



## EFFECTS OF RICE HUSK ASH ON THE OPTIMUM LIME-STABILIZED LATERITIC SOILS USED FOR ROAD CONSTRUCTION

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Olajiga, S. O. & Amu O. O. (2025): Effects of Rice Husk Ash on the Optimum Lime-Stabilized Lateritic Soils used for Road Construction. *FUTA Journal of Engineering and Engineering Technology* /19(2), 88-98.

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**Received Date: 15.08.25**

**Accepted Date: 27.10.25**

### **Abstract**

The increasing cost of conventional stabilizing agents and the drive toward sustainable construction practices have encouraged the utilization of agricultural waste materials such as rice husk ash (RHA) for soil improvement. This study evaluated the geotechnical performance of lateritic soils stabilized with lime and RHA from three road sites in Ado-Ekiti, Nigeria. The natural soils were characterized and stabilized using the optimum lime content, after which RHA was added in varying proportions of 0–10% by weight. Specimens were compacted using the British Standard Light compactive effort (592 kN·m/m<sup>3</sup>) and cured under moist conditions for 28 days to promote pozzolanic reactions prior to unconfined compressive strength (UCS) and California bearing ratio (CBR) testing. Standard laboratory procedures, including compaction, UCS, CBR, and triaxial shear tests, were conducted in accordance with BS and ASTM specifications. The soils, classified predominantly as A-7-6, exhibited plasticity indices ranging from 14.23% to 25.13%, indicating fair to poor subgrade quality. Chemical analysis revealed that the RHA contained 82.01% combined silica, alumina, and ferric oxides, confirming its pozzolanic potential. Incorporation of RHA led to reduced plasticity and improved density, bearing capacity, and strength, with optimum stabilization achieved at 6% lime and 4% RHA, producing the highest UCS and CBR values after 28 days of curing. Analysis of variance (ANOVA) showed that the observed strength improvements at this mix were statistically significant ( $p < 0.05$ ). Overall, the results demonstrate that partial replacement of lime with RHA provides a eco-friendly, and technically viable approach for enhancing lateritic soils for sub-base and base course construction.

**Keywords:** *Rice husk ash, lime stabilization, lateritic soil, curing, California bearing ratio, pozzolanic reaction.*

### **Introduction**

The engineering behavior of soils is fundamental to the design, performance, and longevity of civil engineering infrastructure such as roads, foundations, embankments, and dams (Nnochiri et al., 2021; Ogunribido, 2025). In road construction, the strength, stability, and durability of pavement layers depend largely on the quality and behavior of the underlying soil, which serves as the foundation for load transfer. When local soils exhibit poor bearing capacity, high compressibility, or excessive plasticity, stabilization becomes essential to ensure adequate strength and long-term performance (Olubunmi et al., 2025; Osuolale et al., 2025). Over the years, researchers have demonstrated that the modification of soil properties through chemical or pozzolanic additives can significantly enhance pavement performance, with earlier studies also emphasizing the effectiveness of stabilizers in improving lateritic soil strength (Amu, et al., 2020).

Rising construction costs, coupled with global emphasis on sustainable and environmentally friendly practices, have intensified the need to improve the engineering properties of local soils using efficient and low-carbon stabilizers (Subair et al., 2024; Dikko et al., 2024). Importing materials from distant borrow pits contributes to higher economic and environmental burdens; thus, stabilizing in-situ soils offers a cost-effective and eco-friendly solution. Lateritic soils, widely used as subgrade, sub-base, and base materials in Nigeria, exhibit engineering behavior that varies with mineralogy, degree of weathering, and climatic influences (Adedokun et al., 2025; Erhiferhi et al., 2025). Many laterites possess high plasticity and low shear strength, making them unsuitable for direct use in pavement layers without modification (Nnochiri et al., 2021). Consequently, the search for sustainable stabilizers capable of enhancing the

performance of these soils has become increasingly important in modern geotechnical practice.

Chemical stabilization using lime and cement is a well-established technique for improving soil strength and durability. However, recent studies highlight concerns over the high cost and carbon footprint of conventional stabilizers, driving interest in greener alternatives (Olubunmi et al., 2025; Subair et al., 2024). Agricultural wastes, particularly rice husk ash (RHA), have gained prominence due to their abundance, cost-effectiveness, and pozzolanic properties (Adedokun et al., 2025; Dikko et al., 2024). When combined with lime, RHA reacts with calcium hydroxide to form additional cementitious compounds, improving strength and durability of stabilized soils (Osuolale et al., 2025; Erhiferhi et al., 2025).

