ABUAD Journal of Engineering and Applied Sciences (AJEAS)

ISSN: 2992-5584

Volume 2, Issue 2, 83-90

Effect of Using Palm Kernel Shell Ash and Rice Husk Ash on Stability of Lateritic Soil for Road Pavement

Sulaiman Olayinka SUBAIR[1*], Biliyamin Adeoye IBITOYE[2], Abdulrauf Toyin KURANGA[3], Opeyemi Ebenezer OLAWALE[4]

[1,2]Department of Civil Engineering, Kwara State University, Malete, Nigeria
[3]Centre for Sustainable Energy, Kwara State University, Malete, Nigeria
[4]Department Of Civil Engineering, Jus Partners Cosmopolitan, Lagos, Nigeria

sulaiman.subair@kwasu.edu.ng, biliyamin.ibitoye@kwasu.edu.ng
abdulrauf.kuranga@kwasu.edu.ng, opeyemi1516@gmail.com

*Correspondence: sulaiman.subair@kwasu.edu.ng; Tel.: +2348166061150

Date Submitted: 22/11/2024
Date Accepted: 18/12/2024
Date Published: 31/12/2024

Abstract: This study investigates the stabilization of lateritic soil sourced from a roadside along Iraa Road, near the Nigeria Navy School in Kwara State, Nigeria. The soil was sampled at a depth of 1 meter following the removal of topsoil. Initial testing revealed a California Bearing Ratio (CBR) of 27%, meeting the minimum requirements for subgrade suitability. The addition of 4% Palm Kernel Shell Ash (PKSA) and 2% Rice Husk Ash (RHA) significantly improved the CBR to 41%, reflecting enhanced load-bearing capacity. These findings align with previous research demonstrating the efficacy of PKSA and RHA in improving soil strength. However, stabilization beyond the optimal content of 4% PKSA and 2% RHA resulted in declining CBR values, underscoring the critical importance of maintaining optimal stabilizer proportions for effective performance. The study further observed an increase in the optimum moisture content (OMC) of the soil, rising from 12.60% to 16.10% upon the addition of stabilizers, consistent with the moisture requirements induced by pozzolanic materials. Similarly, the Maximum Dry Density (MDD) of the natural soil increased from 1.67 kg/m^3 to 1.72 kg/m^3 with the inclusion of 4% PKSA and 2% RHA, indicating enhanced compaction properties. These improvements correspond with established standards and corroborate findings from related studies. To comprehensively assess the effects of stabilization, the research also examined mixtures incorporating incremental proportions of RHA (0%, 2%, 4%, 6%, 8%, and 10%) combined with 4% PKSA, previously identified as optimal for enhancing soil properties. The goal was to improve the soil's CBR values, particularly for application in base course construction. The results demonstrate that while PKSA and RHA are effective stabilizers, exceeding optimal levels leads to reduced performance, emphasizing the need for precise proportioning to achieve desired outcomes in lateritic soil stabilization.

Keywords: Rice husk, lateritic soil, maximum dry density, optimum moisture content, California bearing ratio.

1. INTRODUCTION

The rapid expansion of the economy and increasing consumption have result in the creation of significant volumes of waste materials. Items such as scrap tires, glass, steel slag, plastics, construction and demolition debris, and agricultural waste are accumulating in landfills and stockpiles worldwide, creating environmental and financial challenges. Addressing these disposal issues requires collective commitment and strategic management. Recycling and repurposing waste materials in highway construction offer a practical and sustainable approach to mitigate the growing waste problem [1].

For instance, cement production represents about 7% of worldwide carbon dioxide emissions due to its carbonate composition. As the effects of greenhouse gases become increasing and the demand for stabilized roads grows due to increasing population, economic activities, and development projects, the need for alternative or auxiliary stabilizers to cement and lime becomes critical [2].

Soil stabilization in road construction is essential due to the increasing weight of traffic loads and the prevalence of clay-rich soils that weaken under stress. Failures in Nigerian highways are often attributed to the inadequate geotechnical properties of subgrade soils, which compromise the integrity of the pavement. Soil stabilization is therefore a key aspect of civil engineering, aimed at enhancing soil strength, durability, and workability. In recent years, the usage of industrial by-products for soil stabilization has gained traction pertaining to its economic and environmental benefits [3].

