

Effects of Bamboo Leaf Ash on Lime Stabilized Lateritic Soil for Highway Construction

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Abstract: This research determined the effects of bamboo leaf ash on lime stabilized lateritic soil for highway construction. It was necessary to utilize the properties of waste materials such as bamboo leaf in order to determine its usefulness as a possible complement stabilizer for lime and hence reduce highway construction cost. The three samples A, B and C used in this study were collected from different locations in Ile-Ife, Nigeria. Preliminary tests such as the natural moisture content, specific gravity, grain size analysis and Atterberg's limits were performed on them at their natural states and when stabilized with optimum percentages of lime. Engineering tests such as compaction, California Bearing Ratio (CBR) and undrained triaxial were also performed on them at their natural states, when stabilized with the optimum lime percentages and when Bamboo Leaf Ash (BLA) was introduced at 2, 4 and 6% to the samples. The results of the strength tests showed that BLA improved the strengths of all the lime stabilized samples. The unsoaked CBR values increased from 4-11, 2-10 and 2-11%, respectively in lime stabilized samples A, B and C with the addition of BLA. The shear strengths also increased substantially, from 42.16 to 398.96 kN/m², 42.96 to 146.84 kN/m² and 197.48 to 365.90 kN/m², respectively with the addition of BLA to the lime stabilized samples. It was therefore concluded that BLA will further increase the strength of lime stabilized lateritic soil for highway construction since it was found as an effective complement for lime in soil stabilization.

Key words: Bamboo leaf ash treatment, complement stabilizer, construction method, highway materials, lime stabilization, material strength, road upgrade

INTRODUCTION

The generation and disposal of waste is an intrinsic part of any developing or industrial society. Waste, both from domestic and commercial sources has grown significantly in Nigeria over the past decade. It is possible to quote figures which show that the production of waste amounts to millions of tons. The percent of Nigeria's population living in cities and urban areas has more than doubled in the last 15 years. The cities and urban areas experience continuous growth which contributes to the generation of solid and liquid waste. The management of waste is a matter of national and international concern. The volume of waste does not actually constitute the problem, but the ability or inability of governments, individuals and waste disposal firms to keep up with the task of managing waste and the environment. There is no doubt that a dirty environment affects the standard of living, aesthetic sensibilities, health of the people and thus the quality of their lives. The corollary is that improper disposal or storage of this waste can constitute hazards to the society through the pollution of air, land and especially water. Table 1 showed the average waste of

Table 1: Countries with their average waste

Countries	kg	Pounds
Australia	690	1520
Belgium	480	1060
Canada	630	1390
Denmark	540	1190
Finland	410	900
France	590	1300
Germany	400	880
Italy	470	1040
Japan	400	880
Mexico	300	660
Netherlands	570	1260
Norway	590	1300
South Korea	400	880
Spain	370	820
Sweden	440	970
United Kingdom	480	1060
United States	720	1590

Organization for economic cooperation and development, environmental data (1999)

some countries. This study is therefore aimed at finding engineering use for bamboo leaf waste in soil improvement for highway construction.

Lime is an excellent choice for short-term modification of soil properties. Lime can modify almost

Table 2: Chemical analysis of bamboo (Higuchi, 1957)

Species (Bamboo)	Ash (%)	Ethanol-toluene extractives (%)	Lignin (%)	Cellulose (%)	Pentosam (%)
Phyllostachys heterocycla	1.3	4.6	26.1	49.1	27.7
Phyllostachys nigra	2.0	3.4	23.8	42.3	24.1
Phyllostachys reticulata	1.9	3.4	25.3	25.3	26.5

all fine-grained soils, but the most dramatic improvement occurs in clay soils of moderate to high plasticity. Modification occurs because calcium cations supplied by the hydrated lime replace the cations normally present on the surface of the clay mineral, promoted by the high pH environment of the lime-water system.

Soil stabilization with lime achieves the dual goals of producing an impervious layer so water does not penetrate and a tough all-weather surface that allows vehicular traffic under all conditions. Lime-stabilized soil has a hydraulic conductivity similar to clays, i.e., 10⁻⁷ cm/sec., preventing leaching of soluble nutrients from composting mixtures through the soil profile. The lime stabilized soils which go through a 'curing' phase do not swell or shrink with changes in water availability and have a strong load-bearing capacity. Although most soils can be lime-stabilized, some soils are more easily stabilized than others (National Lime Association, 1991). As technology advances and economic conditions change, many more chemical agents are introduced into sub-grades to improve their compactability, durability, and strength. In addition, there are chemicals being used today in the petrochemical industry that are yet to be explored in soil treatment. Another area for research is the process of injection and spray-on techniques for more economical treatment of soil. Improved chemical and mechanical stabilization techniques are needed for such waste materials as crushed old asphalt pavement, copper and zinc slag, paper mill sludge, and rubber tire chips. In Finland, for example, attempts have recently been made to mix paper mill sludge with fly ash for use in the construction of roads, liners for landfills, and stabilized layers in areas where slope stability is of concern. Experiments in South Korea involve mixing waste lime that is produced as a by-product in the manufacturing of sodium carbonate with weathered granite for the stabilization of offshore reclaimed land. At present, the pressure to use waste materials for construction is much higher in Europe than in the United States. With increased emphasis on environmental protection, however, this situation is likely to change.

