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Effect of Palm Kernel Shell Ash Supplement with Egg Shell Ash on Stabilized Lateritic Soil for a Road Work

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Abstract: *Lateritic soil serves as a fundamental material in road construction; however, its engineering properties can be significantly improved through the use of additives. In Nigeria, the abundant generation of agricultural by-products—such as palm kernel shells, eggshells, and wood residues—presents challenges related to waste disposal and management. These materials can contribute to environmental degradation, including air and water pollution, and adversely affect local ecosystems. This study explores the effects of Palm Kernel Shell Ash (PKSA) and Egg Shell Ash (ESA) on the stabilization of lateritic soil for use in road pavement applications. Comprehensive geotechnical testing was conducted on natural lateritic soil to assess various parameters: Specific Gravity (SG), percentage passing sieve No. 200 (F-200), Liquid Limit (LL), Plastic Limit (PL), Plasticity Index (PI), Maximum Dry Density (MDD), Optimum Moisture Content (OMC), and both unsoaked and soaked California Bearing Ratio (CBR). These parameters were also measured for stabilized soil samples incorporating 4% PKSA and varying percentages of ESA (0%, 2%, 4%, 6%, 8%, and 10%) by dry weight of the lateritic soil, in accordance with West African Standards (WAS). The analysis revealed that the natural lateritic soil exhibited an SG of 2.53, F-200 of 27.00%, LL of 29.00%, PL of 17.20%, PI of 11.8%, MDD of 1820 kg/m³, OMC of 11.5%, and CBR of 22%. Conversely, the stabilized samples demonstrated SG values ranging from 2.3 to 2.5, F-200 between 27% and 28%, LL from 27.0% to 30.0%, PL between 10.0% and 17.2%, PI ranging from 10.3% to 11.8%, MDD between 1860 and 2000 kg/m³, OMC values between 8% and 11%, and CBR results from 25% to 80%. Notably, the combination of 4% PKSA and 8% ESA resulted in significant improvements in the engineering properties of the soil, rendering it suitable for use as sub-base material in road construction. Therefore, this blend is recommended for effectively stabilizing lateritic soil for road infrastructure projects.*

Keywords: *Palm Kernel Shell Ash, Egg Shell Ash, Lateritic Soil, Geotechnical Tests, Stabilization, Road Pavement*

1. INTRODUCTION

Lateritic soils are among the most widely used construction materials globally, particularly in regions where they are abundant. Given that almost all construction relies on soil as a foundation or building material, understanding and enhancing the geotechnical properties of these soils is crucial for their application in engineering projects [1]. When engineers encounter suboptimal soil conditions during road construction, they have several options: relocating the construction site, redesigning the structure, removing and replacing the poor soil, or improving the soil's engineering properties through stabilization [2].

Soil stabilization involves enhancing the in-situ properties of soil to improve its performance in construction applications. The goal is to make poor lateritic soils serviceable throughout their design life by improving their hydraulic conductivity, compressibility, strength, and density. Palm kernel shell, a by-product of palm oil extraction, is one such agricultural waste that has been studied for its potential as an additive in soil stabilization. Between 2010 and 2021, Nigeria produced approximately 330 thousand metric tons of palm kernel oil, leading to significant palm kernel shell waste. Research has explored the potential of this waste as a pozzolanic material or additive to stabilize lateritic soils for road pavements [1].

In Nigeria, highway agencies are responsible for ensuring that roads are safe and serviceable, managing the network as a public asset [3]. Pavement engineers play a key role in designing and constructing reliable paved areas, taking into account factors such as load requirements, climate conditions, and long-term maintenance costs. While the performance specifications for pavement foundations are still developing, the importance of a well-constructed foundation for long-term pavement serviceability is increasingly recognized [4]. Although the knowledge and technologies for assessing pavement foundation materials lag behind those for upper pavement layers, ongoing research continues to advance our understanding and improve construction practices.

