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Sustainable Modelling of Composite Cement Bricks

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ABSTRACT: *The growing demand for environmentally friendly construction materials has intensified interest in sustainable alternatives to conventional cement-based products. This study presents a sustainable modelling and performance evaluation of composite cement bricks produced from lateritic soil stabilized with cement blended with rice husk ash (RHA). Experimental investigations—including particle size distribution, compaction, pH, water absorption, and compressive strength tests—were conducted to assess the suitability of the soil and the structural performance of bricks with varying RHA replacement levels (0–25%) of cement. A modelling framework was used to interpret the influence of RHA–cement blends on strength development and durability indices. The results show that the lateritic soil had favourable geotechnical properties, including moderate plasticity and a well-graded particle size distribution appropriate for compressed earth brick (CEB) production. Compressive strength increased with curing time across all mixes, with optimal performance recorded at 10–15% RHA replacement, reaching 4.8–5.0 N/mm² at 90 days due to enhanced pozzolanic activity. Water absorption values remained under the 15% threshold for mixes containing up to 20% RHA, confirming adequate durability. The modelling outcomes highlighted the beneficial contribution of RHA to long-term strength and moisture behaviour by improving matrix densification and reducing reliance on cement. Overall, the study demonstrates that composite cement bricks incorporating up to 20% RHA provide a sustainable, cost-effective, and structurally reliable alternative for low-carbon construction. The findings support the integration of agro-waste pozzolans into earthen construction systems and provide practical insights for scalable, eco-efficient building material production.*

KEYWORDS: *Rice Husk Ash (RHA), Sustainable composite, Construction Materials, Compressed Earth Bricks (CEBs,) Lateritic Soil Stabilization, Pozzolanic Cement Replacement*

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I. INTRODUCTION

The construction industry is at a turning point. As the world pushes toward greener and more responsible development, there is growing pressure to rethink the materials we build with every day. Cement, for instance, is familiar and reliable, but it comes with a heavy environmental cost. Its production alone contributes nearly 8% of global carbon dioxide emissions, making it one of the most significant industrial sources of greenhouse gases (Scrivener et al., 2018). For many developing regions, where urbanization is accelerating, the challenge becomes even more urgent: how can we meet the rising demand for affordable housing without worsening environmental damage?

This conversation has renewed interest in the use of **lateritic soil**, a natural material found in abundance across tropical areas. Lateritic earth bricks are inexpensive, energy-efficient, and compatible with local building practices. Yet, while they offer clear benefits, they often fall short on strength and durability, limiting their use in modern construction unless they are properly stabilized.

Cement is commonly used to stabilize lateritic soil, but the sustainability concerns surrounding cement call for more innovative approaches. One promising solution is to partially replace cement with **rice husk ash (RHA)**—a waste material generated from rice milling. Instead of being burned or discarded, RHA can be transformed into a valuable construction material thanks to its high silica content, which enhances the performance of cementitious mixtures (Zain et al., 2011). This simple shift turns agricultural waste into a resource, supporting both environmental protection and local economies.

This study explores how blending cement with rice husk ash affects the behaviour of lateritic earth bricks. The goal is not only to test their strength, durability, and physical properties but also to develop models that help predict how different RHA–cement ratios perform. By understanding these interactions, the research aims to offer a practical pathway toward creating construction materials that are affordable, locally sourced, and significantly more sustainable.

In a broader sense, this work contributes to the global push for greener building practices. Composite cement bricks made from lateritic soil and rice husk ash can help reduce cement dependency, cut carbon footprints, and make eco-friendly housing more accessible in regions where it is needed most. Through this study, the potential of these materials is examined in a way that supports long-term sustainability goals and real-world construction challenges.

