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Geotechnical Properties of Lateritic Soil Stabilized with Rice Husk Ash and Potassium Carbonate for Pavement Construction

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ABSTRACT

Rice Husk Ash (RHA) is a potential cementitious material with a high surface area. The high cost of cement and greenhouse gas emissions from its production necessitate exploring the use of agricultural residues. This study investigates the geotechnical properties of lateritic soil stabilized with RHA and potassium carbonate (potash) for highway pavement. Lateritic soil samples, rice husk, and potash were obtained from Aroje, Olojo, and Takkie, respectively, in Ogbomoso. The Natural Moisture Content (NMC), Plasticity Index (PI), and percentage passing through sieve No. 200 were determined for the natural lateritic soil using standard methods. Rice husk was washed, dried, calcinated at 600°C, ground, and sieved through sieve No. 200. Oxide composition of silica, alumina, and iron oxide was determined using X-Ray Fluorescence. Lateritic soil was stabilized with varying proportions of RHA and potash. Liquid Limit (LL), Plastic Limit (PL), Optimum Moisture Content (OMC), Maximum Dry Density (MDD), California Bearing Ratio (CBR), and Unconfined Compressive Strength (UCS) were determined according to BS 1377. Effects of RHA and potash were analyzed using two-way ANOVA at a 95% significance level. The NMC, PI, and percentage passing sieve No. 200 for natural soil were 10%, 50%, and 32.76%, respectively. RHA contained 84.20% silica, 2.82% alumina, and 0.86% iron oxide. For stabilized soil, LL, PL, PI, MDD, CBR, and UCS ranged 28.0-31.50%, 28.0-31.0%, 0.5-3.5%, 10-13.9 g/cm³, 78-99%, and 200-368 kPa, respectively. Two-way ANOVA revealed significant effects for MDD ($p = 0.0024$) and OMC ($p = 0.00007$), while PI and CBR showed non-significant results ($p > 0.05$). Stabilization with RHA and potash enhanced geotechnical properties, making the soil suitable for subgrade materials in road construction.

INTRODUCTION

Highway pavement is a vital component of modern infrastructure, designed to provide a smooth and durable surface for vehicular traffic. It is engineered to distribute the loads from vehicles across the underlying layers to prevent damage and ensure a long lifespan (Pavement Interactive, 2023). The subgrade layer in pavement construction, which is the natural soil layer, serves as the foundation of the pavement structure. Materials for their construction are natural soil, which may be treated with stabilizers like lime or cement to improve its load-bearing capacity (Muthuswamy and Robinson, 2020).

Laterite is a highly weathered material, rich in secondary oxides of iron, aluminum, or both (Amadi *et al*., 2010). Laterite typically has a porous or vesicular appearance, which tends to crush easily under impact, disintegrating into a soil material that may be plastic (Amu *et al*., 2012). Lateritic soils are broadly used as fill resources for different construction works in most tropical countries. These soils are weathered under circumstances of elevated temperatures and humidity with definite irregular wet and dry seasons, ensuing in poor engineering features such as high permeability, swelling, affinity to hold moisture and high natural water content (Osinubi *et al.,* 2021) The efficient use of lateritic soil is consequently often mired by complexity in handling under moist and damp conditions typical of tropical regions and can only be used after modification and or stabilization (Amu *et al.,* 2011; Oluremi *et al.,* 2020).

Rice husk is a major agricultural by-product obtained from the food crop of paddy. For every 4 tons of rice, 1 ton of rice husk is produced (Singh *et al.,* 2021). Burning of rice husk generates about 15-20% of its weight as ash. Rice Husk Ash (RHA), being very light, is easily carried by wind and water in its dry state. RHA is difficult to coagulate and thus contributes to air and water pollution. Additionally, the cumulative generation of ash requires a large space for its disposal. Rice Husk Ash (RHA) exhibits pozzolanic properties and can improve the strength and engineering performance of soils, particularly when used in combination with activators such as lime or cement. However, due to its low calcium content, RHA alone is often insufficient for effective stabilization without a reactive additive (Rajoli and Nagaraju, 2022).

The high percentage of siliceous materials in rice husk ash indicates it has potential pozzolanic properties. The normal method of conversion of husk to ash is incineration. The properties of RHA depend upon whether the husk has undergone complete destructive combustion or has been partially burnt. RHA has been classified into high carbon char, low carbon ash and carbon-free ash (Goyal *et al.,* 2021). Based on temperature range and burning duration, a crystalline or amorphous form of silica is obtained from husk ash. The rice husk ash contains approximately 65- 90% of silica, which is highly chemically reactive (Rajoli and Nagaraju, 2022).

Production of Ordinary Portland Cement (OPC), which is a common stabilizing agent for soil materials, has been reported to be one of the sources of CO_2 emission to the environment, approximately 7% of CO_2, a major greenhouse gas, is released into the atmosphere and contributed nearly 65% of global warming which is negatively affecting the ecology and future of human being (Adedokun *et al.,* 2022). Wastes produced from industrial, agricultural and commercial activities are increasing substantially in Nigeria, due to rapid urbanization. The volume of these wastes, such as rice husk ash, has increased beyond what city authorities can handle, leading to a poor waste management system and resulting in serious environmental crises in many Nigerian cities (Oluremi *et al.* 2021).

