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Stabilization Of Lateritic Soil With Bamboo Stem Ash And Oil Palm Frond Ash Mixtures

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Abstract: *Soil stabilization is a critical process in improving the load-bearing capacity, strength, and durability of soils for construction purposes, especially in regions with weak soils with high plasticity. This study investigates the stabilization of lateritic soil using bamboo stem ash (BSA) and oil palm frond ash (OPFA) as eco-friendly stabilizers. Laboratory experiments, including Atterberg limits, compaction, and California Bearing Ratio (CBR) tests, were conducted on untreated soil and soil treated with varying proportions of the stabilizers (2%, 4%, 6%, 8%, and 10%). The results showed that the addition of bamboo stem ash and oil palm frond ash had no significant impact on the soil's mechanical properties. The optimum moisture content increased, while the maximum dry density decreased with higher stabilizer content, indicating poor compaction behavior for highway pavement construction. The CBR values of the stabilized soil increased, with maximum improvement observed at 4% stabilizer content. The study concludes that bamboo stem ash and oil palm frond ash mixtures cannot effectively enhance the engineering properties of lateritic soil, and thus other agricultural waste materials should be studied in view of promoting sustainable construction and environmental conservation through the reuse of agricultural waste.*

Keywords— Soil stabilization, lateritic soil, bamboo stem ash, oil palm frond ash, compaction, California bearing ratio, sustainable construction.

1. Introduction

Soil stabilization is a crucial aspect of construction engineering, particularly in regions where the natural soil composition presents challenges such as poor load-bearing capacity, high plasticity, and susceptibility to erosion [6]. It involves improving the engineering properties of soils to make them suitable for construction purposes by altering their physical, chemical, or mechanical characteristics to enhance strength, durability, and stability. Ref [1] revealed that effective pozzolanic stabilization is often accompanied by the formation of dense cementitious gels that bind soil particles together, improving strength and reducing permeability. In contrast, the absence of such microstructural bonding in untreated or poorly stabilized samples explains the limited mechanical improvement observed in some cases.

Traditionally, various techniques have been employed for soil stabilization, including the use of chemical additives such as lime, cement, and fly ash, as well as mechanical methods like compaction and reinforcement [7]. However, these conventional methods may not always be sustainable or cost-effective, especially in resource-constrained environments. Consequently, there is a growing interest in exploring alternative and eco-friendly approaches to soil stabilization, particularly those utilizing locally available materials [9].

Environmental sustainability also remains a key driver for exploring alternative stabilizers. Life Cycle Assessment (LCA) studies have shown that utilizing agro-waste materials in construction significantly reduces greenhouse gas emissions, material costs, and landfill waste. For instance, [5] reported that stabilizing soil with agro-waste ashes resulted in up to 50% lower carbon emissions and 30% cost savings compared to traditional cement-based stabilization. These findings support the argument that agro-waste-based stabilization is not only technically feasible but also environmentally beneficial, particularly in developing regions where resource efficiency is critical.

One such approach is the use of agricultural waste products like bamboo stem ash and oil palm frond ash. Bamboo stem ash, a by-product of bamboo combustion, is rich in silica and possesses pozzolanic properties that contribute to soil strength enhancement [10][11]. Similarly, oil palm frond ash, derived from burning oil palm fronds, contains silica, potassium, calcium, and magnesium, making it a valuable pozzolanic material for soil stabilization [12]. The combined use of these materials offers the potential for a sustainable and cost-effective alternative to conventional soil stabilizers [15]. Several studies have validated the use of agricultural waste for soil improvement, especially in tropical regions where such materials are abundant. According to [12], cassava peel ash improved the strength and reduced plasticity of lateritic soils, highlighting the viability of agricultural by-products in geotechnical applications. In a similar vein, [10] conducted a sustainability assessment of bamboo stem ash and found it to be both environmentally and structurally beneficial in construction materials.

