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Carbon Footprint Reduction in Laterite-Based Stabilised Blocks by Using Rice Husk Ash in Partial Cement Replacement

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ABSTRACT: *The construction sector remains a significant source of CO_2 emissions worldwide due to activities such as cement production. The potential of rice husk ash (RHA), a by-product of agricultural waste, to partially substitute cement in stabilised laterite blocks for environmentally friendly walling applications is examined in this study. Lateritic soil was stabilised with 6% and 10% cement by dry weight of soil, with cement largely substituted by RHA at 0–40%. A cradle-to-gate embodied carbon assessment was considered to evaluate CO_2 savings relating to the partial replacement of RHA. Carbon footprint analysis indicated a decrease of up to ~40% in embodied CO_2 at 40% RHA replacement with cement when RHA is viewed as a zero-burden agricultural waste, and a 12–17% reduction when accounting for controlled combustion emissions. 10–20% RHA replacement appears to provide the best mix between mechanical performance, durability, and carbon reduction when experimental performance and environmental studies are combined. The findings support the feasibility of RHA as a low-carbon supplemental cementitious material for inexpensive, climate-responsive, and resource-efficient walling units in developing regions.*

KEYWORDS: *Rice Husk Ash (RHA), Lateritic soil, CO2 emissions and Carbon footprint*

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I. INTRODUCTION

The production of cement is a significant contributor to worldwide greenhouse gas emissions, with cement manufacturing accounting for approximately 7–8% of global CO_2 emissions, primarily due to the energy required for kiln heating and the CO_2 emitted during limestone calcination. Minimising cement intensity in masonry and block manufacturing is a significant strategy for decreasing the embodied carbon in the building industry (Purton, 2024). In numerous tropical and sub-Saharan regions, including Nigeria, lateritic soils are prevalent and frequently used as the foundation for economically manufactured, locally produced blocks (compressed stabilised earth blocks, lateritic bricks, etc.). The stabilisation of lateritic materials with Portland cement (or a combination of cement and lime) results in durable masonry units; nevertheless, this process incurs the significant embodied carbon and cost associated with cement, impacting otherwise plentiful local resources. This imposes environmental and cost limitations on low-income dwellings and minor public infrastructure (Okafor & Okonkwo, 2009; Olumodeji & Oluborode, 2023). In Nigeria and throughout West Africa, rice husk is a common by-product of the agro-industrial sector. Rice husk ash (RHA), a silica-rich, highly pozzolanic substance that can react with calcium hydroxide from cement hydration to form extra cementitious phases, is produced when it is thermally processed (Ubi et al., 2021; Gautam, 2019). As a partial substitute for cement, RHA can: (a) enhance the mechanical and durability characteristics of stabilised soils and blocks; and (b) lower the quantity of Portland cement needed per unit, which lowers embodied carbon and diverts agricultural waste from disposal or open burning. RHA can be effectively added to laterite/cement mixtures and crushed earth blocks with respectable compressive strength and durability when the right proportions and curing schedules are followed, according to several experimental investigations and field tests (Ojerinde et al., 2019). From a life-cycle perspective, measurable reductions in embodied energy and potential global warming can be achieved by replacing some of the cement with RHA (Henry & Lynam, 2020). RHA-inclusive mixes frequently have significantly lower cradle-to-gate impacts than traditional cement-rich mixes, according to life-cycle analyses and embodied-energy studies. In certain situations, RHA production (when using low-intensity calcination or capturing otherwise wasted energy) contributes very little to net embodied energy. However, the magnitude of carbon savings depends strongly on (i) the replacement percentage, (ii) the method and energy intensity of RHA production (controlled calcination vs. open burning), (iii) transportation distances, and (iv) the functional performance (strength/durability) required for the block's intended use (Suárez Silgado et al., 2024; Montazeri et al. 2025). Higher replacement levels may decrease early-age strength unless mix design and curing are optimised for example, using lime-cement blends or geopolymer binders (Alhassan & Mohammed, 2007). However, partial replacement levels in the range of 10–30% RHA (by mass of binder) can frequently preserve or even enhance compressive strength, according to several laboratory and field studies focused on laterite stabilisation. This suggests a theoretically viable window for reducing carbon emissions without sacrificing structural performance; however, the precise ideal is site-specific due to regional variations in laterite mineralogy, rice-husk chemistry (including ash, amorphous silica percentage), and production techniques (Olorunfemi et al., 2025). Even with widespread adoption in Nigeria and similar contexts, there are still significant research and implementation gaps despite promising experimental results: (1) There are not many localised life-cycle assessments (LCAs) that compare laterite=RHA blocks to conventional cement blocks under realistic local production scenarios; (2) standardised protocols for low-energy RHA production need to be scaled and verified to avoid negating the carbon benefits through high-temperature calcination; and (3) socio-economic pathways for community-level production (quality control, training, market uptake) need to be demonstrated at pilot scale (Suárez Silgado et al., 2024). By filling in these gaps, a cradle-to-gate (or cradle-to-site) LCA, laboratory mechanical and durability testing, and a small demonstration will provide the evidentiary basis required to support low-carbon masonry utilising garbage that is sourced locally (Olumodeji & Oluborode, 2023). The purpose of this study is to measure the carbon footprint reductions that can be achieved by substituting some of the cement in laterite-based stabilised blocks with rice husk ash (with replacement amounts of 10–40%).

