Uniosun Journal of Engineering and Environmental Sciences (UJEES), Vol. 8 No. 2, Sept., 2026
DOI: 10.64980/ujees.v8i2.026 **Salami and Akinleye**
Published: September 30, 2026

INFLUENCE OF BRITISH STANDARD LIGHT COMPACTIVE ENERGY ON RICE STRAW ASH AND MILLED PALM KERNEL SHELL STABILISED LATERITIC SOIL

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Abstract
Lateritic soil commonly adopted in road construction often contain high clay content, high plasticity and inadequate strength, limiting it direct use in pavement layers. This study investigates the performance of lateritic soil stabilised with Rice Straw Ash (RSA) and Milled Palm Kernel Shell (MPKS) using British Standard Light (BSL) compactive energy. Lateritic soil was stabilised with RSA and MPKS independently at a proportion of 0 –15% at 2.5% intervals by weight of the soil. An optimum 7.5% RSA content was combined with varying MPKS contents. Compaction and California Bearing Ratio (CBR) were evaluated. The compaction result was 1620 kg/m^3 for unstabilised soil and 1530 – 1609 kg/m^3 for RSA stabilised soil, respectively. The corresponding values were 1420 – 1600 kg/m^3 for MPKS stabilised soil and 1411 – 1583 kg/m^3 for combined RSA-MPKS stabilised soil, respectively. The CBR increased with increase in proportion of the agricultural residues with 7.5% RSA + 5% MPKS blend outperforming the individual residues. The findings established that the combined application of 7.5% RSA and 5% MPKS provided a viable approach for improving lateritic soil. Thus, lateritic soil stabilisation with the combined additives is more suitable for soil performance enhancement in road construction. However, further research should be carried out using higher compactive energies.

Keywords
Lateritic soil, Rice straw ash, Milled palm kernel shell, Atterberg limit, Road construction

1. INTRODUCTION

In Nigeria and some other parts of the world, especially tropical countries, lateritic soils are used as subgrade, sub-base and base course material for road construction. However, when used as construction materials, some lateritic soils contain significant presence of clay giving no guaranteed good bearing capacity and stability especially in moist condition [1]. Occasionally, these soils possess geotechnical problems such as road settlement, dam seepage, deformation, erosion, slope instability, poor bearing capability, leachate permeation through hydraulic barriers, plasticity, and high compressibility. Where these geotechnical problems are encountered and the source for alternative soil proves uneconomical, there is need to enhance the weak available soil in order to achieve the desired soil properties [2-5]. Numerous researches have established that materials sourced locally are gaining prominence, because of their zero or low emission of CO_2 gas as compared to cement production process which generate high emission [6-9]. Agro-industrial wastes such as rice husk ash, bagasse ash, locust bean waste ash, quarry dust, iron ore tailing cement kiln dust, crush concrete powder, blast furnace slag, etc., had been used to improve deficient soils. Previous study has shown that these wastes have significant effects on the geotechnical properties of weak soils [10]. Waste products, mostly biomass waste materials, have been reported to be cost-effective, and nature-friendly alternative materials to cement and lime. There are large amounts of biomass residues generated across the world which is estimated to be more than one (1) billion tonnes per year, of which the management of such wastes causes problems to our immediate environment [11-13].

Meanwhile, Rice Straw Ash (RSA) is widely used to improve the strength of lateritic soil by acting as a pozzolanic material, reacting with lime (or other alkali activators) to form cementitious compounds that bind soil particles, which has led to an increased strength and durability [14]. The RSA, especially when calcined, contains a high amount of Silica (SiO_2) and other oxides that can form a reaction with lime ($Ca(OH)_2$) in the presence of water to form calcium silicate hydrate (C-S-H), a major constituent of cement. The C-S-H formed during the time of reaction fills the pores and voids within the soil, creating a denser and stronger matrix [15]. Furthermore, Palm Kernel Shell (PKS), which is the shell housing the palm kernel seed, is derived from palm tree, an economically valuable tree that is widely present in the tropics. The PKS can be used to modify lateritic soil, improving its geotechnical properties and suitability for construction,

particularly as a road base material [7]. The PKS which is a byproduct of palm oil production, offers advantages like improved compaction characteristics, reduced swelling, and increased strength [16]. Also, Milled Palm Kernel Shell (MPKS), a byproduct of PKS, has been reportedly used in civil construction works, including concrete works [13, 17].

Over the years, studies have revealed that RSA and MPKS have shown considerable performance as "stand-alone" stabilisers in lateritic soil improvement [7, 14-16, 18-22]. However, there has been limited or no study of their synergistic effects of RSA and MPKS as a binary stabilising agent for lateritic soil. The potential synergistic behaviour between RSA's pozzolanic reactivity and MPKS's structural modification capacity remains unexplored. This research studied the synergistic effect of RSA and MPKS on the characteristics of lateritic soil for road construction applications to enhance pavement layers especially for road in the rural communities in Nigeria.

2. MATERIALS AND METHOD

The materials and method are spelt out in the subsequent sections.

2.1 Materials

The lateritic soil studied as shown in Figure 1d was sourced from an open plot of land off Osogbo-Iwo Highway in Egbedi (latitude 7° 47' 50.67" N and longitude 4° 27' 42.76" E), Osun State, Nigeria. Rice straw was obtained from a rice farm in Ilorin (8º29'41.56''N latitude and 4º32'43.40''E longitude), Kwara State, Nigeria. The palm kernel shell was gotten from a palm kernel processing factory located in Awo (7º 46' 9.35" N latitude and 4º 23' 26.47" E longitude), Osun State, Nigeria.