Utilizing agricultural waste materials like palm kernel shell ash, eggshell powder, coconut husk ash, or coir fiber ash can significantly lower construction costs while also mitigating environmental hazards associated with these wastes. Studies have demonstrated that coal combustion by-products possess beneficial properties for soil stabilization, including soil drying, improving sub-grade support capacities for floor slabs and pavement, reducing soil shrink-swell behavior, and acting as stabilizers in aggregate asphalt recycling and road base construction.[5] [6] highlighted that Portland cement production generates substantial CO2 emissions, contributing to ozone layer depletion.

Palm kernel shells (PKS), an industrial by-product abundantly available in palm oil-producing regions of southern Nigeria, contain low ash content (approximately 3% by weight) and minimal sulfur content (about 0.09% by weight) [7]. PKS has been primarily used as an aggregate in concrete.[8][9][10][11] and asphalt concrete [12]. Research by [13] suggests that sawdust ash (SDA) and PKS ash can serve as effective soil stabilizers, enhancing soil strength and stability. However, the additives are less effective in soils with high clay content. The compaction tests revealed that these additives improve the mechanical properties of soil by reducing clay content, although the overall suitability of the treated soil as a sub-base material remains limited due to persistent high clay content.

This research has added to the body of knowledge in the following ways; It reduces the cost of stabilization of weak soil, reduces disposal problem, hazardous and pollution in the environment, make a weak soil serviceable through its design life, after it’s been stabilized. The possibility of using 4% optimum palm kernel shell ash admixture with egg shell ash to stabilized lateritic soil of (A-3) for sub-base material was ascertained.

2. MATERIALS AND METHODS

2.1 Palm Kernel Shell Ash (PKSA)

Palm kernel shell sample was obtained from small oil milling centers at (OSI-EKITI KWARA) Kwara State. The palm kernel shells were burnt properly to ashes inside a blast furnace to about 900^{o}Cto attain a complete ash. It was carried out at the fabrication workshop, Institute of Technology, Kwara State Polytechnic, Ilorin. The ashes were sieved through a 0.075 mm aperture. Figure 1: shows the different sizes of Palm Kernel Shell, while Figure 2: shows the Palm Kernel Shell Ash.

Figure 1: Different sizes of palm kernel shell

Figure 2: Palm kernel shell blended to ash

2.2 Eggshell Ash (ESA)

Eggshell sample was obtained from Snacks bakeries beside Royal eatery located at Ilorin-East L.G.A, Kwara State. Eggshell waste was washed and kept in hot sun to dry for 5days. The dried eggshell was burnt to ash inside a furnace. The eggshell ash was sieved using BS Sieve No. 200 and the powder passing the sieve was used. The sieve is used to achieve a uniform powdery. The specific gravity of egg shell ash is 2.09. Figure 3: shows the Egg Shell while Figure 4: shows the Egg Shell Ash.

2.3 Lateritic Soil (LS)

The lateritic soil sample was collected from Asomu-Moro L.G.A along Kwara state University main campus road at a depth of 0.5 – 2.5 m from a ground surface, after the removal of the topsoil. They were been stored and kept dry in sacks at room temperature at the soil mechanics laboratory of the Department of Civil Engineering, University of Ilorin. The Figure 5: shows the location of the lateritic soil map.

Figure 3: Egg shell

Figure 4: Eggshell ash

Table 1: Properties of lateritic Soil

Soil Property	**Results**
Natural Moisture Content	2.8
Specific Gravity (g)	2.53
Liquid Limit (%)	29
Plastic Limit (%)	17.2
Plasticity Index (%)	11.8
Maximum Dry Density (kg/m^3)	1820
Optimum Moisture Content (%)	11.5
Percentage Passing BS No. 200 Sieve (0.075mm)	27
UnsoakedCBR(%)	52
Soaked CBR (%)	22
Colour	Brown
AASHTO Soil Classification system	A-3 (fine sand)

Figure 5: Location of lateritic soil sample (Google map)