II. Materials and Methods

A. MATERIALS

A. Lateritic Soil

A government-approved borrow pit in Awka, Anambra State, Nigeria, with mature laterite deposits rich in iron and aluminium, provided the lateritic soil used in this study. To guarantee consistent particle size and enhance compaction for the creation of stabilised earth blocks, the soil was air-dried, manually crushed, and sieved through a 4.75 mm mesh screen. Physical characterisation using Atterberg Limits tests (BS 1377: Part 2: 1990) classified the soil as an inorganic silt of low plasticity (ML) with a liquid limit of 42%, plastic limit of 40%, and plasticity index of 2.02%, indicating stable engineering behaviour with minimal risk of swelling or shrinkage as shown in Table 1.

Table 1. Physical characterisation using Atterberg Limits on Lateritic soil

LL (%)	PL (%)	PI (%)	LS (%)	Description
42.00	40.00	2.02	1.31	Lateritic soil (reddish)

In terms of chemical composition carried out, SiO_2 (52%), AlO_3 (12.5%), and FeO_3 (7%) make up the majority of the lateritic soil, with trace amounts of CaO, TiO_2, and MgO as shown in Table 2. When combined with pozzolanic materials like rice husk ash, it can further improve its stability and suitability as the main load-bearing matrix in sustainable block manufacturing. The high silica, alumina, and iron concentration indicates strong cohesion and flexibility.

Table 2. Chemical Composition of Lateritic Soil.

chemical compound	SiO_2	Al_2O_3	FE_2O_3	CaO	MgO	LOI	SO_3	K_2O	P_2O_5
Laterite	52.20	12.53	7.05	0.37	0.89	-	0.05	0.20	0.26

B. Rice Husk Ash (RHA)

The Achala Isuani Rice Mill in Awka North, Anambra State, Nigeria, provided the rice husk used in this investigation. The husks were air-dried and then burned in a controlled muffle furnace at 500°C to create RHA rich in amorphous silica, which increases its pozzolanic reactivity. To increase the fineness of the ash and effectiveness as a partial cement substitute, it was sieved through a 75 µm screen. The specific gravity, mean particle size, and Blaine fineness of RHA are believed to influence its physical properties. These characteristics are believed to affect the mechanical and durability properties of structural concrete, which in turn influence the use of RHA. According to research studies, the specific gravity of RHA is between 2.05 and 2.53, which is significantly lower than the specific gravity of regular Portland cement, which is between 3.10 and 3.14 (Karim et al., 2013). The physical characteristics of the RHA under investigation are displayed in Table 3.

Table 3. Physical Properties of Rice Husk Ash (RHA).

Porosity	Specific gravity	Particle size	Bulk density	Fineness
High	2.04	6.00	2.11	94

RHA has a strong pozzolanic activity and is mostly constituted of SiO_2 (~77%), with minor oxides (FeO_3, AlO_3, CaO, KO, and MgO) making up less than 2% as shown in Table 4. RHA improves the hydration, durability, and mechanical strength of stabilised concrete and laterite blocks by reacting with calcium hydroxide from cement or lime to create calcium-silicate-hydrate (C-S-H) gels.

Table 4. Chemical Composition of Rice Husk Ash (RHA)

chemical compound	SiO_2	Al_2O_3	FE_2O_3	CaO	MgO	LOI	SO_3	K_2O	P_2O_5
RHA	76.95	0.73	0.76	0.78	1.65	-	0.14	1.30	2.63

METHODS

A. Mix Proportions

Lateritic soil, Portland limestone cement (OPC), rice husk ash (RHA), and water made up the stabilisation mix employed in this investigation. RHA was partially replaced with cement at 0%, 5%, 10%, 15%, 20%, 25%, 30%, 35%, and 40% of the dry weight of the soil, whereas cement was added at 6% and 10%. In order to determine the ideal ratios for strength and durability performance, eighteen mix combinations were created. This study was guided by previous studies that have demonstrated that adding RHA at 30–40% of the cement replacement can increase durability, decrease water absorption, and improve compressive strength (Habeeb & Mahmud, 2010; Olutoge et al., 2018). As a result, the chosen mix proportions offer a dependable process for creating robust and long-lasting lateritic compressed earth blocks and are backed by research, experimental data, and early trials.