METHODOLOGY

Collection of materials

Lateritic soil samples were collected at the Aroje area in Ogbomoso, Oyo State, Nigeria. The lateritic soil samples were air-dried, pulverized, and sieved in accordance with BS 1377 (1990) before their use without the addition of any additive to achieve uniform texture and color. Rice Husk Ash used was produced by collecting a considerable amount in volume of rice husk from a rice milling factory at Iresa, Ogbomoso, Oyo State, Nigeria. The collected rice husk was taken to Ladoke Akintola University of Technology, Ogbomoso, Oyo State, Nigeria, where it was sundried for 24 hours and calcinated at 600 °C. The oxide composition of silica, alumina and iron oxide was determined using the X-ray Fluorescence method. Potassium carbonate was purchased in a local shop at Ogbomoso, Oyo State, Nigeria.

Stabilization of the lateritic soil

Various percentages of rice husk ash and potassium carbonate (potash) were introduced in replacement of the reduced proportion of lateritic soil, as shown in Table 1. The RHA and potassium carbonate addictive were thoroughly mixed and added to the lateritic soil. Water was added to the soil and the additive mix.

Equipment

The equipment used for this study included set of sieves, mechanical sieve shaker, weighing balance, drying oven, flat glass plate about 10mm thick, Cassagrande apparatus, grooving tool, desiccator, palette, knives, wash bottle, cylindrical moulds, metal rammer, spatula, California Bearing Ratio (CBR) machine, Unconfined Compressive Strength (UCS) machine, X-Ray Fluorescence (XRF) machine, X-Ray Diffraction (XRD) machine and Scanning Electron Microscopy (SEM) machine.

Table 1: Variation of potash and rice husk ash

	RHA (%)				
Potash (%)	**0**	**4**	**8**	**12**	**16**
0	0,0	0,4	0,8	0,12	0,16
1	1,0	1,4	1,8	1,12	1,16
2	2,0	2,4	2,8	2,12	2,16
3	3,0	3,4	3,8	3,12	3,16
4	4,0	4,4	4,8	4,12	4,16

Geotechnical Investigation on Samples

The laboratory tests that were conducted on the natural lateritic soil and lateritic soil admixed with varied percentages of rice husk ash and potassium carbonate (potash) samples include particle size distribution analysis, Atterberg limits, Compaction, California Bearing Ratio (CBR) for unsoaked conditions and Unconfined Compressive Strength (UCS).

Particle size distribution

This test was conducted to determine the various sizes of soil particles in a given sample of soil and also the percentage of the total weight represented by various range of grain sizes. The particles were divided into groups in agreement with BS 1377 (1990): Part 2. The equipment that was used for this experiment was a set of sieves, a mechanical sieve shaker, a weighing balance, a mortar and rubber pestle, an evaporating dish, a drying oven and a scoop. 400 g of the dry soil was wet-washed on a sieve 75 µm and the retained sample was oven-dried for 24 hours at a temperature of 105 °C, before sieving was done. The sieves were arranged chronologically from the largest sieve size (4.75 mm) to the smallest sieve size (75 µm) on a pan as a dust collector, and placed into the mechanical sieve shaker, which was operated for about 5 minutes.

The sample was placed on the topmost sieve, covered and the mechanical sieve shaker was operated. After sieving, the amount of soil sample retained in each sieve was determined and the percentage passing for each sieve was estimated. After the calculation, the graph of percentage passing was plotted against the sieve size. The same procedure was repeated for other lateritic soil samples admixed with varied percentages of potash and rice husk ash. This was done in agreement with BS 1377 (1990) Part 2 Section 9.2.

Atterberg limits

Atterberg Limits are basic measures of the nature of fine-grained soils appearing in four states: solid, semi-solid, plastic and liquid relative to the quantity and type of clay minerals present in it. The regularity and behavior of different soils are different; thus, their engineering properties are too. The Atterberg consistency limit test was used to determine certain soil properties, including Liquid Limit (LL), Plastic Limit (PL) and Plasticity Index (PI). The apparatus that was used for this experiment is a drying oven, a flat glass plate about 10mm thick, a Cassangrade apparatus, a grooving, a desiccator, palette knives, a wash bottle, a sieve of size 425 µm, and corrosion corrosion-resistant container. These tests were done in accordance with BS 1377 (1990) Part 2 Section 5.0.

Compaction

Compaction of soil is the procedure through which the solid particles are packed more strongly together, usually by mechanical means, thereby increasing the dry density of the soil. The dry density that can be achieved depends on the degree of compaction applied and on the amount of water present in the soil. For a given compaction of a given cohesive soil, there is an optimal moisture content at which the dry density obtained reaches a maximum value.

As described in BS 1377 (1990) Part 4 Section 3.6 for West African Standard (WAS), the natural soil was compacted inside a 1000 cm^3 BS mould in 5 layers using 10 blows of a 4.5 kg rammer dropped from 450mm height. The soil sample was mixed with 4% of water by weight of the soil sample as assumed moisture content and then compacted in 5 layers using 10 blows of a 4.5 kg rammer dropped from 450 mm height. Each of the compacted soils was carefully leveled with a straight edge.

The weight of the soil samples in the mould was determined with the corresponding moisture content. From the data obtained, the bulk density and the dry density were calculated for each compacted sample. Thereafter, the maximum dry density (MDD) and the optimum moisture content (OMC) were determined from the graphical representation of the connection between dry density and the moisture content.