2.4 Geotechnical Test

Preliminary tests, including natural moisture content, specific gravity, sieve analysis, and Atterberg limits, were conducted on samples of lateritic soil. Palm Kernel Shell Ash (PKSA) was incorporated at a rate of 4%, along with varying percentages (0, 2, 4, 6, 8, and 10%) of Eggshell Ash (ESA). Both materials were added to the soil based on its weight. The study included Atterberg limits and strength tests, such as compaction and California Bearing Ratio (CBR), to assess the impact of PKSA and ESA as stabilizing agents. All testing followed the West African Standards (WAS) guidelines. According to [14], it was stated that 4% palm kernel shell ash is the optimum percentage used to stabilized lateritic soil of A-2-6, he also said in further studies, that an admixture such as lime, egg shell ash and so on, which are rich in CaO can be blend with optimum palm kernel shell ash to stabilized lateritic soil in order to attain a higher strength of CBR for base course materials.

The tests involved preparing compacted soil samples with 4% PKSA and varying amounts of ESA. These samples were formed in a CBR standard mold at the optimum moisture content determined from earlier compaction tests. The CBR values were obtained through load-penetration tests on both unsoaked and soaked samples for each percentage of PKSA and ESA added.

3. RESULTS AND DISCUSSIONS

3.1 Classification of the lateritic soil

The natural moisture content of the lateritic soil was measured at 2.8%. Based on the AASHTO classification system, the soil samples can be categorized as A-3, which denotes fine sand with potential non-plastic components. A-3 soils, characterized as lateritic, are generally suitable for road construction applications. However, the requirements for maximum dry density (MDD) indicate instability for direct use as base material, with parameters set at a liquid limit (LL) of less than 35%, a plasticity index (PI) of less than 12%, and an MDD exceeding 2000 kg/m³. Despite these limitations, the soil can be effectively utilized as sub-base material following stabilization.

3.2 Atterberg Limit of Eggshell Ash with Palm Kernel Shell Ash

The Atterberg limit tests were conducted for mixtures containing 0%, 2%, 4%, 6%, 8%, and 10% eggshell ash combined with 4% palm kernel shell ash, which was determined to be the optimum percentage. The findings are summarized in Table 3. The variation in liquid limit across the mixtures is illustrated in Figure 4.6. Results indicate that the combination of 4% PKSA with 4% ESA yields a minimum liquid limit of 23%, while the addition of 10% ESA results in a maximum liquid limit of 30%.

Regarding the plastic limit, the data show that mixtures with 4% PKSA and 6% ESA achieve the lowest plastic limit of 10%, while the highest plastic limit of 15.9% occurs with the addition of 10% ESA. The plasticity index values for the mixtures range from 10.3% (with 8% ESA) to 14.1% (with 10% ESA). Overall, the liquid limit varies between 22.5% and 30%, the plastic limit ranges from 10% to 15.9%, and the plasticity index falls between 10.3% and 14.1%.

The results indicate that the liquid limit increases with the addition of ESA up to a combination of 4% PKSA and 8% ESA, which shows optimal performance. Beyond this point, specifically with 4% PKSA and 10% ESA, the liquid limit significantly increases to 30%, highlighting that 4% PKSA combined with 8% ESA represents the best mix for achieving desirable liquid limit properties.

Table 2: Summary of Atterberg limit test result for Palm kernel shell ash and eggshell ash

PKSA & ESA Content (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
0%	29	17.2	11.8
4%PKSA&2% ESA	25	14.4	10.6
4%PKSA&4% ESA	23	12.6	10.4
4%PKSA&6% ESA	23.5	10	13.5
4%PKSA&8% ESA	22.5	12.2	10.3
4%PKSA&10% ESA	30	15.9	14.1