2.1.1 Rice straw ash

The leaves were detached; the stalk was segmented into smaller pieces and sun-dried to eliminate moisture from the straw. This was followed by heating using an electrical furnace at 700 ℃ and 4 hours of retention to obtain the ash [19]. After cooling, the ash was ground to improve fineness before sieving through sieve No. 200 (75 µm) as shown in Figure 1a. The RSA was kept inside a sealed plastic container with silica gel to prevent moisture absorption.

2.1.2 Milled palm kernel shell

The palm kernel shell was washed to remove any unwanted dirty material present in it. The palm kernel shell was milled to a particle size of 0.045-2 mm to ensure uniform blending with lateritic soil as shown in Figure 1b.



(a) Rice straw ash



(b) Milled palm kernel shell



(c) Lateritic soil

Figure 1: Materials used

2.2 Method

The RSA was mixed together with lateritic soil in percentages (by weight) of 0, 2.5, 5, 7.5, 10, 12.5 and 15% until an optimum percentage was achieved using the proportion with highest California Bearing Ratio (CBR). This range of RSA was adopted based on past studies of stabilisation of lateritic soil using RSA which showed significant improvement within this range [23-25]. Similarly, MPKS was mixed separately with lateritic soil at percentages (by weight) of 0, 2.5, 5, 7.5, 10, 12.5 and 15% until an optimum percentage was achieved. This proportion of MPKS was adopted based on past studies of stabilisation of lateritic soil using MPKS which showed significant improvement within this range [12, 26, 27]. Geotechnical tests such as Atterberg limits test, Compaction and CBR tests were carried out on all modified lateritic soil samples in accordance with the standards [28-30].

3. RESULTS AND DISCUSSION

The results and discussion are spelt out in the subsequent sections.

3.1 Index Properties of the soil samples

The index properties of the soil samples are spelt out in the subsequent sections.

3.1.1 Natural moisture content and specific gravity

The properties of the unstabilised soil sample are depicted in Table 1. From the table, the moisture content of the soil sample was 26.2% which is an indication that the soil sample retains significant amount of water due to the presence of fine particles with large surface area. This result is in line with that of [31, 32]. The specific gravity of the lateritic soil sample, RSA and MPKS were 2.32, 2.22 and 1.57, respectively. The specific gravity value of the soil sample is an indication that the soil may contain lager clay fraction in it. It is also linked closely to the mineralogy and or chemical composition of the soil [33].

Table 1: Properties of Unstabilised Soil Sample

Properties	Quantity
Natural moisture content (%)	26.2
Specific gravity	2.32
Liquid limit (%)	62.5
Plastic limit (%)	22.2
Plasticity index (%)	40.3
% Passing BS No. 4 sieve	99.2
% Passing BS No. 200 sieve	67.18
Maximum dry density (kg/m^3)	1620 (BSL), 1804 (BSH)
Optimum moisture content (%)	20.60 (BSL), 18.30 (BSH)
AASHTO classification	A–7–5 (9)
USCS classification	CH

3.1.2 Particle size distribution

The particle size distribution curves are shown in Figures 2 and 3 for the lateritic soil and MPKS, respectively. The percentage of soil sample that passed through sieve No. 200 and No. 4 were 67.18% and 99.20%, while that of MPKS were 1.2% and 98.8%, respectively. This is in line with the work of previous researches [34, 35]. From the particle distribution curves, the coefficient of curvature and uniformity values were obtained to be 0.86 and 2.22 for the lateritic soil and 1.02 and 3.5 for MPKS, respectively. This signifies the lateritic soil is poorly graded and the MPKS is uniformly graded. This is in line with previous researches [34, 35, 36]. Also, the particle size of MPKS conforms to that of a stone dust. Hence, the MPKS can serve as stabiliser for the lateritic soil. [37] states that before a soil can be used for road construction, the percentage that should pass through BS sieve No 200 must not be greater than 35%. This result shows that the soil sample deviated from the standard since the percentage passing Sieve No. 200 is greater than 35%.