California bearing ratio (CBR)

For unsoaked, the soil material was compacted at its OMC and its MDD. The sample was compacted in a CBR mould relative to the WAS compaction effort selected for this work. For WAS, compaction was done in five layers with 27 blows of a 4.5 kg rammer drop from a height of 450 mm per layer. The compacted sample was placed on the CBR machine and an incremental load was applied via piston at the top and the base of the sample, which was read from the load dial gauge at varying penetration depths. The graph of dial load was plotted against penetration. The dial loads at 2.5 mm and 5 mm were recorded and the corresponding CBR values were determined. The same procedure was repeated for other lateritic soil samples admixed with varied percentages of potash and rice husk ash. This was done based on BS 1377 (1990) Part 4 Section 7.2.4.

Unconfined compressive strength (UCS)

Unconfined compressive strength is the load per unit area at which an unconfined cylindrical specimen of soil fails in a simple compression test. It is suited for measuring the unconsolidated undrained shear strength of intact and saturated soil. The mass of the prepared test specimen was determined to the nearest 0.1g. At least three measurements of the length and diameter of the specimen were made to the nearest 0.1mm and the average dimensions were determined. The specimen was placed centrally on the pedestal of the compression machine between the upper and lower platens. The machine was adjusted so that contact is just made between the specimen, the upper platen and the force-measuring device. The axial deformation gauge was adjusted to read zero or a convenient initial reading. The initial readings of the force and compression gauges were recorded.

Chemical Characterization of Rice Husk Ash and Lateritic Soil

The chemical characterization of rice husk ash and lateritic soil was carried out using X-Ray Diffraction (XRD) and X-Ray Fluorescence (XRF) as specified in BS EN 196-2 (1995) at the National Geological Survey, Kaduna, Kaduna State, Nigeria.

Statistical Analysis

A two-way Analysis of Variance (ANOVA) without replication was conducted to assess the efficiency of RHA and Potassium Carbonate in the stabilization process. The evaluation focuses on key performance indicators, including plasticity index (PI), maximum dry density (MDD), optimum moisture content (OMC), and unsoaked California bearing ratio (CBR), using a 95% confidence level.

RESULTS AND DISCUSSION

Sieve Analysis Results

The results indicate that the soil is predominantly sandy (62.44%) with a high percentage of fines (32.76%) and minimal gravel (4.80%) as presented in Figure 1. It is classified as a coarse-grained soil under the Unified Soil Classification System (USCS) and identified as either silty sand (SM) or clayey sand (SC), depending on the plasticity of the fines. While the sand content contributes positively to strength and drainage, the high fines content could negatively impact performance. Especially in terms of stability, compaction, and water movement. As such, further tests such as Atterberg Limits and compaction tests are recommended to provide a more accurate classification and determine the suitability of the soil for various civil engineering applications.

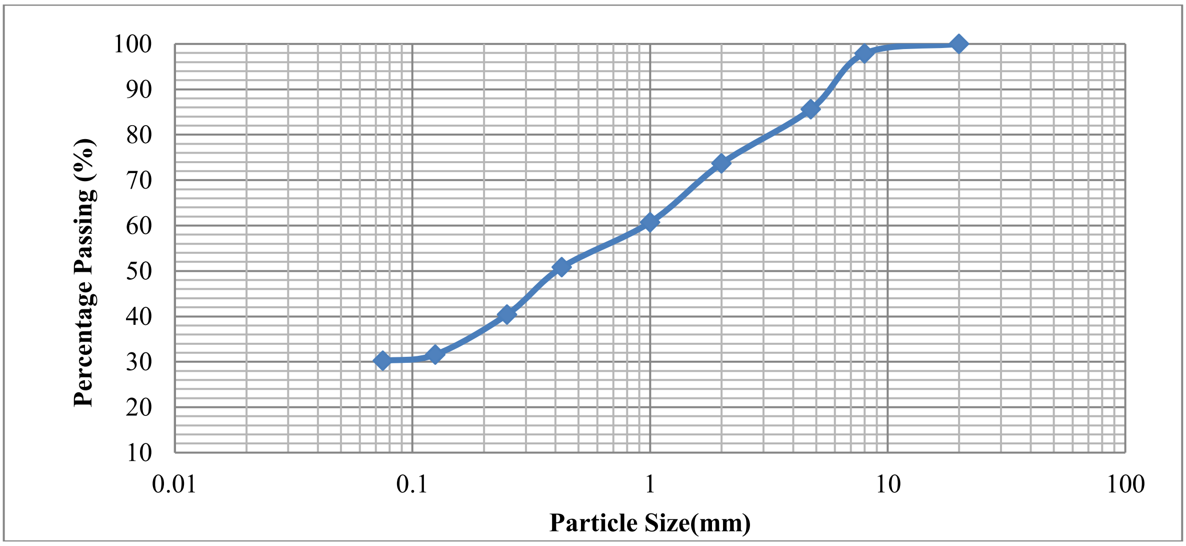

Figure 1: Graph of Sieve Analysis

Atterberg Limit Results

The analysis indicated that when no potash was added to the mixture, the plasticity index decreased by almost 50% when lateritic soil was treated with 8% RHA as compared to when it was treated with 4% RHA. Further treatment with only RHA material for 12% led to an additional 16.67% decrease in the plasticity index of the mixture. Further additional treatment with only RHA produced a mixture with a constant plasticity index.

