Characteristics of Bamboo Leaf Ash Stabilization on Lateritic Soil in Highway Construction

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Abstract*– This research was carried out to study the characteristics of bamboo leaf ash stabilization on lateritic soil in highway construction. Preliminary tests were performed on three samples, A, B, and C for identification and classification purposes followed by the consistency limit tests. Geotechnical property tests (compaction, California bearing ratio (CBR), and triaxial) were also performed on the samples, both at the stabilized and unstabilized states by adding 2, 4, 6, 8 and 10% bamboo leaf ash (BLA) by weight of sample to the soils. The results showed that the addition of BLA improved the strengths of the samples. Optimum moisture contents reduced to 20.20, 19.60 and 9.32% at 8, 4 and 6% BLA additions in samples A, B and C respectively while MDD increased to 1400, 1676 and 1941 kg/m^3 respectively at 8, 2 and 4% BLA additions in samples A, B, and C. The unsoaked CBR values of samples A and B increased from 5.44 to 38.21% and from 11.42 to 34.99% respectively. The shear strengths of samples A and B also increased from 181.31 to 199.00 kN/m^2 and from 144.81 to 155.90 kN/m^2 respectively. It was therefore concluded that bamboo leaf ash has a good potential for stabilizing lateritic soils in highway construction.

***Index Terms*- Alternative material, bamboo leaf ash, construction method, highway stabilization.**

I. INTRODUCTION

As the conventional road construction materials become scarce or more expensive, there is the need to turn to alternatives. Nearly all industrial activities lead to depletion of natural resources, a process which may result in accumulation of by-product and/or waste materials. In most occasions there are problems with the disposal of these waste heaps. In recent years, there has been an intensified research towards the use of these by-products and waste materials in geotechnical engineering. The use of these as alternative materials result in two folds advantages – conservation of natural resources and disposal/reduction in the size of waste heaps. Most of these wastes have been used in many countries of the world; a good example is Japan where all the waste products are recycled. In Nigeria, these dignified wastes and by-products have not been known to have much economic value; rather they have constituted environmental hazards.

Laterite develops beneath the surface in soil zones, unconsolidated sediments, or decomposed rocks where interrelations of ground water, soil/water table, and topography are favourable. A critical factor in its formation is an alternating or variable moisture cycle, and it is formed in association with grasslands and forests on lowland surfaces in tropical and temperate regions. Precipitation from the water table is now generally considered to be of much greater importance as an effective agent in laterite formation than capillary action. Although laterite does not develop in arid regions, it is found in them as a relict from earlier, wetter climates. The name covers a broad range of materials, the origins of which are not well understood. There is still disagreement, especially between pedologists and soil chemists, over naming and classifying lateritic materials.

It has been found that lateritic soils are generally good construction materials and are therefore extensively used in construction. Laterite is a residual of rock decay that is red, reddish in colour and has a high content of oxides of iron and hydroxides of aluminium and low proportion of silica. The word laterite describes no material with reasonably constant properties; it can signify a different material to people living in different parts of the world. In this tropical part of the world, lateritic soil are used as a road making material and they form the sub-grade of most tropical road, they are used as sub base and bases for low cost roads and these carry low to medium traffic. Furthermore, in rural areas of Nigeria they are used as building material for moulding blocks and plastering.