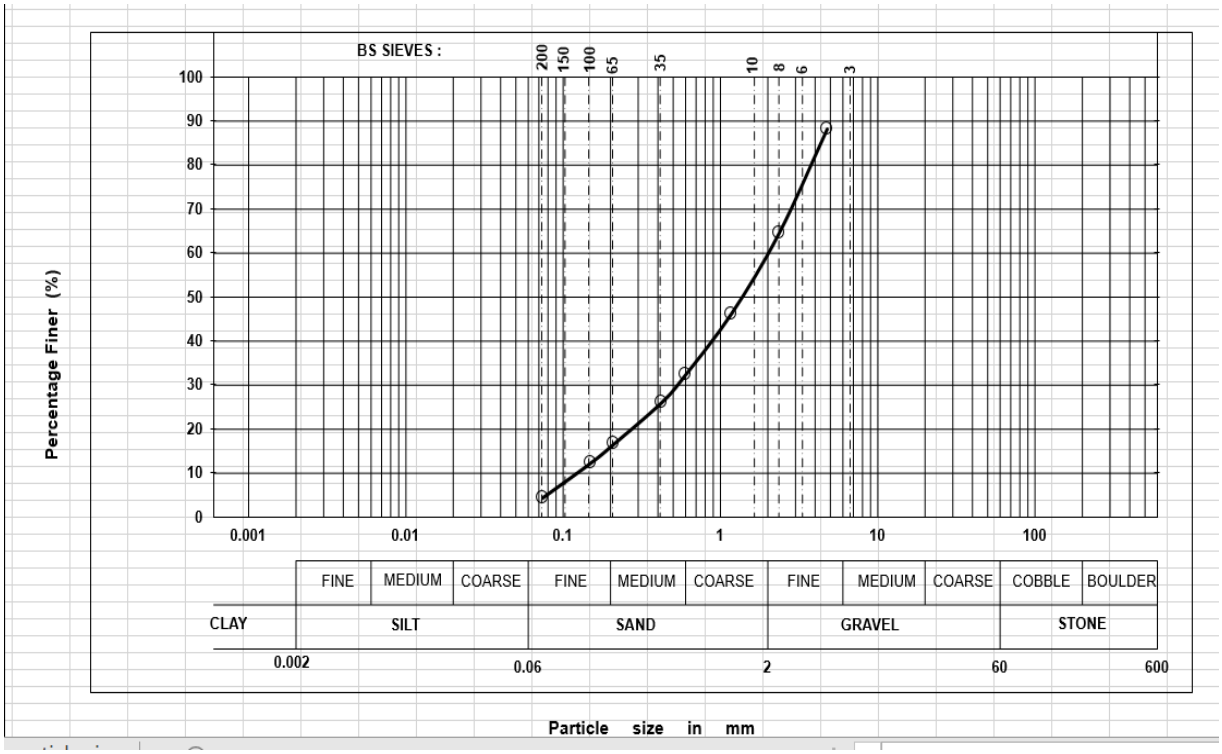


Figure 2: Particle size distribution curve of lateritic soil

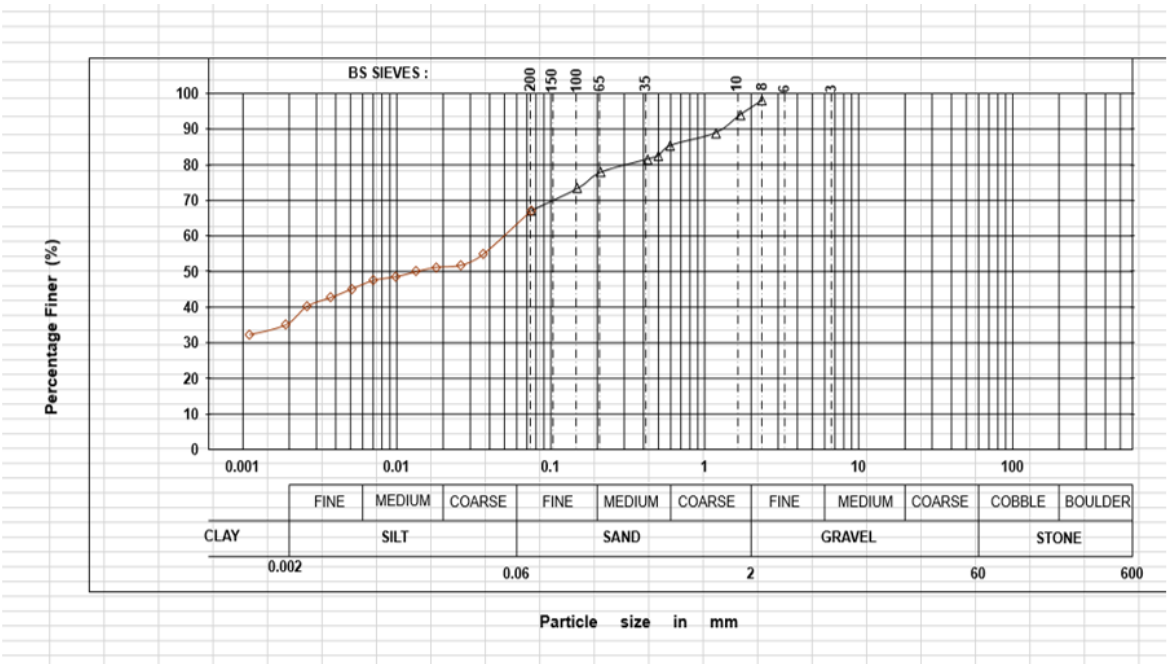


Figure 3: Particle size distribution curve of MPKS

3.1.3 Atterberg limits

The Atterberg limits test results (liquid limit, plastic limit and the plasticity index) of the soil sample at both unstabilised and stabilised state are presented in Figures 4 - 6. The Liquid Limit (LL) of the lateritic soil sample is 62.5%. At the natural state, the lateritic soil has high plasticity as reported by [37, 38] that soils with LL less than 35% are of low plasticity, those with LL between 35% and 50% exhibit medium plasticity. If the LL is between 50% and 70%, it has high plasticity. However, if it is between 70 and 90%, it has very high plasticity and if it is greater than 90%, the plasticity rate is exceptionally high.

