Effect of Sesame Stalk Ash Replacement on Compressive Strength and Density of Cement-Stabilized Compressed Earth Bricks Produced from Yobe Lateritic Clay

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ABSTRACT

This study investigated the effect of sesame stalk ash (SSA) replacement on the compressive strength and dry density of cement-stabilized compressed earth bricks (CEBs) produced from Yobe lateritic clay. A base content of 10% cement was utilized for stabilization, with SSA incorporated as a partial cement substitute at 0%, 10%, 20%, and 30% replacement levels. The bricks were produced via manual compaction and moist-cured for 7, 14, 28, and 56 days prior to mechanical testing. Experimental results indicated that the control mixture (0% SSA) achieved compressive strengths of 1.88, 2.36, 3.06, and 4.04 MPa at 7, 14, 28, and 56 days, respectively. Incorporating 10% SSA yielded marginal strength reductions, recording values of 1.82, 2.26, 3.00, and 3.95 MPa across the respective curing ages. Higher replacement levels (20% and 30% SSA) exhibited a more pronounced decline in strength, dropping to minimum values of 1.67 MPa (7 days) and 3.57 MPa (56 days) at 30% SSA. Conversely, brick density consistently decreased with higher SSA content; at 28 days, densities recorded were 2.13, 2.03, 1.98, and 1.93 g/cm³ for 0%, 10%, 20%, and 30% SSA, respectively. Notably, the 10% SSA mixture retained approximately 98% of the control compressive strength at later curing ages (28 and 56 days). The findings demonstrate that a moderate 10% SSA replacement can successfully minimize cement demand and reduce brick self-weight while maintaining structural performance thresholds suitable for sustainable masonry applications.

Keywords: Agricultural waste, cement stabilization, compressive strength, density, lateritic clay, sesame stalk ash.

INTRODUCTION

Compressed earth bricks are produced by compacting suitable soil, with or without stabilizers, into masonry units. Their use can reduce dependence on fired clay products because production does not require the high-temperature firing stage. The engineering performance of compressed earth bricks depends on soil characteristics, compaction, stabilizer content, moisture and curing conditions. Recent research confirms that lateritic soils can be suitable for compressed earth brick production when their physical and mechanical characteristics are properly assessed. A 2022 study on lateritic soils in Cameroon, for example, reported that soil properties, density, stabilizer content and water absorption were important factors governing compressed earth brick performance (Darman *et al*., 2022).

Cement is widely used to stabilize lateritic soils because hydration products improve bonding between soil particles. However, increasing cement use has cost and environmental implications. Partial replacement of cement with agricultural residues is therefore being investigated as a route to reduce cement demand and provide useful applications for agricultural waste. Research on rice husk ash-cement compressed stabilized earth bricks has demonstrated the feasibility of combining agricultural ash with cement in earth-brick production (Olumodeji *et al*., 2023).

Sesame stalk ash is a less studied agricultural ash. Sesame production generates stalk residues after harvesting, and controlled processing can convert these residues into an ash containing silica, alumina, iron oxide and calcium oxide. Sulaiman et al. (2022) investigated sesame straw ash as a cement substitute and reported that curing age and ash content influenced strength and setting characteristics. More recent work by Sulaiman et al. (2025) further examined the characterization and optimization of sesame straw ash in cement-based materials.

Despite the established potential of agricultural wastes in soil stabilization, limited published evidence addresses the specific application of sesame stalk ash (SSA) in compressed earth bricks (CEBs) produced from lateritic clay. This research gap is particularly critical in northern Nigeria, where lateritic soils and sesame residues are highly abundant yet underutilized. Therefore, this study evaluates the impact of SSA replacement levels and curing age on the compressive strength and density of cement-stabilized compressed earth bricks manufactured from Yobe lateritic clay. The primary objective is to determine the optimal blending proportions that satisfy structural engineering standards, thereby providing a sustainable, cost-effective, and eco-friendly masonry alternative for the region.

