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DEVELOPMENT OF SUSTAINABLE LOW-CARBON CLAY BRICKS USING RICE HUSK AND GROUNDNUT SHELL ADDITIVES

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ABSTRACT

The increasing demand for sustainable construction materials has encouraged the use of agricultural waste in clay brick production. This study investigates the effects of rice husk ash (RHA) and groundnut shell ash (GSA) on the physical and mechanical properties of fired clay bricks. Rice husk and groundnut shell samples were calcined at 800 °C, pulverized, and sieved before incorporation into the clay matrix at varying proportions of 0+10 wt.%. The molded bricks were air-dried for 48 h and cured for 7 days. Compressive strength, bulk density, and failure load tests were conducted on the developed bricks. Results showed that increasing RHA content reduced compressive strength and density due to increased porosity. However, the combined RHA-GSA additive exhibited superior performance, achieving a maximum compressive strength of 4.20 MPa within the recommended range for structural clay bricks. The findings demonstrate the potential of RHA and GSA as sustainable additives for lightweight and eco-friendly clay brick production.

Keywords: Clay bricks, Rice husk, Groundnut shell, Sustainability, Construction

1.0 INTRODUCTION

Clay bricks remain one of the most utilized construction materials due to their durability, low production costs, heat resistance, and the accessibility of raw materials [1]. Fired clay bricks are widely utilized in residential and infrastructure projects worldwide owing to their advantageous mechanical characteristics and long service life. The conventional brick production process involves moulding, drying, and firing of clay materials at a high temperature to achieve the desired structural integrity [1,2]. The heated clay brick industry is extensively utilized; yet, it is linked to significant environmental issues, including elevated energy consumption, loss of natural clay supplies, and greenhouse gas emissions during the firing operations. Consequently, current research activities have focused on incorporating waste elements from industrial and agricultural sources into clay matrices as a sustainable method to enhance brick characteristics and reduce environmental effects [2–5]. Agricultural by-products such as rice husk ash (RHA), groundnut shell ash (GSA), sawdust ash, fly ash, and wood ash have received much attention because of their pozzolanic properties and silica-rich compositions. These materials may alter the microstructure of clay bricks, adjust porosity, decrease density, and enhance thermal insulation performance [6]. Rice husk ash is recognized for its elevated amorphous silica content, which imparts pozzolanic reactivity, whereas groundnut shell ash comprises oxides that enhance particle bonding in ceramic matrices [3,7]. Previous studies reported that the incorporation of agricultural waste additives can improve sustainability and reduce brick production cost [5,8,9]. However, the addition of too many additives may increase the porosity and reduce the compressive strength, hence limiting the structural performance. To the best of the researcher's knowledge, no recorded work has revealed the synergistic application of rice husk ash and groundnut shell ash as combined additions in clay brick production. Hence, this study aims to investigate the synergistic effect of rice husk ash and groundnut shell ash on the mechanical, physical, and microstructural properties of clay bricks. The main focus is on compressive strength, bulk density, and failure load properties to assess the suitability of the developed bricks for sustainable building applications.

2.0 MATERIALS AND METHODS

2.1 Raw Materials

The clay used in this study was obtained from the bank of the River Benue, Makurdi, Nigeria. Rice husk was collected from a rice mill located in Wurukum, Makurdi, while groundnut shells were sourced from North Bank Market, Makurdi. The collected materials were cleaned to remove impurities before use.

2.2 Preparation of Rice Husk Ash and Groundnut Shell Ash

The rice husk and groundnut shell samples were separately calcined in a furnace at 800 °C to obtain ash products. After cooling to room temperature, the ashes were pulverized and sieved using a 1.18 mm mesh sieve to achieve a uniform particle size distribution.

2.3 Preparation of Clay Brick Specimens

Clay brick specimens were prepared using three additive formulations: rice husk ash (RHA), groundnut shell ash (GSA), and a combined rice husk ash-groundnut shell ash mixture (RHA-GSA).