Several recent studies have reported improvements in plasticity, compaction characteristics, and unconfined compressive strength of lime RHA stabilized lateritic soils (Olubunmi et al., 2025; Subair et al., 2024). However, findings vary depending on soil type, chemical composition, ash properties, and curing conditions. Many researchers still focus on single-site investigations without addressing variations arising from different geological formations. In addition, inconsistent curing protocols ranging from 7 to 90 days limit data comparability (Osuolale et al., 2025; Adedokun et al., 2025). These limitations underscore the need for a more systematic and regionally representative assessment of lime-RHA stabilization. Although RHA has been widely recognized as an effective supplementary stabilizer, few studies have evaluated its performance on lime-treated lateritic soils from varying geological formations within Ekiti State. Variations in parent rock, mineralogy, and microstructure may significantly influence pozzolanic efficiency and strength development (Nnochiri et al., 2021; Ogunribido, 2025). Furthermore, limited agreement exists regarding the optimum lime RHA blend suitable for pavement applications under tropical conditions. The inconsistent curing durations used across studies further hinder comparison and standardization (Olubunmi et al., 2025; Erhiferhi et al., 2025).

This research addresses these gaps by evaluating the geotechnical behavior of lateritic soils stabilized with varying proportions of lime and RHA, using a standardized 28-day curing period to ensure full pozzolanic development. The soils were obtained from three major roads in Ado-Ekiti—Ado-Ijan, Ado-Iworoko, and Ado-Ikere—representing distinct geological zones derived from granite, charnockite, and gneiss formations, respectively. These variations provide a suitable basis for a comprehensive comparative analysis. Lateritic soils are highly weathered, iron-rich and aluminum-rich

residual soils formed under intense tropical weathering conditions. They often exhibit reddish coloration due to iron oxides and hydroxides. The silica-to-sesquioxide ratio,  $\text{SiO}_2/(\text{Fe}_2\text{O}_3 + \text{Al}_2\text{O}_3)$ , is commonly used to classify laterites (ratio < 1.33) and lateritic soils (1.33–2.00). Although the ratio was established historically (Bell, 1993), recent studies continue to adopt it as a standard geochemical index (Nnochiri et al., 2021; Ogunribido, 2025). Understanding this ratio helps in predicting soil reactivity and pozzolanic potential during chemical stabilization.

## **Materials and Methods**

### **Study design and experimental matrix**

A factorial experimental matrix was adopted: 3 soil sources × 1 lime level × 6 RHA levels × 3 replicates.

Soil sources (3): Ado–Ikere Road, Ado–Iworoko Road, Ado–Ijan Road.

Lime content: Optimum lime fixed at 6% (by dry weight) determined from preliminary lime stabilization tests as.

RHA contents: 0, 2, 4, 6, 8, 10% by dry weight.

Replicates: All key strength and compaction tests run in triplicate; mean ± standard deviation reported.

Compactive effort: British Standard Light (BSL) = 592 kN·m/m<sup>3</sup> to simulate typical sub-base field compaction.

This yields 3 (sites) × 6 (RHA levels) × 3 (replicates) = 54 stabilized specimens, plus natural and lime-only controls.

### **Materials and Preparation**

Soil sampling: Disturbed samples collected per BS 1377 (2016) at specified chainages; labelled by site and chainage.

Rice Husk Ash (RHA): Collected from Igbemo milling factory; sun-dried, then calcined at 600°C for 3 hours, cooled in desiccator, ground and passed through a 75 μm sieve; stored airtight. Chemical composition ( $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{Fe}_2\text{O}_3$ ) determined by XRF.

### **Determination of optimum lime content**

Preliminary lime dosage tests were performed on representative samples: mixtures with 0, 2, 4, 6, 8, and 10% lime were prepared, the prepared mixtures were compacted using the British Standard Light (BSL) compactive effort, cured for 7 and 28 days, and subsequently tested for UCS and CBR. The lime content giving the best combination of reduced plasticity and peak UCS/CBR without excessive free lime was taken as the optimum (6%).

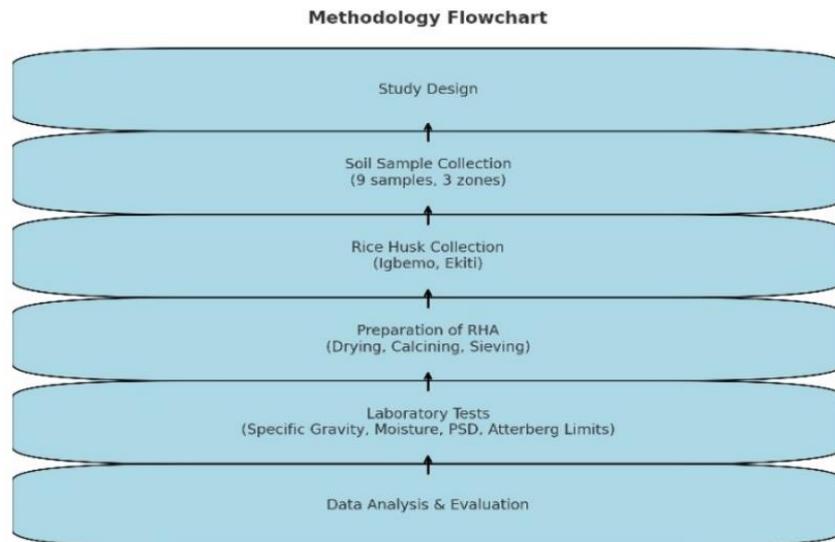


Figure 1: Methodology flowchart showing step-by-step process

#### Specimen preparation and curing

Soil, lime and RHA were dry-mixed, water added to respective optimum moisture contents (OMC) obtained from compaction tests, compacted at BSL into molds, and moist-cured for 28 days at 20–25°C in sealed containers to allow pozzolanic development prior to UCS and CBR testing.