Rice Husk Ash (RHA) and Palm Kernel Shell Ash (PKSA) are abundant and cost-effective materials with promising applications in soil stabilization. PKSA, a by-product of the palm oil industry, is rich in silica and

https://doi.org/10.53982/ajeas.2024.0202.12-j

enhances soil compressive strength while reducing plasticity and shrinkage. Similarly, RHA, derived from rice milling, is known for its pozzolanic properties, which improve soil strength and binding characteristics. Both materials contribute to sustainable construction practices by reducing waste and enhancing the performance of treated soils [1].

Rice husk ash (RHA) is composed of about 90% silica and features a highly porous, lightweight structure with a significant specific surface area. Its special properties have made it a valuable additive in various materials and industries. RHA is mostly used in applications such as refractory bricks, insulation materials, and flame-retardant products. These characteristics contribute to its versatility in enhancing material performance and durability, as noted by [4].

Rice Husk Ash (RHA), a by-product of rice milling, is produced by the combustion of rice husks. Due to its high silica (SiO_2) content, RHA possesses excellent pozzolanic characteristics, reacting with calcium hydroxide to create calcium silicate hydrates that improve soil strength. Early studies, such as those by [5], highlighted the potential of RHA in enhancing the properties of cementitious materials, paving the way for its use in soil stabilization. Research by [6] demonstrated that RHA incorporation in clayey soils enhances the California Bearing Ratio (CBR) and lowers plasticity, while [7] observed improvements in soil strength and permeability, making RHA-treated soils well-suited for subgrade construction. Other investigations, such as [8] shown that RHA can optimize soil compaction, leading to higher Maximum Dry Density (MDD) and improved workability.

Palm Kernel Shell Ash (PKSA) is derived from the combustion of palm kernel shells, an agricultural residue. Rich in silica and alumina, PKSA offers pozzolanic properties that enhance soil strength and compaction characteristics. Studies by [9] revealed that lateritic soils treated with PKSA exhibit improved CBR values, lower plasticity indices, and greater durability, making them ideal for road construction applications. Further research by [10] found that PKSA boosts the shear strength of soils, especially when combined with other stabilizers such as lime. Additionally, [11] emphasized the synergistic effects of PKSA and other pozzolanic materials, such as RHA, in further enhancing soil properties.

The California Bearing Ratio (CBR) is a widely used parameter for evaluating the strength of stabilized soils in comparison to a standard crushed rock. Higher CBR values indicate greater load-bearing capacity, a key requirement for subgrade and base course materials. [12] found that incorporating pozzolanic materials like RHA and PKSA into lateritic soils significantly enhances their CBR, making them more suitable for heavy-load applications in pavement construction. Similarly,[13] demonstrated that optimized combinations of RHA and PKSA can increase CBR values by over 50%, showcasing their efficacy in soil stabilization.

Optimum Moisture Content (OMC) refers to the moisture level at which a soil achieves its maximum density under compaction. Stabilizers such as RHA and PKSA tend to increase OMC due to their water-retention capacity, attributed to their fineness and pozzolanic activity. For instance, research by [6] and [9] found that the addition of RHA and PKSA to soils leads to higher OMC, facilitating better compaction and enhanced soil structure. [14] reported that RHA-treated lateritic soils showed an increase in OMC from 12% to 16%, demonstrating its effectiveness in improving moisture-related properties.

Maximum Dry Density (MDD) represents the highest density a soil can achieve under standard compaction energy. Soil stabilization using materials like RHA and PKSA typically increases MDD, improving soil structure and strength. [8] observed that RHA inclusion in soil mixtures enhanced MDD, creating denser and more stable compositions. Similarly, [12] reported that PKSA-treated soils exhibited slight increases in MDD, reflecting their improved compaction potential and load-bearing properties.

Soil stabilization using agricultural by-products like RHA and PKSA aligns with the principles of sustainable engineering by promoting waste reuse and minimizing reliance on conventional stabilizers such as cement and lime. Combining RHA and PKSA with lateritic soils has been shown to significantly improve engineering properties, including CBR, OMC, and MDD [15]. [11] noted that the optimal blending of these materials results in substantial performance enhancements, achieving cost-effective and environmentally sustainable soil stabilization solutions.

2. LITERATURE REVIEW

2.1 Rice Husk Ash

Rice husk ash (RHA) is a byproduct generated from the combustion of rice husks, the protective outer layer of rice grains, typically produced during rice milling operations. It consists predominantly of silica (SiO_2), along with trace amounts of other minerals and organic residues. RHA is formed through the controlled burning of rice husks in industrial boilers or furnaces, where the organic components are incinerated, leaving behind ash. The resulting ash is then collected and processed to produce RHA suitable for various applications [16].

