materials.

iii. Produce blends of Kankia clay and groundnut shell samples.

iv. Evaluate the influence of groundnut shell addition on selected refractory properties.

The investigations of this research article will give insight into the potential use of GS to produce refractory bricks. The use of the aforementioned alternative raw material has the potential to lessen the environmental effect of traditional refractory brick production while providing a sustainable solution to the production of refractory bricks. The results obtained from this research can be used to advise future research and advancement in refractory brick production and provide a basis for further exploration of agricultural waste as a raw material for other industries.

MATERIALS AND METHODS

Sample Collection

Potter's clay samples of Kankia clay Katsina state, Nigeria were collected manually from the deposit for laboratory analyses through the Katsina state youth craft village (KYCV).

Kankia clay source is roughly located between latitude 12.5580472°N and 7.8102644°E in Kankia Local Government which is approximately 50kilometres Southeast of Katsina city.

The groundnut shell was obtained from the local market of Jikamshi village under Musawa local government of Katsina state.

Sample Preparation

The clay and groundnut shell samples were air dried for 72 hours, crushed finely and ground using ball milling machine. They were then sieved using a 0.25 mm mesh size in order to obtain finer particles for several reasons which include improved packing density, enhanced homogeneity and smoother surfaces. The clay and groundnut shell samples were then mixed together at varying percentages of groundnut shell (0, 5, 10, 15, 20, 25) wt%. The samples were blended for 3 minutes to create a dry mixture that is homogeneous. 5wt% water was added to the mixture before moulding. The clay and groundnut shell samples were then moulded using 15 g for each sample and the 15 g was poured into the steel mortal ensuring that it is evenly distributed and properly compacted with a hydraulic press. Samples with 16mm length and 25mm in diameter were obtained as shown in figure 1. One batch of the samples was immediately used for the green compression strength test. The other compacted samples were air-dried for a day and then at a temperature of 110º C, the samples were dried in the oven for 6 hours. An electric muffle furnace was used to slowly fire the dried bricks to a temperature of 1000º C and maintained for 6 hours to allow for sintering and fusion of particles. Thereafter, slow cooling was done to room temperature.

The mixing ratio of the clay and the agricultural waste (GS) is presented in table 1.

Figure 1 Compacted samples

Figure 2 Fired Samples

Table 1 Different Varieties of Samples Prepared to Test for Refractory Properties

Samples	Compaction load (KN)	Clay content (g)	Groundnut shell content (g)	Water content (%)
A	15	15	0.00	5
B	15	14.25	0.75	5
C	15	13.5	1.5	5
D	15	12.75	2.25	5
E	15	12	3	5
F	15	11.25	3.75	5

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Chemical Characterization

The oxide composition of Kankia clay and groundnut shell were determined using X-ray Flourescence is analytically controlled and aimed to detect and measure elemental composition in the samples of solid materials, powders and liquids (Nathan, 2020).

Sample testing

The following tests were carried out in order to determine the characteristics of the fired samples: Apparent Porosity, Bulk Density, Cold Compressive Strength, and Particle Density.

Apparent Porosity

In refractory materials, the apparent porosity is measured as the mean percentage of the open pores, relative to the total volume of the refractory material. High porosity materials tend to have lower thermal conductivity because air possesses low thermal conductivity, which makes them highly insulating (Oryina et al., 2025).

The apparent porosity was calculated as shown in equation 1 (Ibrahim et al., 2018).

$$P = \frac{W-D}{W-S} \times 100 \qquad (1)$$

W; soaked weight,

D; dried weight, and

S; suspended weight respectively.