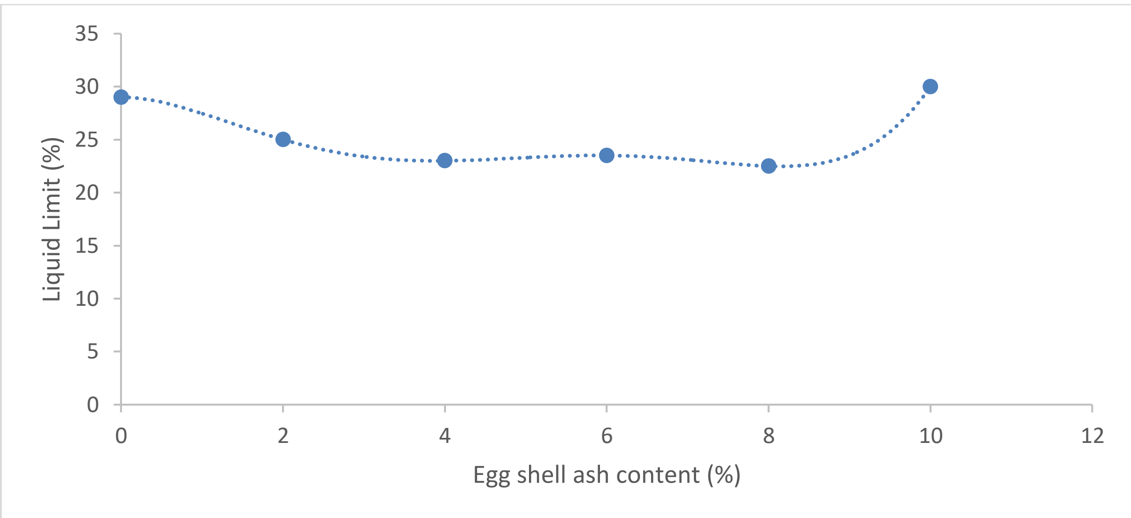

Figure 6: Variation of average liquid limit with egg shell ash content for 4% palm kernel shell ash

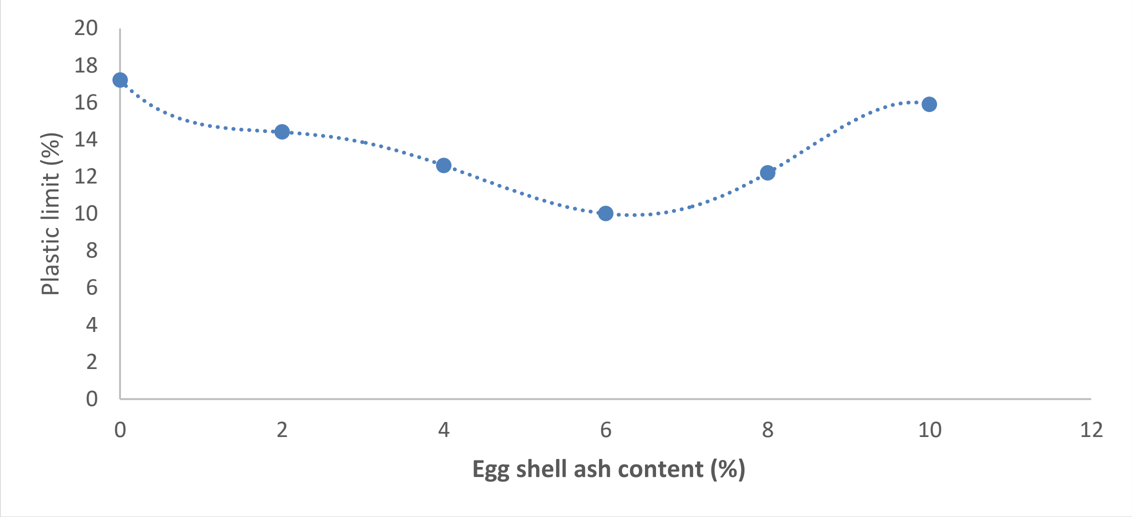

Figure 7: Variation of average plastic limit with egg shell ash content for 4% palm kernel shell ash