Several recent studies have investigated the engineering potential of these waste ashes. [4] reported that bamboo stem ash improved the unconfined compressive strength of weak soils, particularly when used in combination with small amounts of lime. [13] found that OPFA contributed to strength gains in lateritic soils, especially when allowed sufficient curing time for pozzolanic reactions to develop, similarly a study by [2] demonstrated that incorporating bamboo charcoal, along with quarry dust and lime, significantly enhanced the California Bearing Ratio (CBR) and reduced the plasticity index of expansive soils, making them more suitable for road subgrade applications. These findings align with the conclusions of [3], who showed that agro-waste ashes can effectively improve Atterberg limits, CBR values, and shear strength, provided they are optimally proportioned.

Furthermore, the increasing emphasis on environmental conservation and sustainable development has accelerated the need for green construction solutions. Using agricultural wastes not only reduces the burden on landfills but also curtails the carbon emissions associated with the production of conventional stabilizers. As such, bamboo stem ash and oil palm frond ash present a compelling case for sustainable construction practices. For instance, [8] reported that incorporating bamboo straw ash into lateritic soil led to enhanced strength properties and compaction characteristics, suggesting its suitability for sustainable road construction applications. Similarly, research by [14] indicated that a combination of lime and BSA significantly improved the geotechnical properties of soils in southwestern Nigeria, highlighting the synergistic effects of using BSA with traditional stabilizers.

The relevance of this approach is not limited to technical performance. It also addresses important environmental and socio-economic objectives. Reusing agricultural waste diverts materials from open dumping and burning, which contribute to greenhouse gas emissions and air pollution. By incorporating such materials into engineering applications, communities can reduce dependence on expensive industrial inputs and promote sustainable infrastructure development aligned with the UN Sustainable Development Goals (SDGs).

This study investigated the effectiveness of bamboo stem ash and oil palm frond ash mixtures in stabilizing lateritic soil, focusing on improving the soil's geotechnical properties for construction applications.

2. Materials and Methods

2.1 Materials

a) Lateritic Soil

The lateritic soil used for this research was collected from Bayduk area in Akure, Nigeria. The soil sample was air-dried, pulverized, and sieved through a 4.75 mm sieve to ensure uniformity before testing. Preliminary tests classified the soil as A-6, indicating a clayey soil with high plasticity and poor load-bearing capacity.

b) Bamboo Stem Ash (BSA)

Bamboo stems were sourced locally around North Gate, Akure. The stems were sun-dried, cut into pieces, and burnt in a controlled open-air environment to obtain ash. The ash was sieved to remove larger particles and stored in airtight containers for use as a stabilizing agent.

c) Oil Palm Frond Ash (OPFA)

Oil palm fronds were collected from the same locality. The fronds were dried and burnt under controlled conditions to produce ash. The resulting ash was also sieved and stored for laboratory tests.

2.2 Methods

a. Sample Preparation

The soil was divided into several batches for treatment. Stabilization was achieved by mixing the soil with varying proportions of bamboo stem ash and oil palm frond ash in equal ratios. Stabilizer contents of 2%, 4%, 6%, 8%, and 10% by weight of dry soil were used. A control sample without any stabilizer was also tested for comparison.

b. Laboratory Testing Procedures

Atterberg Limits Tests

The Atterberg limits, including liquid limit and plastic limit, were determined according to standard procedures to assess the effect of stabilization on soil plasticity. The tests were conducted using a Casagrande apparatus and rolling method for liquid and plastic limits, respectively.

Particle Size Distribution (Sieve Analysis)

Sieve analysis was carried out to determine the grain size distribution of the soil samples. A standard set of sieves ranging from 4.75 mm to 75 µm was used to classify the soil based on particle size.

Standard Proctor Compaction Test

Standard Proctor compaction tests were conducted to determine the optimum moisture content (OMC) and maximum dry density (MDD) of the treated and untreated soils. The soil was compacted in three layers with 25 blows each using a 2.5 kg rammer.