(a) Liquid limit

From Figure 4, all the additive causes a reduction in LL. The inclusion of RSA reduced the LL of the lateritic soil from 62.5 to 53.2% at 7.5% RSA content. The 7.52% reduction in LL was due to the presence of active clay minerals in the lateritic soil replaced with RSA leading to a reduced surface area available for water

adsorption, thus, lowering water content required to reach liquid state. Also, the pozzolanic property of RSA provides Silica (SiO_2) which react with Calcium in the soil (CaO) in the lateritic soil. This behaviour is consistent with findings in soil stabilisation using pozzolanic materials. The addition of MPKS caused a steady decease in LL from 62.5 to 57.8% at 10% MPKS content. The 7.35% reduction in LL was as a result of the dilution of active clay minerals with granular, non-plastic MPKS, transforming the forming of a cementitious compound (C-S-H-), which binds soil particles together, resulting in lateritic soil that has less affinity for water and reduced plastic behaviour. Lateritic soil structure from cohesive to frictional behaviour, increasing clay flocculation and improved particle parking. These mechanisms reduce the soil's affinity for water and enhance the workability, stability and load bearing capacity. This behaviour is consistent with findings in soil stabilisation using non-plastic materials [39].

With RSA- MPKS soil stabilisation, LL reduced from 53.2 to 47.8% at 7.5% RSA+ 5% MPKS, which was about 25.12% reduction in LL. The reduction in LL is more pronounced in lateritic soil stabilised with combined RSA- MPKS compared to RSA or MPKS individually which may be due to synergetic interaction between chemical (pozzolanic property from RSA) and mechanical (granular property from MPKS) stabilisation mechanism. This combined mechanism resulted in a more effective reduction in soil water affinity and plastic behaviour, which explains the sharper decline in LL. The RSA induces cementation, that is the formation of C-S-H, while MPKS high water absorption property, absorbs free water in the lateritic soil, reducing effective water available for soil to flow and particle packing property. This resulted in stronger soil structure and reduced water-holding capacity. Study show that combined stabilisers produce improved soil properties due to simultaneous cementation and densification mechanism [40].

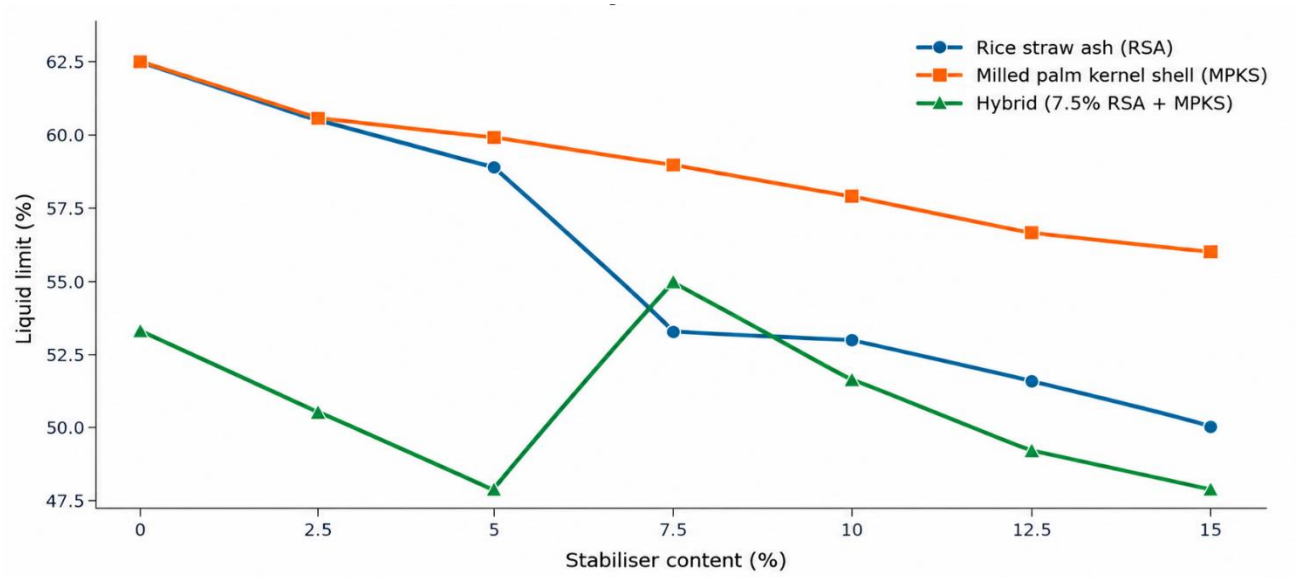


Figure 4: Liquid limit relationship between MPKS, RSA and RSA+MPKS

(b) Plastic limit

Furthermore, Figure 5 reveals the Plastic Limit (PL) relationship between MPKS, RSA and RSA+MPKS. The MPKS stabilised lateritic soil has the smallest PL increment, which increases from 22.0% for natural soil to 24.3% with 10% MPKS. The 10.50% increase in PL was due to the particle rearrangement of soil particles leading to smaller increase in water required for plastic deformation. This finding agrees with observations in previous study for a variety of soil stabilised palm kernel shell [12].