Bulk Density

Bulk Density is a critical variable used in determining how well, burnt clay bricks will perform (Maafa et al., 2023). The weight per unit volume of a refractory material including the volume of open pore is referred to as bulk density (Muhammadu, 2013). Equation (2) was used to calculate the bulk density of the samples (Maafa et al., 2023);

$$\text{Bulk Density} = \frac{\text{mass of fired bricks (g)}}{\text{volume of fired bricks (cm3)}} \qquad (2)$$

Compressive Strength

This is important in ascertaining the structural reliability in the presence of mechanical stresses, in materials like refractory linings that are exposed to massive weight in industry. Refractories that have good compressive strength are less prone to breaking under pressure, thereby elongating the lifespan of the materials (Keke et al., 2025). Equation 3 was used to calculate the compressive strength of the samples (3)

$$C = \frac{\text{P (N)}}{\text{A (mm2)}} \qquad (3)$$

P; the maximum load, and

A; the average cross-sectional area of the fired bricks (Maafa et al., 2023).

Particle Density

Particle density describes the density of the solid mineral phases that make up the refractory. Changes in particle density may indicate differences in mineralogical composition, impurities, or the incorporation of additives (Dekker, 2004). In this method, the sintered samples were crushed and the resulting particles were weighed using a sensitive electronic weighing machine. They were then displaced in to a graduated cylinder along with a known volume of water. The volume of the particles was then determined from the apparent volume change of the liquid.

RESULTS AND DISCUSSION

Chemical Composition (XRF analysis)

The elemental constituents of Kankia clay and groundnut shell were determined using XRF spectroscopy with the results summarized in table 2 and table 3. This analysis confirmed that Kankia Clay has a silica content of 68.11%, an amount which falls within the range of silica present in fireclays ~ 46-69% as reported by (Yami & Umaru, 2007). This high silica content validates the effectiveness of the clay as a refractory material and by implication can be used as a fireclay in terms of SiO_2 content. The characterized clay sample can be described as moderate alumina clay (17.55%). The combined SiO_2 and Al_2O_3 content of approximately 86wt% indicates that the clay has an aluminosilicate composition consistent with clay-based refractory. In contrast, the groundnut shell is rich in CaO (30.2%). During firing, the organic constituents decompose and burn out, generating pores within the ceramic matrix, thereby reducing density and improving the insulating properties of the refractory. The oxide composition of Kankia clay compares favourably with those reported for several Nigerian refractory clays. Its silica content is comparable to Amaiji, Ikere, Bosso and Doko clays (Chima et al., 2017; Ijagbemi, 2002; Muhammadu, 2013), while its alumina content is relatively higher than those reported for Amaiji, Nguzu, Gur, , Nguzu, Gur, Yamarkumi, Ifon Iseyin and Mubi Vintim clays (Chima et al., 2017; Yami & Umar 2007; Folorunso et al., 2014; Nathan 2020).

The interplay between the aluminosilicate clay matrix and the pore-forming groundnut shell provides a chemical basis for the observed trends in bulk density, apparent porosity and compressive strength, demonstrating the potential of Kankia clay for the production of lightweight insulating refractory materials.

XRF analysis yields information about the chemical or oxide composition of the raw materials, but it does not give any information regarding the mineralogical phases or the association of the phases in the raw materials. The absence of such characterization is a represents a limitation of the present study.

Table 2 Composition of Kankia clay

Oxide	SiO_2	Al_2O_3	MgO	Fe_2O_3	K_2O
Composition	68.11	17.55	1.741	3.852	1.84

Table 3 Composition of groundnut shell

Oxide	CaO	Al_2O_3	SiO_2	K_2O	P_2O_5
Composition	30.2	7.6	15.4	9.6	8.0

Green Compressive Strength

Green compressive strength determines whether the refractory can be safely handled, transported, stacked, and loaded into the kiln without cracking or permanent deformation. Figure 3 shows the graph of green compressive strength plotted against the % addition of groundnut shell. It can be observed that, the green compressive strength of the sample increases with increasing groundnut shell percentage. It can also be seen that the highest green compressive strength (5.7MPa) was obtained with sample B additive which is 5% groundnut shell and the lowest compressive strength was obtained with sample A which is 100% Kankia clay. It can be concluded that the increase in groundnut shell percentage increases the green compressive strength of the clay sample.

