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Sustainable Stabilization of Lateritic Soil Using Rice Husk Ash: A Review of Its Application in Ghanaian Construction.

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Abstract

The rapid expansion of urban centers in Ghana has led to an increased demand for construction materials, creating both economic and environmental challenges. Cement production, a major contributor to carbon emissions, accounts for nearly 8% of global CO_2 emissions, while unsustainable sand mining continues to degrade ecosystems. Lateritic soil, a locally abundant material, offers a viable alternative for construction but suffers from limitations such as poor tensile strength and susceptibility to erosion. Conventional stabilization methods, including cement and lime, are costly and environmentally unsustainable. However, agricultural waste, particularly rice husk ash (RHA), has emerged as a promising and sustainable soil stabilizer. This study critically reviews the effectiveness of integrating rice husk ash (RHA) with lateritic soil in Ghana by consolidating experimental data from prior research. It assesses improvements in geotechnical and mechanical properties, identifies optimal stabilization ratios, and discusses the potential for large-scale application. The findings support the adoption of RHA as a cost-effective and environmentally friendly alternative for soil stabilization in Ghana. Key findings reveal that increasing RHA content significantly reduces the plasticity index while increasing the compressive strength of lateritic soil, enhancing the soil's mechanical properties, durability, and workability. The review consolidates data demonstrating that RHA-stabilized lateritic soil is both cost-effective and environmentally sustainable for construction. Furthermore, the study aligns with Ghanaian building practices by integrating indigenous knowledge with engineering standards. The findings highlight the potential of RHA-stabilized lateritic soil in promoting low-cost and eco-friendly construction.

Keywords: Sustainable construction, Lateritic soil, Rice Husk Ash, soil stabilization, indigenous materials, environmental impact.

Introduction

Historically, indigenous African societies have utilized locally available materials in construction, relying on methods that demonstrate resilience, affordability, and adaptability to the environment. In Ghana, lateritic soil has been widely used in traditional construction due to its availability and cost-effectiveness. Structures such as the Larabanga Mosque, built in the 17th century, exemplify the longevity and practicality of lateritic soil in sustainable architecture (Bredwa-Mensah & Dakwa, 2010). However, despite its benefits, lateritic soil presents several limitations, including poor tensile strength, shrinkage, and high susceptibility to erosion, which restrict its modern application in construction (Osinubi, 2006). Lateritic soil stabilization has traditionally relied on cement and lime, both of which improve soil strength but contribute to environmental degradation and high costs. Given Ghana's abundant agricultural waste, particularly rice husk ash (RHA), this study explores its suitability as a stabilizer. This paper consolidates data from studies in regions with similar tropical climates (e.g., Ghana, Nigeria, Sri Lanka) to assess the feasibility of RHA in Ghana's construction sector. The search for eco-friendly and economically viable stabilizers has led to the exploration of alternative materials, particularly agricultural waste products. Among these, rice husk ash (RHA) has gained attention as a promising stabilizer due to its pozzolanic properties and potential for improving soil strength and durability (Hossain, 2011). Ghana's agricultural sector generates significant amounts of rice husk waste, which is often discarded or burned, contributing to environmental pollution (Quansah et al., 2020). Studies have shown that approximately 13,043 tonnes of rice residues, including husks, are produced annually in the Ejisu-Juaben District, highlighting the scale of waste generation (Adjei, 2017). By integrating RHA into lateritic soil, this waste material can be repurposed to create a sustainable and cost-effective construction material while addressing waste management concerns. The primary objectives of this study are to (1) assess the geotechnical and environmental benefits of RHA stabilization for lateritic soil, (2) consolidate findings from existing studies to propose optimal RHA-soil ratios, and (3) bridge indigenous knowledge with modern engineering practices to advance Ghana's sustainable infrastructure goals. The potential of RHA as a stabilizing agent has been demonstrated in various studies across Africa and Asia (Okwadha & Nyingi, 2016). Successful applications of RHA in Nigeria (Oyediran & Kalejaiye, 2011), India (Karthik & Kumar, 2017), and Ghana (Alhassan & Alhaji, 2017) validate its cross-regional efficacy. Research findings indicate that incorporating RHA into lateritic soil reduces its plasticity index, improves compressive strength, and enhances resistance to erosion and water absorption (Ayininuola & Ola, 2006). The successful use of RHA in soil stabilization has been observed in Nigeria, India, and Ghana, where RHA-modified lateritic bricks and road subgrades have shown improved mechanical performance and economic viability (Muntohar, 2017; Oyediran & Kalejaiye, 2011; Karthik & Kumar, 2017). However, despite these promising findings, large-scale application and policy adoption of RHA-stabilized lateritic soil remain limited in Ghana. Further research is required to fully explore its engineering properties, economic feasibility, and environmental benefits in the Ghanaian construction industry.

This study investigates the role of traditional construction materials in indigenous African societies, with a specific focus on integrating rice husk ash (RHA) as an agricultural waste material with lateritic soil for sustainable construction in Ghana. By examining the geotechnical, mechanical and environmental implications of this integration, the research contributes to the broader discourse on green construction and circular economy practices in the built environment. Aligned with the United Nations Sustainable Development Goals (SDGs), particularly Goal 11 (Sustainable Cities and Communities) and Goal 12 (Responsible Consumption and Production), this study promotes resource-efficient and eco-friendly construction methods (United Nations, 2015). By integrating agricultural waste into traditional construction materials, it seeks to bridge the gap between indigenous knowledge and modern engineering practices, fostering sustainable development in Ghana's built environment.