B. Block Production

In order to produce the lateritic blocks, the various materials were first batched, and the laterite was dry-mixed with the necessary amounts of stabilising binders, which corresponded to replacement levels of 0–40% RHA. The Optimum Moisture Content (OMC) was then reached by adding water. The Nigerian Building and Road Research Institute (NBRRI) developed a manual press for compaction that applies a medium pressure of around 4 N/mm². The bulk density of the materials was used to calculate the mould capacity, plus an extra 5% to account for losses. To ensure even distribution, the prepared mix was put into the mould in three equal layers, levelled, and compacted with ten lever strokes. Each pressing cycle of this procedure yielded two blocks. Each block was cast to conventional dimensions of 290 × 140 × 110 mm and marked with the mix proportion. To track the increase in strength over time, the blocks were air-cured for 7, 28, and 90 days after moulding.

RESEARCH APPROACH

This work employs a hybrid experimental-analytical methodology to assess the feasibility of partially substituting cement with Rice Husk Ash (RHA) to reduce the carbon footprint of stabilised laterite blocks. The methodology comprises cradle-to-Gate life cycle Assessment (LCA) of constituent materials and quantification of carbon footprint based on the embodied CO_2 of constituent materials.

A. Cradle-to-Gate Life Cycle Assessment (LCA)

In accordance with ISO 14040 and ISO 14044 standards, a cradle-to-gate Life Cycle Assessment (LCA) was carried out to measure the environmental effects of stabilised laterite blocks that partially substitute cement with rice husk ash (RHA). Using IPCC characterisation variables, the study focuses on Global Warming Potential (GWP_{100}) over a 100-year horizon (IPCC, 2014). This assessment seeks to determine the embodied greenhouse gas emissions related to laterite blocks made with ordinary Portland cement (OPC) and the different RHA replacement. Additionally, the study seeks to evaluate the environmental performance and the potential for CO_2 reduction of the constituent materials. Previous studies have carried out similar cradle-to-gate evaluations for different binders, as illustrated in Fig. 1 (Habert et al., 2011; Chen et al., 2010; Andrew, 2018; Heath et al., 2014).

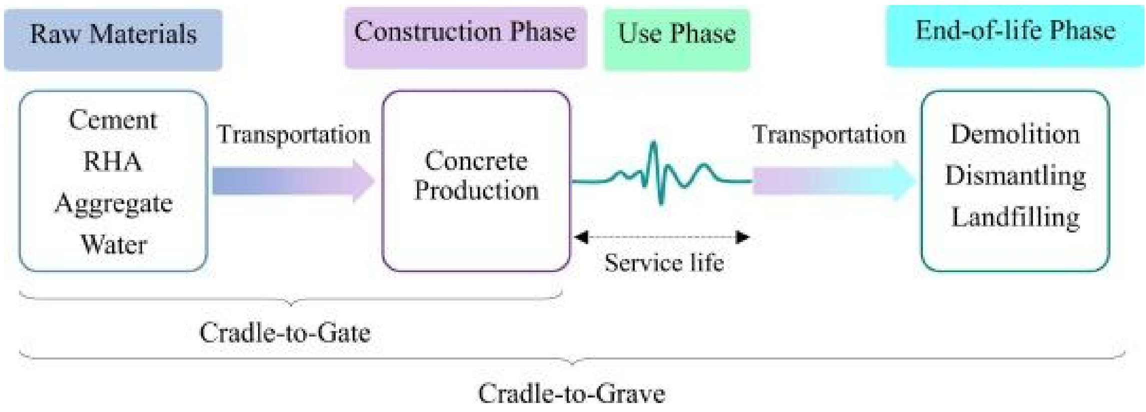

Fig. 1. Cradle-to-grave system border for blends (Bamshad & Ramezanianpour, 2024).

One stabilised laterite block with notional dimensions of 290 × 140 × 110 mm is referred to as the functional unit (FU). This is based on a comparison with masonry carbon footprint studies by using a per-block FU (Kua & Wong, 2008). In accordance with standard procedure for material-level LCAs in building materials, a cradle-to-gate system boundary was used (Bui, 2005; Ecoinvent Centre, 2019). The condition consists of the extraction and processing of raw materials, transportation to the production site, and block manufacturing energy.

Block densities and laboratory mix designs were used to determine the material quantities per block. The emission factor of the OPC was determined to be 0.90 kg CO2/kg, which is in line with normal production values found in global LCI database and cement environmental product declarations (WBCSD/CSI, 2011; Spielmann et al, 2007). The emission factor was obtained from the summation of the process CO_2 from calcination (≈0.53 $kgCO_2/kg$), fuel combustion for kiln heating (≈0.28 $kgCO_2/kg$), electricity for grinding and auxiliaries (≈0.06 $kgCO_2/kg$), and small upstream/transport contributions (≈0.03 $kgCO_2/kg$). The falls within reported ranges of 0.7–1.0 kg CO_2/kg for OPC and is in line with industry and global LCA evaluations (Olorunfemi et al., 2025) Two scenarios were used to predict RHA emissions, which are Rice husk is treated as agricultural residue in waste allocation (0 kg CO_2/kg) and Process-based allocation with controlled burning emissions of 0.18 kg CO_2/kg (International Energy Agency, 2023; Nair et al., 2008).