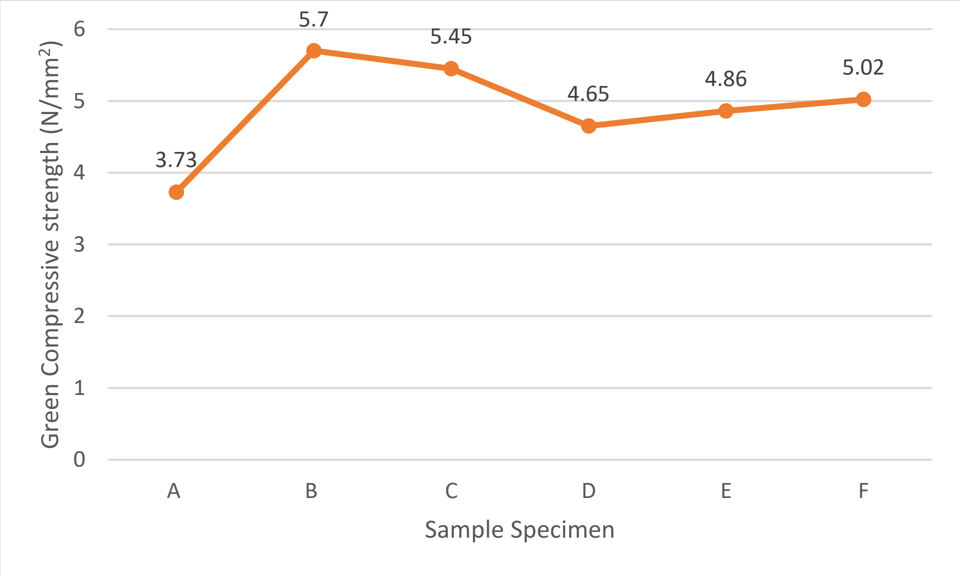

Figure 3 Green compressive strength (N/mm^2)

Apparent Porosity

As can be observed in figure 4, the increase in apparent porosity, is attributed to the thermal decomposition and volatilization of the lignocellulosic constituents of the groundnut shell during firing. The burnout of these organic phases is expected to generate interconnected pore networks within the clay matrix, reducing the bulk density while improving the insulating capability of the refractory. Similar pore-forming behavior has been reported for other agricultural residues used in the production of refractories (Adeyemi et al., 2025; Abdel Hafez et al., 2022; Maafa et al., 2023; and Onyia et al., 2023).