MATERIALS AND METHODS

A. Materials

The primary materials utilized in this investigation comprised Yobe lateritic clay soil, Portland cement, sesame stalk ash (SSA), and water. The lateritic clay was sourced from Yobe State, Nigeria. Sesame stalks were harvested locally, processed, and converted into ash under controlled, optimal burning temperatures before undergoing pulverization and sieving through a standard mesh. Ordinary Portland Cement (OPC) was employed as the base stabilizing binder.

B. Experimental Variables

Four distinct SSA replacement levels were systematically evaluated: 0%, 10%, 20%, and 30%. The control mixture was formulated with a constant base of 10% cement and 0% SSA. For the remaining stabilized mixtures, SSA served as a partial substitute for the cement content at the designated percentages. The experimental matrix was designed to isolate the effects of increasing SSA replacement levels while maintaining the principal stabilization baseline uniform.

A cement content of 10% by weight was deliberately selected as the stabilization baseline for the present study. This selection falls within the 5% to 10% cement stabilization range reported by the Nigerian Building and Road Research Institute (NBRRI, 2024). NBRRI states that its cement-stabilized earth blocks are produced from laterite soils stabilized with 5% to 10% cement (NBRRI, 2024). The selection of 10% cement was further supported by Okere (2017), who investigated soilcrete blocks stabilized with 6%, 8% and 10% cement and reported the highest 28-day compressive strength of 2.15 N/mm² at 10% cement. Therefore, 10% cement was adopted in the present study as a consistent stabilization baseline for evaluating the effect of sesame stalk ash (SSA) replacement. The cement content was maintained at 10% for all mixtures, while SSA replacement was varied at 0%, 10%, 20% and 30%. The mixture containing 10% cement and 0% SSA served as the control, while the other mixtures were used to assess the effect of increasing SSA replacement."

C. Brick Production and Curing

The raw materials were precisely proportioned by mass, thoroughly dry-mixed to achieve homogeneity, moistened with an optimized amount of water, and consolidated using a manual mechanical brick-molding press. The reason is that manual compaction was used because the research was laboratory based, and recommend future field-scale studies using mechanized compaction.The freshly molded compressed earth bricks (CEBs) were left undisturbed for 24 hours under laboratory ambient conditions before the commencement of a systematic moist-curing regime. Specimen testing was conducted at curing intervals of 7, 14, 28, and 56 days.

D. Compressive Strength

Compressive strength tests were executed to evaluate the structural resistance against axial loading and monitor structural development across the curing duration. In accordance with standard testing guidelines specified in BS EN 772-1, three duplicate specimens were crushed per mixture at each predefined curing age, and the computed arithmetic mean was utilized for data interpretation.

E. Density

The dry density of the bricks was calculated by dividing the measured mass of the cured specimens by their physical dimensions. This physical property was tracked to analyze the combined impact of SSA replacement levels and curing age on the compact structural matrix and unit mass of the final CEBs.

RESULTS AND DISCUSSION

A. Compressive Strength Evaluation

The experimental values documenting the variations in compressive strength over time are organized and presented in Table 1.

Table 1. Compressive Strength of CEBs at Varied SSA Replacements and Curing Ages with Standards

SSA replacement (%)	7 d (MPa	14 d (MPa	28 d (MPa	56 d (MPa	NBRRI and ARSO
0%	1.88	2.36	3.06	4.04	≥1.65–2.5 MPa
10%	1.82	2.26	3	3.95	Satisfactory
20%	1.79	2.19	2.76	3.72	Satisfactory
30%	1.67	2.11	2.67	3.57	Satisfactory

As illustrated in Table 1, the compressive strength properties increased progressively across all testing intervals for every investigated mixture. For instance, the control batch expanded from an early strength of 1.88 MPa at 7 days to an ultimate value of 4.04 MPa at 56 days. Concurrently, the 10% SSA mixture developed from 1.82 MPa to 3.95 MPa within the identical timeline. Continuous strength gain was similarly observed in the 20% and 30% SSA batches, concluding at 3.72 MPa and 3.57 MPa at 56 days, respectively. This continuous trend highlights the uninterrupted development and maturation of the calcium silicate hydrate (C-S-H) cementitious matrix provided by hydration processes during curing.