B. Quantification of carbon footprint based

For each blend, embodied CO_2 was determined using:

$$CO_{2,\ block} = m_{cement} \times EF_{cement} + m_{RHA} \times EF_{RHA} \quad (1)$$

The relative CO_2 reduction was calculated as follows:

$$\text{Reduction (\%)} = \frac{CO_{2,control} - CO_{2,mix}}{CO_{2,control}} \ x\ 100 \quad (2)$$

This formulation is consistent with standard procedure in cementitious material comparative life cycle assessments (Gursel & Ostertag, 2016).

III. RESULTS AND DISCUSSION

Embodied Carbon of Stabilised Laterite Blocks

The cement mass at 6% and 10% stabilisation was computed based on the data represented in Tables 5 and 7, respectively.

Table 5. Computation for cement mass at 6% stabilisation

Step	Value
Volume of a block	0.29×0.14×0.11=0.0045 m^3
Density adopted	1700 kg/m³ (a safe midpoint) from the lab. result
Block mass	0.004466 x 1700 = 7.5920
Cement % at 6% stabilisation	0.06
Cement mass	0.06 x 7.592 = 0.4560 kg

From equation 1, and with scenarios 1 and 2 adopted accordingly, the embodied carbon of blocks stabilised with 6% and 10%binder content was obtained, with the result presented in Tables 6 and 8.

Table 6. Embodied carbon of blocks stabilised with 6% binder content

RHA replacement (%)	Cement mass (kg)	RHA mass (kg)	CO_2 (RHA = 0) (kg CO_2/block)	CO_2 (RHA=0.18) (kg CO_2/block)
0	0.456	0.000	0.410	0.410
5	0.433	0.023	0.390	0.394
10	0.410	0.046	0.369	0.377
15	0.387	0.068	0.349	0.361
20	0.364	0.091	0.328	0.344
25	0.342	0.114	0.308	0.329
30	0.319	0.137	0.287	0.312
35	0.296	0.160	0.266	0.295
40	0.274	0.182	0.247	0.280

Table 7. Computation for cement mass at 10% stabilisation

Step	Value
Volume of a block	0.29×0.14×0.11=0.004466 m^3
Density adopted	1700 kg/m³ (a safe midpoint) from the lab. result
Block mass	0.004466 x 1700 = 7.592
Cement % at 10% stabilisation	0.10
Cement mass	0.10 x 7.592 = 0.759 kg

Table 8. Embodied carbon of blocks stabilised with 10% binder content

RHA replacement (%)	Cement mass (kg)	RHA mass (kg)	CO_2 (RHA = 0) (kg CO_2/block)	CO_2 (RHA=0.18) (kg CO_2/block)
0	0.759	0.000	0.683	0.683
5	0.721	0.038	0.649	0.656
10	0.683	0.076	0.615	0.629
15	0.645	0.114	0.581	0.601
20	0.607	0.152	0.547	0.574
25	0.569	0.190	0.512	0.546
30	0.531	0.228	0.478	0.519
35	0.493	0.266	0.444	0.492
40	0.455	0.304	0.410	0.465

From the obtained tables 6 and 8, 2 was generated to compare the RHA replacement level (%) and embodied carbon emissions (kg CO2 per block) for laterite blocks stabilised with two cement concentrations (6% and 10%).

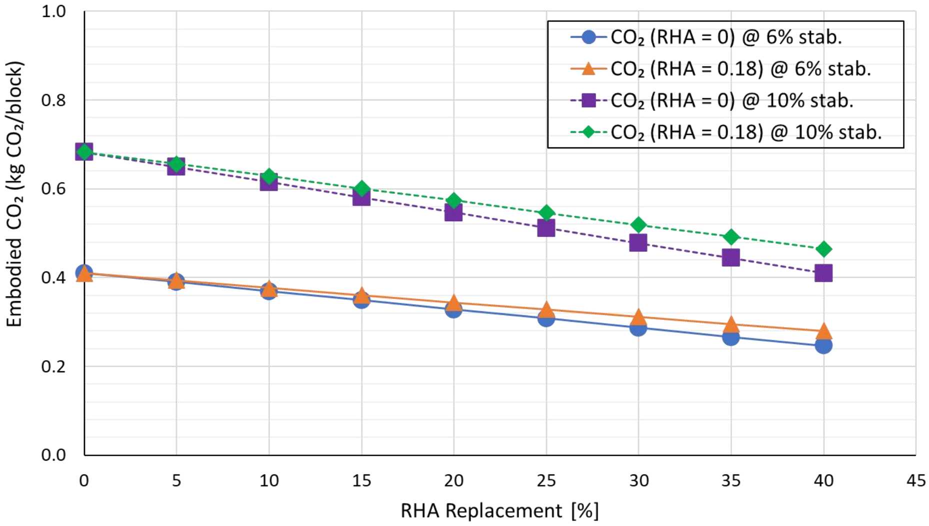

Fig. 2: Comparison between RHA replacement level (%) and embodied carbon emissions (kg CO_2 per block) for laterite blocks stabilised with two cement concentrations (6% and 10%).