California Bearing Ratio (CBR) Test

CBR tests were performed to assess the load-bearing capacity of the soil. The samples were compacted at OMC and subjected to penetration tests to determine their CBR values. Unsoaked conditions were tested to simulate field conditions.

c. Stabilization Treatment Application

Each batch of soil was mixed thoroughly with the appropriate percentage of the ash mixture. Water was added to achieve the desired moisture content for compaction.

d. Analysis and Data Presentation

Data from the laboratory tests were analyzed to evaluate changes in the engineering properties of the stabilized soil. Graphs were plotted to compare variations in OMC, MDD, and CBR values with different stabilizer contents. The optimum stabilizer content was identified based on changes in soil strength and workability.

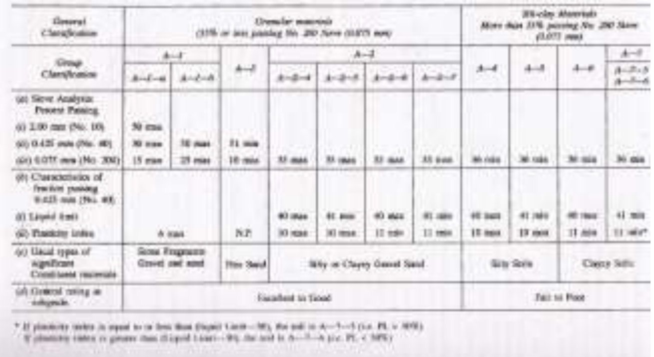
3. Results and Discussion

3.1 AASHTO Classification

The natural soil sample was classified as A-6 under the American Association of State Highway and Transportation Officials (AASHTO) system, indicating a clayey soil with high plasticity and poor load-bearing capacity. The Atterberg limits tests revealed a Plasticity Index (PI) of 28.4, reflecting the soil's high plasticity and susceptibility to volumetric changes when exposed to moisture variations. This classification underscores the need for stabilization to improve the soil's engineering properties. The AASHTO Classification table and the particle size analysis table are as shown in tables 1.0 and 2.0 respectively The gradation curve for the control sample is as shown in Figure 1.0.

Table 1.0: AASHTO Classification Table

Sieve No	Dia (mm)	Soil Retained (g)	cumulative Retain (gm)	% Mass Retained	% Passing
#4	4.75	21.3	21.3	4.27	95.73
#10	2.00	54.3	75.6	15.15	84.85
#20	0.85	75.4	151	30.27	69.73
#40	0.43	91.12	242.12	48.53	51.47
#60	0.25	40.68	282.8	56.69	43.32
#200	0.075	36.1	318.9	63.92	36.08
Pan		180	498.9		



General Classification	Granular materials (35% or less passing No. 200 Sieve (0.075 mm))							Silt-clay Materials More than 35% passing No. 200 Sieve (0.075 mm)			
Group Classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5 A-7-6
(a) Sieve Analysis: Percent Passing											
(i) 2.00 mm (No. 10)	50 max										
(ii) 0.425 mm (No. 40)	30 max	50 max	51 min								
(iii) 0.075 mm (No. 200)	15 max	25 max	10 max	35 max	35 max	35 max	35 max	36 min	36 min	36 min	36 min
(b) Characteristics of fraction passing 0.425 mm (No. 40)											
(i) Liquid limit				40 max	41 min	40 max	41 min	40 max	41 min	40 max	41 min
(ii) Plasticity index	6 max		N.P.	10 max	10 max	11 min	11 min	10 max	10 max	11 min	11 min*
(c) Usual types of significant Constituent materials	Stone Fragments Gravel and sand		Fine Sand	Silty or Clayey Gravel Sand				Silty Soils		Clayey Soils	
(d) General rating as subgrade	Excellent to Good							Fair to Poor			