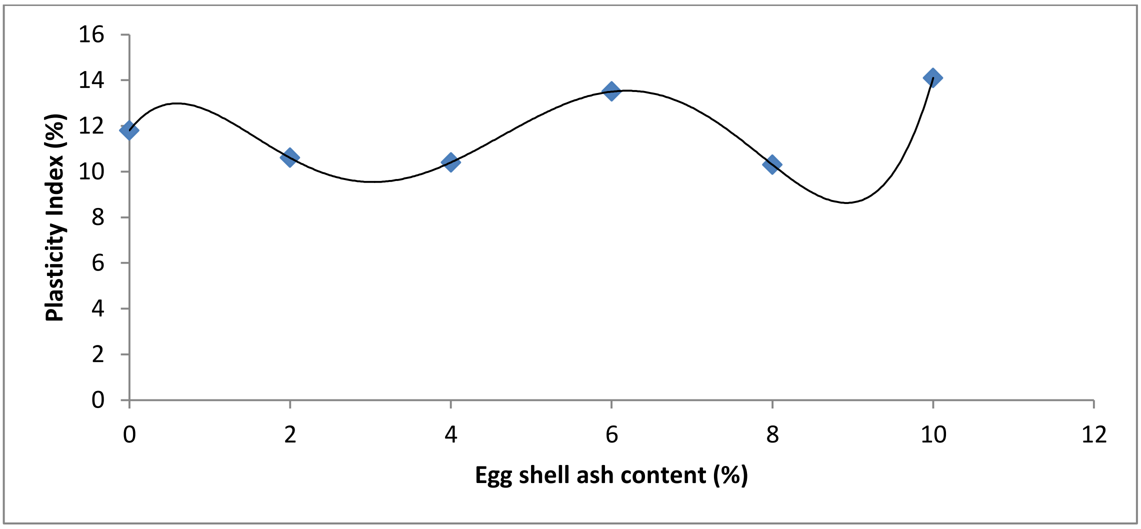

Figure 8: Variation of average plasticity limit with egg shell ash content for 4% palm kernel shell ash

3.3 Compaction of Eggshell Ash with Palm Kernel Shell Ash

The optimum moisture content (OMC) for mixtures of eggshell ash (0% to 10%) combined with 4% palm kernel shell ash was assessed. The findings suggest that the OMC remains relatively stable at approximately 11% for mixtures up to 6% ESA, while the combination of 4% PKSA with 8% ESA achieves the lowest OMC of 8%. In terms of maximum dry density (MDD), the analysis indicates that the mixture containing 4% PKSA and 10% ESA results in the lowest MDD of 1850 kg/m³.

Table 3: Summary of Compaction Test Result for 4% PKSA added with 0% to 10% ESA

4%PKSA&ESA Content (%)	**Optimum Moisture Content (OMC) (%)**	**Maximum Dry Density (MDD) (kg/m^3)**
4%PKSA&2% ESA	11	1860
4%PKSA&4% ESA	11	1920
4%PKSA&6% ESA	11	1940
4%PKSA&8% ESA	8	2000
4%PKSA&10%ESA	10.5	1890