MATERIALS & METHODS

Materials

The materials considered in this study were selected based on their availability and suitability for lateritic soil stabilization using agro-waste composites. Since laboratory tests were not conducted directly, the study relies on existing research findings that have investigated similar stabilization approaches. This study synthesizes data from peer-reviewed studies conducted in regions with similar lateritic soil profiles and tropical climates, including Alhassan & Alhaji (2017) in Ghana, Rahman & Ahmed (2016) in Nigeria, and Pushpakumara & Mendis (2022) in Sri Lanka. These studies were selected based on their methodological rigor, use of standardized tests (e.g., ASTM and BS codes), and relevance to Ghana's construction industry. To ensure applicability, the reviewed data were cross-verified against soil characteristics reported in Ghanaian studies.

Lateritic soil, widely found in tropical and subtropical regions, is commonly used in road construction, embankments, and foundation works. It is rich in iron and aluminum oxides, which influence its strength and stability. Stabilization techniques, particularly with pozzolanic materials like RHA, have been explored to improve its properties. Research indicates that lateritic soil samples for stabilization tests are typically collected from borrow pits at depths of 1.0 to 1.5 meters to minimize organic matter contamination (Akinwumi et al., 2019; Olatunde et al., 2020). Studies report that the lateritic soils used generally exhibit a liquid limit of 35%–50% (Akinyemi & Okeke, 2019), a plasticity index of 10%–25% (Ogunbode & Olusola, 2021), a maximum dry density of 1.80–2.10 g/cm³ (Mustapha et al., 2020), and an optimum moisture content of 12%–18% (Ezeokonkwo & Umeh, 2022).

RHA, a pozzolanic material derived from the controlled burning of rice husks, is widely used in soil stabilization and concrete due to its high silica (SiO_2) content (Givi et al., 2010). The preparation process involves collecting raw rice husks from rice mills, washing them to remove impurities (Olawuyi & Olaleye, 2020), and subjecting them to controlled burning at 600°C–700°C for six hours to achieve amorphous silica formation (Ajibade et al., 2021). The resulting ash is finely ground and sieved through a 75 µm mesh for uniform particle size distribution (Chikwendu & Adeyemo, 2019). The chemical composition of RHA varies based on burning conditions but typically consists of silica (65%–90%), alumina (1%–5%), iron oxide (0.5%–2%), calcium oxide (0.5%–5%), and magnesium oxide (0.5%–2%) any reference . The loss on ignition (LOI) ranges from 5% to 15%, indicating residual carbon and volatile components. The high silica content enables RHA to react with calcium hydroxide ($Ca(OH)_2$) in the soil, forming cementitious compounds that improve soil strength and durability, making it a sustainable alternative for soil stabilization in construction.

Methods

The methodology adopted in this study is based on established experimental procedures reported in previous research on lateritic soil stabilization with Rice Husk Ash (RHA). While no new laboratory tests were conducted, the data were cross verified for consistency across studies and contextualized to Ghana's environmental conditions, such as rainfall patterns and soil organic content. Sieve analysis was conducted in line with ASTM D6913 (ASTM, 2017) to determine grain size distribution, a procedure similarly employed by Alabi, Olutaiwo, and Adeboje (2015) in their classification of soil consistency. The Atterberg limits, including liquid limit (LL), plastic limit (PL), and plasticity index (PI), were determined following ASTM D4318 (ASTM, 2017), consistent with approaches used in related studies on soil behavior at varying moisture contents. Compaction characteristics were examined using the Modified Proctor test (ASTM D1557, ASTM, 2017), as documented in prior research assessing the influence of RHA on soil density and moisture content. The California Bearing Ratio (CBR) test, following ASTM D1883 (ASTM, 2017), was utilized to evaluate strength improvements in stabilized soil under soaked and unsoaked conditions. Studies such as those by Alhassan and Alhaji (2017) and Alabi et al. (2015) have demonstrated that RHA enhances CBR values, improving the suitability of lateritic soil for subgrade applications. Furthermore, the Unconfined Compressive Strength (UCS) test was conducted as per ASTM D2166 (ASTM, 2017) to assess the strength development of untreated and treated soil samples. Similar to methodologies applied in previous investigations, specimens were compacted at their optimum moisture content and cured for 7, 14, and 28 days to analyze the effect of curing on strength gain. These established testing protocols, widely referenced in soil stabilization research, provide a comparative framework for evaluating the effectiveness of RHA in modifying lateritic soil properties.

RESULTS

The results presented in this study are drawn from existing research on the effect of Rice Husk Ash (RHA) on lateritic soil properties. Various laboratory tests have been conducted in previous studies to assess the influence of RHA on soil behavior, including grain size distribution, Atterberg limits, compaction characteristics, California Bearing Ratio (CBR), and Unconfined Compressive Strength (UCS).

Atterberg Limits (Liquid Limit, Plastic Limit, and Plasticity Index)

The Atterberg Limits test assess the workability of fine-grained soils. Excessive plasticity leads to expanding and contracting soil, structural instability. The Atterberg limit test confirms that RHA stabilization reduces plasticity and improves lateritic soil strength, making it ideal for road and earthworks.