The RSA shows a gradual and consistent increase in PL increasing from 22.0% in natural soil to 24.7% with 7.5% RSA stabilised lateritic soil. The 12.3% in PL is attributable to its high amorphous silica content, similar to Rice Husk Ash (RHA). The RSA participates in pozzolanic reactions, forming calcium silicate hydrate (C–S–H) in the presence of calcium ions. This leads to particle bonding and aggregation, increased water demand and reduced clay activity. [41] reported similar findings, where ash-treated soils exhibited increased PL due to slow pozzolanic reactions and improved soil fabric

The resultant combination of RSA and MPKS produces a significantly higher PL of 27.32% when 7.5% RSA and 5% MPKS were used to stabilised the lateritic soil. The PL is higher than when either RSA or MPKS were used individually. This demonstrated a synergistic effect, where RSA provided reactive silica for pozzolanic reactions and MPKS contributed to particle packing and structural densification. This combination enhances flocculation and aggregation, inter-particle bonding, and moisture retention capacity. The result is a soil matrix that requires greater water content to reach plasticity, hence leading to a higher PL. [42] reported similar findings with hybrid stabilisation of lateritic soil.

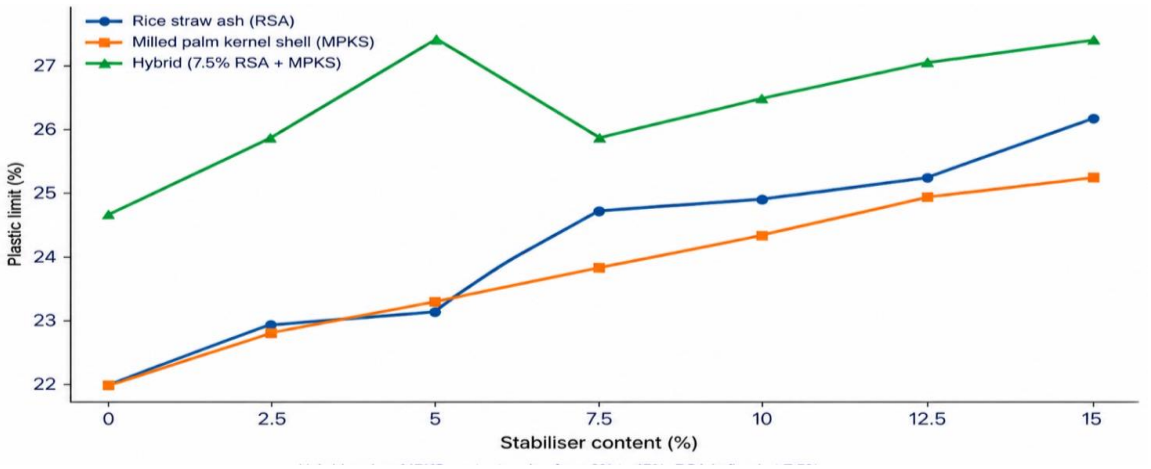


Figure 5: Plastic limit relationship between MPKS, RSA and RSA+MPKS

(c) Plasticity index

A progressive reduction in Plasticity Index (PI) observed across all stabilising agents reflects a fundamental transformation of the lateritic soil from a highly active clay system to a more stable, flocculated, and cemented structure. With RSA and MPKS added individually, PI reduced from 40.30 to 28.9% and 33.1% at 7.5% and 10% concentration, respectively. Their combined application further reduced the PI to 20.03% at 7.5% RSA + 5% MPKS, producing a synergistic effect that significantly enhances soil stability through improved particle bonding and reduced clay activity. The unstabilised lateritic soil, with a plasticity index of 40.30%, fails to satisfy the [37] for subgrade and sub-base applications, indicating high plasticity and poor engineering performance.

Also, stabilisation with RSA results in marginal improvement but remains slightly above the acceptable limit for subgrade materials. The MPKS stabilisation achieves compliance with subgrade requirements, while the combined RSA + MPKS system demonstrates a synergistic effect, significantly reducing plasticity and enhancing soil suitability for subgrade applications. The outcomes highlight the importance of selecting appropriate stabilisers based on performance requirements, with RSA–MPKS providing a sustainable alternative for low-cost road construction.

Lastly, the plasticity behaviour of the studied lateritic soil is likely fundamentally governed by its mineralogical composition, particularly the interplay between kaolinite and montmorillonite. The high PI of the unstabilised soil indicates the significant influence of expansive clay minerals, most notably montmorillonite, which exhibits high water adsorption and swelling capacity [43]. Stabilisation with RSA and MPKS progressively reduces plasticity by altering the physicochemical environment of the clay minerals, promoting flocculation and limiting water interaction. Combination of RSA–MPKS enhances this effect through synergistic chemical and physical mechanisms, effectively suppressing montmorillonite activity and shifting the soil behaviour toward that of kaolinite-dominated systems.

