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Geotechnical Properties of Cement-Stabilized Lateritic Soil with Bamboo Leaf Ash in the Takie Area of Ogbomoso

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ABSTRACT

This paper presents findings related to the impact of Bamboo Leaf Ash (BLA) and cement stabilization on the lateritic soil in the Takie Area of Ogbomoso. The study employed various testing methodologies to assess soil characteristics, particle size distribution, and California Bearing Ratio (CBR) under different stabilization conditions. Chemical analysis compared Ordinary Portland Cement (OPC) and BLA, demonstrating distinct differences between the two materials. The results of particle size distribution affirmed an intermediate, moderately graded soil with low clay content primarily comprising sand and gravel. The CBR tests unveiled the considerable influence of cement and BLA percentages on the soil's bearing capacity in both unsoaked and soaked conditions. Notably, the introduction of 2% cement displayed the highest CBR value, especially when paired with 10% BLA, showing promising results for soil strength enhancement. Conversely, the impact of BLA on soil strength in soaked conditions was less pronounced. This research provides valuable insights into the use of BLA and cement stabilization in lateritic soil, contributing to the understanding of soil behavior for engineering applications.

Keywords: Geotechnical Properties, Cement Stabilization, Lateritic Soil, Bamboo Leaf Ash, California Bearing Ratio.

Aims Research Journal Reference Format:
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1. INTRODUCTION

This research project focuses on investigating the geotechnical properties of cement-stabilized lateritic soil when combined with bamboo leaf ash *(Gigantochloa scortechinii)* as an additive. The study is specifically conducted in the Takie Area of Ogbomoso, emphasizing the unique characteristics and challenges of the local soil. The research aims to assess how the inclusion of bamboo leaf ash influences the engineering properties of the soil and its potential implications for construction and environmental sustainability in this specific geographic context.

The Takie area of Ogbomosho, situated within the Ogbomosho North Local Government area of Oyo State, serves as a significant urban center characterized by a diverse population comprising traders, artisans, private sector employees, civil servants, and students. Consequently, the locale hosts a multitude of commercial enterprises, educational institutions, medical facilities, and residential structures. The comprehensive transportation network in this region accommodates various modes of transit, including motor vehicles, motorcycles, heavy-duty trucks, and pedestrians, supporting their daily activities. As such, the need for a stable soil substrate with exceptional bearing capacity is paramount, alongside the necessity for a well-maintained road infrastructure. Notably, a major freeway traverses this area; nevertheless, certain sections of the road have exhibited signs of deterioration.

This degradation may be attributed to factors such as excessive loads, suboptimal design, and inadequate maintenance practices. Therefore, the imperative arises to reinforce the external works material to mitigate current and prospective failures in the external works infrastructure (Adagunodo et al 2014). The primary objective is to facilitate smoother mobility for commuters and enhance the operational efficiency of businesses along the road. This endeavor not only addresses the immediate transportation needs but also contributes to long-term cost-effective solutions, thus justifying the selection of this research focus.

Research has pursued alternative construction materials due to cost and availability concerns, exploring waste materials to alleviate waste challenges (Vagtholm et al., 2023; Liu and Hung, 2023). Utilizing waste materials offers cost-effective stabilization, conserves resources, and reduces waste accumulation (Younis et al., 2023). Lateritic soils are prevalent in tropical construction, especially in road construction (Emmanuel et al., 2021). Cement stabilization, involving the addition of small cement quantities to alter soil properties, relies on the soil's type and desired characteristics (Solihu, 2020).

Globally, pozzolans have emerged as an alternative binding material to cement, particularly in partial replacement applications (Arum *et al.,* 2022). Pozzolans, comprising fine silica and alumina-rich substances, when combined with hydrated lime, produce a cementitious material suitable for construction and stabilization purposes (Arum *et al.,* 2022). Recent studies highlight bamboo leaf ash as a promising pozzolanic material (David *et al,* 2022), reacting with calcium hydroxide to yield additional calcium silicate hydrate (C-S-H), a principal cementitious element. Bamboo leaf ash demonstrates robust strength compared to other natural fibers and exhibits high water absorption properties.