When the mechanical stability of a soil cannot be obtained by combining materials, it may be advisable to order stabilization by the addition of lime, cement, bituminous materials or special additives. Cement stabilization is most used in road construction especially when the moisture content of the sub grade is high. Lime or waste is also sometimes applied for stabilization. Calcium hydroxide (slaked lime) is most widely used for stabilization. Calcium oxide (quick lime) may be more effective in some cases; however this may corrosively attack equipment and cause severe skin damage or burns to personnel. Reference [1] recommended the criteria of lime mixture. Stabilization has been defined as any process by which a soil material is improved and made more stable [2]. It was also described as the treatment of natural soil to improve its engineering properties [3]. In general, soil stabilization is the process of creating or improving certain desired properties in a soil material so as to render it stabled and useful for a specific purpose. Soil stabilization may be broadly defined as the alteration or preservation of one or more soil properties to improve the engineering characteristics and performance of a soil. There are three purposes for soil stabilization which includes; strength improvement, dust control and soil waterproofing. Engineers are responsible for selecting or specifying the correct stabilizing material, method, technique, and quantity of material required. Many procedures have been outlined for making correct decisions in selection but most of them are not precise. Soils vary throughout the world, and the engineering properties of soils are equally variable. The key to success in soil stabilization is soil testing. The method of soil stabilization selected should be verified in the laboratory before construction and preferably before specifying or ordering materials.

Bamboo leaf fired in an open atmosphere and then heated at 600^oC for 2 hours in a furnace was found with amorphous material containing amorphous silica. Plate 1 shows the bamboo leaf. The ash was characterized by chemical analysis powder X-ray diffraction and SEM techniques. Reactions of the ash with calcium hydroxide showed it to be pozzolanic in nature. The pozzolanic reactivity increased with time and temperature. The chemical composition of bamboo leaf ash and Portland cement are given in Table 1.

Table 1. Chemical Composition of Bamboo Leaf Ash and Ordinary Portland Cement

System	**Composition (Wt %)**									
	$Si0_2$	**Al_20_3**	**Fe_20_3**	**Ca0**	**Mg0**	**K_20**	**Na_20**	**$Ti0_2$**	**$S0_3$**	**IR**	**L0I**
OPC	21.40	5.03	4.40	61.14	1.35	0.48	0.24	-	2.53	1.65	1.29
BLA	75.90	4.13	1.22	7.47	1.85	5.62	0.21	0.20	1.06	-	-

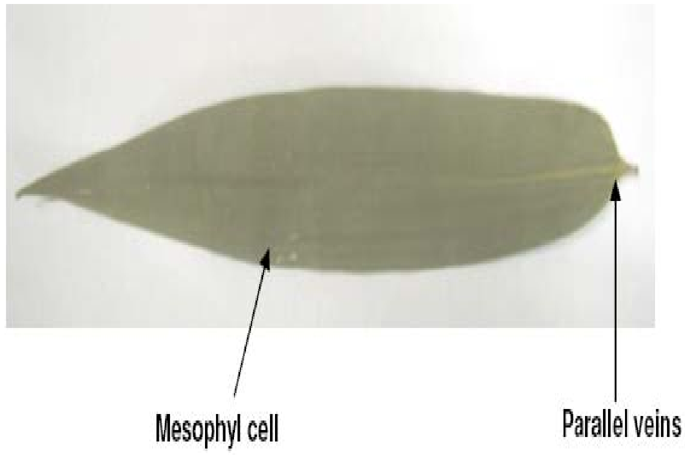

Plate 1: Bamboo leaf

In order to understand the role of bamboo leaf ash as a pozzolanic material during the hydration of Portland cement, the hydration studies of 20 weight percentage of bamboo leaf ash blended Portland cement were made. Free lime values were found to increase with time indicating an increase in hydration. In blended cement, the values also increased with time, but the values are much lower than that of Ordinary Portland Cement. This is due to reaction of $Ca(OH)_2$ obtained during hydration with amorphous silica of bamboo leaf ash. The variation of compressive strength of cement mortar with time is shown in Fig. 1. The compressive strength values increase with time but the values are lower in the case of blended cement.