2.2 Palm Kernel Shell Ash

Palm Kernel Shell Ash (PKSA) possesses several notable properties physical, chemical, and mechanical that make it valuable for various applications. Chemically, it attains a high concentration of silica (SiO_2), which contributes to its effectiveness as a pozzolanic material. It also includes little amounts of alumina (Al_2O_3) and calcium oxide (CaO). The calcium oxide content imparts cementitious properties, enabling PKSA to serve as a partial substitute for cement in construction. Additionally, PKSA reacts with calcium hydroxide through its pozzolanic function, forming cementitious compounds that enhance the durability and strength of concrete. From an environmental perspective, PKSA supports sustainability by repurposing waste from palm oil manufacturing, reducing landfill accumulation, and promoting circular economy practices. Furthermore, using PKSA as a cement alternative contributes to lower CO_2 emissions, addressing the ecological footprint associated with traditional cement production, a significant source of carbon emissions [17]. Table 1 shows the summary of recent literature reviews on agricultural waste additive for soil stabilization (2015-2019).

Table 1: Summary of recent literature reviews on agricultural waste additive for soil stabilization (2015-2019)

Author	Year	Study	Methodology	Findings
[18]	2015	Laboratory tests on lateritic soil with varying PKSA proportions	Increased maximum dry density and reduced moisture content with higher PKSA content	Limited validation of laboratory findings through field tests
[19]	2016	Field investigation on road sections stabilized with RSA and PKSA	Improved strength and durability compared to control samples	Lack of long-term performance monitoring
[20]	2017	Laboratory experiments on lateritic soil stabilized with RHA	Improved properties, including higher CBR values and reduced plasticity index	Insufficient analysis of the long-term effects of RHA
[21]	2018	Comparative study of PKSA and RHA stabilization on lateritic soil	Both materials were effective; PKSA demonstrated slightly better strength enhancement	No evaluation of environmental implications
[22]	2019	Long-term performance evaluation of road sections stabilized with PKSA and RHA	Sustained soil improvement with minimal maintenance required	Absence of a detailed economic analysis

3. MATERIALS AND METHODS

3.1 Materials

The materials utilized in this research to achieve the research objectives included agricultural by-products like palm kernel shells, rice husks, and lateritic soil. Additionally, various tools and laboratory equipment were employed for testing and analysis.

3.1.1 Palm kernel shell

Palm kernel shells as shown in Figure 1 were sourced in bulk from a local oil production facility located in Irra, (Oyun Local Government Area), Kwara State, Nigeria. The shells were gently washed with water to eliminate impurities, sun-dried to remove moisture, and stored in waterproof sacks to maintain their condition prior to use.

Figure 1: Palm kernel shell

3.1.2 Rice husk

Rice husks shown in Figure 2 were collected from a rice farm in Ganmo, (Ifelodun Local Government Area), Kwara State, Nigeria. The husks were packed into sacks to facilitate convenient handling and transportation.

Figure 2: Rice husk

3.1.3 Palm kernel shell ash

The cleaned palm kernel shells were incinerated in a blast furnace at a controlled temperature range of 900 °C to 1000 °C in the laboratory. The achieved ash was sieved as shown in Figure 3 through a No. 200 mesh sieve with a 0.075 mm aperture, in accordance with [23, 24].

Figure 3: Palm kernel shell ash

3.1.4 Rice husk ash

Subjected to controlled combustion, then grind into finer particles and passed through a 200 mm sieve as shown in Figure 4.

Figure 4: Rice husk ash

3.1.5 Location of the soil used

The lateritic soil was collected from a roadside along Iraa Road, near the Nigeria Navy School as shown in Figure 5 in Kwara State, Nigeria, at a deepness of 1 meter below the ground surface, following the excavation of the topsoil. The soil was then stored in a dry condition at room temperature.

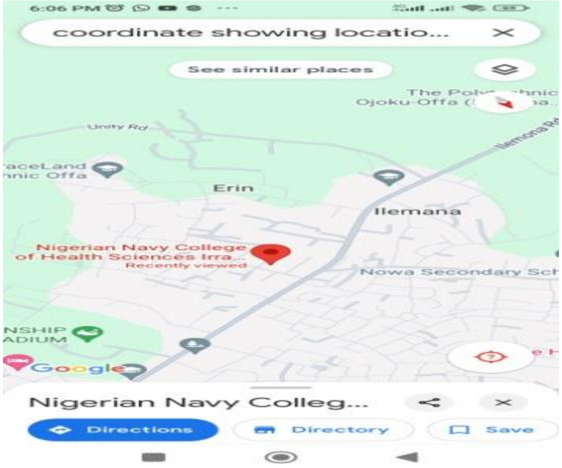

Figure 5: Map of the Area

3.2 Material Mix Ratio

Rice Husk Ash -RHA; varies from 0%,2%, 4%,6%,8% and 10% respectively with lateritic soil.