Tables 1 and 2 show data retrieved from literature describing how Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI) change with varying amounts of added RHA. The observed reduction in plasticity index (PI) with increasing RHA content aligns with findings by (Alhassan & Alhaji, 2017) and (Rahman, 1986), demonstrating the pozzolanic reaction of RHA. However, variations exist between studies, possibly due to differences in soil composition and burning conditions of RHA. Further comparative analysis in Ghana-specific conditions is required to validate these trends.

Table 1. Atterberg Limit test Results (Alhassan & Alhaji, 2017).

RHA Content (%)	Liquid Limit (LL) (%)	Plastic Limit (PL) (%)	Plasticity Index (PI) (%)
0 (Control)	45.2	22.4	22.8
5	42.1	24.6	17.5
10	38.3	27.1	11.2
15	35.0	30.5	4.5
20	33.5	32.1	1.4

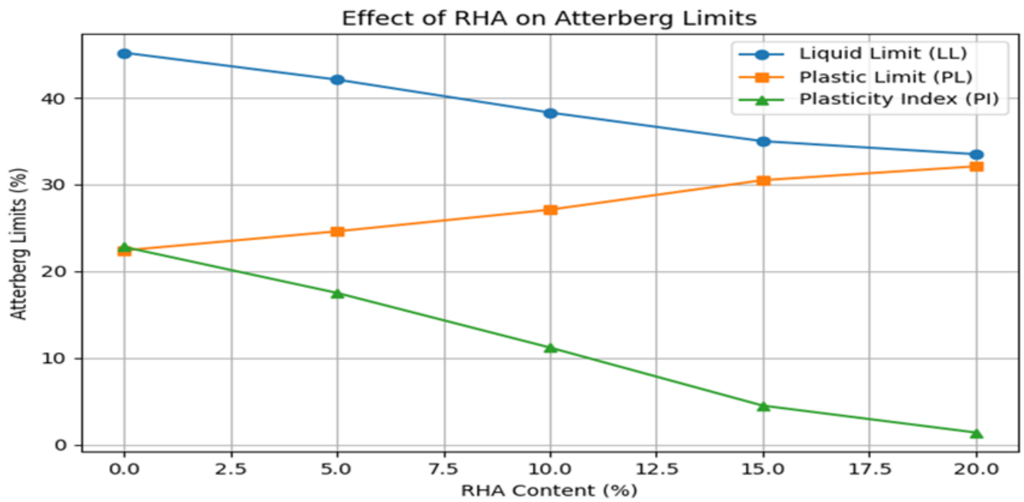

Figure 1. Effects of RHA on Atterberg limits (Alhassan & Alhaji, 2017).

Table 2. Atterberg Limit test Results (Rahman & Ahmed, 2016)

RHA Content (%)	Liquid Limit (LL) (%)	Plastic Limit (PL) (%)	Plasticity Index (PI) (%)
0	49.8	22.6	27.2
4	51.4	26.1	25.3
8	52.2	29.5	22.7
12	52.6	31.9	20.7
16	53.4	35.2	18.2
20	54.3	38.6	15.7

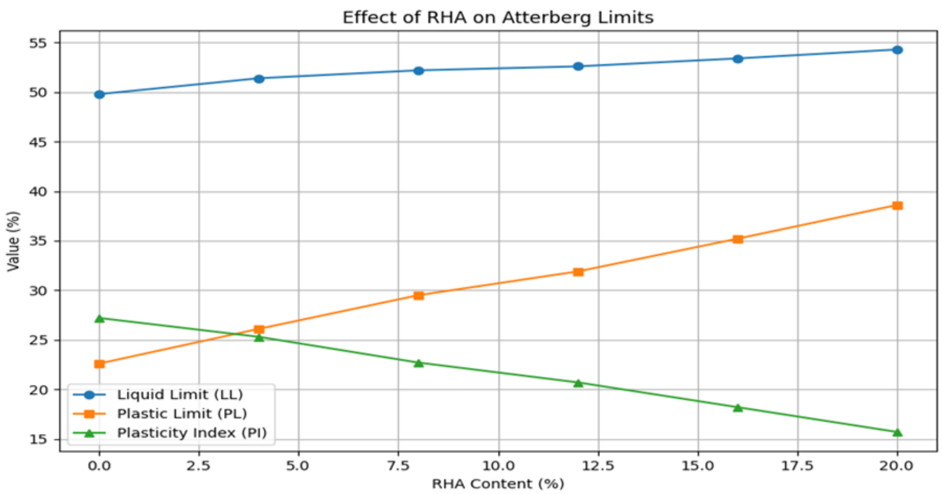

Figure 2. Effects of RHA on Atterberg limits (Rahman & Ahmed, 2016)

Compaction Characteristics (Optimum Moisture Content and Maximum Dry Density)

Compaction enhances RHA stabilized lateritic soil's strength and stability through its enhanced density, lesser permeability, and better load-carrying capacity. As a pozzolanic material, RHA reacts with the soil and forms cementitious products, influencing optimum moisture content (OMC) and maximum dry density (MDD).

Tables 3 and 4 shows the variations in Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) at different RHA contents.

Table 3. Compaction Tests Results (Alhassan & Alhaji, 2017).