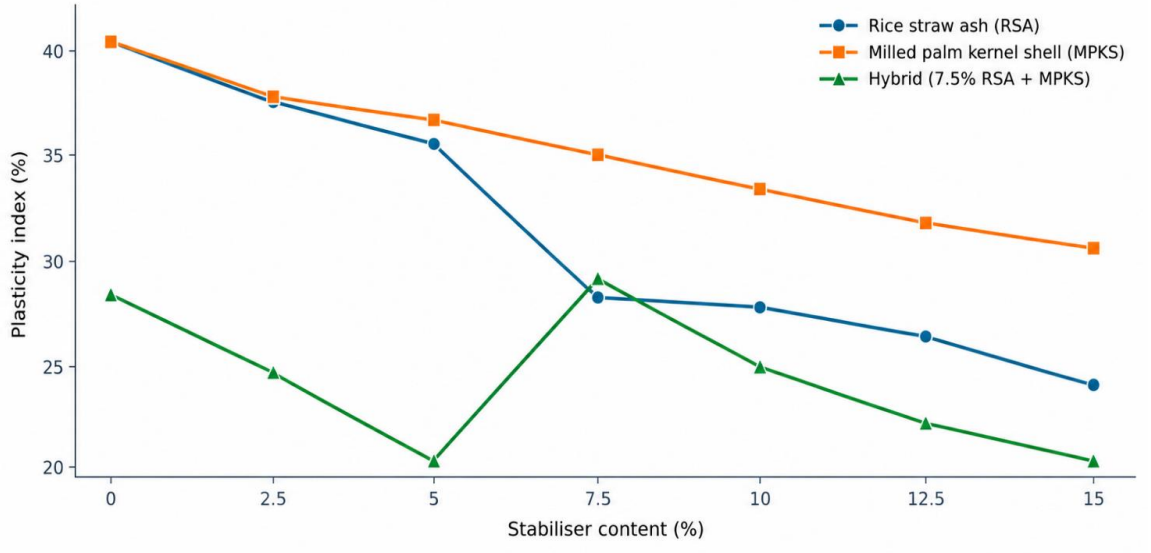


Figure 6: Plasticity index relationship between MPKS, RSA and RSA+MPKS

3.2 Engineering properties

The engineering properties of the soil samples are spelt out in the subsequent sections.

3.2.1 Compaction

The compaction properties of the soil samples are spelt out in the subsequent sections.

(a) Maximum dry density

The Maximum Dry Density (MDD) for each of the adopted compactive energy in relation to the percentage RSA, MPKS and RSA-MPKS is presented in Figure 7. The MDD reduced from 1620 kg/m^3 for the unstabilised lateritic soil to 1530 kg/m^3, 1420 kg/m^3 and 1411 kg/m^3 with RSA, MPKS, and RSA-MPKS, respectively as their percentage increases from 2.5 to 15%. These results show regular consistency with previous studies on ash and cement stabilisation [8, 44, 45], confirming that density behaviour under BSL compaction is primarily governed by material properties rather than chemical stabilisation effects. Low-energy compaction highlights the influence of material density and particle characteristics. Hence, higher compaction energies (British Standard Heavy and West African Standard) are needed to enhance particle rearrangement and bonding mechanisms.

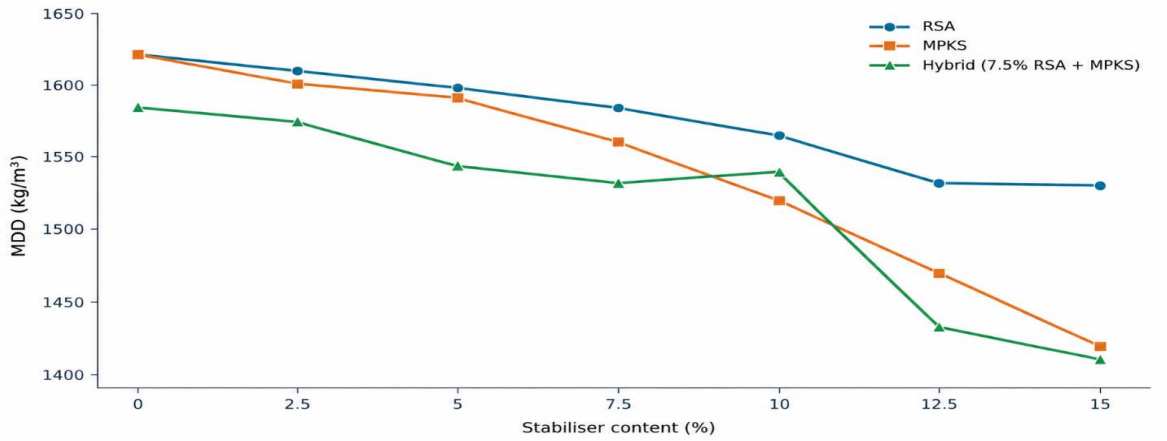


Figure 7: MDD variations of stabilised lateritic soil with RSA, MPKS, and RSA-MPKS

(b) Optimum moisture content

The variation in Optimum Moisture Content (OMC) of the lateritic soil stabilised with RSA, MPKS and RSA-MPKS are presented in Figure 8. The OMC of the lateritic soil increased with increasing additive content for RSA, MPKS, RSA–MPKS. This behaviour indicate that the additives increase moisture demand and higher compaction energy may reduce water requirement. For the BSL compaction energy level, OMC increased from 20.60% at natural soil to 25.60% at 15% RSA stabilised lateritic, MPKS increased from 20.60 to 24.42% at 15%, RSA-MPKS increased from 23.50 to 27.2%. The corresponding OMC obtained is in tandem with the results of previous studies [9, 46]. The variation of OMC, increased compaction energy and stabiliser type may likely reflect an interplay between particle characteristics, water absorption capacity, and compaction mechanics. In addition, increased compaction energy may likely reduce the moisture requirement by enhancing particle rearrangement, the introduction of agricultural waste stabilisers such as RSA and MPKS significantly increases OMC as a result of their high surface area and porosity [47].