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The additives were incorporated into the clay matrix at replacement levels ranging from 0-10 wt.%. For each composition, 560 g of clay was mixed with the required quantity of additive and 500 mL of water to obtain a homogeneous mixture. The resulting paste was molded into rectangular specimens of dimensions 10 × 15 × 30 cm. The molded bricks were air-dried for 48 h and subsequently cured for 7 days before testing.

2.4 Characterization

The prepared brick specimens were characterized for compressive strength, bulk density, and failure load. Compressive strength testing was carried out using a Universal Testing Machine (UTM, Model 1000/RF-2) in accordance with standard testing. The prepared brick specimens were characterized for thermal stability analysis, compressive strength, bulk density, failure load, and microstructure. Compressive strength testing was carried out using a Universal Testing Machine (ZwickRoell, Ulm, Germany), in accordance with standard testing procedures. The scanning electron microscopy (SEM) (JEOL JSM-6010LV) was used for the microstructure analysis

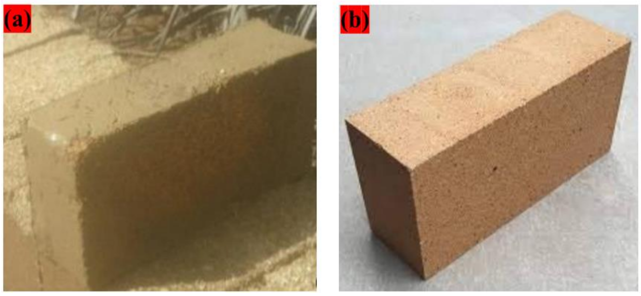

Figure 1: Manufactured burned clay bricks: (a) pre-firing, (b) post firing.

3.0 RESULTS AND DISCUSSION

3.1 Thermogravimetric (TG) and derivative thermogravimetric (DTG) analysis

The thermogravimetric (TG) and derivative thermogravimetric (DTG) analyses were conducted to study the thermal stability of the clay, as shown in **Figure 2.** The figure reveals multiple stages of heat degradation. An initial mass loss of 0.92 % was seen between 147 and 386 oC with a heat effect of 35.10 j/g, which can be attributed to the evaporation of thermally absorbed water and the removal of crystal lattice clay from clay minerals. The second thermal event occurred between 545 °C and 850 °C with a heat impact of 42.32 J/g and further weight loss 0.87% associated with dehydroxylation, breakdown of oxides, and quartz transformation. The progressive loss of mass with the increase in temperature supports the stabilization of the structure and the creation of the glassy phase during firing, in line with the processes of dehydration and mineral transformation reported in literature [10,11]

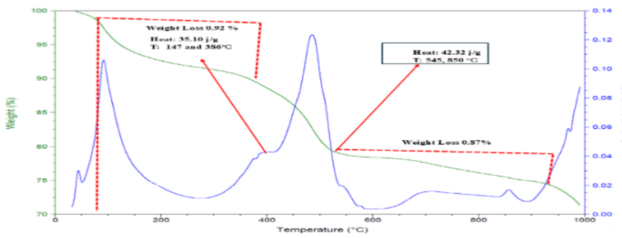

Figure 2: Differential thermal analysis of clay

3.2 Compressive strength

The compressive strength values of the fabricated clay brick specimens are displayed in **Table 1 and Figure 3.** The compression rate was set at 8 mm/min in accordance with the specifications of standard NF XP P13-901 [11], resulting in specimen failure within 1 to 2 min. The findings demonstrate that the inclusion of rice husk ash markedly affected the mechanical properties of the bricks. An elevation in RHA concentration led to a gradual decline in compressive strength, attributable to enhanced pore formation and diminished bulk density within the clay matrix.