The analysis indicated that the addition of 1% potash and 16% RHA, 2% potash and 12% RHA, 2% potash and 16% RHA, 3% potash and 12% RHA, 3% potash and 16% RHA, 4% potash and 8% RHA, 4% potash and 12% RHA, 4% potash and 16% RHA in the lateritic soil sample produced a mixture with 0.00% plasticity index.

The plasticity index of lateritic soil treated with 2% potash showed a 56.3% increase compared to lateritic soil treated with 1% potash, both measured before the introduction of RHA material. Further treatment of the lateritic soil with 1% increase in the amount of potash used led to a consequential decrease of 66.67%, a 20% decrease in the plasticity index for every increment of 1% potash used in treating the lateritic soil. Hence, the individual decreasing effect of the increment in the amount of potash and RHA material when used in relatively large percentages to treat the lateritic soil led to a mixture of zero plasticity index. Thus, as an indication, the workability of the mixture decreases with increasing amounts of both potash and RHA used in the treatment. Table 2 shows that the plastic limit increases with the inclusion of RHA. This is attributed to the porous nature and high silica content of RHA, which absorbs moisture and modifies the soil texture, resulting in higher resistance to plastic deformation.

Table 2: Atterberg Limits

Potash percentage	RHA percentage	Liquid limit	Plastic limit	Plasticity index
0%	4%	31.50	28.00	3.50
	8%	31.00	29.20	1.80
	12%	31.00	29.50	1.50
	16%	29.50	28.00	1.50
1%	0%	31.00	29.40	1.60
	4%	31.00	29.80	1.20
	8%	28.00	27.50	0.50
	12%	29.50	28.00	1.50
	16%	26.00	30.00	0.00
2%	0%	32.50	30.00	2.50
	4%	31.00	29.00	2.00
	8%	30.00	29.00	1.00
	12%	29.00	30.00	0.00
	16%	27.00	29.50	0.00
3%	0%	31.50	30.00	1.50
	4%	30.00	29.00	1.00
	8%	30.00	29.00	1.00
	12%	29.00	29.00	0.00
	16%	26.00	30.00	0.00
4%	0%	30.00	29.00	1.00
	4%	31.00	29.00	2.00
	8%	30.00	30.00	0.00
	12%	28.00	30.00	0.00
	16%	28.00	31.00	0.00

The addition of potash further enhances this effect by promoting the flocculation of clay particles, leading to a more stable soil matrix that can hold its form at higher moisture contents. The finding that RHA reduces the plasticity of soil is well-documented. Osinubi and Stephen (2007) found that

RHA increased the plastic limit and decreased the liquid limit of lateritic soil, leading to a reduced PI. Similarly, Brooks (2009) reported a decrease in the PI of clayey soils stabilized with RHA alone. However, the complete elimination of plasticity (PI = 0%) achieved in this study is a more profound effect than typically reported with RHA alone

Compaction Results

The compaction test results show significant changes in soil behavior with stabilization. As RHA and potash percentages increase, the maximum dry density (MDD) generally decreases due to the low specific gravity of RHA particles. This finding is consistent with previous studies on pozzolan-stabilized soils. At low RHA levels (2-4%), potash addition leads to predictable increases in optimum moisture content (OMC). This indicates higher moisture demand for optimal compaction due to the hygroscopic nature of RHA and chemical reactions with potash. At medium RHA levels (6-8%), the trend becomes less predictable as competing mechanisms influence compaction behavior. At high RHA levels (10-16%), the relationship between OMC and potash content stabilizes, suggesting saturation of chemical reactions.

This translates to practical implications for field construction. Lower RHA percentages provide better compaction characteristics with manageable moisture requirements. Higher RHA percentages, while offering superior strength gains, require careful moisture control during construction. The optimal range for field application appears to be 4-16% RHA with 2-4% potash, balancing compaction efficiency with strength enhancement.

Figure 2 reveals that OMC increases progressively with higher RHA and potash dosages. RHA's high surface area and absorptive capacity increase the water required to lubricate particles for optimum compaction. Potash further influences OMC by chemically interacting with soil particles, possibly leading to increased water demand during the compaction process. Figure 3 shows that MDD values decrease with rising RHA content. This is due to the low specific gravity of RHA, which dilutes the soil mass and makes it less dense. The reduced MDD is acceptable as long as strength and stability are retained, which is supported by later CBR and UCS results.

This trend is universally acknowledged in studies involving lightweight pozzolanic additives. Amu *et al*. (2011) observed a similar reduction in MDD and increase in OMC when stabilizing lateritic soil with sugarcane straw ash, another low-specific-gravity agricultural waste. The results of this study are therefore entirely consistent with the established mechanics of soil-additive interactions for this class of materials.