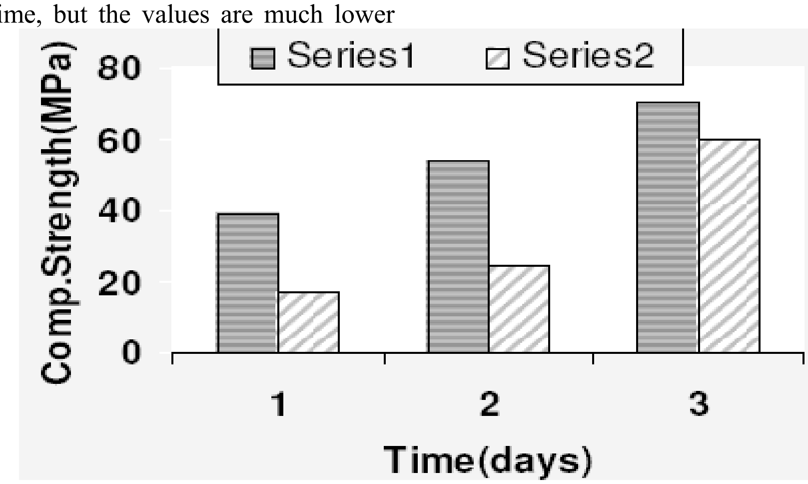

Fig. 1. Compressive strength of cement mortar with time

Many studies have been done to determine the feasibility of using bamboo to reinforce concrete. Feasible uses of bamboo with concrete include making stirrups with 9 month old bamboo. Also tanks can be made by applying cement plaster to bamboo baskets. These can be used for toilets, water storage or boats. Waffle slabs of concrete can be formed utilizing bamboo baskets to create the void spaces. Woven bamboo mesh at 6" on centre can be used to reinforce a 5" concrete slab. The aim of this study is therefore to determine the suitability of bamboo leaf ash as stabilizer in lateritic soil for highway construction.

II. MATERIALS AND METHODS

Materials and Preparation: The lateritic soil samples used for this study were obtained from different locations in Osun State, Nigeria. These samples were tagged with unique identification numbers A, B and C. They were dug out from the ground at a depth not less than 150mm (natural ground formation with at least 300 mm top soil removed). The soil samples were kept safe and dry in a jute bag in the Geotechnics laboratory at the Department of Civil Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria. The soil samples were kept in clean plastic bags and properly sealed with adhesive tapes. Sample number with soil description, sampling depth and date of sampling were marked clearly on a paper and stapled on each of the plastic bags. The samples were kept in the shade to prevent loss of moisture. Portable water was obtained from the laboratory. Bamboo leaves were collected from Obafemi Awolowo University Campus, and burnt in a furnace at the Centre for Energy Research and Development Laboratory, Obafemi Awolowo University, within the range of 800^0C to 1000^0C. The ashes of the bamboo leaves obtained were kept in well sealed polythene to prevent moisture absorption.

Methods: Classification test (natural moisture content, specific gravity, particle size analysis and Atterberg's limits test) was performed on the three soil samples. Bamboo leaf ash (BLA) in 2, 4, 6, 8 and 10% were mixed with the soil samples. Atterberg's limits and strength tests (compaction, California bearing ratio (CBR), undrained triaxial) were then performed on soil samples. The stabilizing potentials of BLA on the soil samples were thereafter determined. The procedures for the various tests were carried out in accordance with that stipulated in BS 1377-1990:1-8.

III. RESULTS AND DISCUSSION

The results of the preliminary tests (grain size analysis, natural moisture contents, specific gravity, and Atterberg's limits) as well as the strength tests (compaction, CBR and unconsolidated undrained triaxial) are discussed below.

Preliminary Tests: The summary of the results of preliminary analysis on the samples is shown in Table 2. The natural moisture contents of samples A, B and C are 22.22, 12.01 and 21.31% respectively. Sample A had the highest natural moisture content and sample B the lowest.