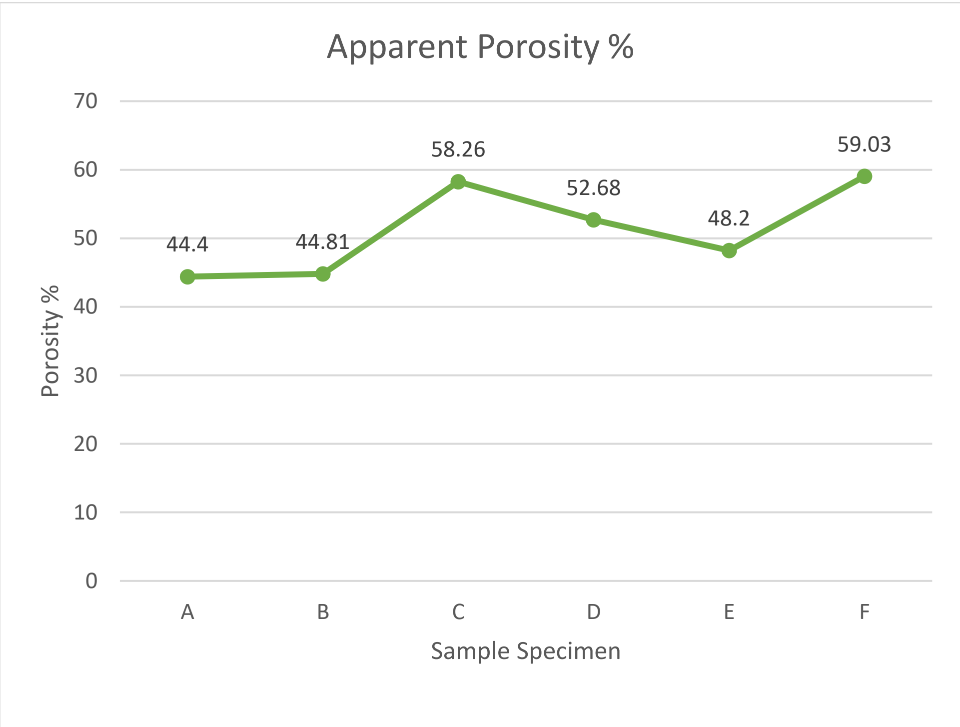

Figure 4 % Apparent Porosity

Bulk Density

The variation of bulk density for the fired refractory specimens with the addition of groundnut shell is shown in figure 5. This decrease in bulk density is attributed to the increase in apparent porosity and linear shrinkage. The decomposition of organic matter during firing is the reason for the decrease in density which increases the pore size (Maafa et al., 2023). This phenomenon agrees with some research conclusions that noted the correlation between bulk density, apparent porosity and linear shrinkage and hence, stated that denser clay materials are less porous and likely to shrink as reported by (Chima et al., 2017). This suggests a characteristic of a high lightweight refractory material that can be used in applications that prioritize thermal insulation and weight reduction (Adeyemi et al., 2025).

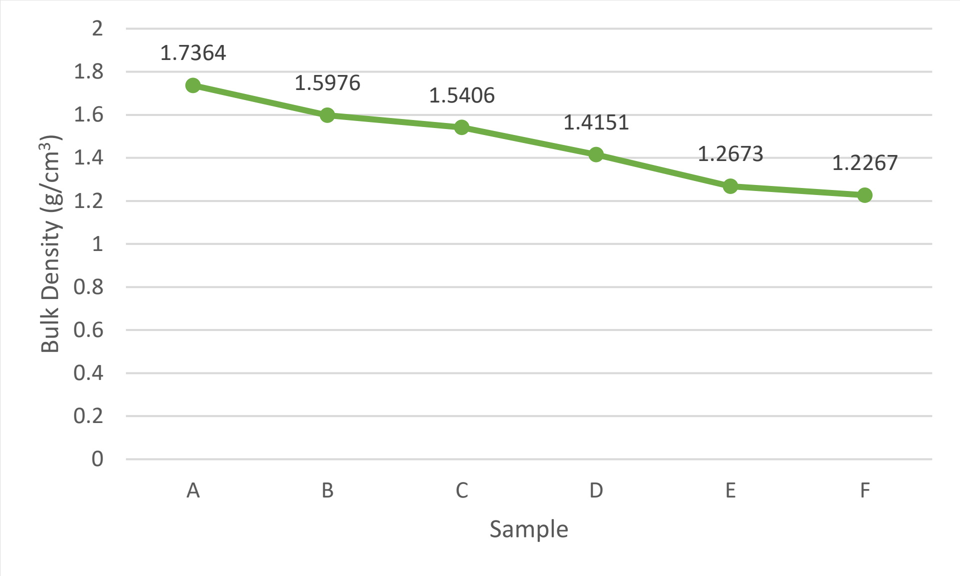

Figure 5 Bulk density (g/cm^3)