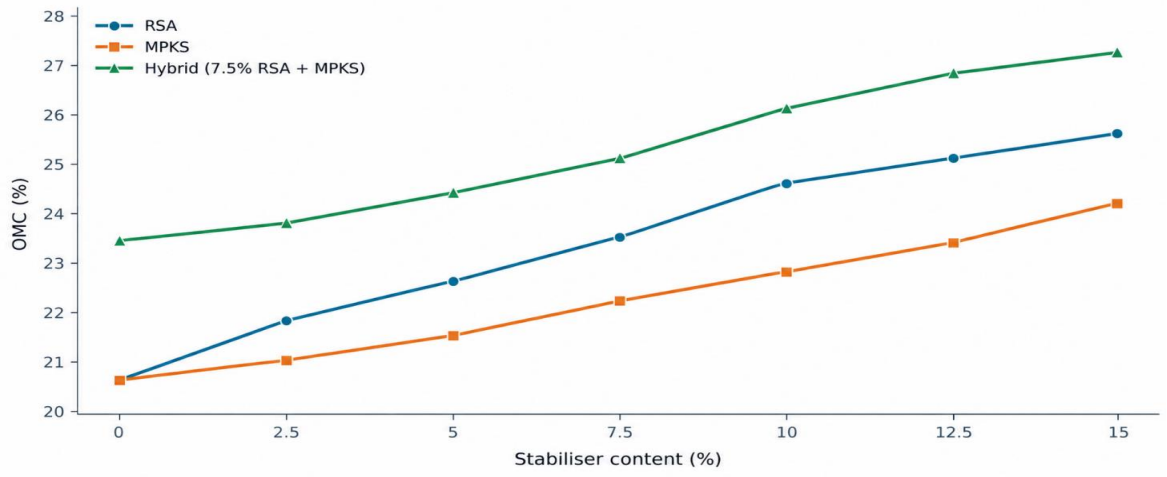


Figure 8: OMC variations of stabilised lateritic soil with RSA, MPKS, and RSA-MPKS

3.2.2 California bearing ratio

The California Bearing Ratio (CBR) of the soil samples are spelt out in the subsequent sections.

(a) Unsoaked CBR

The variation of unsoaked CBR of stabilised lateritic soil with RSA, MPKS and RSA-MPKS are shown in Figure 9. From the Figure, unsoaked CBR value increase for all additives. For RSA stabilised lateritic soil, the CBR value increase from 12.22% at natural state to 16.44% at 7.5% RSA content before reducing to 13.68% at 15% RSA content of the adopted compactive effort. For MPKS stabilised lateritic soil, the CBR value increased from 12.22% to 15.68% at 10% MPKS, then reduces to 12.92% at 15% MPKS content. Optimum RSA was achieved at 7.5% concentration; MPKS was added at this point from 2.5 to 15% to achieve an RSA-MPKS stabilised lateritic soil. The CBR value increased as the MPKS increases, optimum CBR value was achieved at 7.5% RSA + 5.0% MPKS resulting in a CBR value of 19.45%.

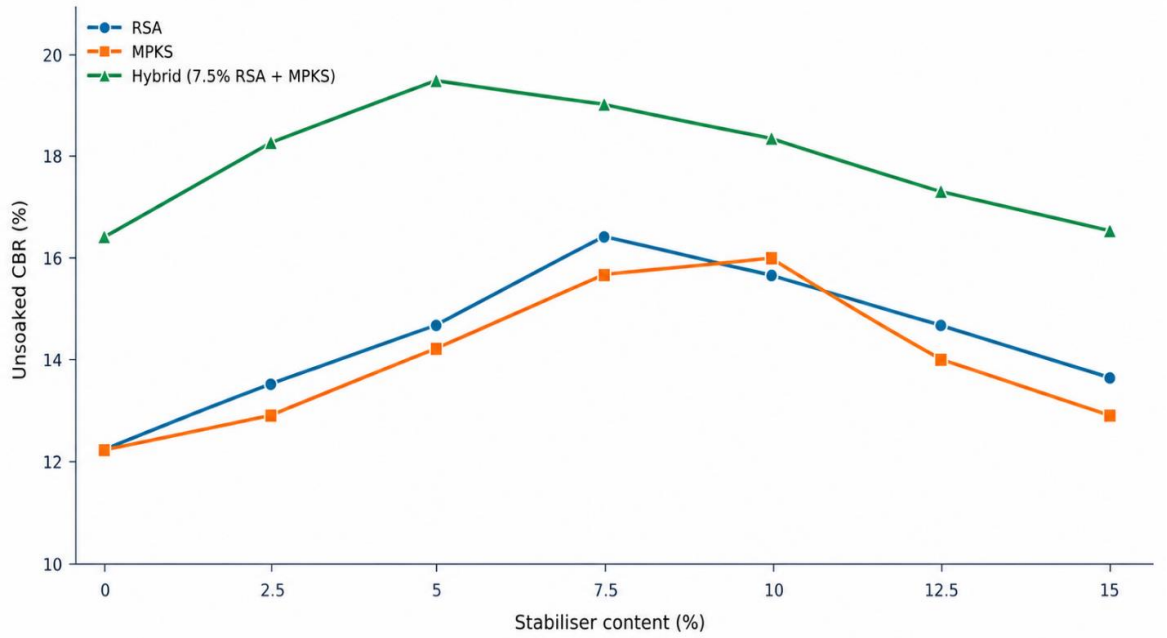


Figure 9: Unsoaked CBR variation of lateritic soil stabilised with RSA, MPKS and RSA-MPKS stabilised lateritic soil

However, the decline beyond 7.5% RSA indicates that excessive ash content caused increased void ratio, reduction in cohesion and weakening of soil matrix due to insufficient cementitious bonding. This behaviour is similar with the findings of [48], who reported that agricultural ashes improve CBR only up to an optimum level, beyond which strength decreases because excess ash behaves as unbound filler material. The hybrid RSA–MPKS stabilisation produced significantly higher CBR values (19.45%) than individual RSA (16.44%) or MPKS (15.68%) stabilisation, indicating synergistic interaction between the two materials. The substantial improvement is attributed to improved particle gradation, enhanced inter-particle bonding and filler effect of the MPKS.

