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Index and Strength Properties of Rice Husk Ash Stabilized Laterite Soil Using Calcium Hydroxide and Sodium Silicate as Activators

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Abstract

This paper examined the impact of alkali activator (calcium hydroxide and sodium silicate) and rice husk ash (RHA) on geotechnical features of A-7-6 (7) classified laterite soil. Soil samples were admixed with 0-15%RHA and 0-6% activator solution, containing $Ca(OH)_2$ and Na_2SiO_3 in ratio 1:2, by dry weight of soil specimen. Chemical tests were carried out on the soil and RHA specimens to assess their oxide compositions. Atterberg limits, unconfined compressive strength (UCS) and statistical tests were conducted at 5% significant level to evaluate the influence of alkaline activation and RHA on soil properties. Results showed that the soil sample is a laterite with the Silica Sesquioxide Ratio (SSR) of 1.28 while the RHA is a class F pozzolan having the sum of silica, alumina and ferrite amounted to 80.96%. The liquid limit (LL) slightly increased with the addition of 15%RHA from 41.37 to 43.84%, but decreased to 37.36% as 6% activator was added to the soil. Conversely, the plasticity index (PI) increased from 16.37 to 31.79% when treated with 6% activator solution, but declined to 3.97% as 15%RHA was added. Adding 15%RHA to the soil enhanced the workability, leading to about 80% decline in plasticity. The UCS values at 28th day curing increased from 290 to1469 kN/m^2 and 946 to 1663 kN/m^2 under British Standard Light and Heavy compactions, respectively. The lower p-value of 9.31E-06 observed for activator showed the more significant impact of the activator in enhancing strength values of soil than the RHA that has a p-value of 1.01E-05. Findings revealed that the addition of activator and RHA improved the index and strength properties of the soil. The 4-6% activator addition that achieved a higher strength than the minimum UCS of 1500 kN/m^2 specified for subbase course is thereby recommended for strength enhancement of the soil.

Keywords: Alkali activation, Geotechnical features, Rice husk ash, Laterite soil, Sodium silicate.

Introduction

Soil stabilization is a fundamental aspect of geotechnical engineering, particularly in regions where weak, expansive, or highly compressible soils pose significant challenges to construction, infrastructure development, and long-term structural stability. Weak soils often lack the necessary load-bearing capacity, making them susceptible to excessive settlements, heaving, and erosion, all of which can lead to foundation failures, road deterioration, and costly maintenance (Alabi, 2024). Weak and expansive soils continue to pose significant engineering challenges, leading to structural instability, excessive settlements, and increased maintenance costs for roadways, buildings, and other infrastructure projects (Fondjo *et al*., 2021; Puppala, 2021; Onyelowe *et al*., 2023, Adedokun *et al*., 2025). Inadequate stabilization often results in premature failures, requiring frequent repairs and rehabilitation efforts. While conventional cement- and lime-based stabilization techniques have been widely implemented, their environmental impact, high energy consumption, and cost concerns necessitate the exploration of alternative solutions (Al-Subari *et al*., 2023; Roshan and Rashid, 2024; Yue, and Wang, 2024). Traditional stabilization methods, such as cement and lime treatment, had been widely used to improve soil strength and durability. However, these conventional methods come with their environmental drawbacks, particularly in the form of high carbon dioxide (CO_2) emissions during cement and lime production, contributing to global change in climate (Mohamad *et al*., 2022, Vaz Jr. *et al*., 2022; Al-Subari *et al*., 2023). As the demand for sustainable and eco-friendly alternatives grows, researchers have turned to alkali activation techniques that utilize industrial and agricultural by-products to improve soil properties without the associated environmental costs.

Alkali activation is a chemical process that stimulates the reactivity of pozzolanic or cementitious materials through the use of alkaline solutions. This involves the reaction of pozzolanic materials with alkaline activators (silicates, carbonates and hydroxides of sodium and potassium), resulting in cementitious products, which enhance soil strength (Ayodele *et al*., 2024). These alkaline solutions, play important roles in mobilizing the silica and alumina within the precursor materials, resulting in the formation of aluminosilicate gel binders that improve soil structure and strength (Oluremi *et al*. 2020; Nassar and Kathirvel, 2023; Ayodele *et al*., 2024). Alkali activation is recognized as a viable option to cement or lime-based stabilization as a result of its decreased carbon emissions and use of industrial waste (Mohammed *et al*., 2023). Each of NaOH, Na_2SiO_3 and $Ca(OH)_2$ had been studied in isolation (Huang *et al*., 2023), but the synergistic effects of combining sodium silicate and calcium hydroxide remain underexplored. Abhishek *et al.* (2024) acknowledged the need for more research in this area, specifically regarding their combined use in activating agricultural wastes.