California Bearing Ratio (CBR) Results

The California Bearing Ratio (CBR) results (Figure 4) revealed that higher potash percentages generally enhance soil strength, with CBR values increasing from a range of 77- 88 at 0% potash to 91-99 at 4% potash, indicating that 4% potash consistently yields the highest and most effective stabilization, while RHA shows a mixed impact where, at 0% potash, increasing RHA content from 4 to 10% gradually improves CBR from 77 to 88. At 1% potash, the effect is inconsistent and fluctuates between 77 and 82, whereas at 2-4% potash, the addition of higher RHA (especially 16%) significantly boosts CBR values, confirming that the best results are achieved when both stabilizers are combined, particularly at 4% potash and 16% RHA, which gives the maximum CBR value of 99, suggesting this combination forms the strongest subgrade material. This supports the conclusion that potash is the primary stabilizer with a dominant effect on CBR improvement, while RHA provides supplementary

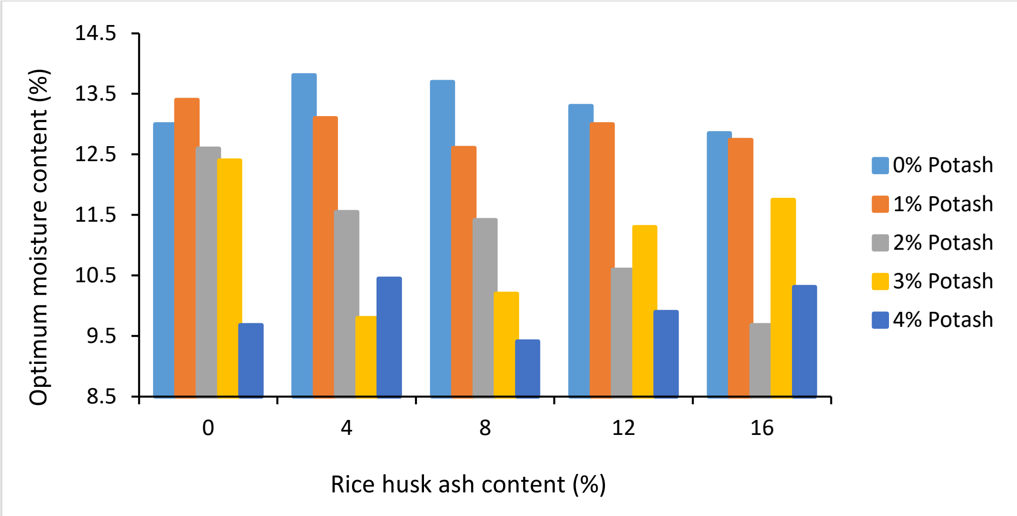

Figure 2: Optimum moisture content with percentage potash and RHA chart

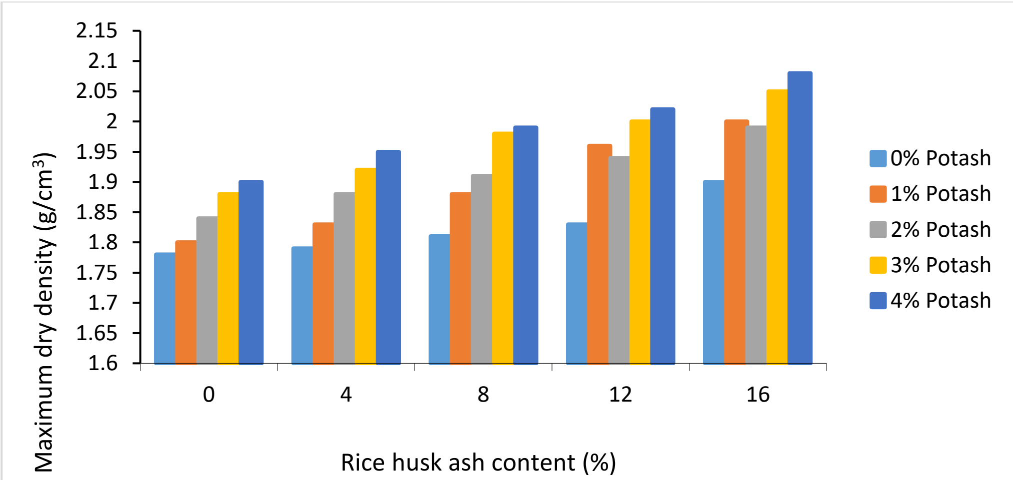

Figure 3: Maximum dry density with percentage potash and RHA chart

benefits likely due to pozzolanic activity that becomes more effective in the presence of potash. Although RHA alone can enhance CBR to some extent, especially at higher percentages, it is not as effective without potash, making 4% potash + 16% RHA the optimal mix for maximum soil strength, with further evaluation on durability, economic viability, and field performance recommended to guide practical applications.

Figure 4 indicates that the CBR values generally increase with higher potash content, especially when paired with 8–12% RHA. The peak CBR value was recorded at 12% RHA + 4% potash, indicating enhanced load-bearing capacity of the treated soil. The improved CBR is attributed to the pozzolanic reaction between silica in RHA and the alkaline environment created by potash, forming cementitious compounds that improve soil stiffness and strength. This enhancement is vital for highway pavement layers where high CBR values are required.

The CBR values above 90% are exceptionally high and meet requirements for sub-base and base courses in pavement design. Jha and Gill (2006) reported CBR values of around 30-40% for clay soil stabilized with RHA and lime. The significantly higher values in this study highlight the efficacy of potassium carbonate as an activator compared to traditional lime, at least for this specific soil type.