RHA Content (%)	**Maximum Dry Density (MDD) (g/cm³)**	**Optimum Moisture Content (OMC) (%)**
0 (Control)	1.98	12.4
5	1.92	14.7
10	1.88	16.2
15	1.82	17.8
20	1.75	19.4

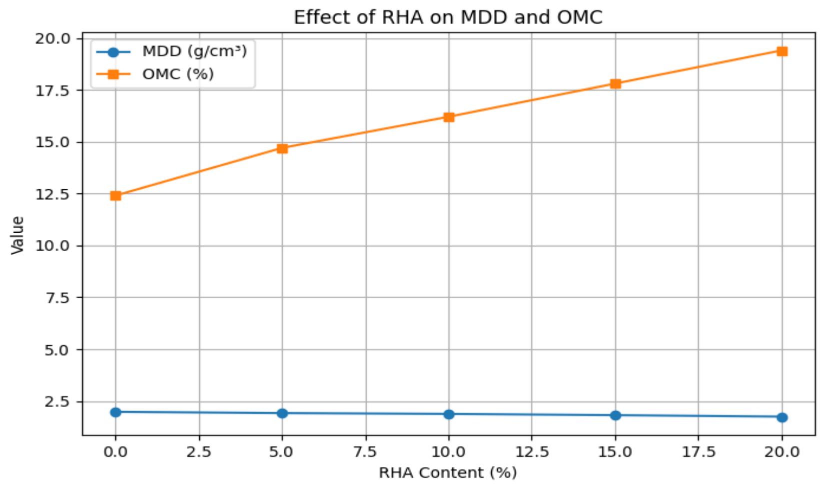

Figure 3. Effects of RHA on MDD & OMC (Alhassan & Alhaji, 2017).

Table 4. Compaction Tests Results (Pushpakumara & Mendis, 2022).

RHA Content (%)	**MDD (g/cm³)**	**OMC (%)**
0	1.98	12.4
4	1.92	14.7
8	1.88	16.2
12	1.82	17.8
16	1.75	19.4
20	1.70	21.0

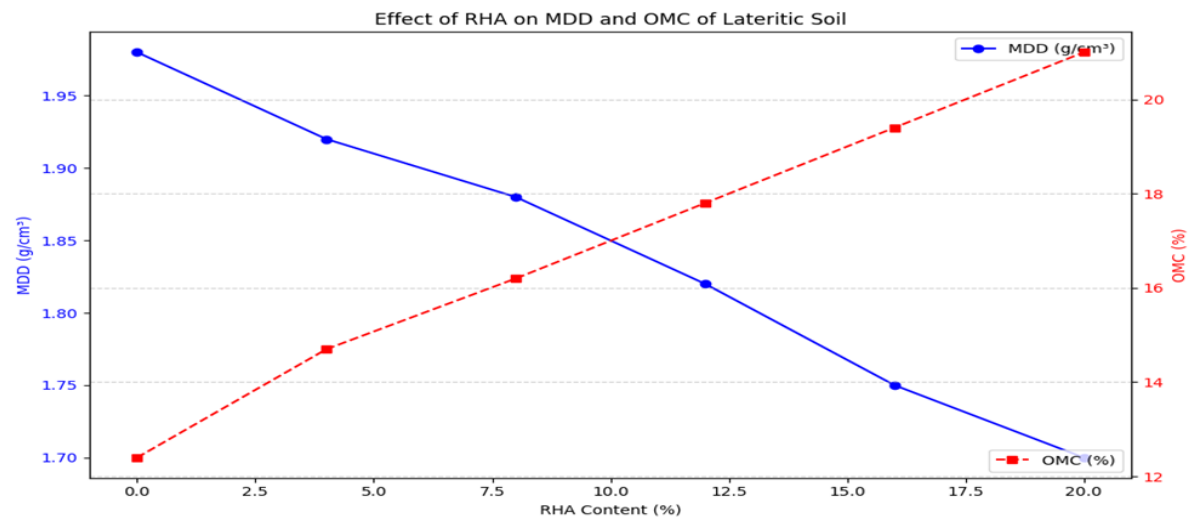

Figure 4. Effects of RHA on MDD & OMC of Lateritic soil (Pushpakumara & Mendis, 2022).

Unconfined Compressive Strength (UCS) Test

Unconfined Compressive Strength (UCS) testing is used to ascertain the strength development of the stabilized soil samples at different curing periods. UCS approximates the increase in soil strength due to stabilization by RHA.

RHA addition alters the compressive strength, which is one of the key parameters for soil stabilization.

Table 5 and 6 shows the strength test of different RHA contents.

Table 5. Compressive Strength test results (Alhassan & Alhaji, 2017).