Palm Kernel Shell Ash- PKSA; 4% optimum. It has been suggested by [25], that 4% palm kernel shell ash is the optimal percentage for stabilizing lateritic soil classified as A-2-6. Additionally, further research indicates that combining this optimal amount of palm kernel shell ash combine with admixtures, such as lime or egg shell ash, which are rich in CaO, can enhance the power of the soil. This blend has the potential to achieve higher California Bearing Ratio (CBR) values, making it more appropriate for use as base course material in construction. Table 2 displays the mix ratio of RHA, PKSA and laterite soil for all the laboratory tests.

Table 2: Mix ratio of RHA, PKSA and laterite soil for all the laboratory tests

Materials	Mix Percentage
Lateritic Soil	0% Control
PKSA +Lateritic Soil	4% + Lateritic Soil
PKSA +RHA +Lateritic Soil	4% + 2% + Lateritic Soil
PKSA +RHA +Lateritic Soil	4% + 4% + Lateritic Soil
PKSA +RHA +Lateritic Soil	4% + 6% + Lateritic Soil
PKSA +RHA +Lateritic Soil	4% + 8% + Lateritic Soil
PKSA +RHA +Lateritic Soil	4% + 10% + Lateritic Soil

3.3 Sieve Analysis Test

The sieve analysis was conducted in compliance with [23], standards by passing a 500 g soil sample through a difference sieves. The sieves were arranged in descending order, and the soil was put on the topmost sieve. A vibratory sieve shaker was used to automate the process. Once activated, the machine vibrated the sieves, allowing smaller soil particles to pass through according to the sieve openings. The procedure was done for 15 minutes.

3.4 Specific Gravity Test

The specific gravity of the soil was determined using the pycnometer method, which is suitable for cohesionless soils. The pycnometer, a 1-liter glass jar with a brass conical cap and a screw-type cover, was utilized. The cap features a small hole with a 6 mm diameter at its apex, enabling accurate measurements during the procedure.

3.5 Atterberg Limit Test

The Atterberg limit test assesses the plasticity characteristics of soil, including the liquid and plastic limits:

i. Liquid Limit (LL): The moisture content at which soil transitions into a liquid state was achieved using the Casagrande apparatus. A groove was created in the soil placed in a standard cup, and the cup was repeatedly dropped until the groove closed. The moisture content of the sample was then measured.

ii. Plastic Limit (PL): This test involved rolling a thread of the fine soil portion on a flat, non-porous surface until it crumbled at a specific diameter. The procedure followed [26].

3.6 California Bearing Ratio Test

The CBR test measures the strength of soil by determining the pressure required to penetrate a soil sample with a standard plunger. This pressure is then related to the pressure needed to achieve the same penetration in a standard crushed rock material. The higher the resistance of the soil, the higher its CBR value, indicating better load-bearing capacity.

4. RESULTS AND DISCUSSION

4.1 Analysis of Particle Size

The sieve analysis was done following [23] standards by passing a 500 g soil sample through a sequence of sieves. The results of the particle size analysis are presented in Tables 4.1 and 4.2, where the percentages of soil passing through sieves No. 4, 8, 20, 50, 100, 200, and the pan were recorded as 91.9%, 87.7%, 65.1%, 41.7%, 33.9%, 31.6%, and 0.0%, respectively.

The particle size curve distribution in Figure 6 shows that the soil sample consists of 5.2% gravel, 93.8% sand, and 1% fines. Based on the Unified Soil Classification System (USCS), the soil is categorized as SW (Well-Graded Sand), and according to the AASHTO classification, it is categorized as A-1-a. The particle size distribution was determined using the [26] standard, and the results were documented using the corresponding analysis data sheet template.