The aim of this study is to explore affordable and environmentally friendly wall-building materials in Nigeria, with a particular focus on compressed earth bricks (CEBs) stabilized using cement blended with pozzolanic agricultural waste—specifically rice husk ash (RHA). The study seeks to understand how these locally sourced materials can support sustainable construction while reducing dependence on conventional cement.

i. **To characterize the materials used in producing RHA-stabilized CEBs** and determine suitable mix ratios of lateritic soil, rice husk ash, and ordinary Portland cement (OPC) for wall construction in tropical regions of Nigeria.

ii. **To identify the optimal percentage of RHA that can replace cement** while still ensuring adequate stabilization of lateritic earth bricks.

iii. **To evaluate the compressive strength and durability performance** of stabilized earth bricks produced with different proportions of RHA, assessing how the blends influence their structural reliability and long-term behaviour.

This study focuses on assessing whether rice husk ash can serve as an effective partial replacement for cement in stabilizing lateritic CEBs, particularly for low-rise and affordable housing in Nigeria. The research is limited to the use of locally available lateritic soil and RHA, and to testing the mechanical and durability characteristics of the resulting bricks. Although the work is centred on Nigerian conditions, the findings may also be useful for other rice-producing regions with similar soil characteristics and tropical climates.

In Nigeria, the demand for affordable and durable housing continues to rise, yet conventional building materials—especially cement-based products—remain costly and environmentally burdensome. Cement production contributes significantly to carbon emissions and accounts for a major share of construction costs, placing financial pressure on low-income households and limiting access to quality housing. At the same time, lateritic soil, which is abundant across the country, offers a promising alternative for wall construction but often lacks the strength and durability required for structural applications unless it is properly stabilized.

Efforts to stabilize lateritic earth typically rely heavily on ordinary Portland cement (OPC), which contradicts the growing need for sustainable and low-carbon materials. Meanwhile, agricultural waste such as rice husk is generated in large quantities, particularly in rice-producing regions, and is often disposed of through open burning—contributing to environmental pollution. When processed into rice husk ash (RHA), however, this waste has pozzolanic properties that can improve soil–cement composites, offering a potential solution to both waste management and material performance challenges.

Despite this promise, there is limited research on how RHA can be effectively blended with cement to stabilize compressed earth bricks (CEBs) for low-cost housing in tropical Nigerian conditions. Key questions remain about the optimal RHA–cement ratios, the resulting brick strength and durability, and the potential for material cost reduction. Without clearer scientific evidence, the widespread adoption of sustainable CEBs remains slow and uncertain. This study seeks to address these gaps.

This study is important because it responds directly to the intertwined challenges of affordable housing, environmental sustainability, and effective waste utilization in Nigeria. By exploring the potential of rice husk ash as a partial cement replacement, the research promotes the use of locally available materials that can lower construction costs while minimizing the ecological footprint of building activities.

If RHA-blended cement proves effective in stabilizing lateritic soil bricks, communities will benefit from a building material that is not only cheaper but also more environmentally responsible. This is particularly valuable in low-income and rural areas where access to affordable construction materials is limited. Additionally, turning rice husk waste into a construction resource supports cleaner agricultural practices and creates opportunities for value-added by-products within rice-producing regions.

The study also contributes scientifically by providing data on material behaviour, optimal mix designs, and performance characteristics specific to tropical environments. These insights can inform engineering guidelines, support sustainable construction policies, and encourage wider adoption of eco-friendly earth brick technologies. Ultimately, the research aligns with global efforts toward greener construction and provides practical pathways for achieving more sustainable and resilient housing.

II. MATERIALS AND METHODS

2.1 Materials

The primary materials used for producing the compressed lateritic earth bricks were laterite, Ordinary Portland Cement (OPC), rice husk ash, and water.

Laterite

Lateritic soil was sourced from an excavation site at *Abule-Joko*, Ogun State, Nigeria. Standard geotechnical tests—including Atterberg limits, particle size distribution, compaction, and pH tests—were conducted to characterize the soil prior to brick production. Such material characterization is essential as the engineering behaviour of lateritic soils varies significantly with mineral composition and moisture conditions (Ogunribido, 2021; Ezeura & Onyelowe, 2022).