Table 1: Average compressive strengths of RHACB, GSACB, and RHAGSACB

Samples	RHACB	GSACB	RHAGSAB
Block 1	1.93	1.15	1.69
Block 2	1.18	1.04	1.82
Block 3	1.04	1.02	2.00
Block 4	1.19	1.06	2.08
Block 5	1.12	1.11	2.20
Average±*SD*	1.09±0.36	1.08±0.05	2.00±0.21

Among the single-additive formulations, the RHA specimens demonstrated an average compressive strength of 2.09 MPa, whereas the GSA specimens revealed an average value of 1.90 MPa. The diminished strength noted in GSA-modified bricks may be linked to the existence of surplus calcium oxide and sulfate chemicals, which could negatively impact particle adhesion during burning [12]. In contrast, the hybrid RHA-GSA additive system exhibited enhanced mechanical performance, with a maximum compressive strength of 4.20 MPa. This number is within the advised compressive strength range for typical structural clay bricks (4-6 MPa) [10], suggesting that the incorporated additives enhanced the structural integrity of the bricks. The higher performance can be ascribed to superior particle packing and synergistic pozzolanic interactions between the ash components and the clay matrix.

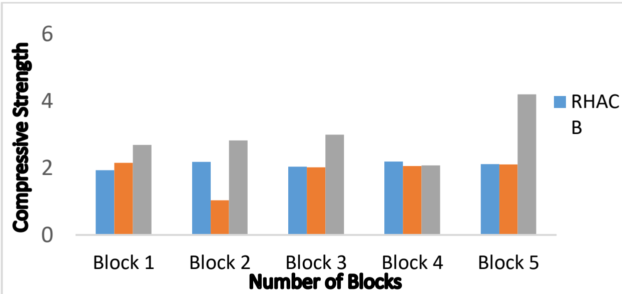

Figure 3: The Compressive Strengths of Clay Brick Additives

3.3 Bulk Density Analysis

The bulk density values of the fired clay brick specimens containing rice husk ash (RHA), groundnut shell ash (GSA), and the combined rice husk ash–groundnut shell ash additive (RHAGSA) are presented in Table 2 and Figure 4. The results revealed that the incorporation of agricultural waste additives significantly influenced the density of the developed clay bricks [10]. Among the investigated formulations, the RHAGSA specimens exhibited the highest average bulk density of 1.52 g/cm³, whereas the RHA and GSA specimens recorded average densities of 1.44 g/cm³ and 1.46 g/cm³, respectively. The relatively higher density observed in the RHAGSA specimens suggests improved particle packing and a more compact internal

Table 2: Average bulk densities of RHACB, GSACB, and RHAGSACB

Samples	RHACB	GSACB	RHAGSACB
Block 1	1.52	1.52	1.35
Block 2	1.48	1.38	1.42
Block 3	1.38	1.46	1.84
Block 4	1.45	1.48	1.43
Block 5	1.38	1.46	1.58
Average ±*SD*	1.44±0.062	1.46±0.035	1.52+0.020

The lower density observed in RHA specimens is attributed to increased pore formation caused by the combustion of organic matter during firing [9]. In contrast, the combined RHAGSA additive produced a more compact structure with improved particle packing and densification. The relatively low bulk density of the developed bricks compared with conventional concrete indicates their potential suitability for lightweight and sustainable construction applications [13].

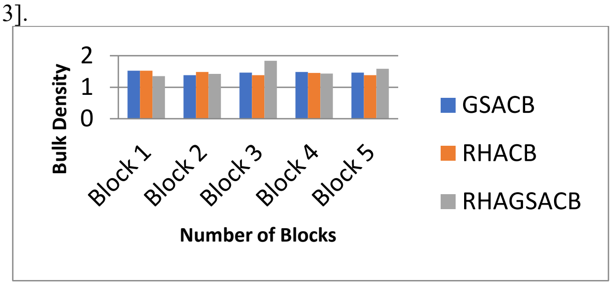

Figure 4: Bulk Densities of the Clay Brick Additives

3.4 Failure Load Analysis

The results of the failure load of RHA, GSA, and RHAGSA were examined using calculations of mean and standard deviation in Microsoft Excel, shown in **Table 3** and **Figure 5**. The specimens demonstrated the greatest load-bearing capacity, with the fifth sample registering a maximum failure load of 40400±4743 N. The higher performance of the RHAGSA bricks is ascribed to superior particle packing, augmented bonding, and increased microstructural stability [1,14].