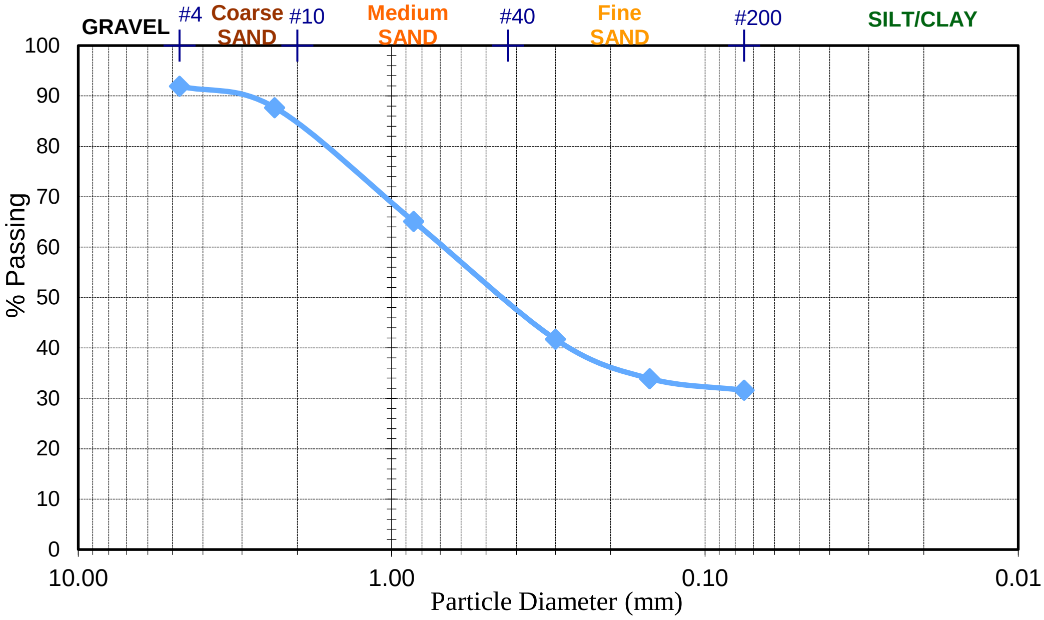

Figure 6: Particle size distribution

4.2 Properties of Lateritic Soil Sample

The preliminary test results for the soil sample, including particle size analysis, natural moisture content, Atterberg limits, specific gravity, and plasticity index, prior to the addition of stabilizers. Specifically, the natural moisture content was found to be 21.50%, with a specific gravity of 2.19. The plasticity index, plastic limit, and liquid limit were recorded as 58.2%, 23.55%, and 24.65%, respectively. According to [16], the soil is classified as A-7-5, while it is categorized as Silt-Clay (SC) in the Unified Soil Classification System (USCS). The soil was further categorized as SW – Well-Graded Sand in the USCS. The structure of the soil consisted of 5.2% gravel, 93.8% sand, and 1% fines. Table 3 shows the typical oxide compositions of rice husk ash (RHA) and palm kernel shell ash (PKSA) based on x-ray fluorescence (XRF) analysis.

Table 3: Typical oxide compositions of rice husk ash (RHA) and palm kernel shell ash (PKSA) based on x-ray fluorescence (XRF) analysis

Oxide Composition (%)	Rice Husk Ash (RHA)	Palm Kernel Shell Ash (PKSA)	Author
Silica (SiO_2)	80–95	40–65	[6][8][9][10]
Alumina (Al_2O_3)	1–5	15–30	[9][10][11]
Ferric Oxide (Fe_2O_3)	0.5–2	5–10	[8][9][10]
Calcium Oxide (CaO)	1–3	5–10	[6][9]
Magnesium Oxide (MgO)	0.5–1.5	1–5	[8][10]
Potassium Oxide (K_2O)	0.5–3	1–3	[6][9][11]
Other Oxides (e.g., Na_2O, TiO_2)	Trace	Trace	[9][10]

4.3 Optimum Moisture Content (OMC)

As defined by [26], the OMC is the moisture level at which a soil gains its maximum dry density. For fine-grained soils, OMC typically ranges from 12% to 20%, depending on the soil type and any additives. Research by [28] indicates that the addition of RHA raises the OMC, as the higher surface area requires more moisture for saturation. The natural soil had an OMC of 12.60% as shown in Figure 7, which is within the expected range. When 4% PKS and 2% RHA were added, the OMC increased to 16.10%, which relate with findings from studies such as [28], which showed that increased amounts of pozzolanic material led to increased OMC.