2. METHODOLOGY

In this study, the primary objective is to assess the potential benefits of using bamboo leaf ash as an additive in cement-stabilized lateritic soil for external construction applications. Soil samples were meticulously collected from the Takie area of Ogbomoso to analyze their geotechnical characteristics. Bamboo leaves were procured in Ogbomoso, Oyo state. The collected soil samples were handled with care and transported to the geotechnical laboratory using specially designed bags to maintain their natural state.

The stabilization process began with a series of trials, incorporating varying percentages of cement (ranging from 0% to 6%) to identify the optimum cement content for stabilization. Once the optimal cement level was determined, soil samples, mixed with the optimal cement amount, were further stabilized with bamboo leaf ash at concentrations of 5%, 10%, and 15% after undergoing a calcination process. The chemical composition of cement and bamboo leaf ash (BLA) were determined using X-ray fluorescence (XRF) and scanning electron microscopy techniques (SEM). The analysis of the soil samples involved a series of comprehensive laboratory procedures to determine their engineering properties. The tests conducted include Classification Tests (Sieve Analysis and Atterberg's Limits Tests), Compaction Tests, California Bearing Ratio Tests (Soaked and Unsoaked Methods) and Specific Gravity Test. The results of these tests provide valuable insights into the geotechnical properties of the soil samples after they were mixed with bamboo leaf ash.

The California Bearing Ratio (CBR) test assesses soil strength and bearing capacity by measuring the force and penetration relationship of a cylindrical plunger within the soil sample at a specific penetration rate. The CBR is defined as the ratio of the force applied to a standard force. The process involves air-drying and breaking up the soil sample, sieving to eliminate coarse particles, and employing separate material batches for each test specimen. Compaction is carried out to determine Optimum Moisture Content (OMC) and Maximum Dry Density (MDD). The study investigates the most effective percentage of cement and the impact of bamboo leaf ash at varied percentages (5%, 10%, 15%) on CBR for optimal cement percentage and OMC. Following compaction, CBR readings are taken using a specific apparatus to evaluate soil strength in relation to cement and bamboo leaf ash content.

3. RESULTS AND DISCUSSION

Chemical Composition of OPC and BLA

The chemical characterization of the bamboo leaf ash (BLA) in comparison with those of ordinary Portland cement (OPC) using X-ray fluorescence (XRF) and scanning electron microscopy techniques (SEM) is as shown in Table 1. It should be noted that the chemical characterization of bamboo leaf ash is generally dependent on the species of bamboo that produce the ash.

Table 1: Chemical composition of BLA and OPC by percentage weight

Material Composition	OPC (%)	BLA (%)
SiO_2	17.76	51.99
Al_2O_3	4.47	10.10
Fe_2O_3	3.16	6.85
CaO	63.47	12.51
MgO	2.37	2.10
K_2O	0.60	3.39
Na_2O	0.24	1.69
TiO_2	0.27	0.20
SO_3	3.0	2.74
IR	0.74	-
LOI	2.56	0.09

Particle Size Distribution Test Results

The sieve analysis involved using various sieve sizes (20mm, 8mm, 4mm, 2mm, 1mm, 500µm, 250µm, 125µm, 75µm) to determine the particle distribution in the soil sample. The percentages of particles passing through each sieve were as follows: 100% for 20mm, 94.52% for 8mm, 77.62% for 4mm, 65.58% for 2mm, 55.70% for 1mm, 27.48% for 500µm, 21.40% for 250µm, 12.68% for 125µm, and 10.06% for 75µm. These results suggest an intermediate moderately graded soil sample with a lower clay content. The soil primarily consists of 65.58% sand and 34.42% gravel, with some finer silt content passing through the 75µm sieve, as depicted in Figure 2.