Table 2. Summary of the Preliminary Analysis of Soil Samples

Sample	Natural Moisture Content (%)	Specific Gravity	Liquid Limit (%)	Plastic Limit (%)	Plastic Index (%)	AASTHO classification	Soil Type
A	22.22	1.80	62.10	32.89	29.21	A-2-7(2)	Silty
B	12.01	1.89	49.80	28.80	21.00	A-2-4(1)	Silty
C	21.31	2.21	45.10	25.32	19.78	A-2-5(3)	Sandy

This could be ascribed to the void ratio and the specific gravity [4]. Sample A probably had the largest void ratio compared to others. This also showed that the soil samples contained appreciable amount of moisture, which is a function of the climatic condition, such as temperature, amount, intensity and duration of rainfall. The specific gravities of samples A, B and C are 1.80 and 1.89 and 2.21 respectively. These values ranged within that given in [5] for clay minerals, as Halloysite (1.60-2.55). However the specific gravity of the bamboo leaf ash (BLA) was found to be 0.59. Reference [6] stated that most clay minerals have specific gravity that fall within a general range (1.6 – 2.9). Therefore, the soil samples are halloysites and were classified using the AASHTO soil classification system. All the samples fell within the SILTY OR CLAYEY GRAVEL AND SAND mineral under the general classification because their percentages passing 75μm sieve were all less than 35%. The percentages passing were 3.78, 1.54 and 1.80 respectively for samples A, B and C. Based on their LL and PI; samples A, B and C were further classified as A-2-7(2), A-2-4 (1) and A-2-5(3) respectively.

The summary of the results of BLA stabilization on Atterberg's limits of samples is shown in Table 3. At the natural state, the liquid limits (LL), plastic limits (PL) and the plastic index (PI) are 62.10, 32.89 and 29.21% for sample A ; 49.80, 28.80 and 21.00% for sample B; and 45.10, 25.32 and 19.78% for sample C.

Table 3. Summary of BLA Stabilization on Atterberg's Limits of Samples

Samples	Percentage stabilization	Liquid Limit(LL)%	Plastic Limit(PL)%	Plasticity Index(PI)%
A	0% BLA	62.10	32.89	29.21
	2% BLA	53.20	25.88	27.32
	4% BLA	55.54	26.35	29.19
	6% BLA	55.50	16.20	39.30
	8% BLA	62.00	40.48	21.52
B	0% BLA	49.80	28.80	21.00
	2% BLA	44.60	30.36	14.24
	4% BLA	45.20	37.04	8.16
	6% BLA	48.60	30.83	17.77
	8% BLA	46.04	21.47	21.57
C	0% BLA	45.10	25.32	19.78
	2% BLA	63.40	61.32	2.08
	4% BLA	60.00	57.12	2.88
	6% BLA	40.00	14.79	25.21
	8% BLA	53.40	34.69	19.23

Liquid limit less than 35% indicates low plasticity, between 35% and 50% intermediate plasticity, between 50% and 70% high plasticity and between 70% and 90% very high plasticity [7]. This shows that sample A has high plasticity while samples B and C have intermediate plasticity. The addition of varying percentages of bamboo leaf ash to the soil samples caused a change in the liquid and plastic limits of all the samples. The minimum P.I occurred at 8, 4 and 2% in samples A, B and C respectively. A reduction in P.I gives an indication of a more stable soil with marked increased workability. It can be concluded that the optimum stabilization mixes are 8, 4 and 2% BLA in samples A, B and C respectively.

Strength Tests: The summary of compaction test results is shown in Figs. 2-3. The natural Optimum Moisture Contents (OMC) of samples A, B and C are 25.00, 22.80 and 24.30% while the Maximum Dry Densities (MDD) are 1307, 1456 and 1652 kg/m^3 respectively. The addition of increasing percentages of BLA mostly caused a corresponding reduction in OMC of the samples. The values of OMC at the natural states reduced to 20.20, 19.60 and 9.32% at 8, 4 and 6% of BLA in samples A, B and C respectively while MDD values increased at the natural states to 1400, 1676 and 1941 in samples A, B and C respectively. Reference [4] stated that 'for good soil, the lower the OMC, the better its workability and that increase in dry density is an indicator of improvement'. Thus, it has been shown that BLA stabilization has generally improved the soil samples and enhanced their workabilities.