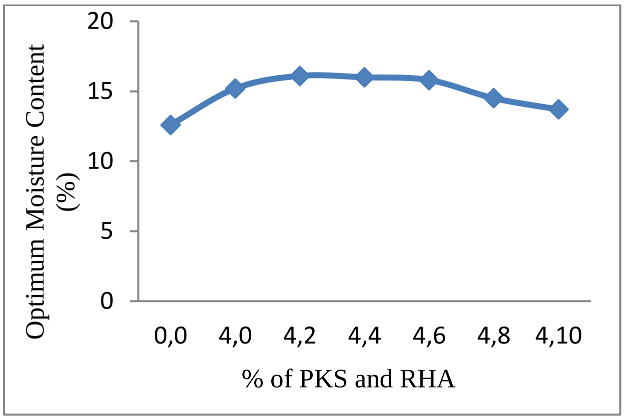

Figure 7: Optimum moisture content (%)

4.4 Maximum Dry Density (MDD)

Maximum Dry Density (MDD) is measured according to [26], for fine-grained soils, MDD values typically fall between 1.6 and 2.0 kg/m³. The introduction of lightweight materials like RHA can reduce the MDD because these materials have a lower specific gravity. The MDD for the natural soil was 1.67 kg/m³ as shown in Figure 8, which is within the expected range for fine-grained soils. However, with the addition of 4% PKS and 2% RHA, the MDD slightly increased to 1.72 kg/m³, indicating an improvement in the soil's compaction characteristics. Similar findings by [29], observed that while small amounts of stabilizers initially increase the MDD, further addition of RHA often leads to a decrease in MDD due to its low density.

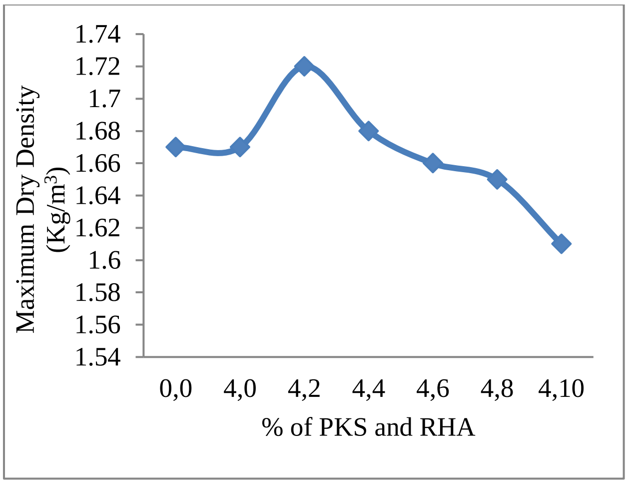

Figure 8: Maximum dry density (Kg/m^3)

4.5 California Bearing Ratio

The (CBR) California Bearing Ratio test, as defined by [27], is used to assess the strength of subgrade soils. For soils to be suitable for use in pavement construction, CBR values typically need to exceed 20%. Soil stabilization aims to enhance the CBR value to improve load-bearing capacity.

The natural soil initially exhibited a CBR value of 27%, which is above the minimum requirement for subgrade suitability. When 4% PKS and 2% RHA were added, the CBR value increased to 41%, indicating a substantial improvement enhancement in the soil's strength and load-bearing capacity. This finding related with previous studies, such as those by [30], which demonstrated that RHA and PKS improve soil strength. However, as the percentage of PKS and RHA exceeded 4%, the CBR values began to decrease, suggesting that there is an optimal level of stabilizers beyond which further additions may reduce the soil's performance. This is consistent with the observations of [29]. The CBR test results are summarized in Table 4 and illustrated in Figure 9.

Table 4: California bearing ratio values

% of PKS, RHA	California Bearing Ratio values (%)
0	27
4,0	38
4,2	41
4,4	37
4,6	32
4,8	29
4,10	28

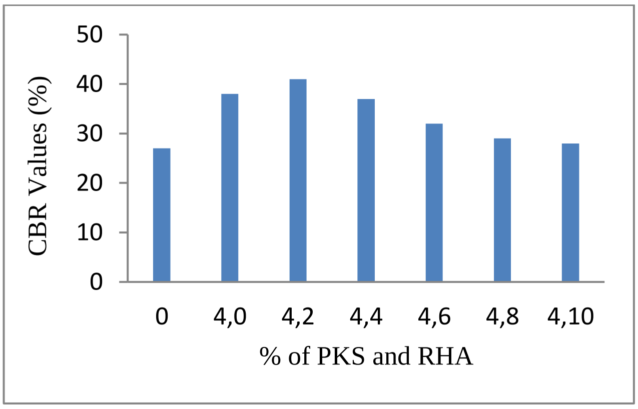

Figure 9: California bearing ratio values (%)