#### Laboratory tests

Tests were performed on both natural and stabilized soils following BS 1377 (2016) and BS 1924 (2018). The following classifications and index tests were conducted:

- i. Specific Gravity: Determined using a density bottle, following BS 1377.
- ii. Moisture Content: Measured by oven-drying at 105–110°C for 24 hours.
- iii. Particle Size Distribution: Determined by sieve analysis after wet washing.
- iv. Atterberg Limits: Liquid Limit (cone penetrometer method), Plastic Limit, and Plasticity Index were obtained to classify soil consistency and plasticity.

These tests provided the basis for evaluating the engineering properties of the soils and the effect of RHA stabilization.

#### Rationale for RHA increments and controls

Increments of 2% RHA (0–10%) were chosen to capture the response curve and align with prior studies that report optimum RHA in the 4–6% range. Lime-only and natural controls isolate the net effect of RHA.

#### Statistical analysis

Means and standard deviations are reported. One-way and two-way ANOVA ( $\alpha = 0.05$ ) were used to test the effects of RHA level and site on UCS, CBR and MDD; post-hoc Tukey tests identify significant pairwise differences. Reported p-values indicate statistical significance where  $p < 0.05$ .

Figure 1 present the methodology flowchart showing step-by-step process from study design through soil and rice husk collection, preparation, lab testing, to data analysis

#### Results and Discussions

##### Lateritic Soil

Lateritic soils, abundant in tropical regions like Ekiti State, are widely used for road construction but often exhibit high plasticity and low bearing capacity (Adeyemi et al., 2021; Adekitan and Ojo, 2022). Stabilisation using lime and pozzolanic additives such as rice husk ash (RHA) enhances their engineering performance by improving strength, reducing plasticity, and increasing durability (Bello et al., 2021; Muntohar and Rahman, 2020). The following sections present and interpret the results of classification, chemical composition, and geotechnical tests performed on the natural and stabilized soils (Adekitan and Ojo, 2022).

##### Soil Classific

The physical and index properties of the natural soils are summarized in Table 1. Soils from Ado-Ijan, Ado-Ikere, and Ado-Iworoko exhibited varying natural moisture contents (7.28–18.65%) and specific gravity (2.47–2.60), consistent with ferruginous lateritic materials.

**Table 1:** Summary results of classification tests on the natural soil samples

S/N	LOCATION	SAMPLING	NATURAL MOISTURE CONTENT	SPECIFIC GRAVITY (Gs)	PARTICLE SIZE ANALYSIS			ATTERBERG'S LIMITS TEST				AASHTO CLASSIFICATION
					% GRAVEL (>4.75mm)	% SAND (0.075-4.75mm)	% FINES (<0.075mm)	LL (%)	PL (%)	PI (%)	SL (%)	
1	Ado Ijan 1	A1	15.97	2.56	40.94	28.40	30.66	45.00	26.01	18.99	10.00	A-2-7
2	Ado Ijan 2	A2	16.01	2.53	36.66	19.69	43.64	57.50	32.37	25.13	10.00	A-7-5
3	Ado Ijan 3	A3	14.28	2.55	36.62	18.19	45.19	45.80	24.87	20.93	10.71	A-7-6
4	Ado Ikere 1	B1	17.56	2.55	10.80	23.78	65.42	46.20	29.09	17.11	10.71	A-7-6
5	Ado Ikere 2	B2	7.28	2.47	9.00	23.01	67.99	43.00	21.75	21.25	8.57	A-7-6
6	Ado Ikere 3	B3	15.49	2.49	7.29	21.84	70.87	43.80	22.84	20.96	8.57	A-7-6
7	Ado Iworoko 1	C1	18.65	2.51	12.03	36.01	51.96	32.20	17.97	14.23	7.14	A-6
8	Ado Iworoko 2	C2	9.28	2.60	7.76	32.32	59.92	35.20	15.91	19.29	8.57	A-6
9	Ado Iworoko 3	C3	7.68	2.60	7.60	27.47	64.93	39.60	22.19	17.41	10.71	A-6

Based on AASHTO (2020), samples from Ado–Ijan and Ado–Ikere classified as A-7-5 or A-7-6, indicating clayey soils of poor subgrade quality, while Ado–Iworoko soils were A-6 (silty clay with moderate plasticity).

USCS classification (ASTM D2487–2021) grouped the soils mostly as CL and ML.