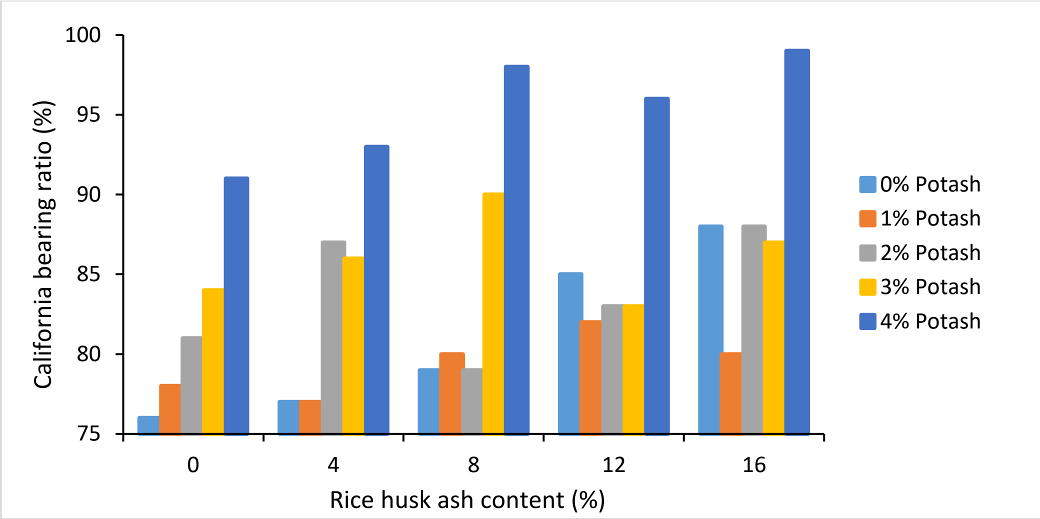

Figure 4: CBR values with percentage potash and RHA chart

Unconfined Compressive Strength (UCS) Results

The Unconfined Compressive Strength results show systematic strength increases with both additives. At 0% potash, UCS rises modestly from 224 to 242 kN/m² with increasing RHA, peaking at 12% RHA. This demonstrates RHA's inherent binding capabilities even without chemical activation. At 4% potash, UCS increases steadily from 268 to 302 kN/m² as RHA content rises to 16%. This represents a 40% strength improvement over natural soil conditions. The highest UCS value (302 kN/m²) occurs at 4% potash + 16% RHA combination, confirming optimal stabilization effectiveness.

Some non-linear behavior is observed at intermediate potash levels. For instance, at 1% potash and 8% RHA, UCS temporarily dips to 218 before recovering to 238 at 12% RHA. This suggests threshold effects where certain combinations achieve better particle arrangement or chemical bonding. The overall trend confirms synergistic relationships between RHA and potash, with strength gains becoming more pronounced at higher additive levels. Compared to similar studies by Singh *et al.* (2021) on RHA stabilization, the current results show superior performance, likely due to potash activation. The strength values achieved (200-302 kN/m²) meet or exceed typical requirements for pavement subbase applications, confirming practical viability.

Figure 5 shows that the UCS values show a positive correlation with increasing RHA and potash levels up to a point. The maximum UCS was achieved at 12% RHA + 3% potash, beyond which strength values began to decline slightly. This peak represents an optimal mix where the combined pozzolanic and alkaline activation reactions are maximized, forming stronger bonds in the soil matrix. The decline in 4% potash could be due to oversaturation of the chemical environment, which may interfere with proper bond formation.

These results confirm that RHA and potash synergistically improve the compressive strength, making the treated soil suitable for sub-base and base layers in pavement systems.

Determination of Optimal Mix Ratio

The optimization methodology employed a weighted scoring system where each engineering property was assigned importance factors based on its relevance to highway pavement construction applications. The weighting factors were established as follows: CBR (30%), UCS (25%), Plasticity Index reduction (20%), Maximum Dry Density (15%), and Optimum Moisture Content (10%).