Conversely, increasing the SSA replacement level within the matrix generated an overall reduction in compressive strength when measured at fixed intervals. At the standard 28-day benchmark, the control brick registered 3.06 MPa, whereas the values decreased to 3.00 MPa, 2.76 MPa, and 2.67 MPa for the 10%, 20%, and 30% SSA batches, respectively. Notably, the 10% SSA replacement dropped by a marginal 1.96% relative to the control, and by 56 days, it remained only 2.23% below the control (3.95 MPa versus 4.04 MPa). This minimal divergence demonstrates that a 10% SSA replacement maintains robust structural integrity, performing closely to the conventional control baseline.

This minimal divergence demonstrates that a 10% SSA replacement maintains robust structural integrity, performing closely to the conventional control baseline. Furthermore, when evaluated against regional regulatory standards, all the tested brick combinations at 28 days exceeded the minimum structural threshold of 2.0 MPa specified by the African Organisation for Standardisation (ARSO) in ARS 1333. Notably, the 10% SSA mixture achieved 3.00 MPa at 28 days, safely fulfilling the Nigerian Building and Road Research Institute (NBRRI) minimum parameter of 2.5 to 3.0 MPa for load-bearing masonry units, confirming its viability for local infrastructure development.

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The reduction in mechanical performance became more profound at higher replacement percentages (20% and 30%). At 28 days, the recorded reductions relative to the control were 9.80% and 12.75%, respectively. This systemic drop is fundamentally attributed to binder dilution, as increasing the ash fraction subsequently limits the volume of raw Portland cement available to undergo primary hydration reactions. Furthermore, this trend may reflect microstructural changes in particle packing configurations and an unequal chemical balance between the highly reactive mineral oxides in the ash and the primary cement hydration products.

This performance pattern aligns with the broader behavior documented in literature regarding SSA blended into cementitious binders. Sulaiman et al. (2022) established that curing duration strongly guides strength development, and that rising percentages of SSA alter the core mechanical characteristics of concrete mixtures. The current laboratory evaluation effectively extends those scientific observations to composite compressed earth masonry units utilizing local Yobe lateritic clay. Therefore, based strictly on the tested experimental matrix, 10% SSA is identified as the best-performing substitution percentage rather than a universally applicable optimum.

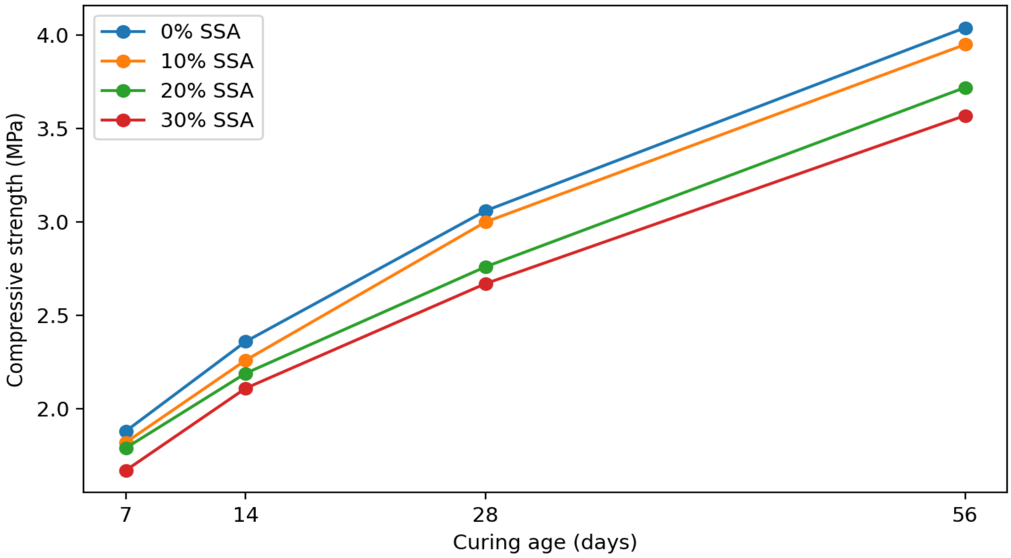

Figure 1. Compressive strength results for the control and SSA-stabilized samples.