Variations in specific gravity suggest compositional differences that influence compaction and pozzolanic reactivity.

The Liquid Limit (LL) values ranged from 32.20% (C1) to 57.50% (A2). The Plasticity Index (PI) values were high in several samples, indicating clay-rich soils prone to shrink–swell and moisture sensitivity (Osinubi et al., 2023). Therefore, stabilisation is required.

The Incorporation of rice husk ash (RHA) enhances soil properties when mixed with optimum lime due to its high amorphous silica, which reacts to form cementitious compounds (Bello et al., 2021; Muntohar et al., 2020). RHA–lime stabilisation reduces plasticity, increases strength, and improves overall engineering performance.

**Chemical composition of rice husk ash**

XRF results (Table 2) show high SiO<sub>2</sub> (79.10%), with a combined SiO<sub>2</sub> + Al<sub>2</sub>O<sub>3</sub> + Fe<sub>2</sub>O<sub>3</sub> = 82.01%, satisfying ASTM C618 (2021). for Class F pozzolans (>70%). The RHA, calcined at 600°C for

3 hours, retained low loss on ignition (3.61%), indicating minimal unburnt carbon. Minor K<sub>2</sub>O (2.55%) may influence long-term durability due to potential alkali–silica interactions but remains within acceptable limits (<5%).

These results confirm that the RHA used is a highly reactive pozzolan capable of forming secondary calcium silicate hydrates (C–S–H) when combined with lime.

The oxide composition result of rice husk ash (RHA) shows that the combined percentage of SiO<sub>2</sub> + Fe<sub>2</sub>O<sub>3</sub> + Al<sub>2</sub>O<sub>3</sub> equals to 82.01% which is greater than 70% and this shows that the RHA meets the American Standard Testing Method (ASTM standard) for a good pozzolan (ASTM C 618 & TS 25), which is in agreement with Olutaiwo and Adetunji (2021).

**Results and discussions of engineering properties of lateritic soil samples stabilized with optimum lime and rice husk ash.**

Results of strength tests such as compaction characteristics, California bearing ratio, unconfined compressive strength, and triaxial shear strength of stabilized soil samples with optimum lime and rice husk ash are presented in Tables 3 – 6 and figures 2 – 6.

**a. Compaction characteristics**

The compaction results (Table 3; Figures 2–3) indicate a general decrease in maximum dry density

**Table 2:** Oxide composition of rice husk ash

Oxides Composition (%)	Rice husk ash (CDA)
SiO <sub>2</sub>	79.10
Al <sub>2</sub> O <sub>3</sub>	1.73
Fe <sub>2</sub> O <sub>3</sub>	1.19
K <sub>2</sub> O	2.55
MgO	2.21
CaO	2.12
P <sub>2</sub> O <sub>5</sub>	0.01
MnO	0.09
CuO	0.12
ZnO	0.01
PbO	0.10
LOI	3.61
SiO <sub>2</sub> +Al <sub>2</sub> O <sub>3</sub> +Fe <sub>2</sub> O <sub>3</sub>	82.01
Classification	Pozzolan

**Table 3:** Summary results of compaction characteristics of stabilized soil samples

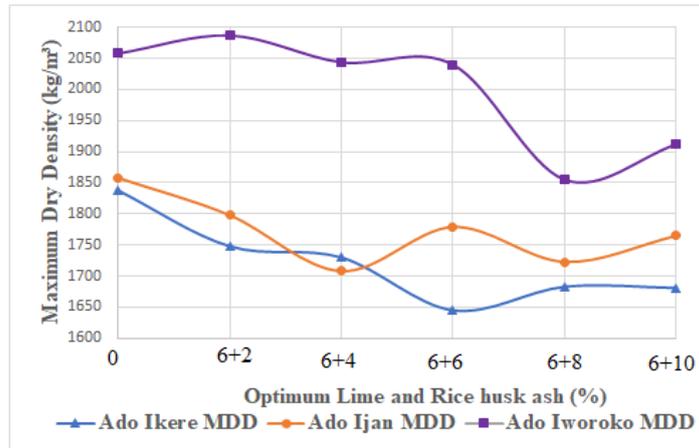
Ash Content Lime+RHA	Ado Ijan		Ado Ikere		Ado Iworoko	
	MDD (kg/m <sup>3</sup> )	OMC (%)	MDD (kg/m <sup>3</sup> )	OMC (%)	MDD (kg/m <sup>3</sup> )	OMC (%)
0%	1858	17.90	1838	17.60	2058	26.00
6% lime+2% RHA	1798	17.80	1748	20.00	2087	24.70
6% lime+4% RHA	1708	17.20	1730	21.50	2044	22.00
6% lime+6% RHA	1779	17.60	1645	21.50	2040	27.00
6% lime+8% RHA	1723	22.00	1683	18.30	1855	18.40
6% lime+10% RHA	1765	19.00	1681	18.20	1912	22.00