Rice husk ash (RHA), a residue of rice milling, has garnered serious attention because of its high silica content and pozzolanic reactivity, making it a viable stabilizer when combined with alkaline activators (Amran *et al*., 2021; Das *et al*., 2022; Adedokun *et al*., 2023; Gautam, and Bhowmik, 2023; Abhishek *et al*., 2024; Nasir *et al*., 2024). Rice husk is abundantly available in many agricultural regions, particularly in rice-producing countries. Instead of being disposed of as a waste causing environmental pollution, it can be repurposed as an environmentally friendly additive in soil stabilization applications. Sodium silicate is an inorganic compound that provides a highly alkaline environment, aiding the dissolution of silica in RHA and promoting the development of a strong gel matrix (Nassar and Kathirvel, 2023; Ayodele *et al*., 2024). Its use can lead to rapid strength gain and improved workability of the stabilized soil. Calcium hydroxide, also known as hydrated lime, not only raises the pH of the substance but also contributes calcium ions that participate in the cementitious reactions, enhancing the long term strength and durability of the stabilized soil (Mudgal *et al*. 2024; Adedokun *et al*., 2025). Lu et al. (2021) investigate sodium silicate in isolation, without exploring its combined use with $Ca(OH)_2$. When combined with RHA, sodium silicate can form strong binding phases that improve soil strength (Abhishek *et al*., 2024), but further testing under different soil types and curing regimes is still needed. Calcium hydroxide helps in the development of C-S-H, improving both strength and durability (Al-Saffar *et al*., 2023), yet the influence of varying activator ratios on performance remains underexplored. Although Huang et al. (2023) acknowledged improved strength from combined activators, they highlight the lack of research on optimal mix designs and long-term effects. Despite the promising attributes, limited research has explored the combined effects of sodium silicate and calcium hydroxide as activators in alkaline-activated RHA-treated soil. The interaction of these activators with RHA in soil stabilization needs further investigation to fully understand its potential benefits in diverse environmental and loading conditions. Alkali-activated materials, particularly those incorporating agricultural waste products such as RHA, present a viable solution for sustainable soil improvement. However, there remains a research gap regarding the effectiveness of sodium silicate and calcium hydroxide as a combined activator in RHA-treated soil. The long-term strength and environmental resilience of this soil treatment method require further study to determine its suitability for widespread application in geotechnical engineering.

This study evaluated the index, compaction and strength behaviours of alkaline-activated RHA-treated soil using a combination of sodium silicate and calcium hydroxide as activators. The study was conducted through an extensive experimental approach, involving laboratory-based testing and analysis. Data obtained from the experimental tests were analysed statistically to identify trends, correlations, and performance variations among different soil stabilization mixtures. By utilizing agricultural waste products such as rice husk ash, this research aligns with global efforts to reduce carbon emissions, minimize reliance on conventional cement-based stabilizers, and promote the circular economy in construction materials. The findings provide valuable insights for geotechnical engineers, urban planners, and policymakers, facilitating the adoption of greener and more cost-effective soil stabilization solutions. Furthermore, the study will enhance understanding of the strength characteristics of alkali-activated RHA-treated soils, ensuring the development of more resilient infrastructure capable of withstanding varying environmental and mechanical stresses. In regions prone to weak or problematic soils, the application of this technology could lead to more stable road networks, foundations, and embankments while reducing overall construction and maintenance costs. Ultimately, this research advance knowledge in the field of sustainable geotechnics, offering practical solutions that support resilient and eco-friendly infrastructure development.

Materials and Methods

Materials

The laterite sample was sourced from a borrow pit in Imota, and was located on coordinates [6° 40' 14" N, 3° 39' 10" E]. The materials were obtained as disturbed samples at 3 m below ground surface and was moved to the geotechnical laboratory of the University of Lagos for experimental analyses. Rice husk, a waste product of rice mill, was sourced at the rice mill at Rafin Kura, Kaduna, Kaduna State (Lat 10.609098º, Long 7.44061º). The rice husk was then taken to a furnace for burning in a controlled system and the furnace was regulated to a temperature of 700ºC for 4 hours. The RHA was varied from 0 to 15% (in 5% increments) by the weight of the soil sample (Table 1). Sodium silicate and $Ca(OH)_2$ used were purchased from Turraco Industrial Limited, Ojota, Lagos, Nigeria. The dosage of calcium hydroxide was calculated as a fraction of the weight total of dry soil sample in percentage (2%, 4%, and 6%), in the ratio of 2:1 with respect to sodium silicate and calcium hydroxide.

Table 1: Alkali activator and RHA combinations.

RHA (%) / Activator (%)	0	5	10	15
0	0, 0	0, 5	0, 10	0, 15
2	2, 0	2, 5	2, 10	2, 15
4	4, 0	4, 5	4, 10	4, 15
6	6, 0	6, 5	6, 10	6, 15

**activator is the first, follow by RHA in each combination, i.e. activator, RHA*

***percentage of soil in each combination = 100 – sum of the %age of activator and RHA*

Experimental methods

Chemical test: The oxide compositions of the laterite soil, RHA, calcium hydroxide, and sodium silicate were determined using X-ray Fluorescence (XRF) analyser at the Central Research Laboratory, Yaba College of Technology, Lagos.

Atterberg limits: The Atterberg limits tests were used to determine the liquid limit, plastic limit, and plasticity index of both natural and stabilised soil samples. The tests on natural soil were performed in relation to AASHTO (2021) and BS 1377 (2022), while the investigations on stabilized soil were done in conformity with BS 1924 (2018). For liquid limit, a minimum of 200g of the soil specimen was sieved using sieve 0.425 mm and progressively combined with water, utilizing two palette knives to form a consistent paste on the glass board. The prepared paste was put into the brass cup of Casagrande apparatus, levelled to prevent air entrapment, and a grooving tool was employed to divide the sample into two equal halves. The crank handle was used to administer blows until a closure formed within the groove, and the number of blows was documented. Subsequently, the wet sample was weighed and oven-dried for 24 hours. The LL was obtained as the water concentration in the soil sample at which a groove is closed under 25 blows in the Casagrande cup. For plastic limit, water was gradually mixed into the sieved sample on the glass board to create a uniform mixture for the natural and stabilized soil samples. This mixture was then rolled into 3 mm threads using the palm. The threads were placed in a moisture can, measured and oven-dried for 24 hr to assess its water content.