Figure 1 provides the visual trend, while Table 1 provides the exact numerical values. The two formats are retained because the figure shows strength development with curing age and separation between replacement levels, while the table permits precise numerical comparison.

Increasing SSA replacement generally reduced compressive strength. At 28 days, strength decreased from 3.06 MPa for the control to 3.00, 2.76 and 2.67 MPa at 10%, 20% and 30% SSA. The reductions relative to the control were 1.96%, 9.80% and 12.75%, respectively. At 56 days, the corresponding reductions were 2.23%, 7.92% and 11.63%.

A. Relative Strength Retention Analysis

To further clarify the performance characteristics of the partial substitution, a strength retention assessment was executed (Table 2).

Table 2. Percentage Compressive Strength Retention Profile

SSA (%)	28-day strength (MPa)	Retention at 28 days (%)	Retention at 56 days (%)
0	3.06	100	100
10	3	98.04	97.77
20	2.76	90.2	92.08
30	2.67	87.25	88.37

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The analytical trends in Table 2 substantiate the structural viability of low-volume ash additions. At 28 days, the 10% SSA mix maintained an excellent 98.04% of the control strength, whereas the 20% and 30% alternatives retained lower values of 90.20% and 87.25%, respectively. Upon reaching 56 days of curing, the corresponding retention values shifted slightly to 97.77%, 92.08%, and 88.37%. The minimal strength loss identified exclusively within the 10% SSA configurations confirms that this specific substitution boundary yields the most stable and favorable mechanical retention.

C. Brick Density Trends

The progression of physical brick density across the experimental timeline is compiled in Table 3.

Table 3. Dry Density Profiles of Compressed Earth Bricks

SSA replacement (%)	7 days (g/cm³)	14 days (g/cm³)	28 days (g/cm³)	56 days (g/cm³)
0	2.1	2.09	2.13	2.16
10	2.03	2	2.03	2.06
20	2	1.95	1.98	2.02
30	1.95	1.87	1.93	1.97

The dry density of the CEBs decreased continuously as the percentage of SSA increased. At 28 days, density values contracted from 2.13 g/cm³ (control) down to 2.03 g/cm³, 1.98 g/cm³, and 1.93 g/cm³ across the 10%, 20%, and 30% SSA levels, respectively. By 56 days, these values adjusted to 2.16, 2.06, 2.02, and 1.97 g/cm³. This persistent reduction is consistent with physical principles, given the significantly lower specific gravity of agricultural sesame ash relative to heavy industrial Portland cement, which alters the cumulative particle framework and matrix weight.

By 56 days, these values adjusted to 2.16, 2.06, 2.02, and 1.97 g/cm³. This persistent reduction is consistent with physical principles... Crucially, all produced variants fell securely within the optimal physical density spectrum of 1.70 to 2.20 g/cm³ prescribed by both NBRRI and ARSO guidelines. This validates that the inclusion of agricultural sesame ash yields a lighter unit mass without dipping below the compaction minimums necessary for architectural structural stability.

This density response holds substantial engineering importance due to the direct correlation between material density and mechanical performance in stabilized, compacted earth media. Historic research on lateritic CEBs establishes that compaction efforts and resulting densities heavily dictate compressive values. For example, Darman et al. (2022) reported dry densities varying between 2.04 and 2.08 g/cm³ alongside high compressive strengths exceeding 5.0 MPa for specialized Cameroonian lateritic materials. While the bricks evaluated in this study match that density domain, they yield a lower overall strength profile. This divergence highlights regional differences in source soil compositions, stabilizer blending, manual compaction forces, and experimental laboratory environments; hence, cross-study numerical comparisons must be drawn cautiously.