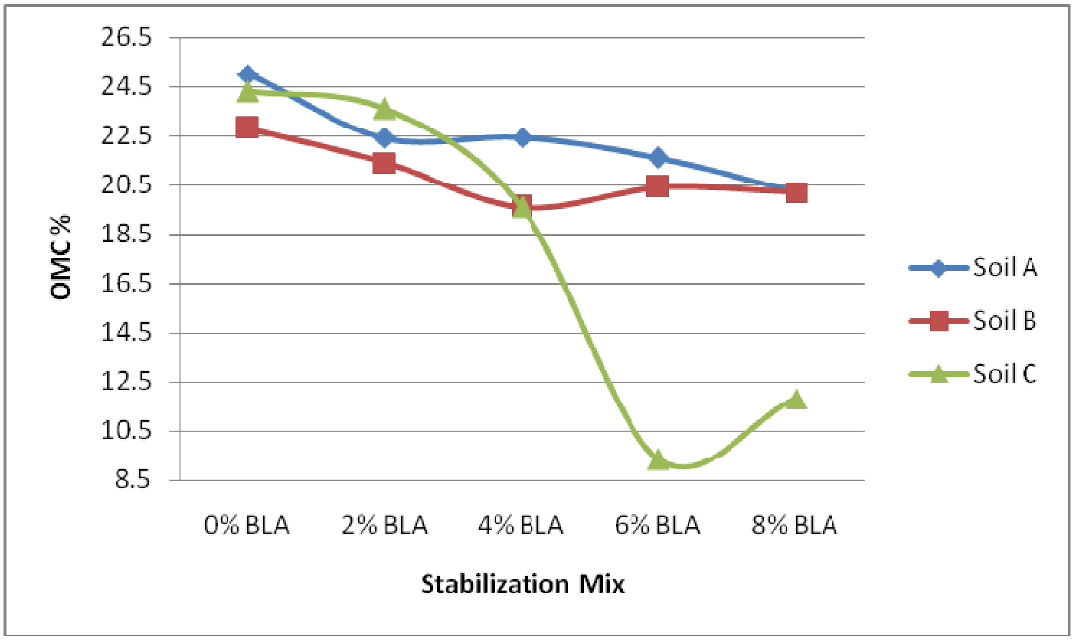

Fig. 2. Effects of the addition of BLA on the OMC of samples.