RHA Content (%)	UCS at 28 Days (kPa)
0 (Control)	320
5	460
10	620
15	710
20	560

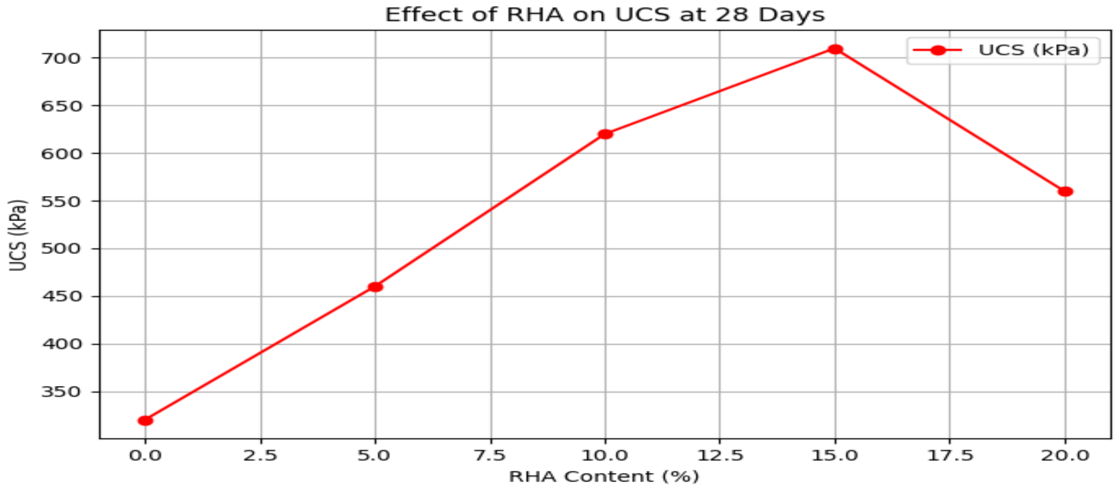

Figure 5. Effects of RHA on UCS at 28d (Alhassan & Alhaji, 2017).

Table 6. Unconfined Compressive Strength test (Tuhin, Hassan, Hasan, & Julfikar, 2020).

RHA Content (%)	**UCS at 1 Day (kN/m²)**	**UCS at 7 Days (kN/m²)**	**UCS at 28 Days (kN/m²)**
0	175	235	289
4	190	265	345
8	210	298	410
12	225	320	460
16	230	335	480
20	225	328	470

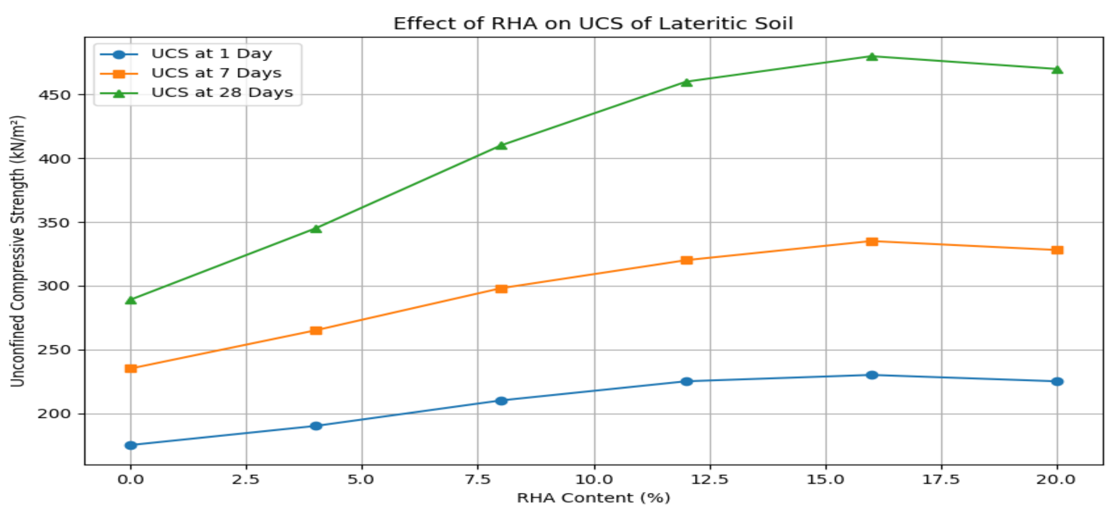

Figure 6. Effects of RHA on UCS of Lateritic soil (Tuhin, Hassan, Hasan, & Julfikar, 2020).

California Bearing Ratio (CBR)

CBR, or California Bearing Ratio, is a measure of the strength of subgrade soil and base courses in road and pavement construction. It indicates the capacity of the soil to withstand shear stress under loading conditions relative to a standard material like crushed stone.

In the present study, CBR is used to analyze the enhancement of bearing capacity of lateritic soil when stabilized with Rice Husk Ash (RHA). From the findings, the CBR values increase with the inclusion of RHA up to an optimal content after which further addition slightly reduces. It suggests that RHA enhances the strength of the soil but must be added in due proportion to provide less stability.

Tables 7 and 8 along with Figures 7 and 8 respectively, summarize the unsoaked and soaked CBR values for different RHA contents.