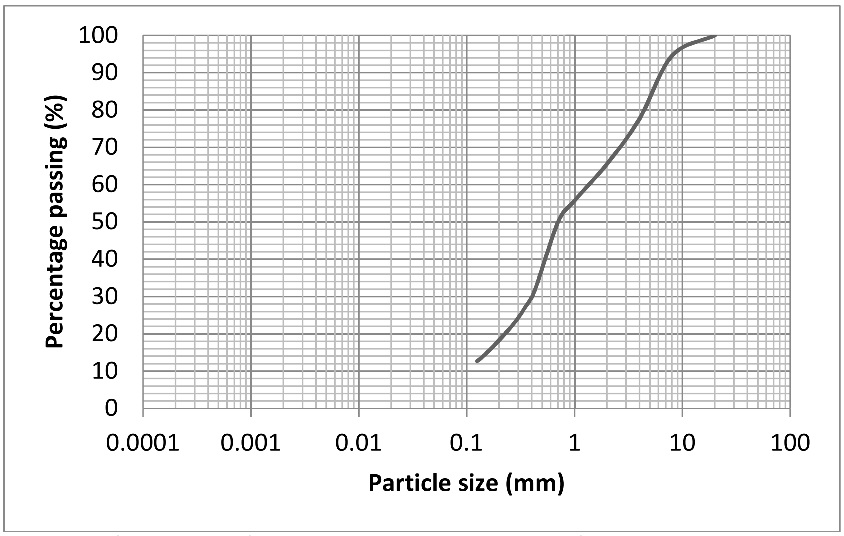

Fig 2: Particle Size Distribution analysis of the soil sample

Other Classification and Compaction Test Results

The results of the liquid limit (LL), plastic limit (PL), plasticity index (PI), optimum moisture content (OMC), dynamic compaction and static compaction test results are presented in Table 2 below. The results show that the sample exhibits lower clay content, necessitating reduced water content for optimal compaction.

Table 2: Classification and Compaction Test Results

						Static Compaction	
Cement Content (%)	LL (%)	PL (%)	PI (%)	OMC (%)	Dynamic Compaction (g/cm³)	Mass (g)	Volume of water (ml)
0	23.00	9.50	13.50	9.80	1.70	3925	360
2	12.00	10.10	1.90	10.00	2.00	4564	456
4	20.80	18.20	2.60	11.70	2.04	4655	514
6	21.50	12.90	8.60	12.15	2.03	4632	532

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California Bearing Ratio (CBR) Test Results

The California Bearing Ratio (CBR) tests were conducted on soil samples with varying cement percentages (0%, 2%, 4%, and 6%), resulting in CBR values of 12.08%, 62.92%, 18.44%, and 11.33% respectively. Notably, the sample with 2% cement displayed the highest CBR percentage at 62.92% and the lowest Optimum Moisture Content (OMC). Through dynamic compaction, the 2% cement sample revealed an OMC of 10.0%. Subsequently, different percentages of bamboo leaf ash (BLA) were added to this sample (unsoaked) to assess their impact on CBR values, aiming to determine the most effective BLA percentage in conjunction with 2% cement for optimal soil strength enhancement. Recorded CBR dial readings were utilized for this comparative analysis. The results are presented in Figures 2 to 4.

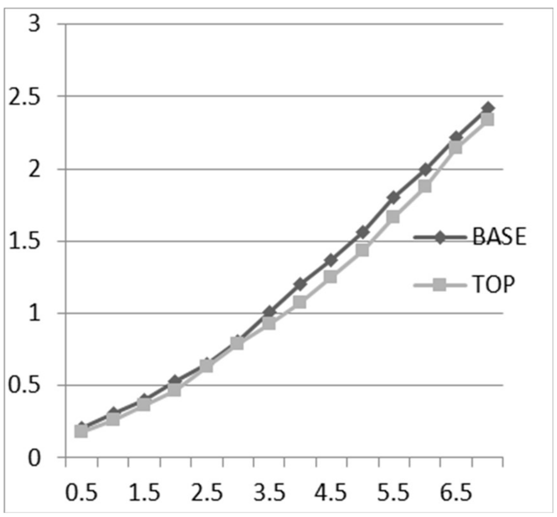

Fig 2: 2% Cement + 5% BLA (unsoaked)

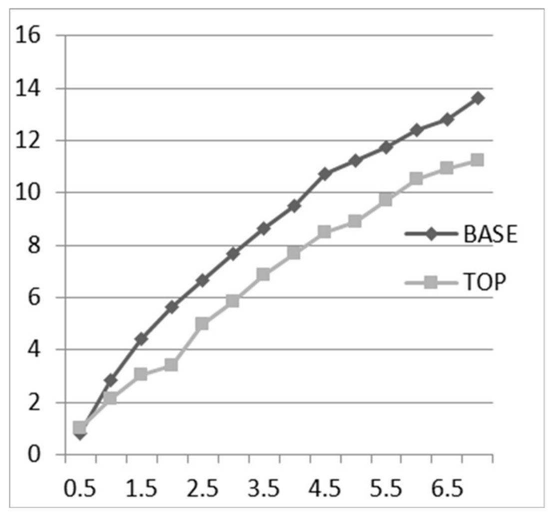

Fig 3: 2% Cement + 10% BLA (unsoaked)