Strength: Compaction tests were first conducted following the BS 1377 (2022) and BS 1924 (2018) standards, using British Standard Light (BSL) and British Standard Heavy (BSH) energy levels for both the natural and activated RHA stabilized samples (Table 1), respectively. The procedure also aligned with that of the Nigerian General Specification (1997). For BSL compaction test, 3 kg of soil was thoroughly combined with 8% water to obtain a homogenous mixture. The moist soil was then placed in a 1000 mm^3 mould and compacted in 3 layers, with each layer receiving 27 blows from a 2.5 kg rammer that dropped from a height of 30 cm. The extension collar was removed after compaction and the surface of the specimen trimmed using a straight edge. Mould was then weighed including the compacted soil, the weight of the empty mould was then subtracted to obtain the weight of the specimen. The results were then used to obtain the MDD and OMC using the moisture content-dry density relationship charted on a compaction curve. In the case of the BSH compaction test, 3 kg of soil was thoroughly combined with 10% water to obtain a homogenous mixture. The moist soil was then placed in a 1000 mm^3 mould and compacted in three equal layers, with each layer receiving 27 blows from a 4.5 kg rammer that dropped from a height of 45 cm. The unconfined compressive strength (UCS) tests were done for BSL and BSH based on the OMC determined from the compaction tests in accordance to BS 1377 (2022) and 1924 (2018) for the unstabilized and stabilized soil specimens, respectively.

Results and Discussion

Geotechnical features of the natural soil

The preliminary results of the geotechnical tests conducted on the natural soil sample are presented in Table 2. The results showed that the soil had 56% fine content, which is higher than the maximum of 35% set for good subgrade soil by the Federal Ministry of Works in Nigeria. This content of high fines lessens the natural suitability of the soil as a subgrade material. The LL, PL and PI were determined to be 41.37%, 25% and 16.37%, respectively. These values classified the soil as A-7-6 (7) and CL under the AASHTO and USCS classifications respectively, describing soil types that are clayey with poorly graded subgrade properties. The specific gravity of the lateritic soil was found to be 2.58, which falls squarely on the general range of 2.55–2.75 reported for quartz–kaolinite–iron-oxide lateritic soils (Mohammed, 2021). The low CBR (0–8.95%) and moderate swelling index (15.4%) are strong indications of weak bearing and potential volume change of the soil when exposed to moisture, justifying the need for stabilization before the soil sample can be used as a road construction material.

Table 2: Properties of the natural soil

Properties	**Value**
Colour	Reddish-brown
Percentage Passing Sieve No. 200 (%)	56.0
LL (%)	41.37
PL (%)	25.0
PI (%)	16.37
Specific Gravity	2.58
Natural Moisture Content (%)	13.0
Swell Index (%)	15.4
AASHTO Classification	A-7-6 (7)
USCS Classification	CL
MDD (BSL) (Mg/m^3)	1.82
OMC (BSL) (%)	16.4

MDD (BSH) (Mg/m^3)	1.97
OMC (BSH) (%)	13.0
CBR (BSL) (%) (Soaked)	1.10
CBR (BSL) (%) (Unsoaked)	1.15
CBR (BSH) (%) (Soaked)	2.23
CBR (BSH) (%) (Unsoaked)	8.95

Chemical composition of the soil, RHA and activator

Table 3 presents the oxide compositions of the natural soil, RHA, and the two activators ($Ca(OH)_2$ and Na_2SiO_3). The natural soil has the silica, alumina and ferrite contents of 53.96%, 29.17% and 12.87%, respectively, resulting in the silica sesquioxide ratio (SSR) of 1.28. This shows that the soil sample is a laterite since the SSR falls within the 0 – 1.33 specified for the laterite soil (Bell, 1993). The results also revealed SiO_2, Al_2O_3 and CaO in the RHA to be 78.26%, 2.70% and 1.13%, respectively. Based on these results, the RHA can be classified as a highly siliceous substance as a result of its higher Silica content. A material is said to be pozzolanic if the addition of silica, alumina, and ferrite is higher than 50% (ASTM C618, 2022), and the summation of these oxides in the RHA is 80.96%. This confirms that material is a pozzolan as a result of its higher SiO_2 (78.264%), containing properties that can enhance the strength of the natural soil. The results of the chemical test revealed the calcium oxide (95.69%) as main substance present in the $Ca(OH)_2$, confirming its suitability as a calcium source for pozzolanic reactions in soil-activator mixture. A higher dominance of the sodium and silicon oxides confirms the suitability of sodium silicate as an alkali activator for enhancing pozzolanic reactions in soil stabilization.