5. CONCLUSION

This study presents the results of tests conducted on a soil sample, leading to the following conclusions. The soil exhibited high plasticity and moisture content, uniform with findings from recent studies, while parameters such as specific gravity, liquid limit, and AASHTO classification confirm its poor engineering properties. These classification inconsistencies suggest that the soil is non-homogeneous, likely containing a mix of sandy matrix with clayey fines, which significantly influences its behavior. For engineering applications, particularly in road construction or subgrade preparation, the soil's high plasticity and moisture retention properties would require stabilization. Recent literature underscores the challenges posed by likely soils, which are common and require careful design and treatment strategies to mitigate their detrimental effects. The introduction of

Rice Husk Ash (RHA) and Palm Kernel Shells (PKS) resulted in significant improvements in the soil's Maximum Dry Density (MDD), Optimum Moisture Content (OMC), and California Bearing Ratio (CBR) up to a specific threshold (4% PKS, 2% RHA). These improvements align with expectations based on ASTM standards and corroborate previous findings in the literature. However, the addition of stabilizers beyond optimal levels led to diminishing returns, particularly in CBR values, highlighting the importance of adhering to appropriate proportions for effective soil stabilization. This research also emphasizes the use of readily available agricultural waste materials, such as PKS and RHA, for soil stabilization, offering an eco-friendly and sustainable alternative to conventional stabilizers. By utilizing waste products, the study contributes to reducing environmental pollution and minimizing agricultural waste, while providing an economically viable solution for soil stabilization, particularly in regions with abundant agricultural by-products. Furthermore, the findings support the enhancement of infrastructure projects, particularly road construction, by improving the mechanical characteristic of lateritic soil. This contributes to stronger, more durable roads with better load-bearing capacity and compaction in subgrade soils. The application of PKS and RHA is consistent with sustainable construction practices, offering a dual benefit of environmental conservation and the provision of affordable, effective materials for civil engineering. This research has the potential to transform the sourcing and application of construction materials, promoting more sustainable development practices worldwide. Lastly, this study provides a strong foundation for upcoming advancement in soil stabilization. As construction methodologies evolve, the insights from this research can be refined and adapted to further enhance soil stabilization techniques, ultimately contributing to more sustainable and cost-effective infrastructure projects globally.

REFERENCES

[1] Oyesiku, K. Onakoya, A.B. Folawemo, A., 2013. The empirical analysis of transport infrastructure investment and economic growth in Nigeria. *Journal: Social Sciences, Science PG*, 2(6), pp.179-188.

[2] Abdeldjouad, L., Asadi, A., Ball, R. J., Nahazanan, H., & Huat, B. B. K., 2019. Application of alkali-activated palm oil fuel ash reinforced with glass fibers in soil stabilization. *Soils and Foundations (Elsevier),* 59, pp.1552-1561.

[3] Osinubi, K. J., & Mustapha, A. A., 2008. Stabilization of lateritic soil using Cement Kiln Dust for road construction. *Geotechnical and Geological Engineering*, 26(2), pp.233-240.

[4] Alhassan, M., & Mustapha, M. A., 2019. Geotechnical Evaluation of Lateritic Soils in Niger State, Nigeria, for Use as Road Construction Material. *Journal of Engineering Research and Development*, 21(2), pp.118-125.

[5] Mehta, P.K. (1977). Properties of Blended Cements Made from Rice Husk Ash. *Journal of the American Concrete Institute*, 74(9), pp. 440-442.

[6] Basha, E.A., Hashim, R., Mahmud, H.B., & Muntohar, A.S., 2005. Stabilization of residual soil with rice husk ash and cement. Construction and Building Materials, 19(6), pp. 448–453.

[7] Ganesan, K., Rajagopal, K., & Thangavel, K., 2008. Rice husk ash blended cement: Assessment of optimal level of replacement for strength and permeability properties of concrete. Construction and Building Materials, 22(8), pp.1675–1683.

[8] Ali, F.H., Adnan, A., & Choy, C.K., 2012. Geotechnical properties of a chemically stabilized soil from Malaysia with rice husk ash as an additive. Construction and Building Materials, 16(5), pp.417–425.

[9] Amu, O.O., & Adetuberu, A.A., 2011. Characteristics of Bamboo Leaf Ash Stabilization on Lateritic Soil in Highway Construction. International Journal of Engineering and Technology, 3(2), pp.219-226.