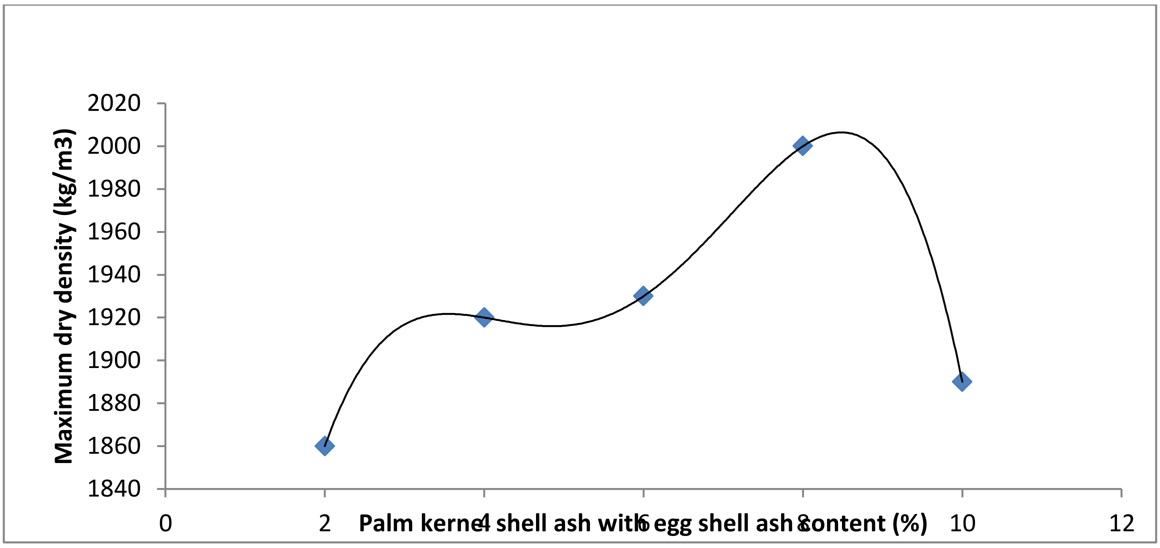

Figure 9: Variation of maximum dry density with ESA and 4% PKSA content.

3.4 California Bearing Ratio (CBR) Test of Eggshell Ash with Palm Kernel Shell Ash

The soaked and unsoaked California Bearing Ratio (CBR) values for the mixtures containing 0%, 2%, 4%, 6%, 8%, and 10% eggshell ash with 4% palm kernel shell ash were evaluated. The results for unsoaked CBR indicate that the lowest value, 58%, is achieved with 4% PKSA and 10% ESA, while the highest value, 70%, is recorded for the combination of 4% PKSA and 8% ESA. For soaked CBR, the lowest value of 54% is found with 4% PKSA and 2% ESA, and the highest soaked CBR of 80% occurs with 4% PKSA and 8% ESA.

Table 4: Summary of CBR Test for PKSA and ESA content

4%PKSA &ESA Content (%)	Unsoaked CBR (%)	Soaked CBR (%)
0	45	15
4%PKSA&2%ESA	55	30
4%PKSA&4%ESA	60	45
4%PKSA&6%ESA	65	64
4%PKSA&8%ESA	70	80
4%PKSA&10%ESA	49	40