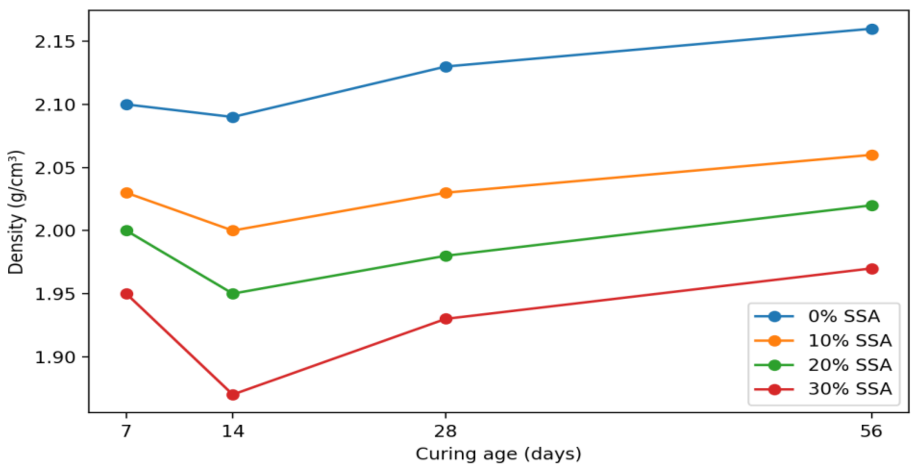

Figure 2. Density results for the control and SSA-stabilized samples.

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The figure shows that the control maintained the highest density, while higher SSA replacement generally produced lower density. This trend is consistent with the lower specific gravity of SSA reported in the wider study.

D. Interrelationship Between Strength and Density

A clear directional relationship exists between the mechanical and physical attributes of the bricks. The control specimens consistently paired the maximum dry density with peak compressive strength, whereas the 30% SSA units paired the lowest density with minimum strength. The 10% SSA configuration successfully occupied a highly practical intermediate balance, reducing unit density while capturing nearly full control strength. This shows that careful, low-volume agricultural ash substitution can effectively modify brick mass and reduce self-weight without imposing significant structural performance penalties.

This operational balance directly supports sustainable building movements. Utilizing a substitution level that preserves strength while minimizing cement content reduces the localized carbon footprint per unit brick. However, because this specific paper omits a formal life-cycle assessment (LCA) or cost-benefit ledger, explicit claims regarding exact regional monetary or environmental savings must be withheld until supplementary data is published.

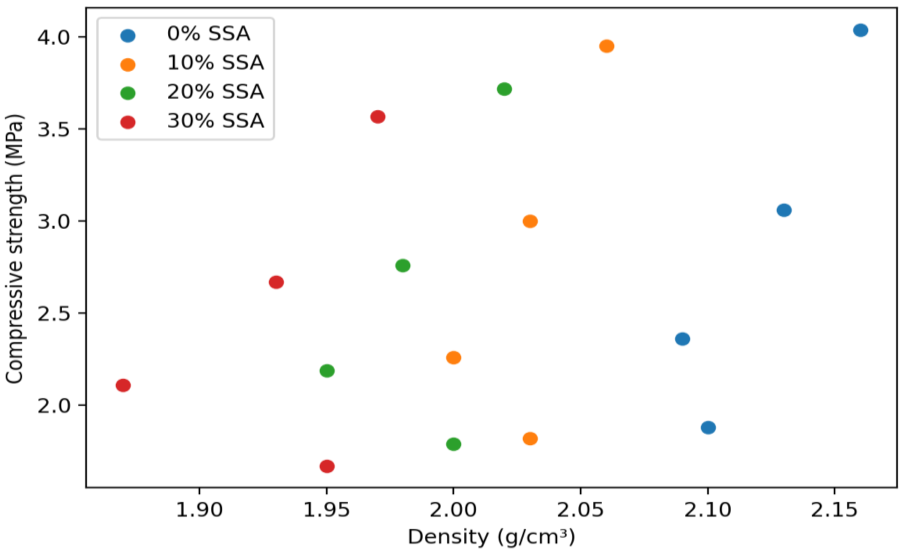

Figure 3. Relationship between density and compressive strength.