Compressive Strength

The cold compressive strength of the fired refractory specimens is given in figure 6, after the samples have been fired to 1000°C. The minimum standard cold compressive strength that a refractory clay should have is 15 MPa. The strength developed by a clay material is influenced by factors such as composition, ramming pressure, firing temperature, particles size, and the amount of water content (Muhammadu, 2013). Sample A has the highest compressive strength (17.31 MPa), while sample F, which has the highest percentage of groundnut shell (25%) has the lowest strength (0.83MPa). In biomass modified refractory materials with agricultural waste additives, the increased porosity has always been found to be accompanied by a decrease in mechanical strength (Nathan, 2020; Onyia et al., 2023). In general, the more vitrified the brick is, the denser it is, and the higher the cold compressive strength (Maafa et al., 2023)

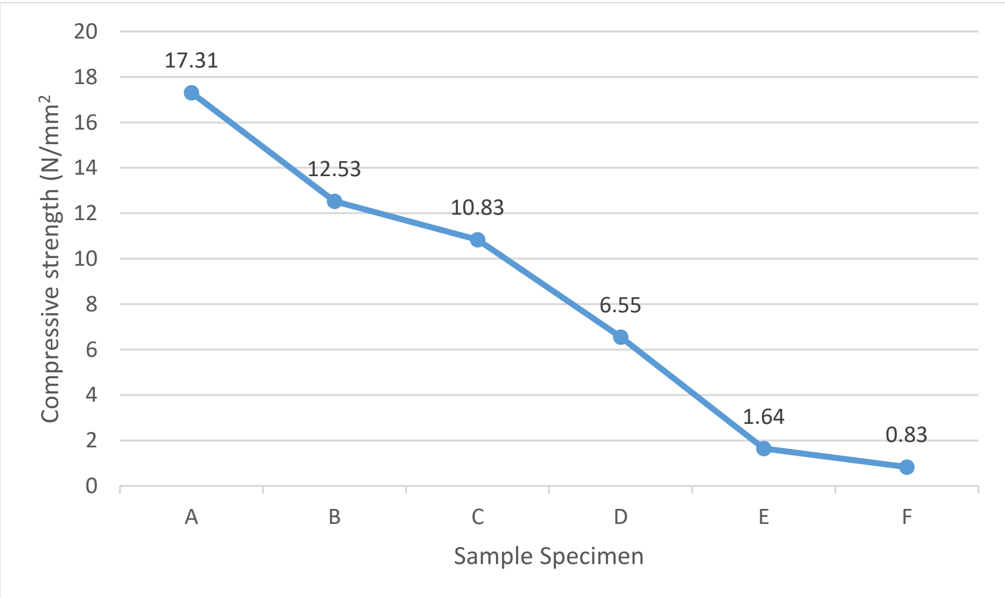

Figure 6 Cold Compressive strength (N/mm^2)

Particle Density

Figure 7 shows the result of the particle density assessment of the compounded clay bricks. This is an important property because it influences the transportation or handling of a refractory material (Omotoyinbo & Oluwole (2008)). It can be seen from figure 6 that the particle density values of the samples varied between 2.4463g/cm^3 and 3.6907g/cm^3. The overall decrease in particle density can be attributed to the thermal decomposition of the lignocellulosic constituents of the groundnut shell during firing. The burnout of cellulose, hemicellulose and lignin generated additional voids within the refractory matrix, thereby reducing the proportion of solid material per unit volume. The relatively higher particle density recorded for sample C suggests that a moderate addition of groundnut shell may have promoted improved particle packing.