[10] Ogunribido, T.H.T., 2011. Geotechnical properties of some lateritic soils stabilized with palm kernel shell ash. Journal of Science and Engineering Technology, 18(2), pp.54-62.

[11] Etim, R.K., Adiukwu, P.A., & Antia, D.D.J., 2017. Stabilization of Nigerian Lateritic Soils using Bamboo Leaf Ash and Palm Kernel Shell Ash. Sustainable Construction Materials and Technologies, 6(3), pp.77–86.

[12] Osinubi, K.J., Eberemu, A.O., & Amadi, A.A., 2016. Compacted lateritic soil treated with agricultural waste ash: A sustainable geotechnical solution. Transportation Geotechnics, 9(2), pp.37-45.

[13] Oluremi, J.R., Afolayan, O.J., & Oyebode, S.A., 2019. Synergistic effects of Rice Husk Ash and Palm Kernel Shell Ash on the engineering properties of residual soils. Case Studies in Construction Materials.

[14] Agbede, I.O., & Joel, M., 2008. Use of cement and calcium chloride in the stabilization of lateritic soil. Research Journal of Applied Sciences, 3(3), pp.191-201.

[15] Koteswara Rao, D., Siva Kumar Reddy, B., & Kumar, A.P., 2012. Study on stabilization of soils with rice husk ash. International Journal of Engineering Science and Technology, 4(6), pp.2199–2203.

[16] Mehta P.K and Monteiro P.J.M., 2006. Concrete: microstructure, properties, and materials, 3rd edition. McGraw-Hill, New York

[17] Okoroafor, U., Edeh, J., &Nwoke, O., 2017. Effect of Rice Husk Ash on the Properties of Lateritic Soil Stabilized with Cement. International Journal of Engineering and Technology Innovation, 7(4), pp.290-298.

[18] Ademola, I. A., 2015. "Laboratory tests on lateritic soil with varying PKSA proportions." International Journal of Civil Engineering and Technology (IJCIET), 6(4), pp.50-58.

[19] Oyebisi, S. A., 2016. "Field investigation on road sections stabilized with RSA and PKSA." Journal of Construction and Building Materials, 15(7), pp.212-220.

[20] Kumar, A., & Mandal, A., 2017. "Laboratory experiments on lateritic soil stabilized with RHA." International Journal of Geotechnical Engineering, 11(3), pp.145-152.

[21] Ogunbayo, O. O., 2018. "Comparative study of PKSA and RHA stabilization on lateritic soil." Construction and Building Materials, 28(9), pp.1214-1223.

[22] Afolayan, O., & Salami, S. A., 2019. "Long-term performance evaluation of road sections stabilized with PKSA and RHA." Journal of Sustainable Civil Engineering, 10(6), pp.83-92.

[23] British Standards Institution. (1990). BS 1377: Methods of Test for Soils for Civil Engineering Purposes. Parts 1–9. London: British Standards Institution.

[24] British Standards Institution. (1990). BS 1924: Methods of Tests for Stabilized Soils. Parts 1–2. London: British Standards Institution.

[25] Ako, T, I.T. Yusuf., 2016. Utilization of Palm Kernel Shell Ash as a Stabilizer of Lateritic Soil for Road Construction. Epistemics in Science, Engineering and Technology., 6(1), pp.423-433.

[26] ASTM D4318-17. Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils. ASTM International, West Conshohocken, PA, 2017.

[27] ASTM International., 2017. Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils (ASTM D4318-17e1). West Conshohocken, PA: ASTM International.

[28] Olawale, D., Alade, G., & Ibrahim, A., 2015. Comparative Study on Stabilization of Clayey and Sandy Soils Using Cement and Rice Husk Ash. International Journal of Civil Engineering and Technology, 6(3), pp.41-50.

[29] Agbede, I. O., & Joel, M., 2009. Use of Cement and Bagasse Ash Mixture to Improve the Engineering Properties of Lateritic Soil. Journal of Engineering and Applied Sciences, 4(3), pp.111-117.

[30] Osinubi, K. J., Eberemu, A. O., &Lawal, A. I., 2019. Effect of Bagasse Ash and Groundnut Shell Ash on the Compaction and Strength Properties of Black Cotton Soil. Nigerian Journal of Technological Development, 16(1), pp.1-9.

[31] Abd EI-Aziz, M.A. and Abo-Hashema, M.A. (2013) “Measured Effects on Engineering Properties of Clayey Subgrade using Lime-Homra Stabiliser,” International Journal of Pavement Engineering, 14(4), 321-332.