The relationship plot provides an additional interpretation of the two measured properties. Mixtures with higher density generally recorded higher compressive strength. The 30% SSA mixture occupied the lower-density and lower-strength region, while the 10% SSA mixture remained close to the control in strength with a lower density.

E. Research Significance

The primary academic contribution of this work is the direct engineering application of sesame stalk ash as a partial stabilizer in compressed earth bricks manufactured from Yobe lateritic clay. While general literature confirms the validity of using lateritic soil for masonry and explores standard agricultural wastes (like rice husks) in earth mixtures, this research provides empirical data validating the mechanics of SSA across four distinct curing ages. These findings explicitly isolate 10% SSA as a highly favorable blending baseline for local infrastructure optimization.

F. Experimental Limitations

The findings and trends derived from this study are strictly bound to the specific mineralogical profile of Yobe lateritic clay, the 10% cement baseline, the four selected SSA increments, and the specific laboratory curing configurations utilized. These outputs should not be broadly generalized across distinct global lateritic soils or variable agricultural burning processes without independent verification. Future long-term testing is necessary to evaluate wet-dry durability, severe chemical exposure, water absorption behavior, and in-field structural durability.

Although the present study focused on the compressive strength and density of cement-stabilized compressed earth bricks, future studies should quantify the economic and environmental implications of incorporating sesame stalk ash. Cost analysis should assess potential reductions in cement consumption, material processing, transportation, and brick production costs. Environmental assessment should also consider the benefits of utilizing agricultural waste and reducing dependence on cement, including potential reductions in waste disposal and greenhouse gas emissions. Such assessments would provide a more comprehensive evaluation of the sustainability and economic viability of SSA-stabilized compressed earth bricks for affordable housing applications in northern Nigeria

CONCLUSION

This investigation successfully evaluated the mechanical and physical impacts of replacing cement with 0%, 10%, 20%, and 30% sesame stalk ash (SSA) in 10% cement-stabilized compressed earth bricks manufactured from Yobe lateritic clay. The major experimental findings are summarized as follows:

1. Compressive strength advanced steadily with increasing curing age across all operational blends, whereas rising SSA substitution levels caused a gradual reduction in strength properties.
2. The 10% SSA mixture demonstrated the most favorable performance among the ash-blended specimens, achieving compressive strengths of 3.00 MPa at 28 days and 3.95 MPa at 56 days, thereby retaining 98.04% and 97.77% of the control brick’s strength properties, respectively.
3. Dry density consistently decreased as a function of increasing ash content due to the lower specific gravity of SSA, with the 10% replacement batch reducing unit mass to 2.03 g/cm³ at 28 days and 2.06 g/cm³ at 56 days compared to the control values of 2.13 g/cm³ and 2.16 g/cm³.

In conclusion, within the boundaries of the tested matrix, a 10% SSA replacement represents the most structurally viable and effective blending level. It successfully minimizes regional cement demand and reduces overall masonry self-weight while maintaining mechanical performance thresholds close to the conventional control baseline, offering a sustainable alternative for affordable housing development in northern Nigeria.

RECOMMENDATIONS

Further research should evaluate the 10% SSA mixture beyond 56 days to establish long-term strength development. Durability tests, including water absorption, abrasion, wetting-drying cycles and chemical exposure, should be reported separately to establish long-term service suitability. Field-scale production should be investigated to assess the effect of manufacturing conditions on strength and density. Cost and life-cycle assessments should also be conducted before recommending large-scale application.

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