(b) Soaked CBR

The results of the soaked CBR are shown in in Figure 10. From the graph, the soaked CBR values followed trends similar to the unsoaked condition but were significantly lower due to water infiltration and reduction in matric suction. Matric suction is the negative pore water pressure that exists in unsaturated soils due to capillary forces and surface tension, which contributes to inter-particle bonding and enhances soil strength. Upon soaking, the soil becomes saturated, eliminating matric suction and leading to a reduction in strength, as reflected in lower soaked CBR values [49-51]. The RSA and MPKS exhibited moderate improvement. The optimum soaked CBR for RSA is 5.68% at 7.5% RSA concentration. The optimum soaked CBR for MPKS is 5.22% at 10% MPKS concentration, respectively. This is in agreement with the study of [52, 53]. The hybrid RSA–MPKS stabilisation showed superior soaked performance compared to RSA and MPKS independently. Optimum soaked CBR for RSA- MPKS at 7.5% RSA+ 5% MPKS is 10.56%. The result of hybrid-soaked RSA –MPKS were lower to the research of [54].

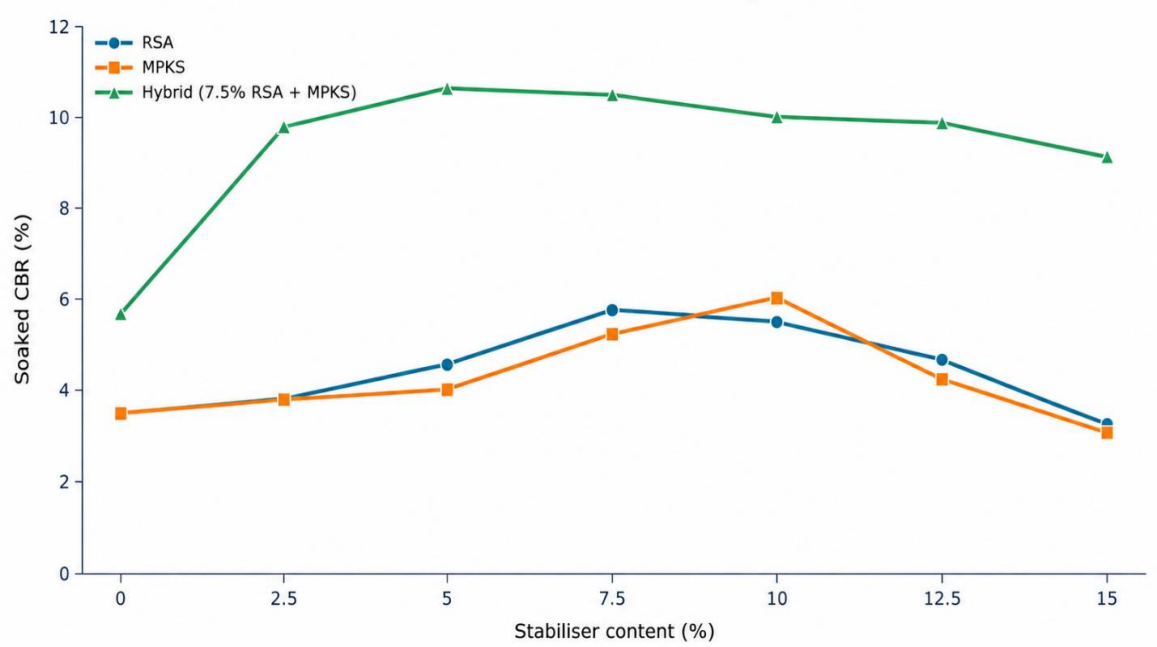


Figure 10: Soaked CBR variation of lateritic soil stabilised with RSA, MPKS and RSA-MPKS stabilised lateritic soil

4. CONCLUSION

This research evaluates the influence of lateritic soil stabilised with rice straw ash and milled palm kernel shell for road construction. Soil classification, index and engineering properties of unstabilised and stabilised soil were determined and the following conclusions are drawn from the study:

i. The lateritic soil was categorized as clay of high plasticity and is designated by AASHTO and the Unified Soil Classification System as an A-7-5(9) and CH soil, respectively.
ii. The results showed that stabilisation reduced soil plasticity, with the optimum 7.5% rice straw ash + 5% milled palm kernel shell combination reducing the plasticity from 40.30 to 20.03%.
iii. The stabilised lateritic soil reduced maximum dry density and increased optimum moisture content.

The California bearing ratio increased with increase in proportion of the agricultural residues with 7.5% rice straw ash + 5% milled palm kernel shell blend outperforming the individual residues.

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