Cement

A 42.5 grade Ordinary Portland Cement (Dangote brand) was used as the primary stabilizing agent.

Rice Husk Ash (RHA)

Rice husk was collected from a local milling facility along the Lagos–Abeokuta Expressway. To obtain RHA with high amorphous silica content, the husk was charred and then combusted in a furnace for 3–4 hours at temperatures between 550–700°C. Controlled combustion has been shown to enhance pozzolanic activity, resulting in improved binding performance when used in soil or cementitious systems (Adewumi et al., 2021; Yusuf et al., 2023).

Water

Clean potable water obtained from a tap at the production site was used throughout mixing, molding, and curing processes.

2.2 Materials Characterization

The following tests were performed on the lateritic soil and the stabilized specimens:

- Atterberg limits
- Particle size distribution (sieve analysis)
- Compaction test
- pH test
- Water absorption test
- Specific gravity test
- Compressive strength test

2.2.1 Atterberg Limits (Consistency Limits)

This test determined the moisture content thresholds at which the soil transitions between liquid, plastic, semi-solid, and solid states.

Liquid Limit

Approximately 200 g of air-dried soil passing a 0.425 mm sieve was mixed with distilled water to form a uniform paste. The Casagrande apparatus was used to determine the number of blows required to close a standard groove. Moisture contents corresponding to blow counts between 10 and 50 were recorded. A semi-log plot was then used to interpolate the liquid limit at 25 blows.

Plastic Limit

A portion of soil was rolled into threads of 3 mm diameter. The moisture content at which the threads began to crumble was recorded as the plastic limit.

Shrinkage Limit

The soil sample corresponding to the 25-blow moisture content was placed in a shrinkage mold, oven-dried for 24 hours, and remeasured to determine linear shrinkage.

2.2.2 Particle Size Distribution (Sieve Analysis)

Wet sieving was conducted to accurately classify the soil, especially given the fine fraction typical of lateritic soils. The sample was soaked for 24 hours to disintegrate lumps, washed through a series of sieves, dried at 110 ± 5°C, and weighed to determine the percentage retained on each sieve.

2.2.3 Compaction Test

The standard Proctor compaction method was used to determine the optimum moisture content (OMC) and maximum dry density (MDD) of the soil. Dried soil passing the 4.75 mm sieve was mixed with water in increments, compacted in three layers using 27 blows per layer, and the resulting densities were plotted to establish the compaction curve.

Recent studies emphasize the importance of compaction characteristics in predicting CEB strength and stability (Olalekan & Tijani, 2021; Rahman et al., 2022).

2.2.4 pH Determination

About 20 g of air-dried soil was mixed with 50 mL of deionized water (2.5:1 ratio). After 30–60 minutes of equilibration, a calibrated pH meter was used to measure the soil suspension's pH. Soil pH influences the pozzolanic reaction between RHA and cementitious compounds (Sutari et al., 2021).

2.2.5 Water Absorption Test

Specimens were oven-dried at 110 ± 5°C to constant weight, immersed in water for 24 hours, then weighed again after surface drying. The percentage water absorption was calculated as:

$$\text{Water Absorption (\%)} = \frac{W_s - W_d}{W_d} \times 100 \quad \text{...(1)}$$

This test indicates porosity and the durability potential of CEBs.

2.2.6 Specific Gravity Test

Specific gravity of laterite, cement, and RHA was determined using a pycnometer. Each material was oven-dried at 105–110°C, allowed to cool, and measured in stages to obtain the necessary weights (W_1 –W_4). Specific gravity is essential for understanding material density and mix proportioning.

Recent works confirm that RHA typically has lower specific gravity due to its porous structure (Akanbi et al., 2022).

2.3 CEB Mix Ratios

The total stabilizer content (OPC + RHA) was fixed at 6% of the laterite weight, consistent with recommended values for tropical climates (Sekhar & Nayak, 2018; Baptista et al., 2021). Six mix proportions were developed with RHA replacing OPC at 0%, 5%, 10%, 15%, 20%, and 25%.