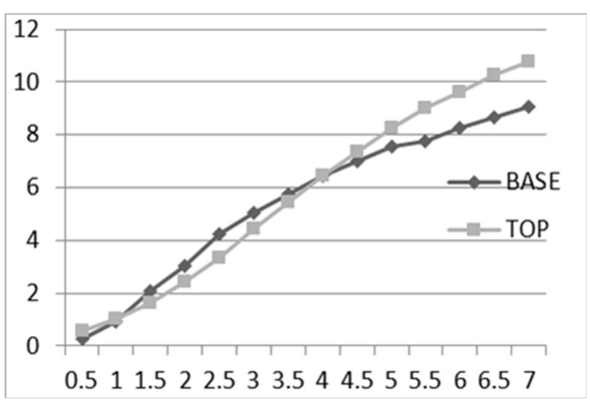

Fig 4: 2% Cement + 15% BLA (unsoaked)

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The addition of 2% cement alongside Bamboo Leaf Ash (BLA) at 5%, 10%, and 15% resulted in varying CBR readings of 9.5%, 51.3%, and 40.3% respectively, with 10% BLA demonstrating the highest CBR reading. The outcomes illustrate an enhancement in CBR values compared to the control result of 12.06%, affirming that BLA at these percentages augments the soil's bearing capacity. Notably, 10% BLA, combined with the optimum 2% cement, showcased the maximum CBR value, indicating that deviating from the 10% BLA dosage might not further improve the soil's bearing capacity. Therefore, incorporating 10% BLA with the optimal cement proportion proves to be both economically viable and yields satisfactory bearing capacity.

For the second part of this test, the specimen, compacted in five layers with a 4.5kg rammer (following the West African Standard of 27 blows), underwent a 48-hour soaking process to simulate adverse conditions, akin to the rainy season. Testing was conducted for Bamboo Leaf Ash (BLA) in conjunction with a control sample and a sample with 2% cement alongside BLA at 5% and 10%. Comparative analysis of California Bearing Ratio (CBR) values demonstrated significant differences from the unsoaked CBR values.

The sample's load-bearing capacity exhibited a reduction with BLA at 5% and 10% in contrast to the unsoaked values, which increased with the inclusion of bamboo leaf ash. The control sample exhibited notably higher strength, recording a CBR value of 54.54%, surpassing the values obtained when stabilized with BLA, which depicted CBR values of 29.56% at 5% and 18.13% at 10%. The results are presented in Figures 5 to 7.

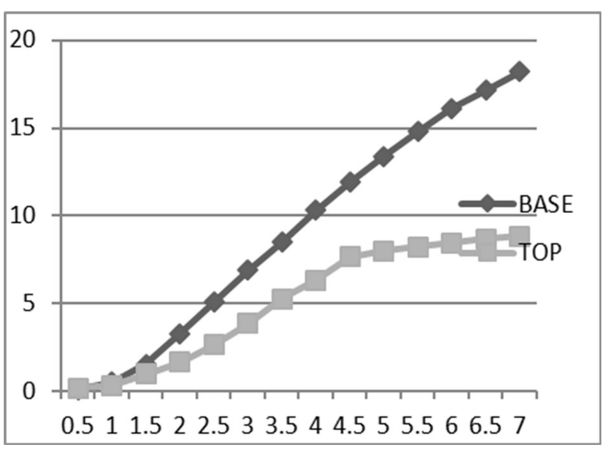

Fig 5: Soaked Sample (Control - 0% cement)

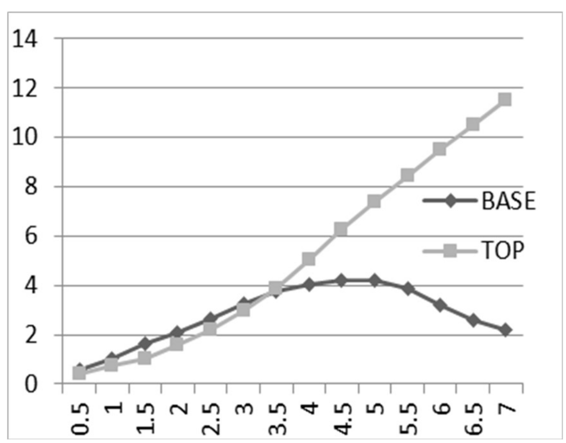

Fig 6: Soaked Sample (2% cement + 5% BLA)