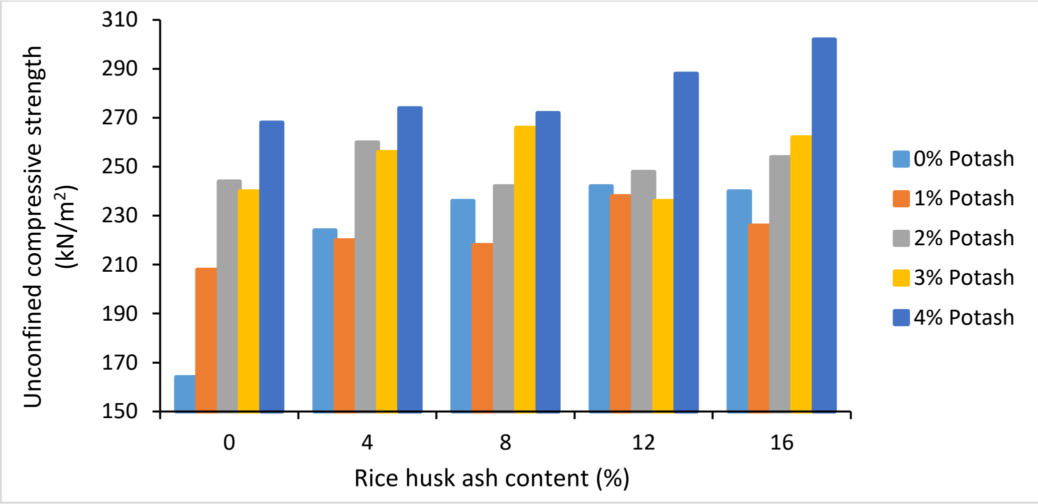

Figure 5: UCS values with percentage potash and RHA chart

For the CBR criterion, the combination of 4% potash + 16% RHA achieved the highest CBR value of 99%, outperforming all other mix combinations. This indicates excellent suitability for pavement sub-base and base course applications. Other high-performing mixes include 4% potash + 12% RHA (96%) and 4% potash + 8% RHA (98%), but the peak performance was consistently achieved at the 4% potash and 16% RHA level. In terms of UCS performance, the same 4% potash + 16% RHA mix recorded the highest unconfined compressive strength of 302 kN/m², indicating exceptional load resistance and structural integrity. Other competitive mixes include 4% potash + 12% RHA (288 kN/m²) and 3% potash + 16% RHA (262 kN/m²). Analysis of the Atterberg limits showed that a Plasticity Index (PI) of 0.00 was achieved consistently at RHA contents of 12%, 16%, and above, regardless of potash content. Specifically, the 4% potash + 16% RHA mix resulted in zero plasticity, indicating a transition from a moisture-sensitive to a dimensionally stable material. This result confirms that 16% RHA is the critical threshold for full plasticity modification. Compaction characteristics revealed that the Maximum Dry Density (MDD) peaked at 2.08 g/cm³ for the 4% potash + 16% RHA combination, while the Optimum Moisture Content (OMC) remained reasonably low at 10.31%. These values demonstrate optimal compaction behavior and moisture efficiency, both critical for pavement stability.

Based on the comprehensive multi-criteria analysis, the optimal mix ratio was determined to be 4% potash + 16% RHA. This combination achieved zero plasticity index, high MDD (2.08 g/cm³), reasonable OMC (10.31%), and the highest CBR value (99%). Optimal dosages in other studies vary widely based on soil type and the activator used. Basha *et al*. (2005) found an optimum of 6-8% RHA with 2-8% cement for residual soils. The 16% RHA dosage in this study is on the higher end, but is justified by the excellent resulting properties and the goal of maximizing waste utilization. The 4% potash dosage appears to be the critical amount needed to fully activate the high volume of RHA.

Chemical Characterization of Rice Husk Ash and Lateritic Soil Results

The chemical characterization of Rice Husk Ash (RHA) and Lateritic Soil was conducted using X-Ray Fluorescence (XRF) and X-Ray Diffraction (XRD) analysis.

a. **XRF Analysis:** The XRF results in Table 3 revealed that RHA is predominantly composed of silicon dioxide (SiO_2) with a significant percentage up to 80%, indicating strong pozzolanic activity. The sum of the contents of SiO_2, Fe_2O_3 and Al_2O_3 is greater than 70% which confirms its pozzolanicity. Also, the lateritic soil contained major oxides such as Fe_2O_3, Al_2O_3, and lesser quantities of SiO_2, confirming its ferruginous nature.

b. **XRD Analysis:** The XRD analysis in Figure 6 did not indicate the presence of silica in RHA, as it was presented in XRF results (Table 3). The broad hump in the 2-theta range of 20-30 degrees is evidence of the presence of amorphous silica, which confirms its pozzolanic potential.

Table 3. Oxide composition of lateritic soil and RHA

Oxide	Lateritic soil Concentration (%)	Rice Husk Ash Concentration (%)
SiO_2	58.057	84.195
V_2O_5	0.040	0.040
Cr_2O_3	0.000	0.003
MnO	0.127	0.339
Fe_2O_3	13.620	0.863
Co_3O_4	0.039	0.000
NiO	0.000	0.002
CuO	0.054	0.093
Nb_2O_3	0.006	0.006
P_2O_5	0.000	0.490
SO_3	0.873	0.864
CaO	1.029	4.529
MgO	2.185	0
K_2O	1.888	2.728
BaO	0.094	0
Al_2O_3	18.212	2.819
Ta_2O_5	0.003	0.005
TiO_2	1.989	0.457
ZnO	0.032	0.033
Ag_2O	0.012	0.007
Cl	1.451	2.549
ZrO_2	0.292	0.017

The silica is masked by the formation of urea (an organic compound) and graphite (Carbon), as shown in Table 4, which resulted from the incomplete combustion of the rice husk. This amorphous nature implies high reactivity potential when exposed to alkaline conditions created by potash, facilitating the formation of calcium silicate hydrate (C-S-H) gels that contribute to soil strength. The XRD spectrum of lateritic soil in Figure 7 indicated peaks corresponding to kaolinite, Quartzite, Albite and Muscovite, as also presented in Table 5 with their percentage concentration. These minerals support its classification as a highly weathered soil with secondary clay minerals. The presence of these minerals indicates good potential for chemical stabilization through ion exchange and pozzolanic reactions.