* If plasticity index is equal to or less than (liquid Limit − 30), the soil is A−7−5 (i.e. PL ≥ 30%)
If plasticity index is greater than (Liquid Limit − 30), the soil is A−7−6 (i.e. PL < 30%)

Table 2.0: Sieve analysis test result

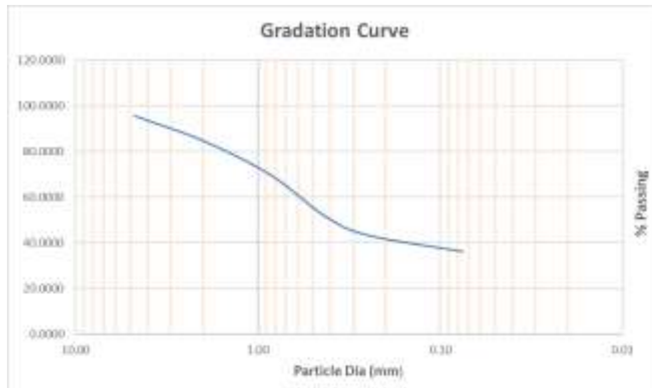


Fig 1.0: gradation curve for control sample

3.2 Compaction Characteristics

The compaction characteristics of both untreated and stabilized soils were examined through Standard Proctor Compaction test thereby determining Optimum Moisture Content (OMC) and Maximum Dry Density (MDD).

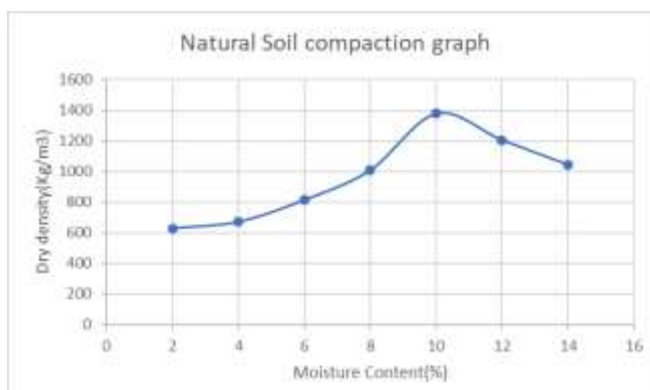


Fig 2.0: compaction graph for control sample

Table 3.0: Summary of Compaction Results:

Stabilizer Content (%)	OMC (%)	MDD (kg/m³)
0 (Control)	17.21	1378

Stabilizer Content (%)	OMC (%)	MDD (kg/m³)
2	13.1	970.6
4	16.66	820.9
6	19.8	778.8
8	20.1	760.8
10	21.1	750.9