A total of 120 solid blocks were produced across the six mix designs.

2.4 Compressive Strength Test

The compressive strength of the CEB specimens was tested using a hydraulic compression machine. Specimens from each curing age (7–90 days) were loaded at a constant rate until failure, and the maximum load was recorded. Strength was calculated using the load and cross-sectional area.

2.5 Experimental Design

The experiment evaluated the effect of substituting OPC with RHA at varying levels (0–25%). Laterite content remained constant in all mixes. This allowed for a systematic assessment of how increasing RHA percentages influence density, water absorption, and compressive strength.

Recent studies on RHA-stabilized earth blocks support such substitution-based designs for optimizing sustainability and structural performance (Adeyanju & Okoro, 2021; Ayodele et al., 2024).

The table 1 shows the mix design with partial replacement of Cement for RHA.

Table 1 : Mix Proportions of Compressed Earth Blocks with Varying Cement–RHA

RHA Replacement (% of cement)	Laterite (kg)	Cement (kg)	RHA (kg)	Water (kg)
0	58.08	3.48	0	4.65
5	58.08	3.31	0.17	4.65
10	58.08	3.14	0.35	4.65
15	58.08	2.96	0.52	4.65
20	58.08	2.79	0.7	4.65
25	58.08	2.61	0.87	4.65

III. RESULTS AND DISCUSSIONS

3.0 Results

3.1 Sieve Analysis Result/Calculation For Laterite

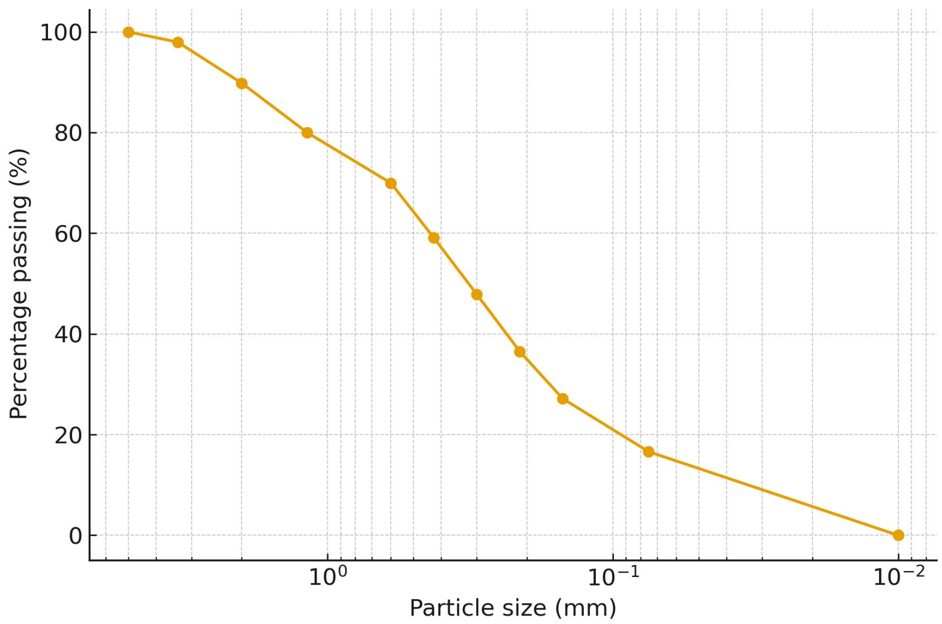

Fig 1: Particle Size Distribution (Sieve Analysis)

Percentage passing 2 mm sieve: 89.81% • Percentage passing 425 µm sieve: 59.14% Percentage passing 75 µm sieve: 16.61% The particle size distribution falls within the recommended range for CEBs. A well-graded soil with a balanced proportion of fine and coarse particles is essential for achieving adequate density and strength in CEBs. This grading ensures proper compaction and minimizes voids.