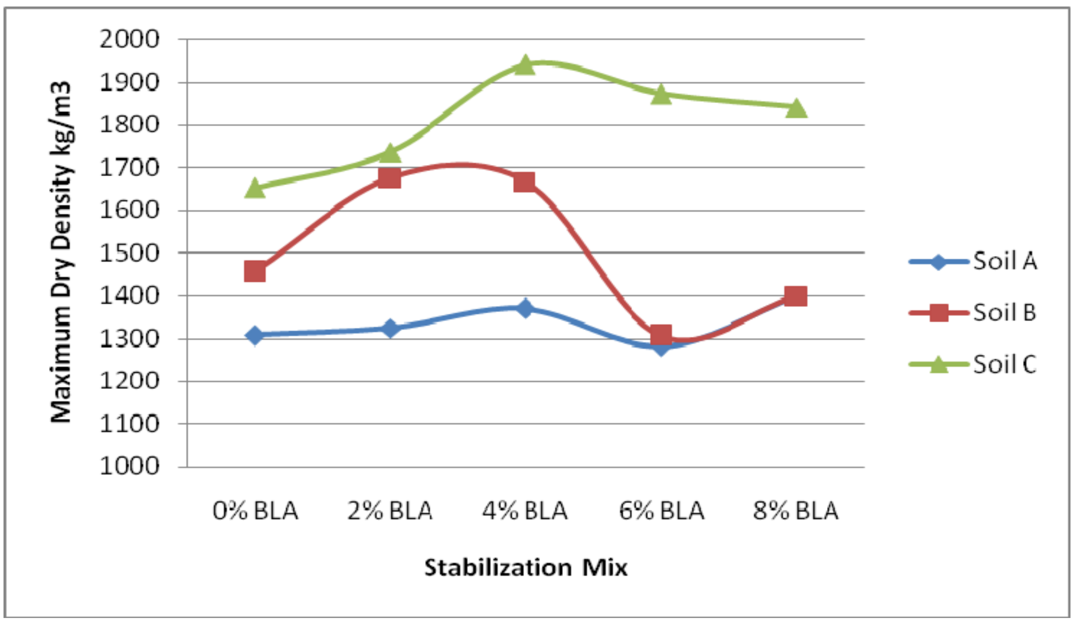

Fig. 3. Effects of the addition of BLA on the MDD of samples.

Table 4 shows the summary of the unsoaked CBR results on samples A and B. The results of the CBR and triaxial tests on sample C could not be concluded due to a technical problem in the laboratory during the study. The results show that the CBR values of samples A and B increased considerably with the addition of bamboo leaf ash. The CBR value of sample A at the natural state increased from 5.44 to 38.21% at 6% BLA stabilization and in sample B, the CBR of the natural soil increased from 11.42 to 34.99% at 6% BLA stabilization. The California Bearing Ratio (CBR) test is a relatively simple test that is commonly used to obtain an indication of strength of a subgrade soil, subbase and the base course materials for use in road and airfield pavement design [8]. The results therefore showed that the strength of the samples in terms of their load bearing capacity greatly increased with BLA stabilization. These improvements in the CBR values of samples A and B satisfy the minimum requirements that qualify them as road construction materials and showed that the soil samples were effectively stabilized by BLA.

The minimum requirements for CBR subgrade, sub base and base courses are 10% CBR (soaked), 30% CBR (soaked) and 80% CBR (unsoaked) [9].

Table 4. Summary of the CBR Results of the Samples

Sample	Percentage stabilization	Unsoaked CBR (%)
A	0	5.44
	2	12.84
	4	17.62
	6	38.21
	8	23.22
B	0	11.42
	2	13.10
	4	18.22
	6	34.99
	8	21.37

Table 5 shows the summary of the triaxial test results of the samples. The natural shear strengths of the samples are 181.31 and 144.81kN/m^2 respectively for samples A and B. The addition of 2% bamboo leaf ash increased the shear strengths to 199.00 and 155.90kN/m^2 respectively for samples A and B. A reduction in the shear strength of sample A was however observed at 4, 6 and 8% BLA and also at 6 and 8% BLA in sample B. These results further confirmed the stabilizing potentials of BLA on lateritic soil if added at the optimum level.

CONCLUSION

It was shown that BLA improved the qualities of the soil samples by significantly reducing their plastic indices. The OMC of the samples were reduced while MDD values increased from those at the natural states. The CBR values and shear strengths of the samples were also increased considerably with the addition of BLA. The study therefore concluded that bamboo leaf ash (BLA) has the potential to effectively stabilize lateritic soils for highway construction.

Sample	**Percentage stabilization**	**Cohesion, c (kN/m^2)**	**Internal Friction Angle(φ)**	**Normal Stress (σ_1- σ_2) kN/m^2**	**Shear Stress $\tau = c + (\sigma_1 - \sigma_2)\tan\varphi$ (kN/m^2)**

A	0% BLA	98.90	15.20	303.33	181.31
	2% BLA	102.50	17.00	317.00	199.00
	4% BLA	91.00	3.80	246.50	131.35
	6% BLA	119.30	2.80	205.66	104.66
	8% BLA	69.70	11.20	188.53	107.03
B	0% BLA	123.60	4.30	282.02	144.81
	2% BLA	132.00	10.00	300.00	155.90
	4% BLA	102.00	18.00	148.82	150.05
	6% BLA	64.80	16.10	192.43	120.34
	8% BLA	54.40	12.40	173.12	92.46

Table 5. Variation of Shear Strength With Stabilization Mix

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