Fig.2 shows the embodied CO2 results for laterite blocks with 0–40% RHA at 6% and 10% cement stabilisation levels, demonstrating a distinct and almost linear decrease in emissions as RHA replacement increases. When RHA was treated as a zero-burden waste material, embodied carbon for blocks with 6% cement dropped from 0.410 kg CO2/block at 0% RHA to 0.328 kg CO_2/block at 20% RHA and 0.247 kg CO_2/block at 40% RHA. Embodied CO2 decreased from 0.683 to 0.547 kg CO_2/block at 20% RHA and to 0.410 kg CO_2/block at 40% RHA in the 10% cement stabilisation scheme.

The savings were still significant when controlled-combustion emissions for RHA (0.18 kg CO_2/kg) were taken into account, resulting in a 12–17% lower carbon footprint over the 10–40% RHA range. This demonstrates that RHA substitution offers significant environmental benefits even when conservative emission allocations are used. Cement manufacture accounted for 84–92% of the total embodied carbon in all mixtures, confirming the position of OPC as the main hotspot in stabilised earth block systems.

The displacement of cement, whose emission factor is about 0.90 kg CO_2/kg, by RHA, whose emissions are much lower, is the direct cause of the virtually linear decline curve. This behaviour is in line with earlier SCM-based LCA studies that show proportionate decreases in cradle-to-gate GWP when biomass-derived ashes are substituted for high-clinker cement. This is in line with known research that identifies the production of cement as the main carbon hotspot in building materials (Flower & Sanjayan, 2007). The contributions from transport and electricity use were comparatively small (less than 10%). According to previous research, RHA processing emissions were negligible because of their low embodied energy (Valdivia et al, 2013;).

A. Impact of RHA on Carbon Reduction Performance

From equation 2, and with scenarios 1 and 2 adopted accordingly, CO_2 reduction with 6% and 10% binder content was obtained, with the result presented in Tables 9 and 10.

Table 9. CO_2 reduction with 6% binder content

RHA replacement (%)	CO_2 reduction (RHA = 0)	CO_2 reduction (RHA=0.18)
0	0	0
5	4.88	3.90
10	10.00	8.04
15	14.88	11.95
20	20.00	16.10
25	25.00	19.76
30	30.00	23.90
35	35.00	28.05
40	40.00	31.71

Table 10. CO_2 reduction with 10% binder content

RHA replacement (%)	CO_2 reduction (RHA = 0)	CO_2 reduction (RHA=0.18)
0	0	0
5	5.00	3.95
10	10.00	7.91
15	15.00	12.05
20	20.00	16.00
25	25.00	20.06
30	30.00	24.01
35	35.00	28.00
40	40.01	32.00

From the obtained tables 9 and 10, Figs. 3 and 4 were generated to compare between RHA replacement level (%) and CO_2 reduction for laterite blocks stabilised with two cement concentrations (6% and 10%).

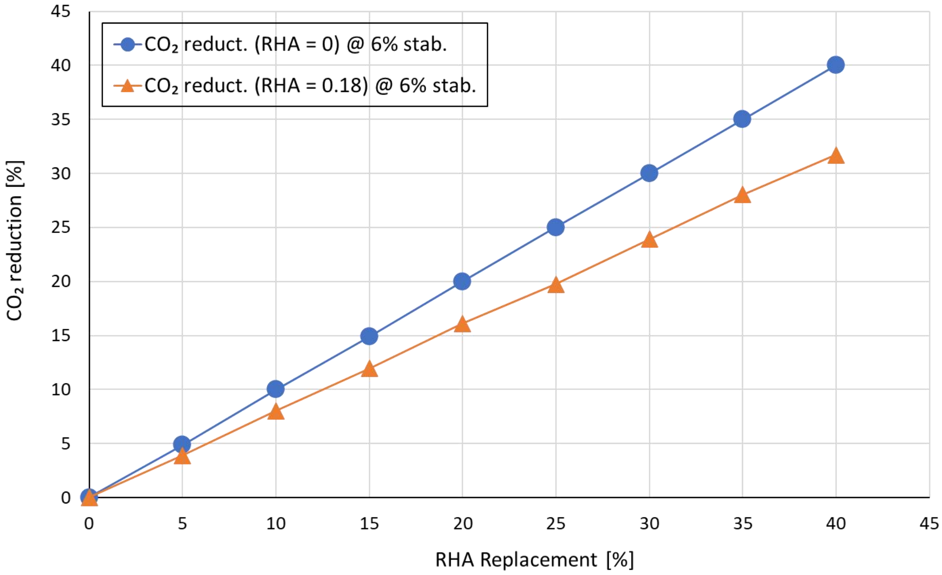

Fig.3: Comparison between RHA replacement level and CO_2 reduction for laterite blocks stabilised at 6%with cement concentration.