Table 3: Oxide composition for natural soil, RHA and activators

Oxide	Soil	RHA	$Ca(OH)_2$	Na_2SiO_3
SiO_2	53.957	78.264	2.142	74.452
Al_2O_3	29.174	2.697	-	-
Fe_2O_3	12.874	-	0.417	0.599
CaO	-	1.130	95.687	-
MnO	-	0.539	0.404	1.365
NiO	-	-	-	1.026
CuO	1.361	3.489	-	-
P_2O_5	-	5.091	-	-
MgO	-	1.675	-	-
K_2O	0.702	4.282	-	-
BaO	-	1.428	-	1.099
TiO_2	1.832	0.449	-	-
ZnO	-	0.955	1.350	-
Cl	0.100	-	-	-
Na_2O	-	-	-	21.460
Silica Sesquioxide Ratio	**1.283**	-	-	-
$SiO_2 + Al_2O_3 + Fe_2O_3$	-	**80.961**	-	-

Influence of alkali activator and RHA on Atterberg limits

Figures 1-3 show the effects of alkali activator and RHA on the LL, PL and PI of the examined laterite soil. From Figure 1, the results of the influence of the activator and RHA revealed that the addition of the activator reduced the liquid limit, whereas the LL increased with increasing content of RHA. The value reduced from 41.37% for natural soil to 37.36% at 6% activator, but increased to 43.84% when 15% RHA was added to the natural soil, indicating less plastic and more stable soil as more activator was added (Ameen *et al*., 2023). The increase in LL with RHA addition is due to higher affinity of RHA for water, and its increased content leads to increasing demand for water. Similar to the trend observed with LL, the plastic limit also decreased with the increasing content of the activator, but increased slightly with the addition of RHA. However, the plasticity index of the soil sample became higher upon the addition of the alkali activator solution, while it reduced continuously when RHA is added to the natural soil. The PI value decreased from 16.37% for natural soil to 3.97% at 15% RHA addition, representing nearly 80% reduction in plasticity index thereby making the soil suitable for use as a subbase material having met the maximum PI of 12% recommended for Subbase material (NGS, 1997). At this addition, the soil changed from clay (CL) to a more stable low plasticity silt. Generally, the results revealed that the soil samples treated with the combination of 0-2% activator and 10-15% RHA improved the plasticity of the soil, making the soil stable, more workable and changed the soil from subgrade to a good subbase material. Subjecting the consistency limits results to statistical test using 2-way analysis of variance (ANOVA) at 95% confidence level (Table 3), indicated that both the activator and RHA have significant effect on the consistency limits of the soil, as their P-values (activator = 6.3E-07 and RHA = 7.98E-06) were much lower than the chosen 0.05 level of significance. However, the impact of the alkali activator across the three Atterberg limits was more significant than that of the rice husk ash, as its P-values were lower compared to that of RHA.

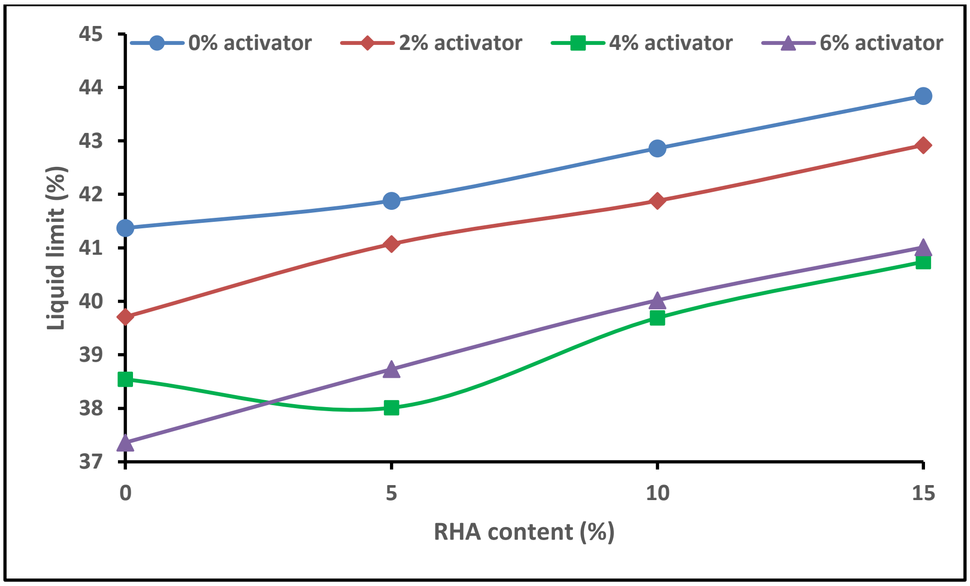

Figure 1: Influence of the activator and RHA on the liquid limit of the analysed soil