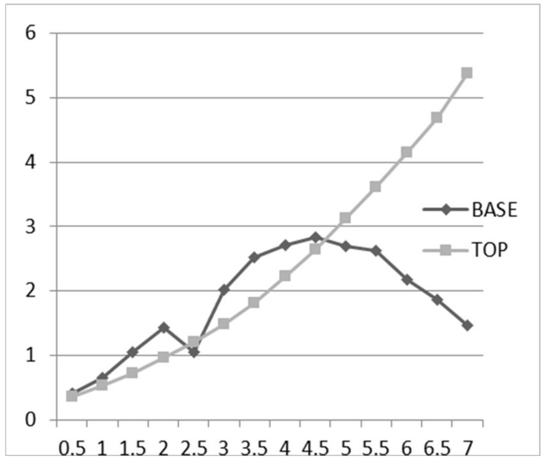

Fig 7: Soaked Sample (2% cement + 10% BLA)

The CBR analysis, delineated in the figures, reflects distinctive findings for unsoaked and soaked conditions in relation to cement and Bamboo Leaf Ash (BLA) stabilization. In unsoaked conditions, 2% cement stabilization exhibited the highest CBR, indicating enhanced strength, notably reducing clay content. Further investigations involved testing different BLA percentages (5%, 10%, 15%), revealing increased CBR values of 9.54%, 51.3%, and 40.3%, respectively, with 10% BLA demonstrating the most significant improvement. However, in soaked conditions, the impact of BLA on CBR was less pronounced, displaying lower values compared to the unsoaked scenario. The unaltered sample with 2% cement exhibited substantial strength, surpassing BLA-stabilized samples (5%: 29.56%, 10%: 18.13%). This reduction in cementitious properties with increased BLA percentages was evident, suggesting implications for the soil's engineering application. The specific gravity of the soil is determined to be 2.54, indicating its inherent density. Ultimately, the unaltered soil sample with 2% cement showcases promise for subgrade use.

4. CONCLUSION

Through a comprehensive series of laboratory tests on the soil samples, several significant conclusions were drawn. The tested sample exhibits a low clay content, necessitating less water for compaction. The addition of cement notably increases the liquidity of the sample, altering the characteristics of the laterite soil. Cement plays a vital role in accelerating soil drying compared to non-cemented samples. The chemical composition of the soil is significantly impacted by cement, leading to changes in its geotechnical properties. During compaction, an exothermic reaction occurs when water is initially added, causing an initial rise in dry density, which decreases with additional water until reaching and surpassing the maximum dry density. The introduction of 2% cement alongside 10% bamboo leaf ash (BLA) in lateritic soil with lower clay content resulted in the highest CBR percentage of 51.3%. For the soaked condition, the control value displayed increased strength with a CBR of 54.54%, surpassing the values of 29.56% at 5% BLA and 18.13% at 10% BLA. This indicates that the cementitious property decreases with higher BLA percentages.

CBR values increased for unsoaked conditions but decreased for soaked conditions when stabilized with BLA. However, the soil with 2% cement (without BLA) is recommended for subgrade use.

5. RECOMMENDATIONS

The soil sample without stabilization can be utilized as subgrade material, especially with a liquid limit below 30%. However, different percentages of added cement increase the liquid limit. For soils with lower clay content, replacing 2% of the soil mass with cement is advisable, particularly when using 2% cement with 10% BLA, as it enhances the soil's CBR and subgrade strength. In moisture-challenged areas, cement aids in quicker soil drying and enhances its strength and bearing capacity. Increased cement content provides a suitable solution for improved mechanical soil properties. While cement proves effective for stabilizing laterite soils, it may reduce the soil's plasticity, necessitating consideration for the amount of cement to be used in stabilization. BLA can address these limitations. The use of Bamboo Leaf Ash hasn't shown any detrimental health or environmental impacts, making it a viable choice in road construction for enhanced soil conditions, especially where durability is critical. BLA stabilization proves effective for unsoaked lateritic soils, yet its effectiveness may vary for soaked conditions.

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