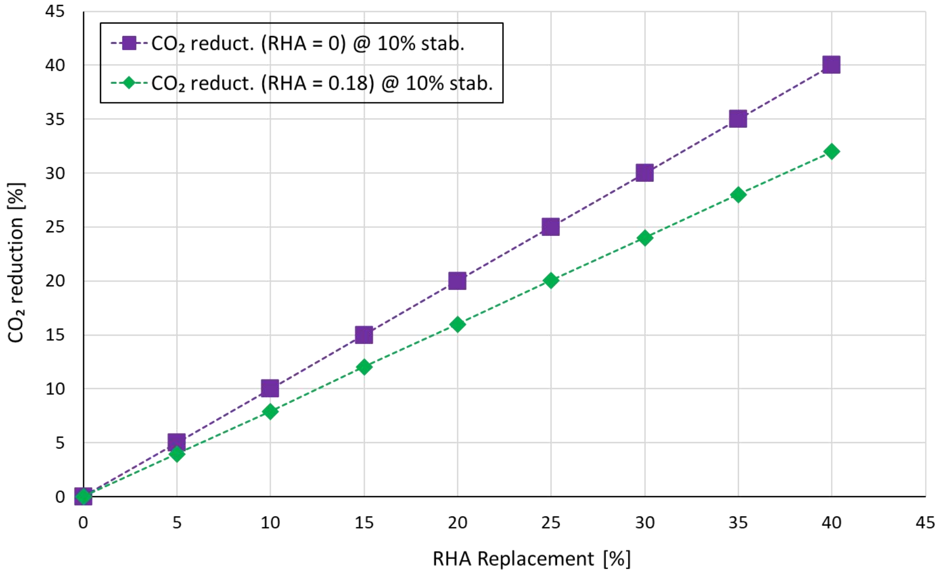

Fig. 4: Comparison between RHA replacement level and CO_2 reduction for laterite blocks stabilised at 10%with cement concentration.

According to Figs. 3 and 4, each additional 5% replacement of RHA results in a predictable drop in embodied CO_2. For instance, carbon reductions increased from 4.9% at 5% RHA to 20% at 20% replacement and 40% at 40% replacement (zero-burden scenario) at 6% cement content. At 10% stabilisation, the same trend emerged, but because there was more cement mass per block, the absolute emissions were higher. The idea that carbon savings increase with the amount of cement displaced is supported by the higher sensitivity of high-cement mixes to RHA substitution. For low-cost housing applications, low-cement systems (6% OPC) show a more advantageous balance between carbon reduction and material viability.

B. Alignment with Mechanical Performance

The 28-day compressive strength data were paired with the matching cradle-to-gate embodied-carbon results for both the 6% and 10% cement-stabilised blocks to determine the RHA replacement level that best combines mechanical performance and environmental benefits. The integrated strength-carbon dataset is shown in Table 11. Since the 28-day strength is the accepted engineering standard for masonry performance, it was selected as the choice variable.

a) **Carbon-Mechanical Interaction and the Optimum RHA Level**

A simple metric, as shown in equation 3, was used to compute the Carbon-Mechanical Interaction.

Score = (28-day compressive strength) ÷ (embodied carbon per block) (3)

This derivative was used because it gives an easy-to-interpret "strength per $kgCO_2$" indicator.

Table 11. Measured 28-day compressive strength and embodied carbon per block for each RHA level at 6% stabilisation.

RHA [%]	Strength at 28 days	Carbon ($kgCO_2$/block)	Score = 28d / Carbon
0	0.770	0.410	1.878
5	0.720	0.394	1.827
10	0.710	0.377	1.883
15	0.750	0.361	2.078
20	0.700	0.344	2.035
25	0.680	0.329	2.067
30	0.720	0.312	**2.308**
35	0.650	0.295	2.203
40	0.610	0.280	2.179

Table 12. Measured 28-day compressive strength and embodied carbon per block for each RHA level at 10% stabilisation.

RHA [%]	Strength at 28 days	Carbon ($kgCO_2$/block)	Score = 28d / Carbon
0	1.550	0.683	2.269
5	1.450	0.656	2.210
10	1.440	0.629	2.289
15	1.510	0.601	**2.512**
20	1.320	0.574	2.300
25	1.210	0.546	2.216
30	1.220	0.519	2.351
35	1.120	0.492	2.276
40	1.160	0.465	2.494

The highest measured (non-interpolated) performance ratio scores were obtained at 6% and 10% cement stabilisation levels. At 6% cement stabilisation, the ideal measured rice husk ash (RHA) content was 30%, resulting in a 28-day compressive strength of 0.72 N/mm² and a corresponding carbon footprint of 0.312 kg CO_2 per block. In comparison, at 10% cement stabilisation, the ideal measured RHA content was 15%, which produced a significantly higher 28-day compressive strength of 1.51 N/mm², with an associated carbon footprint of 0.601 kg CO_2 per block.