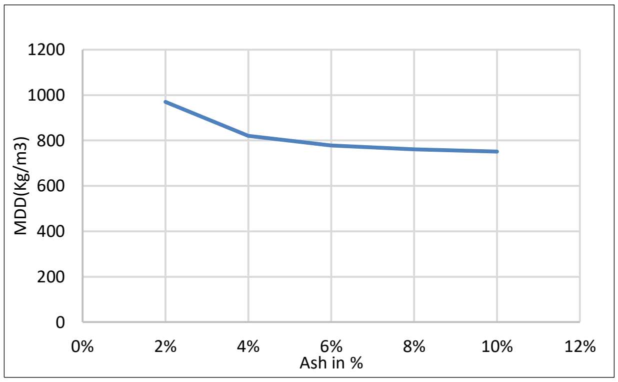


Fig 3.0: Effects of the addition of the ash's mixture on the MDD of Samples

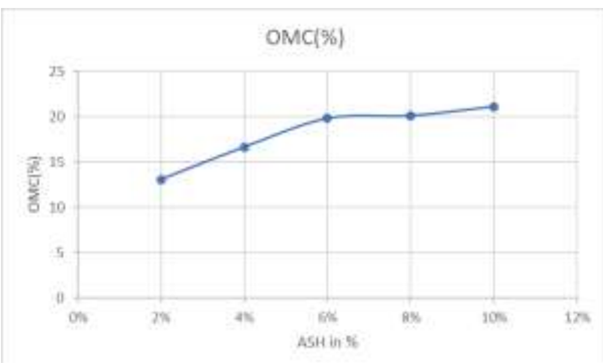


Fig 4.0: Effects of the addition of the ash's mixture on the OMC of Samples

As shown in Figure 3.0 and 4.0, the results revealed a consistent trend where the OMC increased with higher stabilizer content, indicating greater water demand during compaction. This behaviour can be attributed to the high porosity and water absorption capacity of the ash materials, which require more moisture to achieve desired compaction. Conversely, the MDD decreased with increasing *BSA* and OPFA content. This is likely due to the lower specific gravity of the ashes compared to the soil matrix, resulting in a reduction in dry unit weight. The reduction in MDD also suggests increased void ratios, which may affect the load-bearing performance unless properly compacted.

While an increase in OMC can be favourable in certain cases for enhancing workability, the corresponding drop in MDD indicates that the stabilizer blend may compromise soil strength at higher replacement levels. The optimum result appears to occur between 4% and 6% ash content, where compaction characteristics showed an acceptable balance.

3.3 California Bearing Ratio (CBR)

The CBR test results as shown in table 4.0 indicate minimal improvements in the load-bearing capacity of the soil upon stabilization with bamboo stem ash and oil palm frond ash mixtures. The untreated soil exhibited a CBR value of 1.75%, which is below the recommended minimum for subgrade materials in highway construction. Stabilization with 4% *BSA* and OPFA resulted in the highest CBR value (3.23%), representing an 84.57% improvement over the control. However, further increase in ash content beyond 4% led to inconsistent results with fluctuating CBR values. The decline at 8% suggests potential over-stabilization, where excess ash acts as a filler rather than a binder, thereby weakening the inter-particle bond.

These results indicate that while low to moderate inclusion of BSA and OPFA can slightly enhance strength, the limited strength gain suggests that these materials alone may not sufficiently improve soil bearing capacity to meet structural standards.

Table 4.0: Summary of CBR Results:

Stabilizer Content (%)	Unsoaked CBR Value (%)
0 (Control)	1.75
2	1.80
4	3.23
6	2.40
8	1.50
10	2.50

3.4 Discussion of Results

The geotechnical behaviour of lateritic soil improved modestly with the addition of Bamboo Stem Ash (BSA) and Oil Palm Frond Ash (OPFA), particularly at lower stabilizer contents. The compaction characteristics showed a consistent trend: Optimum Moisture Content (OMC) increased, while Maximum Dry Density (MDD) decreased with higher ash percentages. These effects are largely attributed to the physical and chemical nature of the ashes. The relatively low specific gravity and high surface area of the ash particles result in increased water demand for lubrication during compaction, hence the observed increase in OMC. Conversely, the replacement of heavier soil particles with lighter ash particles accounts for the decline in MDD.

Although these compaction changes indicate improved workability and ease of handling, they do not necessarily translate into proportional strength gains. The California Bearing Ratio (CBR) values, which are indicative of the soil's load-bearing capacity, showed only marginal improvement. The peak CBR value of 3.23% occurred at 4% stabilizer content, after which the values either plateaued or declined. This decline may be attributed to the excess ash acting as inert filler, diluting the reactive components of the soil and interrupting inter-particle bonding.

These findings are consistent with previous research on agro-waste stabilizers, such as rice husk ash, sawdust ash, and cassava peel ash, where moderate additions improved strength up to a threshold, beyond which performance diminished [1][7]. It suggests a non-linear relationship between ash content and engineering performance, possibly driven by the limited cementitious reactivity of untreated ashes.