Table 3: Comparing the Failure Load of the Additives

Samples	RHACB	GSACB	RHAGSACB
Block 1	24000N	20000N	34000N
Block 2	22000N	24000N	38000N
Block 3	21000N	22000N	40000N
Block 4	23000N	25000N	44000N
Block 5	23000N	23000N	46000N
Average±*SD*	22600±1140	22800±1924	40400 ±4743

The diminished failure loads noted in the RHA and GSA specimens may be attributed to enhanced pore development during firing, which compromised structural integrity [14]. The findings indicate that the synergistic integration of rice husk ash and groundnut shell ash can enhance the mechanical properties of fired clay bricks and may offer a sustainable approach for developing lightweight construction materials utilizing agricultural waste resources.

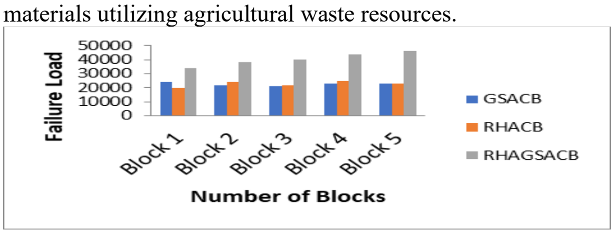

Figure 5: Failure Load of the Additives

3.5 Microstructure Analysis

The surface morphology and microstructural characteristics of clay-based brick samples incorporating rice husk ash (RHA), groundnut shell ash (GSA), and their hybrid combinations (RHAGSA) were analyzed using Scanning Electron Microscopy (SEM), as illustrated in Figures 6 (a-d). Figure 6(a) illustrates the morphology of the control group clay sample, characterized by compactness and density, exhibiting minimal microcracks and porosity, which suggests robust particle bonding and enhanced compressive strength [15]. The RHA-modified sample in Figure 6(b) exhibited a loose, highly porous structure with irregular, fragmented particles, indicating insufficient densification and reduced compressive strength due to an increase in voids and sites for crack propagation [16]. The GSA sample exhibited finer and more uniformly dispersed particles, resulting in enhanced packing density and reduced porosity, which contributed to structural stability and mechanical interlocking **(Figure 6(c)). Likewise**, the RHAGSA hybrid sample in Figure 6(d) demonstrated superior particle contact, partial pore filling, and increased bonding properties relative to the RHA sample, while some agglomeration and residual pores were noted. The SEM results indicate that compressive strength is significantly influenced by the compactness of the microstructure, particle dispersion, and reduction of pores within the clay brick matrix [17].

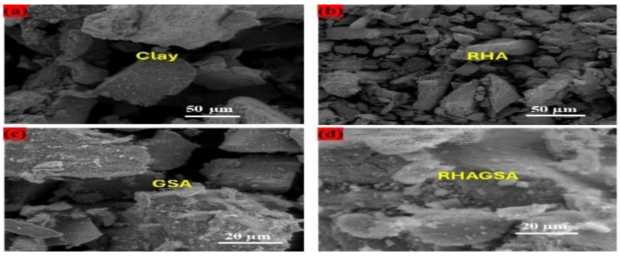

Figure 5: SEM micrographs of clay brick samples illustrating the surface morphology of (a) pure clay, (b) rice husk ash (RHA)-modified clay, (c) groundnut shell ash (GSA)-modified clay, and (d) hybrid rice husk ash and groundnut shell ash (RHAGSA)-modified clay bricks at varying magnifications.

4. CONCLUSIONS

The compressive strength obtained from the agro-waste additives (Rice Husk Ash and Groundnut Shell Ash) used for clay bricks production was below the recommended average of clay bricks (4.00MPa-6.00MPa). However, studies have shown that the chemical properties of this additive are comparable to those of cement. The mixture of rice husk and groundnut shell (RHGSA) ash used for clay brick production resulted in a higher compressive strength and bulk density when compared to the other additives (RH & GS). This result is in agreement with that of Sutas *et al*. (2012), who studied the Effect of Rice Husk and Rice Husk Ash to Properties of Brick at a temperature of 800 ˚C [18]. This study, therefore, has identified the efficacy and potency of the combined additives for a durable clay brick manufacture.

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