According to these findings, carbon intensity dominates the score earlier for high-cement mixes (10%), whereas deeper cement replacement improves the overall efficiency up to almost 30% RH for low-cement mixtures (6%).

b) **Mechanical–Carbon Overlay Plot**

5 shows the results obtained from the carbon footprint reductions, which were compared with experimental findings on the mechanical properties of laterite-RHA blocks, as shown in Tables A1 and A2 in the appendix. The results of the experiment showed that, for both mixtures, compressive strength rises with curing age, peaking between 5 and 15% RHA for both 6% and 10% cement stabilisation. Beyond 20% RHA, strength gradually decreased due to slower pozzolanic kinetics at high ash levels and decreased clinker availability. The most beneficial moisture-resistance behaviour was observed at 10–20% RHA, while durability indices like water absorption improved somewhat with higher RHA values.

A distinct performance–environment trade-off is shown when these mechanical tendencies are compared with the current carbon footprint results, as shown in Figs.5 and 6. These blends correspond with the most notable decreases in compressive strength and increased water absorption noted in the previous study, even though the greatest carbon reductions (up to 40%) occur at replacement levels between 30 and 40% RHA. On the other hand, depending on the allocation scenario, the 10–20% RHA range, which showed the best strength–absorption balance, also offers significant carbon savings (12–25%).

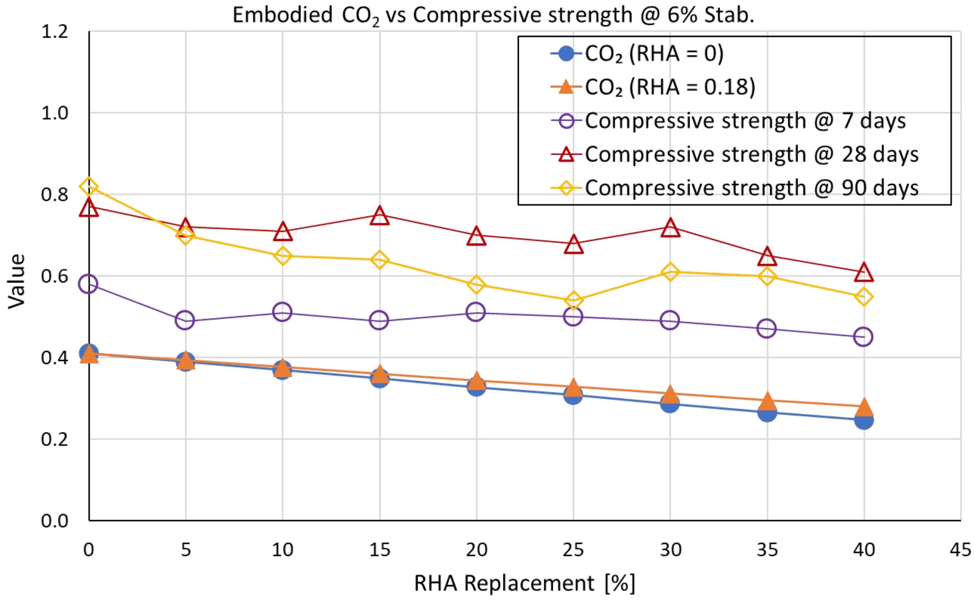

Fig. 5: Comparison between Embodied CO_2 and Compressive strength for laterite blocks stabilised at 6% with cement concentration.

The mechanical-carbon score rises for the 6% stabilised blocks up to the 30% RHA level, where the dataset exhibits the best combined efficiency (0.72 N/mm^2 strength at 0.312 kg CO_2 per block at 28 days of curing). This indicates that 30% RHA is the best-performing balance point for low-cement stabilisation because significant carbon savings counterbalance the slight strength decline beyond 20% RHA.

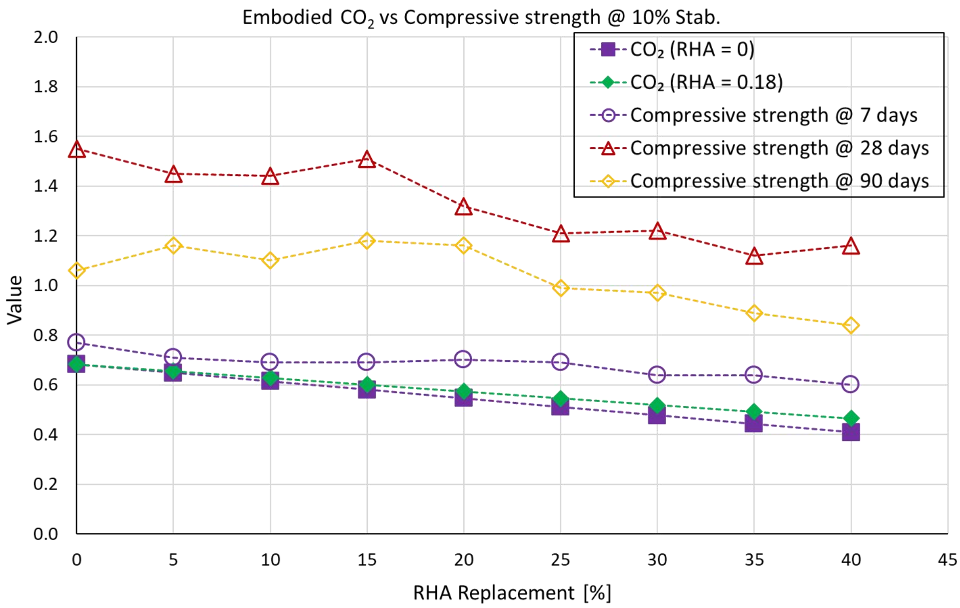

Fig. 6: Comparison between Embodied CO_2 and Compressive strength for laterite blocks stabilised at 10% with cement concentration.