The limited pozzolanic activity of BSA and OPFA may also explain the modest improvements observed. Pozzolanic reactions typically require a source of calcium hydroxide to trigger the formation of strength-giving compounds such as calcium silicate hydrate (CSH). In the absence of a more reactive binder, such as lime or cement, the ashes alone are unlikely to yield sufficient bonding agents for significant strength gain.

Despite the modest gains in strength, the environmental value of using BSA and OPFA should not be overlooked. Their utilization reduces agricultural waste, supports circular economy practices, and can lower the embodied carbon of construction projects when used in combination with conventional stabilizers. As such, while their technical contribution in isolation is limited, their sustainability contribution is significant, especially in low-cost or rural infrastructure applications.

4. Conclusion and Recommendations

4.1 Conclusion

This study investigated the stabilizing potential of Bamboo Stem Ash (BSA) and Oil Palm Frond Ash (OPFA) on lateritic soil, with a focus on their effects on plasticity, compaction characteristics, and California Bearing Ratio (CBR). The untreated soil was classified as A-6 under the AASHTO system, reflecting poor engineering qualities, including high plasticity and low load-bearing capacity.

Upon treatment, the soil exhibited consistent trends of increased Optimum Moisture Content and decreased Maximum Dry Density as stabilizer content increased. These changes highlight improved workability and suggest potential for easier field compaction. However, the strength performance—as measured by CBR—remained suboptimal. The highest CBR value of 3.23% occurred at 4% BSA-OPFA content, but this still falls below the minimum requirements for highway subgrade applications.

The marginal strength improvements observed confirm that BSA and OPFA, in their raw form, possess limited standalone cementitious capability. This is likely due to the absence of a strong activator to initiate and sustain pozzolanic reactions. However, their pozzolanic potential, low cost, and wide availability make them suitable as supplementary stabilizers, especially when blended with lime or cement.

Beyond technical performance, the environmental implications of this research are noteworthy. Incorporating BSA and OPFA into soil stabilization strategies can help reduce reliance on carbon-intensive binders, promote agro-waste recycling, and support more sustainable construction practices. These benefits are particularly relevant for low-volume road construction and other non-critical infrastructure in resource-constrained settings.

The findings indicate that BSA and OPFA, when used in isolation, are insufficient as primary stabilizers for lateritic soil in structural applications such as highway subgrades. However, their pozzolanic potential and environmental value present a strong case for their use as supplementary stabilizing agents in combination with traditional binders like lime or cement.

In conclusion, while BSA and OPFA alone are insufficient to meet engineering performance thresholds, they offer valuable opportunities for sustainable engineering innovation. Their integration into blended stabilizer systems, alongside further optimization and field validation, could unlock broader applications in geotechnical and pavement engineering.

4.2 Recommendations

Based on the findings of this study, the following recommendations are made:

i. **Use as Supplementary Stabilizers:** Bamboo Stem Ash (BSA) and Oil Palm Frond Ash (OPFA) should be used in combination with conventional stabilizers such as cement, lime, or fly ash to improve their overall effectiveness. When blended appropriately, these ashes can reduce binder requirements and enhance environmental sustainability without compromising performance.

ii. **Optimize Mix Designs Through Further Testing:** Additional laboratory studies are recommended to explore wider blend ratios, including the effects of combining BSA and OPFA with other pozzolanic materials. Response Surface Methodology (RSM) or statistical optimization tools may be employed to determine ideal mix proportions for specific soil types and performance targets.

iii. **Chemical Activation Techniques:** Future studies should investigate the effects of chemical activators such as quicklime or sodium silicate to enhance the pozzolanic reaction of the ashes. Pre-treatment processes (e.g., calcination temperature control or particle size reduction) may also improve reactivity.

iv. **Durability and Field Performance Assessments:** While laboratory results provide initial insights, real-world performance can differ. It is recommended that pilot field trials be conducted under actual environmental conditions to evaluate the long-term durability of BSA-OPFA-stabilized soils, particularly in terms of resistance to erosion, moisture fluctuations, and traffic loading.

v. **Policy and Awareness Initiatives:** Government and regulatory agencies should be encouraged to develop guidelines and standards for the use of agro-waste materials in civil engineering applications. Furthermore, public awareness campaigns should promote the benefits of sustainable construction practices that incorporate agricultural residues.