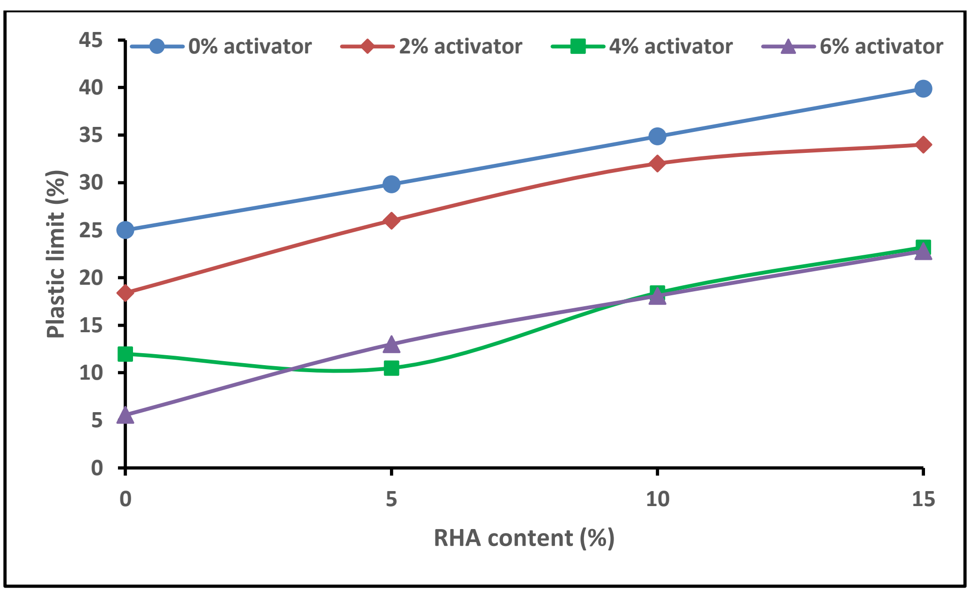

Figure 2: Influence of the activator and RHA on the plastic limit of the analysed soil

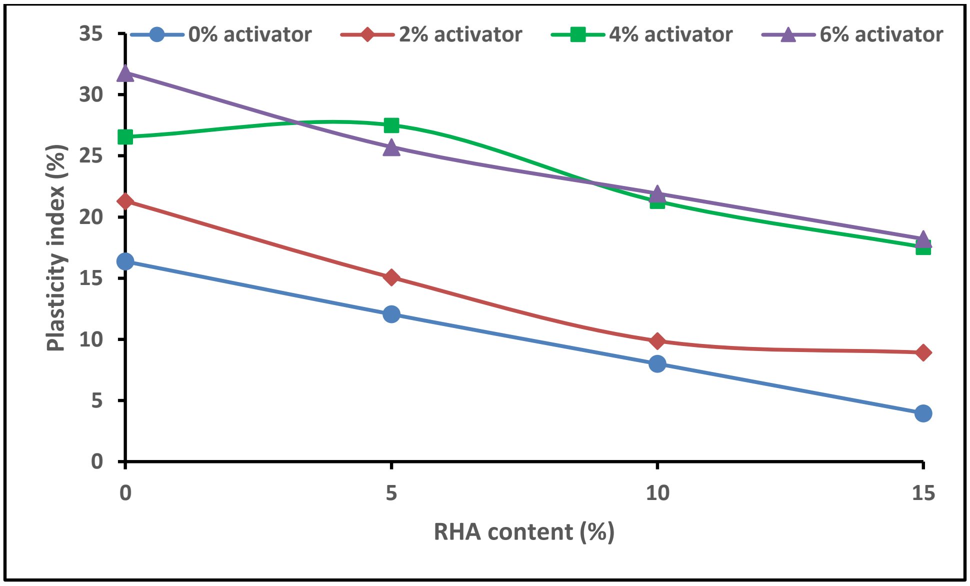

Figure 3: Influence of the activator and RHA on the plasticity index of the analysed soil

Table 3: Influence of activator and RHA on consistency limits using 2-factor ANOVA

Parameter	*Source of Variation*	*Sum of squares*	*Degree of freedom*	*Mean squares*	*Fcal*	*P-value*	*F crit*	*Remark*
Liquid limit	Activator	31.09237	3	10.36412	61.66852	2.53E-06	3.862548	Significant
	RHA	19.56372	3	6.52124	38.80263	1.78E-05	3.862548	Significant
Plastic limit	Activator	895.1135	3	298.3712	84.67751	6.47E-07	3.862548	Significant
	RHA	506.3398	3	168.7799	47.89962	7.39E-06	3.862548	Significant
Plasticity index	Activator	593.677	3	197.8923	85.2012	6.3E-07	3.862548	Significant
	RHA	327.7831	3	109.261	47.0416	7.98E-06	3.862548	Significant

Influence of alkali activator and RHA on unconfined compressive strength

Figures 4 shows the effect of the alkaline activator and RHA on the unconfined compressive strength (UCS) at 7, 14 and 28 days curing for both BSL and BSH compactive efforts.

For BSL compactive effort, the 7 days curing period developed only modest early strength, with UCS values generally increasing from 100 kN/m^2 for natural soil to hghest value of 794 kN/m^2 at 6% activator and 5% RHA content, amounting to approximately 700% increment in UCS value of the stabilised soil. The natural laterite remained weaker than all the treated combinations. The incorporation of the activator inproved the UCS significantly between 0 and 6%, whereas only 5% showed improved strength when RHA was added, indicating limited cementitious bonding and incomplete pozzolanic reactions within the short curing period. The significant increase in strength with the activator reflects the typical early-age behaviour of lime–activator treated soils. At 14 days, the trend was similar to that of 7th day strength but with a marked higher strength across all mix combinations. The UCS values rose from 186 kN/m^2 for unstabilised soil to maximum of 1037 kN/m^2 at 6% activator and 5% RHA content, representing nearly 460% improvement in strength. The improvement can be attributed to the continued hydration and pozzolanic activity, which continuously strengthens the soil particles. At 28 days, the stabilization effect is fully evident, as the strength increased from 290 kN/m^2 for unstabilized sample to the best-performing combinations of 6% activator and

5%RHA peaking at 1469 kN/m^2, reflecting a denser soil structure and well-developed cementitious bonds. The natural laterite again shows significant improvement of above 400% increment in strength, underscoring the significant benefit of lime–activator stabilization. The results of the statistical analyses presented in Table 4 showed that the effects of both the activator and RHA affect the UCS values, however, the activator with much lower P-values is more significant than RHA across all the curing ages.