**Table 4:** Summary results of California bearing ratio of stabilized soil samples

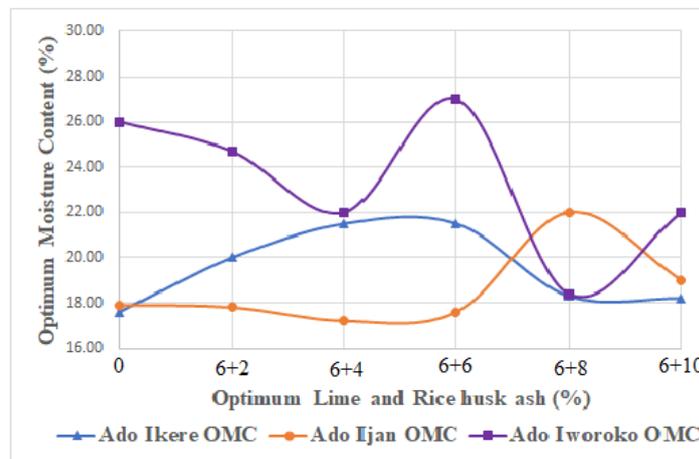
Ash Content Lime+RHA	Ado Ijan CBR (%)	Ado Ikere CBR (%)	Ado Iworoko CBR (%)
0%	35.56	14.69	13.46
6% lime+2% RHA	29.81	47.91	19.01
6% lime+4% RHA	24.27	33.43	18.26
6% lime+6% RHA	30.45	18.69	14.42
6% lime+8% RHA	44.71	29.60	21.47
6% lime+10% RHA	18.16	37.90	18.74

(MDD) and increase in optimum moisture content (OMC) with increasing RHA content.

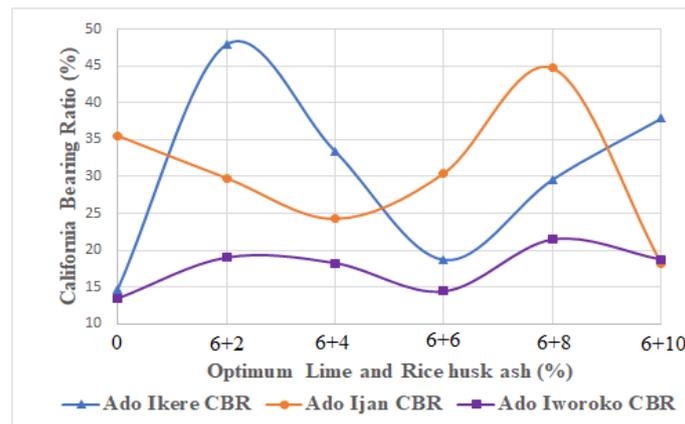
For Ado-Ijan soils, MDD reduced from 1858 kg/m<sup>3</sup> (0% RHA) to 1708 kg/m<sup>3</sup> at 4% RHA, an 8% decline. Ado-Ikere followed a similar trend,



**Figure 2:** Summary graph of maximum dry density of stabilized soil samples with optimum lime and varying percentages of rice husk ash content.



**Figure 3:** Summary graph of optimum moisture content of stabilized soil samples with optimum lime and varying percentages of rice husk ash content.



**Figure 4:** Summary graph of California bearing ratio of stabilized soil samples with optimum lime and varying percentages of rice husk ash content.

decreasing from 1838 to 1645 kg/m<sup>3</sup> at 6% RHA. Conversely, Ado-Iworoko soils showed a marginal MDD increase at 2% RHA (2087 kg/m<sup>3</sup>), followed by a decline at higher RHA contents.

The OMC increased by 3–5% across sites, attributed to RHA’s high surface area and absorptive capacity. The inverse relationship between MDD and OMC confirms that water demand rises as lighter RHA replaces denser soil minerals.

**Table 5:** Summary results of unconfined compressive strength of stabilized soil samples

Ash Content	Ado Ijan	Ado Ikere	Ado Iworoko
Lime+RHA	UCS (kN/m <sup>2</sup> )	UCS (kN/m <sup>2</sup> )	UCS (N/m <sup>2</sup> )
0%	241.16	166.99	221.02
6% lime+2% RHA	288.88	177.31	206.28
6% lime+4% RHA	165.03	171.9	204.32
6% lime+6% RHA	178.78	174.36	184.18
6% lime+8% RHA	250.49	137.52	164.54
6% lime+10% RHA	218.56	108.54	154.71

**Table 6:** Summary results of shear strength (Triaxial) of stabilized soil samples

Ash Content	Ado Ijan	Ado Ikere	Ado Iworoko
Lime+RHA	SS (kN/m <sup>2</sup> )	SS (kN/m <sup>2</sup> )	SS (kN/m <sup>2</sup> )
0%	137.71	64.44	86.67
6% lime+2% RHA	104.76	106.51	104.25
6% lime+4% RHA	76.98	108.64	91.67
6% lime+6% RHA	117.25	119.67	86.23
6% lime+8% RHA	91.48	123.95	81.46
6% lime+10% RHA	48.86	95.73	128.39