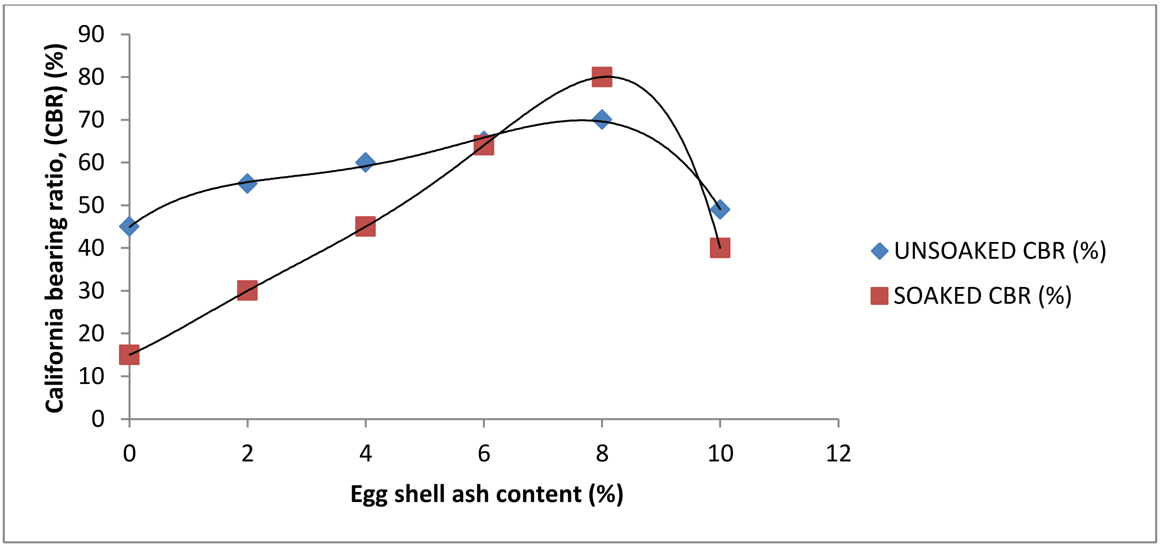

Figure 10: Variation of california bearing ratio with ESA and 4% PKSA content

3.5 Optimal Stabilization of Soaked and Unsoaked California Bearing Ratio (CBR)

The unsoaked and soaked CBR increased and have its peak at 4%PKSA and8% ESA of the treated soil from 40% to 70%, for unsoaked CBR and 15% to 80% for soaked CBR respectively. There is a decrease at further increasing in ESA contents. It can hence, be deduced that a 4% PKSA and 8% ESA content is the optimal for stabilizing an A-3 lateritic soil based on strength criterion, with the requirements of Nigeria General Specifications [15].

4. CONCLUSION

The lateritic soil examined in this study was classified as A-3 according to the AASHTO classification system, indicating its composition as predominantly fine sand. The soil's characteristics include approximately 27% material passing through the BS No. 200 sieve, reflecting its fine sand nature and low plasticity, with unsoaked and soaked CBR values of 70% and 80%, respectively.

The experimental results demonstrated that the incorporation of palm kernel shell ash (PKSA) and eggshell ash (ESA) into the lateritic soil resulted in reductions in both the liquid limit and plasticity limit, decreasing from 29% to 22.5% and from 17.2% to 10%, respectively. Additionally, the plasticity index decreased from 11.8% to 10.3%.

Notably, the Maximum Dry Density (MDD) decreased with the addition of ESA alone, but increased when PKSA and ESA were combined. Conversely, the Optimum Moisture Content (OMC) increased with ESA alone, yet decreased in mixtures of both PKSA and ESA. The CBR test results indicated an increase in the unsoaked CBR value with higher contents of PKSA and ESA. The soaked CBR values also improved, reaching optimal levels at 4% PKSA and 8% ESA before declining with further increases in ESA content

This study underscores the effectiveness of using PKSA and ESA in stabilizing lateritic soils for enhanced road construction applications.

This study highlights the potential of using agricultural waste products, such as PKSA and ESA, as effective additives for improving the engineering properties of lateritic soil. This approach not only promotes sustainability by recycling waste but also addresses environmental concerns related to disposal.

The research demonstrates significant improvements in various geotechnical properties of lateritic soil, including increased California Bearing Ratio (CBR) values, optimal moisture content, and density. This suggests that the combination of PKSA and ESA can effectively enhance soil performance for road applications.

By establishing optimal ratios of PKSA and ESA, the study provides valuable insights into how these materials can be used to produce stable sub-base layers in road work. This has practical implications for infrastructure development in regions where lateritic soil is prevalent.

5. RECOMMENDATIONS

The following recommendations were made;

i. Addition of 4% PKSA and 8% ESA improved the soil to be used as sub-base material and it is therefore, recommended for used in stabilizing lateritic soil.
ii. For further investigation in the optimal blend in palm kernel shell ash with cement and palm kernel shell ash with lime to stabilized lateritic soil should be conducted to attain a higher strength at optimum PKSA content for road works.
iii. Research should focus on the durability and performance of stabilized lateritic soil in various environmental conditions, including wet and dry cycles, to better understand its behaviour over time.
iv. Exploring other locally available agricultural wastes as potential pozzolanic materials could provide additional options for soil stabilization and contribute to sustainable construction practices.
v. Conducting a cost-benefit analysis of using PKSA and ESA compared to traditional soil stabilizers could provide valuable insights for decision-makers in the construction industry.

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