For BSH compaction, the untreated soil achieved peak UCS values of approximately 520 kN/m^2, 647 kN/m^2 and 946 kN/m^2 at 7, 14 and 28 days, respectively. This shows that, even without stabilization, natural cementation processes contributed to strength gain over time, although the absolute strength remained limited when compared to stabilized mixes at later curing ages (Sithole, 2025). The stabilized soils, treated with RHA and alkaline activator blends, displayed a distinct pattern of strength development across curing periods. At 7 days, the UCS values for RHA stabilized samples decreased continuously with increasing RHA content, whereas UCS values generally increased from 520 to 1082 kN/m^2 as the activator content increases from 0 to 6%, respectively, indicating the significant of the activator in enhancing the strength property than the RHA. At 14 days, the stabilized soils showed similar trend to those of 7 days curing, but with considerable strength improvement. The strength increased from 647 – 1502 kN/m^2 as the activator increased from 0 – 6%, representing 132% in strength. The most significant transformation occurred at 28 days, where the stabilized mixes significantly outperformed the natural soil, with peak UCS value reaching 1663 kN/m^2 when 6% activator was added to the soil specimen. It has been recommended that the minimum UCS of 1.5 MN/m^2 and 4.5 MN/m^2 at 28-day curing day for lime-treated soils can be utilized as sub-base and base materials for medium-high traffic roads, respectively (IRC, 2012; Biswal *et al*., 2019). Based on these recommendations, the strength observed for specimens with 4-6% activator content satisfied the minimum UCS of 1500 kN/m^2 specified for subbase layer of the road pavement. This confirms that the chemical reactions responsible for strength development in lime–activator systems are time-dependent, with maximum benefits emerging after extended curing (Sithole, 2025). Results from Table 4 also confirm the significant impact of the alkali activator over the rice husk ash.

Overall, the peak UCS summary across the three curing periods reveals a consistent upward trend: strength roughly doubles from 7 to 14 days and continues to rise by 28 days. These results emphasize that while chemical stabilization significantly improves the strength of lateritic soils, the lighter BSL compaction delays the attainment of high UCS values. For engineering practice, this means that soils stabilized and compacted under BSL energy can achieve satisfactory load-bearing capacity by 28 days, but heavier compaction (BSH) remains preferable when early strength and long-term durability are critical.

Table 4: Influence of activator and RHA on UCS at varying curing days and compactive efforts using 2-factor ANOVA

Parameter	Source of Variation	Sum of squares	Degree of freedom	Mean squares	Fcal	P-value	F crit	Remark
7 days UCS (BSL)	Activator	741671.25	3	247223.75	138.0346	7.66E-08	3.862548	Significant
	RHA	41529.25	3	13843.08333	7.729128	0.00734	3.862548	Significant
14 days UCS (BSL)	Activator	1046714	3	348904.7	64.9427	2.03E-06	3.862548	Significant
	RHA	70986.5	3	23662.17	4.404312	0.036246	3.862548	Significant
28 days UCS (BSL)	Activator	2607386	3	869128.7	65.60366	1.94E-06	3.862548	Significant
	RHA	198987.7	3	66329.23	5.00667	0.025968	3.862548	Significant
7 days UCS (BSH)	Activator	782195.3	3	260731.8	107.3351	2.31E-07	3.862548	Significant
	RHA	163476.3	3	54492.08	22.43268	0.000163	3.862548	Significant

14 days UCS (BSH)	Activator	1255720	3	418573.4	164.6001	3.53E-08	3.862548	Significant
	RHA	534476.8	3	178158.9	70.05932	1.47E-06	3.862548	Significant
28 days UCS (BSH)	Activator	770189	3	256729.7	45.34124	9.31E-06	3.862548	Significant
	RHA	755729.5	3	251909.8	44.49001	1.01E-05	3.862548	Significant

Regression model

This paper used regression analyses to evaluate the correlation between the unconfined compressive strength as the dependent variable (under BSL and BSH compaction methods) and independent variables (activator (A), RHA and PI). Results of the analyses revealed high correlations between the two variables, indicating the considerable effects of those independent variables on the behavior of unconfined compressive strength of the A-7-6 (7) soil. The regression equations (1 and 2) for the BSL and BSH UCS indicate strong correlations between the UCS and independent variables, with very high regression coefficients of 90.0% and 95.3%, respectively. The equations suggest that increase in the activator, PI and RHA will lead to significant increase in the BSL UCS values (equation 1), due to their positive coefficients. However, increase in the RHA under BSH UCS (equation 2) should be monitored during field compaction on the analysed soil, due to its negative coefficient. The higher coefficients of the activator under the two compaction methods confirm the dominant impact of the activator over the rice husk ash in enhancing UCS values of the laterite soil. These results showed that the developed regression equations would be useful in predicting the UCS of the analysed laterite soil when encountered at the construction site. The laboratory's measured and predicted UCS values obtained from the regression equations (under BSL and BSH methods) also confirmed the strong correlations between the UCS and the aforementioned independent variables, with the R^2 values of 0.90 (Figure 5) and 0.95 (Figure 6), respectively.