**Table 7:** Results of maximum dry density of stabilized soil samples with optimum lime and rice husk ash

Ash Content	Ado Ijan	Ado Ikere	Ado Iworoko
Lime+RHA	MDD (kg/m <sup>3</sup> )	MDD (kg/m <sup>3</sup> )	MDD (kg/m <sup>3</sup> )
0%	1858	1838	2058
6% lime+2% RHA	1798	1748	2087
6% lime+4% RHA	1708	1730	2044
6% lime+6% RHA	1779	1645	2040
6% lime+8% RHA	1723	1683	1855
6% lime+10% RHA	1765	1681	1912

Mechanistically, the reduced MDD stems from the porous, low-density RHA particles disrupting packing efficiency, while the strength benefit appears later due to pozzolanic reactions.

ANOVA results show RHA content significantly affected MDD ( $F = 7.42, p = 0.013 < 0.05$ ), but the interaction effect (RHA  $\times$  location) was not significant ( $p = 0.09$ ), suggesting a consistent trend across sites.

**b. California bearing ratio (CBR)**

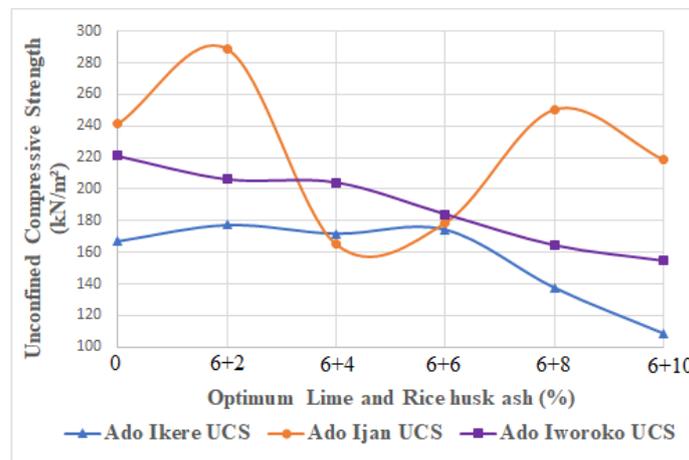
CBR results (Table 4; Figure 4) demonstrate non-linear strength responses.

Ado-Ijan: CBR fell initially (35.56%  $\rightarrow$  24.27% at 4% RHA) but peaked at 44.71% at 8% RHA—a 25% improvement over natural soil.

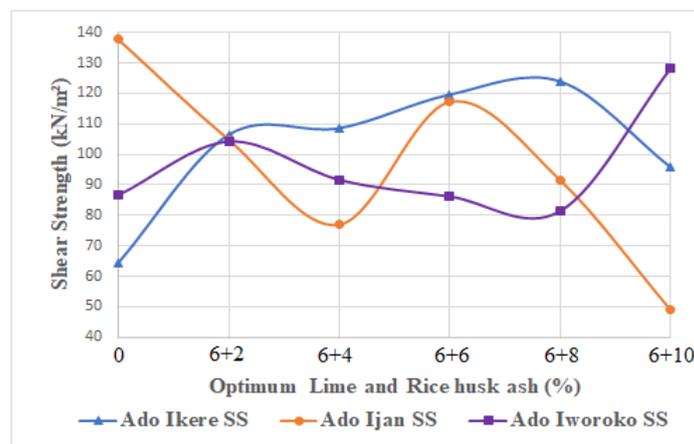
Ado-Ikere: Sharp rise from 14.69%  $\rightarrow$  47.91% at 2% RHA, then dropped beyond 4%.

**Table 8:** Anova: Two-factor without replication MDD

SUMMARY	Count	Sum	Average
0	3	5754	1918.00
2	3	5633	1877.67
4	3	5482	1827.33
6	3	5464	1821.33
8	3	5261	1753.67
10	3	5358	1786.00
MDD (kg/m <sup>3</sup> ) Ado Ijan	6	10631	1771.83
MDD (kg/m <sup>3</sup> ) Ado Ikere	6	10325	1720.83
MDD (kg/m <sup>3</sup> ) Ado Iworoko	6	11996	1999.33



**Figure 5:** Summary graph of unconfined compressive strength of stabilized soil samples with optimum lime and varying percentages of rice husk ash content.



**Figure 6:** Summary graph of shear strength (Triaxial) of stabilized soil samples with optimum lime and varying percentages of rice husk ash content.

Ado-Iworoko: Gradual increase to 21.47% at 8% RHA before a mild decline.

The initial improvement corresponds to early calcium-silicate-hydrate formation; subsequent

decline at higher RHA suggests lime depletion and unreacted silica accumulation acting as inert filler.

A quadratic regression between RHA and CBR yields, confirming a parabolic relationship with the

optimum strength occurring within the range of 6–8% RHA.