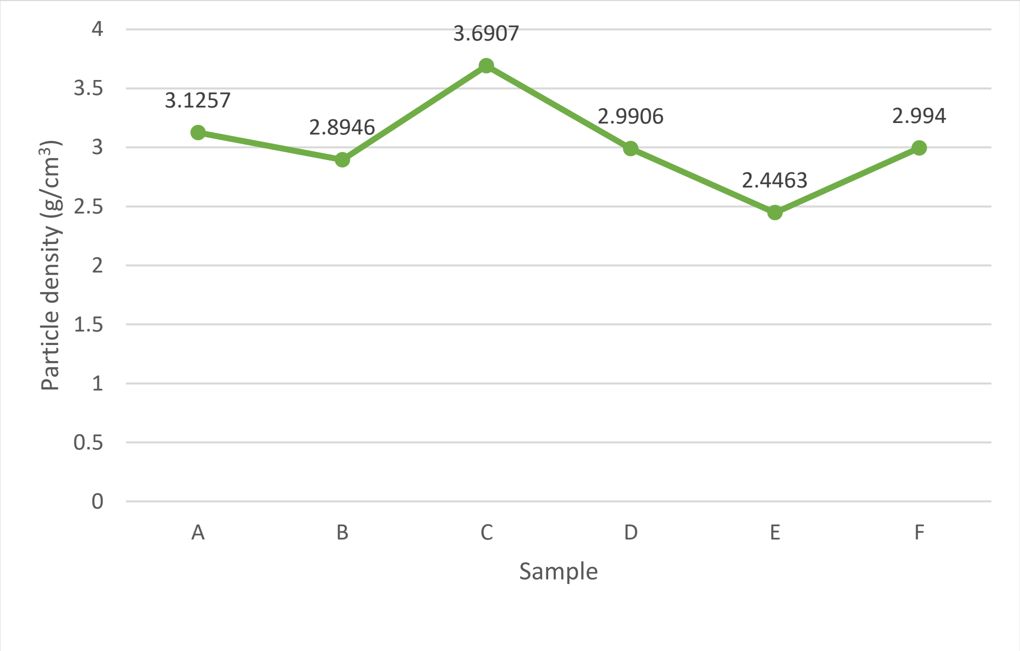

Figure 7 Particle Density (g/cm^3)

CONCLUSION

This study demonstrates that addition of agricultural waste of groundnut shells to aluminosilicate matrix of Kankia clay is an effective method of upgrading a dense fireclay to a highly functional, sustainable lightweight insulating refractory. The chemical composition of the clay and groundnut shell was determined using XRF technique and it confirmed that Kankia clay is a high aluminosilicate clay (17.55 wt% Al_2O_3, 68.11 wt% SiO_2) suitable for high temperature application and the groundnut shell is rich in CaO (30.2 wt%). During firing at 1000°C, the biomass's lignocellulosic components (cellulose, hemicelluloses, and lignin) underwent a systematic phase change and were replaced by an interconnected network of micro-voids in the solid matrix. The pore forming process had a significant effect on the physical properties of the sintered composites, with apparent porosity gradually increasing from 44.4% to 59.03% and bulk density decreasing linearly from 1.7364g/cm^3 to 1.2267g/cm^3. From a mechanical perspective, the cold compressive strength of the fired bricks exhibited a structural trade-off with biomass addition, getting lower than the conventional 15 MPa standard when the porosity rises while the green compressive strength showed the unique trend of rising with the addition of biomass up to 5.7 MPa. This inverse relationship between the porosity and mechanical resilience is in line with the literature for agricultural-residues refractory literature. The increase in apparent porosity would indicate that the thermal conductivity is likely to decrease as the presence of air-filled pores will decrease the overall ability to transfer heat through the ceramic matrix.. The present study did not measure thermal conductivity, however. Thus, higher biomass loadings are detrimental to high-load structural capacity, whereas moderate formulations provide a good balance between applications where structural capacity is more important (e.g., furnace backup lining) and thermal containment and dead-weight reduction is more critical. Overall, this study demonstrates that groundnut shell can serve as an effective sustainable pore-forming additive for Kankia clay, provided that the wt% addition is carefully controlled to achieve an optimal balance between thermal insulation and mechanical performance. Future studies should focus on higher firing temperatures, detailed phase characterization, thermal conductivity, refractoriness under load and thermal shock resistance to further establish the industrial application of the developed refractory material.

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