Table 7. California Bearing Ratio test, (Alabi, Olutaiwo, & Adeboje, 2015)

RHA Content (%)	**CBR (Unsoaked) (%)**	**CBR (Soaked) (%)**
0	12.3	9.2
4	15.7	11.8
8	18.5	14.1
12	20.8	16.2
16	22.1	17.5
20	21.3	16.8

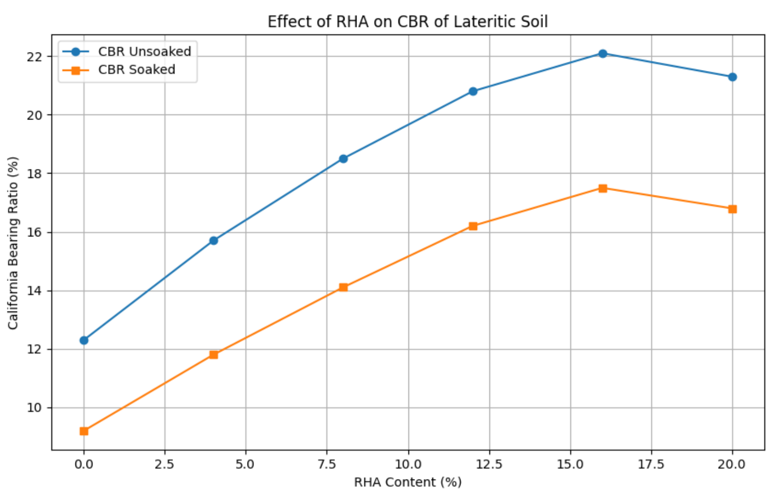

Figure 7. Effects of RHA on CBR of Lateritic soil (Alabi, Olutaiwo, & Adeboje, 2015)

Table 8. Summary of Data from Reviewed Papers for California Bearing Ratio (Alhassan & Alhaji, 2017).

RHA Content (%)	**CBR (Unsoaked) (%)**	**CBR (Soaked) (%)**
0	10	5
2	15	6
4	17	8
6	18	9
8	18	10
10	18	12
12	18	15

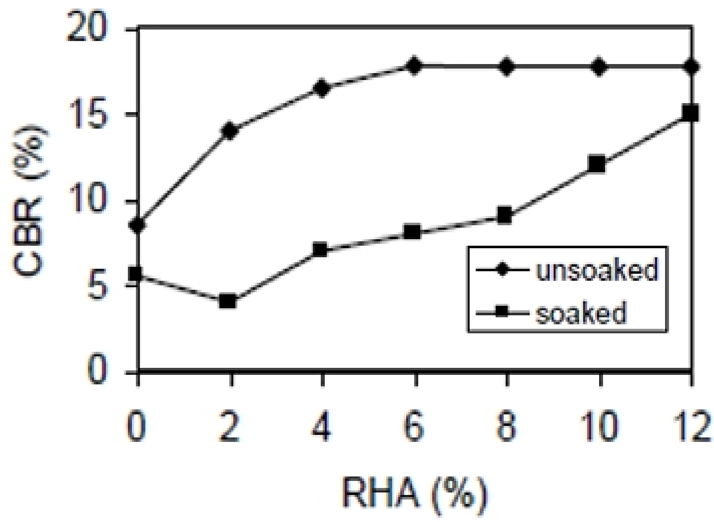

Figure 8. Effects of RHA on CBR of Lateritic soil (Alhassan & Alhaji, 2017).

DISCUSSIONS

Atterberg Limits Test

The Atterberg limits test reveals a dramatic reduction in plasticity with increasing Rice Husk Ash (RHA) content. Plasticity index (PI) decreases from 22.8% at 0% RHA to 1.4% at 20% RHA for Dataset 1 and from 27.2% at 0% RHA to 15.7% at 20% RHA for Dataset 2. The trend aligns with findings from (Alhassan & Alhaji, 2017) and (Rahman, 1986), as they indicate that RHA modulates plasticity in soil by altering its clay content towards a composition that is desirable in construction work.

Table 9. Observations of Atterberg Limits of RHA content stabilized with lateritic soils

RHA Content (%)	Data set 1			Data set 2		
	LL (%) (Source 1)	PL (%) (Source 1)	PI (%) (Source 1)	LL (%) (Source 2)	PL (%) (Source 2)	PI (%) (Source 2)
0	45.2	22.4	22.8	49.8	22.6	27.2
5	42.1	24.6	17.5	51.4	26.1	25.3
10	38.3	27.1	11.2	52.2	29.5	22.7
15	35.0	30.5	4.5	52.6	31.9	20.7
20	33.5	32.1	1.4	54.3	38.6	15.7