$$BSL\ UCS = -18.0226 + 125.7632A + 8.219449RHA + 20.39699PI \quad (1)$$

$$BSH\ UCS = 973.5015 + 79.53471A - 33.255RHA + 6.67123PI \quad (2)$$

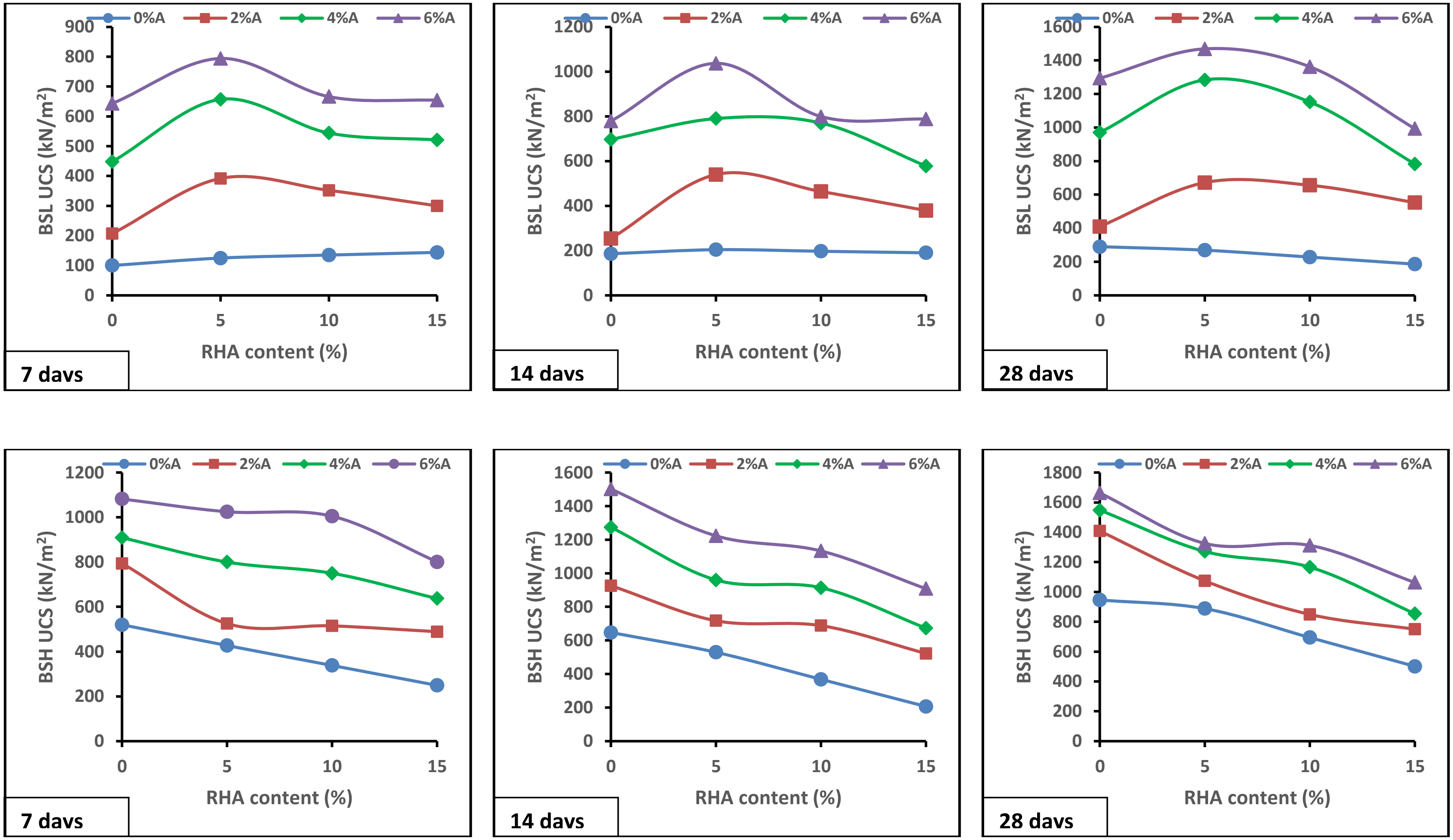

Figure 4: Influence of activator (A) and RHA on BSL and BSH UCS of the lateritic soil