5. REFERENCES

[1] Adeyanju, E., Oke, T., and Olayemi, O. (2020). *SEM analysis of pozzolanic reactivity of agro-waste-based stabilizers*. Journal of Construction Materials, 34(3), 245–256.

[2] Agate, E. E., Timothy, N., Nathaniel, A. O., and Ngassam, I. (2024). Performance of Expansive Soil Stabilized with Bamboo Charcoal, Quarry Dust, and Lime for Use as Road Subgrade Material. *arXiv preprint arXiv:2403.06669*. https://arxiv.org/abs/2403.06669

[3] Aiyewalehinmi, E. O., Adetoro, A. O., and Akinkurolere, O. O. (2021). *Effect of Agro-Waste Ashes on the Geotechnical Properties of Lateritic Soil*. Nigerian Journal of Technological Development, 18(1), 1–8. https://doi.org/10.4314/njtd.v18i1.1

[4] Akinyele, J. O., and Oladele, S. (2019). *Stabilization of Lateritic Soil Using Bamboo Stem Ash and Cement*. International Journal of Scientific and Engineering Research, 10(4), 121–126.

[5] Akinyemi, M. L., and Uche, F. (2019). *Life-cycle cost analysis of agro-waste ash in sustainable road construction*. Sustainable Infrastructure Conference Proceedings, 15(2), 75–84.

[6] Brady, N. C., and Weil, R. R. (2008). *The nature and properties of soils* (14th ed., pp. 43–45). Prentice Hall.

[7] British Standard Institute. (1990). *Methods of test for soils for civil engineering purposes—Part 4: Compaction related tests* (BS1377 ed.). London: BSI.

[8] Busari, A., Oyedepo, J., Ofuyatan, O., Nurain, S., Ajayi, S., and Oti, M. N. (2018). Sustainability in Road Construction: Using Bamboo Straw Ash to Improve the Index Properties of Lateritic Soil. *European Journal of Sustainable Development*, 7(1), 89. https://doi.org/10.14207/ejsd.2018.v7n1p89

[9] Carter, M. R., and Gregorich, E. G. (2008). *Soil sampling and methods of analysis* (2nd ed., pp. 112–115). CRC Press.

[10] Brown, P., and Nguyen, T. (2022). Sustainability assessment of bamboo stem ash utilization. *Journal of Environmental Management*, 35(3), 456–468.

[11] Chang, S. (2018). Enhancing concrete performance with bamboo stem ash. *Journal of Materials Science*, 30(4), 567–579.

[12] Bello, A., Ige, J., and Ayodele, H. (2015). Stabilization of lateritic soil with cassava peels ash. *British Journal of Applied Science and Technology*, 7(6), 642–650.

[13] Edeh, J. E., and Onwualu, A. P. (2020). *Engineering Performance of Lateritic Soil* Stabilized *with Oil Palm Frond Ash*. Nigerian Journal of Technology, 39(2), 460–466. https://doi.org/10.4314/njt.v39i2.26

[14] Faluyi, S. O., Amu, O. O., and Adetoro, E. A. (2024). Geotechnical Properties of Lime and Bamboo Stem Ash Stabilized Soils for Road Construction in South-Western Nigeria. *Journal of Engineering and Engineering Technology*,18(1). https://doi.org/10.51459/futajeet.2022.16.1.28

[15] Jones, A., and Lee, C. (2019). Utilization of bamboo stem ash in cementitious materials. *Construction and Building Materials*, 185, 320–332.