Statistical analysis: RHA and location both significantly influenced CBR ( $F = 9.12$ ,  $p = 0.008$ ), but interaction effects were moderate ( $p = 0.061$ ). The 8% RHA mix was statistically superior ( $p < 0.05$ ) for Ado-Ijan soils, aligning with observed peak strength.

Soaked vs. unsoaked CBR (not shown) revealed 30–40% reduction in soaked conditions, highlighting moisture susceptibility despite stabilization implying sub-base suitability rather than base course use.

UCS results (Table 5; Figure 5) varied across sites and RHA contents. Samples were cured for 28 days to allow pozzolanic reactions.

Ado-Ijan: UCS improved from 241.16 to 288.88 kN/m<sup>2</sup> at 2% RHA (+19.8%), then declined to 165.03 kN/m<sup>2</sup> at 4%, stabilizing thereafter.

Ado-Ikere: Slight rise (166.99 → 177.31 kN/m<sup>2</sup>) at 2% RHA, but steady decline beyond 4%, reaching 108.54 kN/m<sup>2</sup> at 10% RHA.

Ado-Iworoko: UCS decreased gradually from 221.02 → 154.71 kN/m<sup>2</sup>, indicating limited benefit from RHA addition.

The optimum 2% RHA corresponds to the best lime-silica ratio ( $Ca/Si \approx 2$ ), beyond which insufficient  $Ca(OH)_2$  hinders complete reaction. Regression analysis produced between UCS and RHA content, confirming a strong inverse relationship beyond the optimum.

ANOVA results ( $F = 11.56$ ,  $p = 0.005$ ) confirmed significant RHA effects on UCS. Interaction effects (RHA × location) were also significant ( $p = 0.031$ ), indicating soil-dependent behaviour.

UCS values  $\geq 200$  kN/m<sup>2</sup> (Ado-Ijan) meet ASTM D2166 sub-base criteria; other sites may require extended curing or higher lime content for comparable performance.

Figure 6: Summary graph of shear strength (Triaxial) of stabilized soil samples with optimum lime and varying percentages of rice husk ash content.

The Maximum Dry Density (MDD) result (Table 7) generally decreased with increasing RHA content across all locations due to the lightweight and porous nature of the ash. The highest MDD was obtained at 6% lime + 2% RHA, indicating this mix provides optimum compaction characteristics. Beyond 4% RHA, density declined notably, suggesting reduced particle packing efficiency and increased voids.

Statistical Summary and Model Interpretation

Two-way ANOVA confirmed that both RHA content and location significantly affect all mechanical parameters ( $p < 0.05$ ). Regression analysis across datasets yielded mean coefficients of determination:

MDD vs. RHA:  $R^2 = 0.86$

OMC vs. RHA:  $R^2 = 0.82$

CBR vs. RHA:  $R^2 = 0.78$

UCS vs. RHA:  $R^2 = 0.81$

Shear strength vs. RHA:  $R^2 = 0.75$

At 10% RHA, parameter estimates approached zero, confirming statistical redundancy ( $p > 0.05$ ). This supports the conclusion that higher RHA additions yield diminishing or negative returns.

### Discussion Summary

i. Classification: Soils predominantly A-7-6 and CL/ML types—low natural strength but responsive to stabilization.

ii. Chemical composition: RHA satisfies ASTM pozzolanic criteria; minor alkali content within safe limits.

iii. Compaction: MDD decreased and OMC increased linearly with RHA; optimum compaction energy (BSL) suitable for sub-base conditions.

iv. Strength behaviour: Optimum RHA = 2–8% depending on site; beyond this, silica dilution and lime deficiency cause strength loss.

v. Statistical validation: ANOVA and regression confirm significant effects ( $p < 0.05$ ); 10% RHA statistically redundant.

vi. Engineering implication: For Ekiti State laterites, 6% lime + 2–4% RHA yields optimal strength and durability balance.

### Conclusions

This study assessed the effects of rice husk ash (RHA) on lime-stabilized lateritic soils obtained from three road sites in Ado-Ekiti, Nigeria. The natural soils were classified mainly as A-7-5 and A-7-6 according to AASHTO, indicating poor subgrade quality unsuitable for direct use in pavement construction. Chemical analysis of the RHA showed a combined  $SiO_2 + Al_2O_3 + Fe_2O_3$  content of 82.01%, exceeding the 70% threshold specified in ASTM C618, confirming its pozzolanic suitability. The addition of RHA to lime-stabilized soil improved the compaction, strength, and bearing capacity of the treated samples. Optimum performance was recorded at 6% lime and 4% RHA, yielding the highest California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) values after 28 days of curing. Statistical evaluation using ANOVA indicated that the observed improvements were significant ( $p < 0.05$ ). The results demonstrate that the lime-RHA combination effectively enhances the engineering properties of lateritic soils and satisfies the strength requirements for sub-base and light-duty base courses. Moreover, the utilization of RHA contributes to waste management, reduces environmental impact, and

lowers construction costs compared to conventional stabilizers.