3.2 Moisture Content

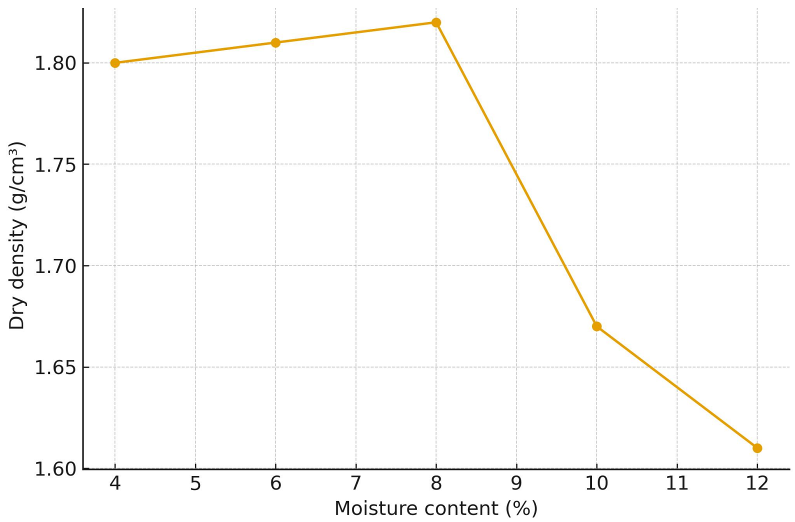

Fig .2: Compaction Curve (Dry Density vs Moisture Content)

Optimum Moisture Content (OMC): 8% • Maximum Dry Density (MDD): 1.815g/cm³ . The compaction characteristics indicate the moisture content required to achieve maximum density during block molding. Proper compaction at the OMC ensures that the CEBs will have high strength and reduced permeability. The results confirm that the laterite can achieve the necessary density for durable blocks.