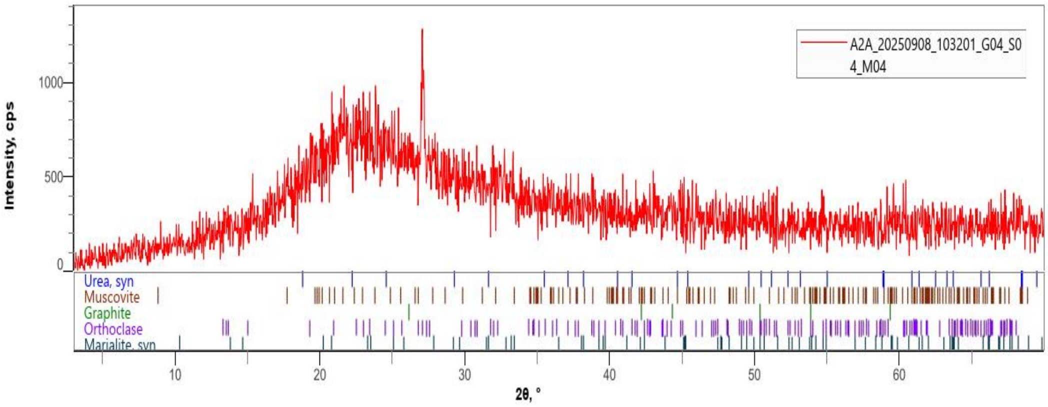

Figure 6: XRD of Rice Husk Ash (RHA)

Table 4. Concentration of minerals in rice husk ash

Mineral Phase Name	Formula	Concentration (%)
Urea, syn	CH_4N_2O	59
Muscovite	$KAl_2(Si_3Al)O_{10}(OH,F)$	13
Graphite	C	17
Orthoclase	$K(Al,Fe)Si_2O_8$	4
Marialite, syn	$Na_4Al_3Si_9O_{24}Cl$	7

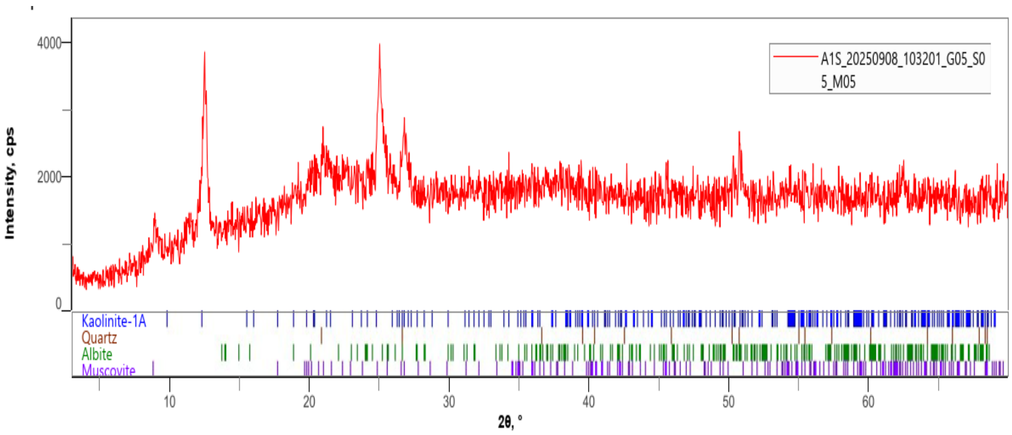

Figure 7: XRD image of Lateritic Soil

Table 5. Concentration of minerals in lateritic soil

Mineral Phase Name	Formula	Concentration (%)
Kaolinite-1A	$Al_2Si_2O_5(OH)$	76
Quartz	SiO_2	9
Albite	$NaAlSi_3O_8$	0.5
Muscovite	$KAl_2(Si_3Al)O_{10}(OH,F)$	15

Statistical Analysis Results

MDD and OMC showed statistically significant differences, indicating that the combination of RHA and potash has a strong influence on compaction behaviour, which is critical for pavement subgrades. Plasticity index and CBR showed notable engineering improvements in raw values but did not exhibit statistically significant differences at the 95% confidence level, implying that further optimization or sample expansion may be needed for conclusive statistical support.

Table 4: Statistical Analysis Results

Parameter	F-Statistic	p-Value	Statistical Significance
Plasticity Index (PI)	2.15	0.133	Not statistically significant ($p > 0.05$)
Maximum Dry Density (MDD)	7.50	0.0024	Significant ($p < 0.05$)
Optimum Moisture Content (OMC)	14.76	0.00007	Highly significant ($p < 0.01$)
California Bearing Ratio (CBR)	0.72	0.554	Not statistically significant ($p > 0.05$)

CONCLUSION

The natural lateritic soil was classified as coarse-grained, predominantly sandy (62.44%), with a high fines content (32.76%) and minimal gravel (4.80%). This particle distribution suggests potential strength and drainage capacity but raises concerns regarding water retention, plasticity, and shrink-swell behaviour. The optimal mix was identified as 4% potassium carbonate + 16% RHA. Chemical and microstructural analyses confirmed the pozzolanic potential of RHA and the beneficial reactions with potassium carbonate. The adoption of 4% Potash + 16% RHA mix for stabilization of lateritic soils in highway pavement construction, especially for sub-base and base layers, due to its superior strength and durability characteristics, is recommended. Utilization of rice husk ash as a sustainable additive in geotechnical applications should be encouraged, reducing dependence on cement and promoting waste valorisation in agricultural economies. Potassium carbonate should be promoted as an effective and eco-friendly alkaline activator, especially where traditional cement usage is costly or environmentally unsustainable.

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