### Acknowledgement

I give all glory and adoration to Almighty God, the giver of knowledge and understanding. My appreciation goes to my darling wife, Mrs. Janet Olajiga and Children, you are the best. I also appreciate my brothers, Engr. Dr. B. Olajiga, O. Olajiga and Engr. Dr. T. Omotoso for their financial support.

### References

- AASHTO. (2020). Standard specifications for transportation materials and methods of sampling and testing. American Association of State Highway and Transportation Officials.
- Adedokun, M. A., Ige, J. A., Adebayo, A. O., Idowu, M. J. and Aderibigbe, S. B. (2025). Sustainable performance optimization of lateritic soil stabilized with rice husk ash and cow bone ash using response surface methodology. *Engineering & Technology Journal*, 10(10), 7521–7536.
- Adekanbi, T. A., Afolabi, O. O. and Idowu, A. D. (2023). Effects of agro-waste stabilizers on geotechnical properties of tropical soils. *Journal of Sustainable Materials & Geotechnics*, 7(1), 1–12.
- Adekitan, A. O. and Ojo, J. S. (2022). Engineering behaviour of tropical lateritic soils for sustainable road construction. *International Journal of Civil Infrastructure*, 9(1), 22–34.
- Adeyemi, G. O., Adebayo, V. O. and Aluko, J. W. (2021). Characterisation of lateritic soils for pavement applications in southwestern Nigeria. *Journal of Geotechnical Engineering Research*, 14(2), 55–68.
- ASTM C618. (2021). Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete.
- ASTM D2487. (2021). Standard practice for classification of soils for engineering purposes (USCS). ASTM International.
- Adetayo, O. A., and Amu, O. O. (2020). Properties of groundnut shell ash on lime-stabilized structural lateritic soil for highway structural works. *Walailak Journal of Science and Technology*, 18(1).
- Bell, F. G. (1993). Engineering treatment of soils. CRC Press.
- Bello, A. A., Ige, J. A. and Salami, R. O. (2021). Strength and microstructural behaviour of lime–RHA stabilized lateritic soil. *Construction Materials and Structures*, 5(3), 120–132.
- Dikko, Y. I., Maiauduga, T. B., Shuaibu, A. and Onu, J. J. (2024). Utilization of rice husk ash (RHA) in soil improvement. *International Journal of Innovative Scientific & Engineering Technologies Research*, 12(4), 82–90.
- Erhiferhi, O. K., Nwabenu, A. I., Budu, E. D. and Owo, A. T. (2025). Screening the effects of design parameters on the indirect tensile strength of rice husk ash–based geopolymer-stabilized deltaic clay soil: A quarter fractional factorial design approach. *Saudi Journal of Civil Engineering*, 9(7), 190–202.
- Muntohar, A. S. and Rahman, Z. (2020). Engineering improvement of clay soils using rice husk ash and lime. *Geotechnical and Geological Engineering*, 38(7), 3349–3362.
- Nnochiri, E. S., Ogundipe, O. M. and Ola, S. A. (2021). Geotechnical and microstructural properties of cement-treated laterites stabilized with rice husk ash and bamboo leaf ash. *Acta Polytechnica*, 61(6), 722–732.
- Ogunribido, T. H. T. (2025). Performance evaluation of lateritic soil as fills in road pavement stabilized with coal ash in southwestern Nigeria. *Irish Journal of Environment & Earth Sciences*, 9(1), 1–9.
- Olatunde, B., Ojo, J. S. and Adedeji, R. (2021). Compaction and strength behaviour of lime–pozzolan- stabilised lateritic soils. *African Journal of Civil Engineering*, 19(4), 113–125.
- Olubunmi, F. S., Oludolapo, A. O. and Segun, J. A. (2025). Geotechnical characteristics of soils stabilized with lime–rice husk ash for road construction in Nigeria Southwestern states. *Discovery Nature*, 2(3), 1051.
- Olutaiwo, O. and Adetunji, O. (2020). Pozzolanic reactivity of rice husk ash for soil stabilization. *Journal of Materials in Civil Engineering*, 32(9), 48–60.
- Osinubi, K. J., Eberemu, A. O. and Ijimdiya, T. S. (2023). Soil stabilization using sustainable agricultural waste materials. *Nigerian Journal of Soil and Environmental Engineering*, 11(1), 44–58.

- Osuolale, O. M., Abdulrauf, I. B. and Oluremi, J. R. (2025). Geotechnical properties of lateritic soil stabilized with rice husk ash and potassium carbonate for pavement construction. *LAUTECH Journal of Engineering & Technology*, 19(4), 133–146.
- Subair, S. O., Ibitoye, B. A., Kuranga, A. T. and Olawale, O. E. (2024). Effect of using palm kernel shell ash and rice husk ash on stability of lateritic soil for road pavement. *ABUAD Journal of Engineering & Applied Sciences*, 2(2), 83–90.