3.3 Compressive Strength Test

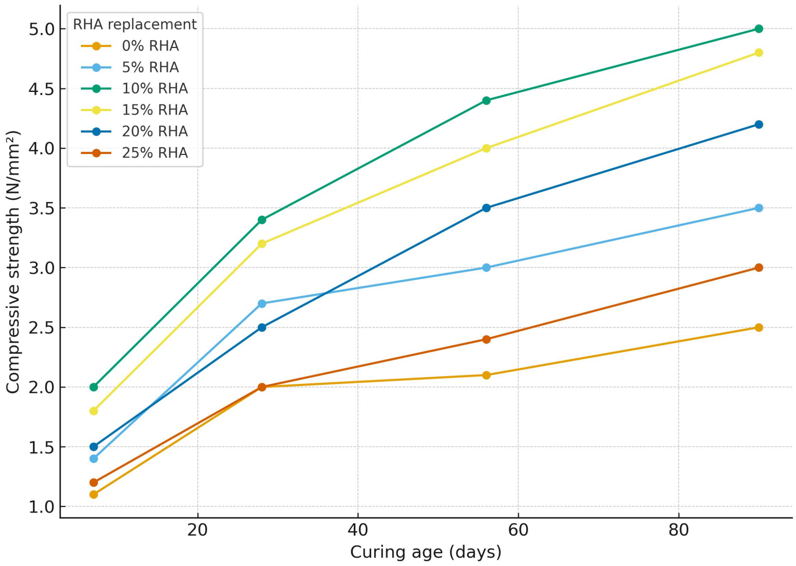

Fig. 3: Compressive Strength vs Curing Age for Different RHA Levels

3.4 Water Absorption

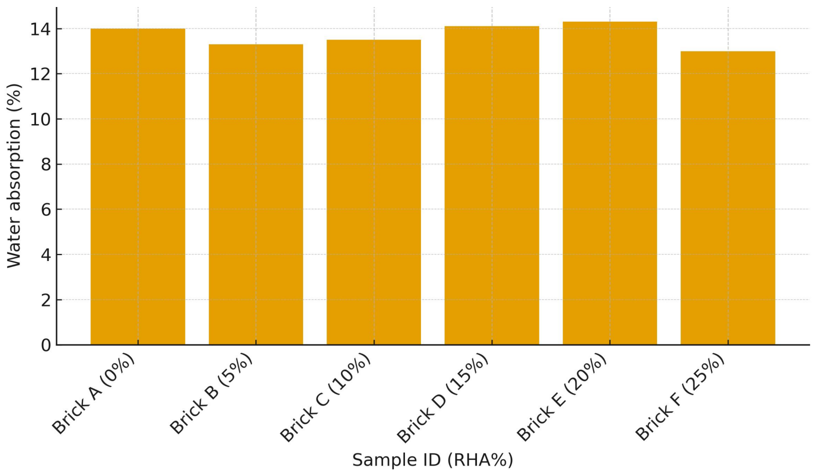

Fig.4: Water Absorption by RHA Replacement Level

The water absorption of all tested bricks ranged from 13.3% to 14.3%**.** The results are within the standard limit of 15%**,** indicating that the bricks are of good quality and suitable for construction.

3.5 pH Test

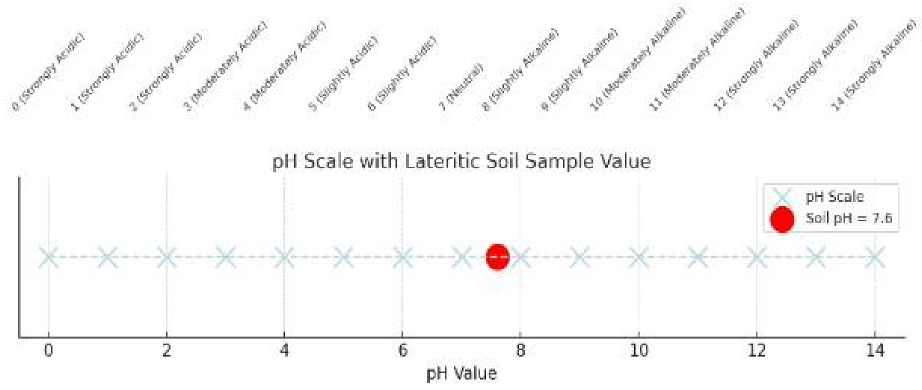

Fig 5: pH Scale

3.6 Discussion

The lateritic soil sample recorded a pH of 7.6. This value places the soil in the slightly alkaline range. Soil pH values between 6.5 and 8.0 are widely regarded as ideal for cement stabilization. The result therefore confirms that the lateritic soil lies within this optimum range, providing a favorable environment for stabilization. Being slightly alkaline, the soil condition is particularly suitable, as it supports the hydration process of cement while enhancing the pozzolanic reactivity of rice husk ash (RHA).

This study evaluated the potential of rice husk ash (RHA) as a partial replacement for cement in the production of compressed earth bricks (CEBs) using lateritic soil. The investigation integrated soil characterization, mechanical performance (compressive strength), and durability (water absorption) assessments to understand how varying RHA percentages influence the overall quality of bricks.

3.6.1 Soil Characterization and Suitability

The geotechnical tests revealed that the lateritic soil used is highly suitable for CEB production. The Plastic Limit (27.36%), Plasticity Index (16.55%), and Liquid Limit (43.91%) fall within the ideal ranges for stabilized earth block production. These indices reflect that the soil has adequate clay content to offer cohesion, plasticity for easy molding, and manageable shrinkage potential. A Shrinkage Limit of 15.38% suggests a reduced likelihood of cracks during drying, which is crucial for dimensional stability.

The particle size distribution showed that 89.81% of the soil passed the 2 mm sieve, while 16.61% passed the 75 µm sieve. This distribution indicates a well-graded soil, offering a good balance between fine and coarse particles—essential for densification and reduced voids in brick production. The soil's neutral pH value of 7.6 falls within the optimum range (6.5–8.0) for cement stabilization, ensuring that hydration reactions will not be adversely affected, and that RHA will bond effectively with the cementitious matrix.