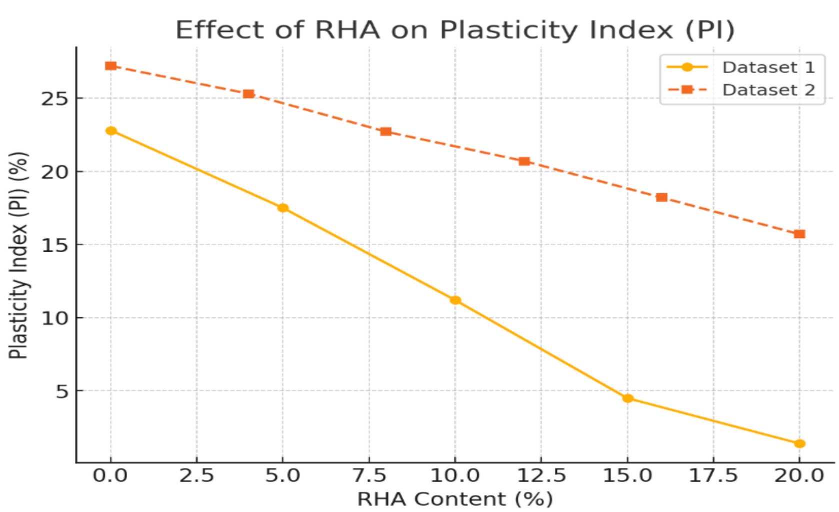

Figure 9. Effects of RHA on PI

Compaction Characteristics Analysis

The compaction test results indicate that maximum dry density (MDD) decreased with increasing rice husk ash (RHA) content, from 1.98 g/cm³ at 0% RHA to 1.70 g/cm³ at 20% RHA. Optimum moisture content (OMC) also increased from 12.4% at 0% RHA to 21.0% at 20% RHA. This trend aligns with findings by (Alhassan & Alhaji, 2008), who observed that adding RHA decreased MDD and increased OMC due to RHA's lower unit weight and higher water absorption capacity. Similarly, a study by (Pushpakumara & Mendis, 2022) reported that increasing RHA content from 0% to 30% led to a decrease in MDD and an increase in OMC in treated soils. These studies collectively demonstrate that incorporating RHA into soil mixtures typically results in decreased MDD and increased OMC, attributed to RHA's physical properties.

Table 10. Observations of RHA content effect on compaction of lateritic soils

RHA Content (%)	(MDD) (g/cm³) (Source 1)	(OMC) (%) (Source 1)	RHA Content (%)	MDD (g/cm³) (Source 2)	OMC (%) (Source 2)
			0	1.98	12.4
0	1.98	12.4	4	1.92	14.7
5	1.92	14.7	8	1.88	16.2
10	1.88	16.2	12	1.82	17.8
15	1.82	17.8	16	1.75	19.4
20	1.75	19.4	20	1.70	21.0

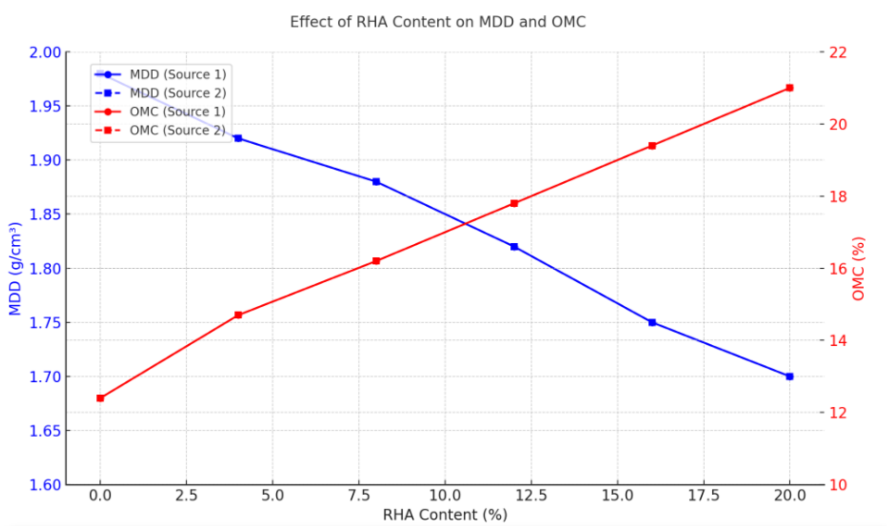

Figure 10. Effects of RHA content on MDD & OMC

Unconfined Compressive Strength (UCS) Analysis

UCS values from both sources increased with the incorporation of RHA, peaking at 15% RHA before dropping. UCS for Source 1 increased from 320 kPa at 0% RHA to 710 kPa at 15% RHA before dropping to 560 kPa at 20% RHA. The same trend was observed in Source 2, increasing from 289 kPa to 470 kPa at 20% RHA. These results mean that while RHA enhances the soil strength, excessive replacement may decrease the matrix strength due to dilution effects. The 28-day UCS peak of 710 kPa at 15% RHA demonstrates viability for low-rise buildings, but long-term durability under Ghana's heavy rainfall requires further investigation.

Table 11. Observations from Different content of RHA on the compressive strength of Lateritic soils

RHA Content (%)	**UCS (kPa) - Source 1**	**UCS (kPa) - Source 2**
0	320	289
5	460	345
10	620	410
15	710	460
20	560	470

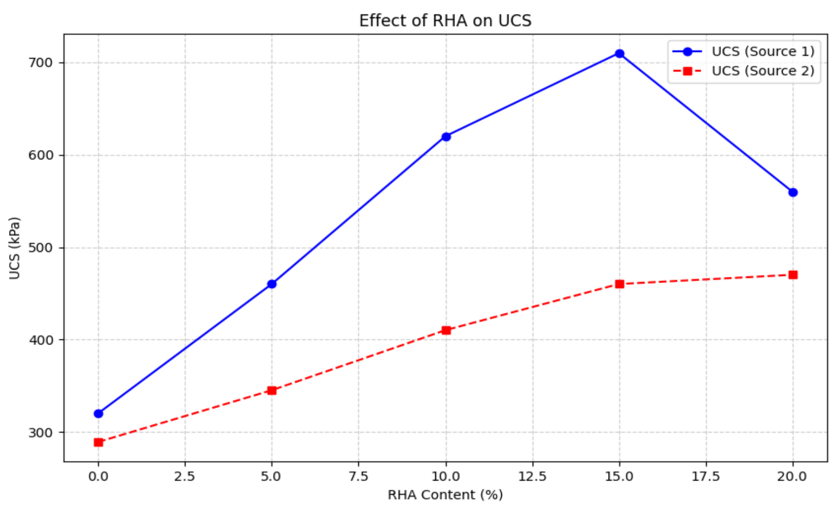

Figure 11. Effects of RHA on UCS

California Bearing Ratio (CBR)

CBR test values exhibit notable enhancement in both unsoaked and soaked state with RHA addition. The unsoaked CBR of Source 1 increased from 12.3% at 0% RHA to 22.1% at 16% RHA before reducing slightly to 21.3% at 20% RHA. In Source 2, unsoaked CBR increased from 10% at 0% RHA to 18% at 12% RHA. Similarly, the CBR of Source 1 improved from 9.2% to 17.5% at 16% RHA, while Source 2 improved from 5% to 15% at 12% RHA.