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The 10% stabilised blocks, as shown in 6, on the other hand, exhibit the maximum combined mechanical–environmental efficiency at 15% RHA, where the strength peaks at 1.51 N/mm² with a carbon footprint of 0.601 kg CO_2/block. This conduct is consistent with pozzolanic kinetics, where regulated RHA incorporation improves medium-cement mixes' long-term strength growth but provides declining benefits after a limited replacement window.

The different hydration dynamics are reflected in the contrasting optima between the 6% and 10% mixes: higher cement contents exhibit optimal synergy at lower RHA levels, where clinker availability remains sufficient for early-age hydration, while low-cement systems benefit from higher RHA substitutions due to the additional reactive silica promoting secondary C–S–H formation. Therefore, the mechanical-carbon overlay offers a comprehensive performance benchmark, demonstrating that the most effective replacement levels for sustainable stabilised laterite block production are 30% RHA (6% cement) and 15% RHA (10% cement).'

IV. CONCLUSION

The mechanical performance and cradle-to-gate carbon footprint of laterite-based stabilised blocks that partially substituted ordinary Portland cement (OPC) with 0–40% rice husk ash (RHA) were assessed in this study. The findings demonstrate that RHA is a useful, cementitious material that can improve sustainability without sacrificing technical performance.

According to the embodied-carbon assessment, cement continues to be the primary source of emissions, making up 84–92% of the total carbon output from the cradle to the gate. As a result, embodied emissions were significantly reduced at all replacement levels when RHA was used. Over the 0–40% RHA range, carbon emissions for the 6% stabilisation system dropped by 32%, from 0.410 to 0.280 kg CO_2/block. Emissions for the 10% stabilisation system decreased by 31.9%, from 0.683 to 0.465 kg CO_2/block.

Two different optima appeared when mechanical performance and carbon footprint were assessed together to get the combined performance optimum. The maximum strength-to-carbon efficiency ratio (0.72 N/mm² at 0.312 kg CO_2/block) was reached at 30% RHA at 6% stabilisation. The optimal value changed to 15% RHA at 10% stabilisation, with a matching strength of 1.51 N/mm² and a carbon footprint of 0.601 kg CO_2/block. Curve-fitted spline analysis provided additional confirmation of these optima.

Overall, the results show that at moderate replacement levels, RHA can provide material carbon reductions of up to 32% while preserving or enhancing strength. The findings demonstrate the potential of RHA-stabilised laterite blocks as a low-carbon, circular economy building material appropriate for Nigerian rural and urban building applications.

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APPENDIX

Table A1. Compressive Strength Test

S/N	COMPRESSIVE STRENGTH N/mm2 AT 7 DAYS CURING	COMPRESSIVE STRENGTH N/mm2 AT 28 DAYS CURING	COMPRESSIVE STRENGTH N/mm2 AT 90 DAYS CURING
M1	0.58	0.77	0.82
M2	0.47	0.72	0.70
M3	0.51	0.71	0.65
M4	0.46	0.75	0.64
M5	0.51	0.70	0.58
M6	0.50	0.68	0.54
M7	0.57	0.78	0.61
M8	0.47	0.65	0.60
M9	0.45	0.61	0.55
M10	0.77	1.55	1.06
M11	0.71	1.45	1.16
M12	0.59	1.24	1.08
M13	0.69	1.58	1.23
M14	0.73	1.32	1.28
M15	0.69	1.21	0.99
M16	0.64	0.83	0.78
M17	0.64	1.12	0.88
M18	0.60	0.78	0.70

Table A2. Density of Lateritic Blocks

S/N	DENSITY kg/m3 AT 7 DAYS CURING	DENSITY kg/m3 AT 28 DAYS CURING	DENSITY kg/m3 AT 90 DAYS CURING
M1	1913	1826	1715
M2	1886	1729	1662
M3	1820	1797	1752
M4	1783	1669	1720
M5	1779	1679	1712
M6	1799	1641	1629
M7	1715	1570	1662
M8	1734	1602	1664
M9	1722	1610	1633
M10	1790	1703	1798
M11	1774	1701	1726
M12	1804	1694	1690
M13	1772	1716	1757
M14	1826	1744	1723
M15	1703	1705	1628
M16	1809	1670	1641
M17	1809	1684	1619
M18	1720	1633	1588