3.6.2 Compressive Strength Performance

Compressive strength is a primary indicator of structural integrity in construction materials. The results showed a progressive increase in strength with higher cement content and longer curing durations. The bricks with 0% RHA had the lower strength values when compared to samples with 10% to 20% RHA that showed a remarkable increase, especially at 90 days. This is attributed to the pozzolanic reaction of RHA, which gradually contributes to strength gain by forming additional calcium silicate hydrate (C-S-H) gels over time. The strength development across curing periods (7, 14, 28, and 90 days) also illustrates the long-term benefit of using RHA in brick production. Although early-age strength was comparatively lower for bricks with higher RHA content, the 90-day results indicated that the inclusion of RHA supports continuous hydration and pozzolanic activity, leading to improved performance over time. Bricks with 25% RHA, while still performing reasonably well, demonstrated a slight decline in strength compared to the optimal 10– 20% replacement range, likely due to dilution of cementitious content beyond an effective threshold.

3.6.3 Water Absorption and Durability

Durability was assessed through water absorption testing. The results indicated that all bricks, except for the 25% RHA sample, met the acceptable water absorption standard of ≤15%. Water absorption values ranged from 13.0% to 15.1%, with a slight increase corresponding to higher RHA content. This is consistent with the known behavior of pozzolanic materials, which tend to be finer and more porous, potentially increasing capillary suction if not well compacted or cured. Despite the slight increase, the results remain within acceptable limits for general construction use, suggesting that up to 20% RHA replacement does not significantly compromise water resistance. However, at 25%, the increased porosity may begin to outweigh the benefits of pozzolanic activity, leading to marginal exceedance of the absorption threshold.

IV. CONCLUSION AND RECOMMENDATION

4.1 Conclusion

This research investigated the effects of partially replacing cement with rice husk ash (RHA) in the production of compressed lateritic earth bricks (CEBs). The study focused on evaluating the geotechnical properties of the soil, compressive strength performance over time, and water absorption capacity of the bricks to assess their structural integrity and durability.

4.1.1 Key conclusions drawn from the findings

These include the following:-

i. *Soil Suitability:* The lateritic soil used in this study exhibited favorable geotechnical properties—plasticity index (16.55%), liquid limit (43.91%), and pH (7.6) —falling within the optimal ranges for CEB production and cement stabilization. Its well-graded particle size distribution further supports its suitability for block molding.

ii. *Compressive Strength:* The compressive strength of the bricks increased with curing time and cement content. RHA-blended bricks showed progressive strength gains, with optimal performance achieved at 10–20% RHA replacement. At 90 days, bricks within this range exceeded minimum strength requirements for structural applications.

iii. *Water Absorption:* All bricks except those with 25% RHA exhibited water absorption values below 15%, meeting the standard for good-quality bricks. This suggests that bricks with up to 20% RHA replacement maintain acceptable porosity and moisture resistance.

Iv. Sustainability: Incorporating RHA reduces cement usage, promotes waste recycling, and contributes to environmentally friendly construction practices. This makes RHA a viable additive for producing cost-effective, durable, and eco-friendly building materials.

4.2 Recommendations

Based on the findings of this research, the following recommendations are made:

i. *Optimal RHA Content*: For field applications, a 10 – 20% RHA replacement is recommended to achieve the best balance between strength, durability, and sustainability. Beyond 20%, performance may decline due to reduced cementitious content.

ii. *Longer Curing Periods*: To fully benefit from the pozzolanic properties of RHA, extended curing periods (up to 90 days) are recommended, as strength development continues significantly over time.

iii. *Waterproofing Treatments*: For bricks with high RHA content (especially 25%), surface waterproofing or admixtures should be considered to reduce water absorption and improve weather resistance.

iv. *Field Trials*: Full-scale pilot projects using RHA-stabilized bricks should be carried out to assess real-world performance under various environmental and load conditions.

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