The findings are in line with those of (Alhassan & Alhaji,2017) and (Alabi et al.,2015), where enhanced CBR values were reported with the addition of RHA to optimal improved from 5% to 15% at 12% RHA. content.

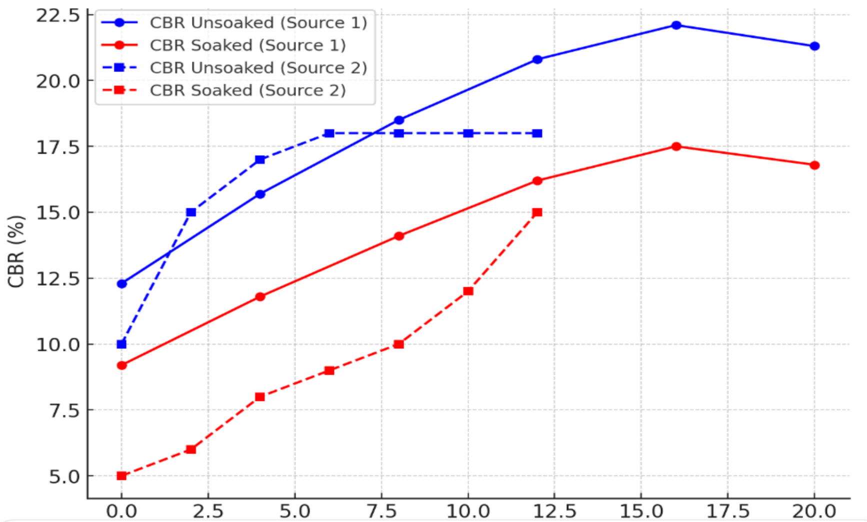

Figure 12. Effects of RHA content on CBR

Observations from Different Sources

Comparison among different sources illustrates uniformity in the improvement of soil properties through the incorporation of RHA. In a number of different studies, including (Alhassan & Alhaji, 2017) and (Alabi et al., 2015), decreases in plasticity index, maximum dry density (MDD), and increases in optimum moisture content (OMC) were observed. Moreover, the highest UCS and CBR values were recorded in the range of 10-15% RHA prior to the decrease in higher percentages. These variations reflect the dependency of ideal RHA content on the soil type and initial composition. The reduction in plasticity index (PI) from 22.8% to 1.4% at 20% RHA aligns with Basha et al. (2005), who reported a 30% PI reduction in Nigerian lateritic soils. However, the optimal RHA content (10–15%) varies slightly across regions due to differences in soil silica content, underscoring the need for localized testing. A limitation of this study is its reliance on secondary data; future work should validate these findings through field trials in Ghana.

Conclusions

This study validates the use of rice husk ash (RHA) as a viable stabilizer for lateritic soil, providing an economic and eco-friendly alternative to conventional stabilization. The incorporation of RHA enhances the geotechnical and mechanical characteristics of lateritic soil, enhancing compressive strength, California Bearing Ratio (CBR), and plasticity behavior. All these improvements render RHA-stabilized soil a viable material for construction applications, particularly in resource-constrained environments where cost and environmental compatibility are critical concerns.

This study confirms that RHA stabilization enhances lateritic soil's strength and reduces plasticity, offering a cost-effective alternative to cement. To scale adoption, Ghana's policymakers should incentivize agro-waste recycling and integrate RHA-soil standards into national building codes. Future research is needed to address long-term durability under local climatic conditions and economic feasibility for rural communities.

In addition to its technical advantages, the use of RHA improves circular economy principles through recycling of farm by-products, reducing the environmental footprint of using cement and uncontrolled sand excavation. The economic benefits include reduced reliance on expensive stabilizers, making construction accessible to low-income communities. The process also favors Ghana's sustainability plans, with a scalable process for sustainable infrastructure development.

However, large-scale implementation of RHA-stabilized lateritic soil requires additional refinement, including standard mix designs, durability testing, and government assistance in regulatory integration. It requires coordination among researchers, industry stakeholders, and policymakers to optimize its application and long-term performance.

Overall, this study not only affirms RHA's role in green building but also highlights its capability to transform the built environment of Ghana and the world at large. Through the combination of local knowledge with modern engineering methods, RHA-stabilized lateritic soil is a futuristic strategy for sustainable and climate-resilient infrastructure construction.

Conflict of Interest Declarations

The authors do not have any conflict of interest in publishing this study. There is no financial, professional, or personal relationship that has influenced the research outcomes, data analysis, or conclusions drawn. All of the information sources have been adequately referenced, and the research work has been conducted in its entirety with academic integrity and impartiality.

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