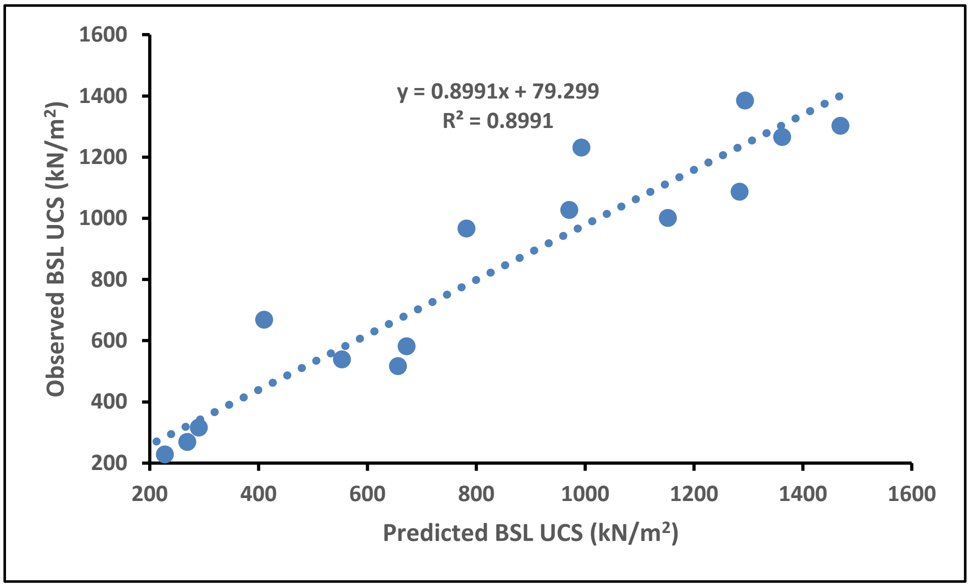

Figure 5: Laboratory's observed against predicted BSL UCS using regression equation (1)

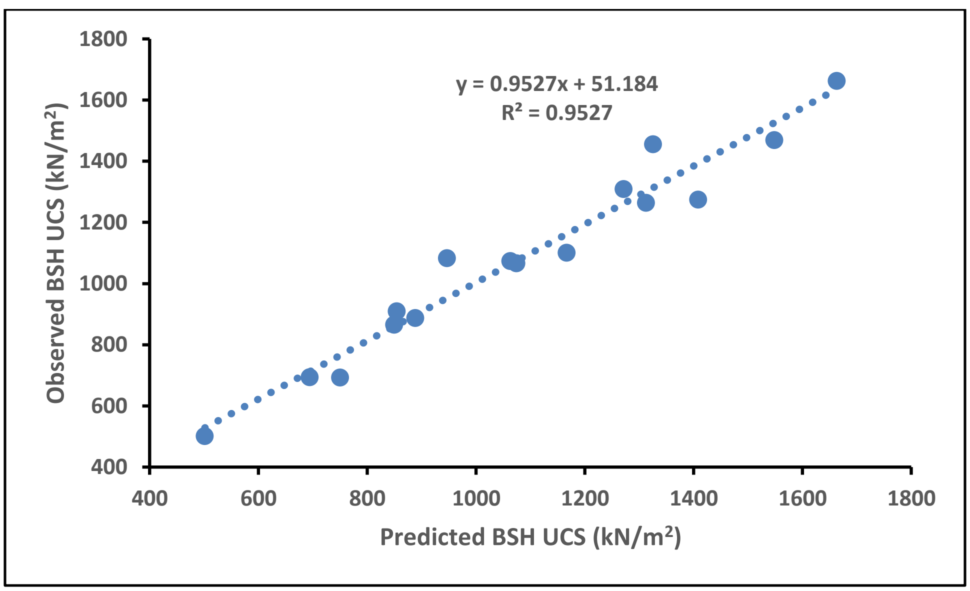

Figure 6: Laboratory's observed against predicted BSH UCS using regression equation (2)

Conclusion

Based on the series of experimental investigations and statistical analyses conducted on the natural and stabilized lateritic soil using activator and RHA, the following conclusions are drawn:

v. The soil sample classified as laterite due to its silica sesquioxide ratio of 1.28, was found to be A-7-6 (7) and CL according AASHTO and USCS classification systems, indicating that laterite soil is a poor subgrade containing low plasticity clay. The rice husk ash showed the combined silica, alumina and ferrite composition of 80.96%, indicating its strong pozzolanic properties.

vi. The incorporation of the activator and RHA significantly enhanced the investigated properties of the laterite soil. Consequently, the liquid limit (LL) reduced from 41.37% to 37.36% as the activator increased from 0 – 6%, whereas the LL increased with increasing content of RHA from 0-15%, indicating less plastic and more stable soil as more activator was added. However, the plasticity index of the soil sample became higher upon the addition of the alkali activator solution, while it reduced continuously when RHA is added to the natural soil.

vii. The strength increased from 290 kN/m^2 for natural soil to 1469 kN/m^2 for the best-performing combinations of 6% activator and 5%RHA under the British Standard Light compaction, reflecting a denser soil structure and well-developed cementitious bonds. However, for the British Standard Heavy compaction, the UCS values increased continuously with increasing content of the alkali activator but decreased as the RHA increased from 0-15%. The peak strength value of 1663 kN/m^2 was achieved at 6% activator content. These outcomes confirm the effectiveness of stabilization in enhancing the load-bearing capacity of lateritic soils, making them suitable for road pavement applications.

viii. The outcomes of the statistical tests carried out on the laboratory data also confirmed the effectiveness of activator combinations (sodium silicate and calcium hydroxide) in enhancing the geotechnical features of A-7-6 (7) laterite soil. Regression equations were developed from the experimental data which would be useful in predicting unconfined compressive strength of the A-7-6 (7) soil.

ix. The 4-6% activator content that yielded the minimum UCS of 1500 kN/m^2, which can be used as medium-heavy traffic subbase materials (IRC, 2012 and Biswal *et al*., 2019), is recommended for strength enhancement of the laterite soil.

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