Bamboo is a naturally occurring composite material which grows abundantly in most of the tropical countries. It is considered a composite material because it consists of cellulose fibers imbedded in a lignin matrix. Cellulose fibers are aligned along the length of the bamboo providing maximum tensile flexural strength and rigidity in that direction (Lakkad and Patel, 1981). Over 1200 bamboo species have been identified globally (Wang and

Shen, 1987). Bamboo has a very long history with human kind. Bamboo chips were used to record history in ancient China. Bamboo is also one of the oldest building materials used by human kind (Abd-Latif *et al.*, 1990). It has been used widely for household products and extended to industrial applications due to advances in processing technology and increased market demand. In Asian countries, bamboo has been used for household utilities such as containers, chopsticks, woven mats, fishing poles, cricket boxes, handicrafts, chairs, and so on. It has also been widely used in building applications, such as flooring, ceiling, walls, windows, doors, fences, housing roofs, trusses, rafters and purlins; it is also used in construction as structural materials for bridges, water transportation facilities and skyscraper scaffoldings. There are about 35 species now used as raw materials for the pulp and paper industry. Massive plantation of bamboo provides an increasingly important source of raw material for pulp and paper industry in China (Hammett *et al.*, 2001). The chemical composition of bamboo is similar to that of wood. Table 2 shows the chemical composition of bamboo (Higuchi, 1957). The main constituents of bamboo culms are cellulose, hemicellulose and lignin, which amount to over 90% of the total mass. The minor constituents of bamboo are resins, tannins, waxes and inorganic salts. Compared with wood, however, bamboo has higher alkaline extractives, ash and silica contents. Yusoff *et al.* (1992) studied the chemical composition of one, two, and three year old bamboo (*Gigantochloa scortechinii*). The results indicated that the holocellulose content did not vary much among different ages of bamboo. Alpha-cellulose, lignin, extractives, pentosan, ash and silica content increased with increasing age of bamboo. Bamboo contains other organic composition in addition to cellulose and lignin. It contains about 2-6% starch, 2% deoxidized saccharide, 2-4% fat, and 0.8-6% protein. The carbohydrate content of bamboo plays an important role in its durability and service life. Durability of bamboo against mould, fungal and borers attack is strongly associated with its chemical composition. Bamboo is known to be susceptible to fungal and insect attack. The natural durability of bamboo varies between 1 and 36 months depending on the species and climatic condition. The presence of large amounts of starch makes bamboo highly susceptible to attack by staining fungi and powder-post beetles (Mathew and Nair, 1988). The ash content of bamboo is made up of inorganic minerals, primarily silica, calcium, and potassium. Manganese and magnesium are two other

Table 3: Summary of properties of soil samples

Property	Sample A	Sample B	Sample C
Percentage passing BS No 200 sieve	2.1	3.9	2.3
Natural moisture content, (%)	22.75	26.60	15.32
Specific gravity	1.85	2.71	2.77
AASHTO classification	A-2-7	A-2-7	A-2-7
Liquid limit, (%)	73.22	74.15	45.23
Plastic limit, (%)	35.62	51.61	26.86
Plasticity index, (%)	37.60	22.54	18.36
Maximum dry density	1317.20	1392.54	1704.51
Optimum moisture content	33.65	29.50	17.44
California bearing ratio (%)	4	3	23
Triaxial shear strength	20.14	30.62	60.57

common minerals. Silica content is the highest in the epidermis, with very little in the nodes. Higher ash content in some bamboo species can adversely affect the processing machinery.

Bamboo leaf fired in an open atmosphere and then heated at 600°C for 2 h in a furnace was found to be an amorphous material containing amorphous silica. 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. When 20 wt% bamboo leaf ash was mixed with Portland cement, the compressive strength at 28 days of hydration was comparable to that without ash. This was due to pozzolanic reactions. There is a continuous search for alternative supplementary materials, which may have hydraulic or pozzolanic properties. In an attempt to this, it was found that ash obtained from bamboo leaf is amorphous in nature and has pozzolanic properties. Its availability makes it more desirable and since it was considered as a waste in past time, its discovery as a pozzolanic material has been a tremendous success.

MATERIALS AND METHODS

Materials and preparation: This study was conducted between February and October 2010 at the Transportation laboratory of the Department of Civil Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria. The materials used were: lateritic soil, lime, bamboo leaf ash and potable water. The lateritic soil samples were obtained from different existing borrow pit located in Ile-Ife, Nigeria, while hydrated lime was purchased in 25 kg-bags from a standard chemical store. Bamboo leaf was obtained from a bamboo forest located in Obafemi Awolowo University, Ile-Ife in bags and burnt in an open drum to get the bamboo leaf ash. Potable water was obtained from treated water available in the laboratory. These materials were specially handled before conducting the experiments. Tags were stapled on the lateritic soil samples to indicate their dates of extraction, depths of extraction from the borrow pit and their locations. The samples were placed on sacks in the laboratory to air-dry them for a minimum of two weeks. The samples were prevented from water and sunlight contacts during the

drying process and were turned over frequently to avoid local drying, a situation where only some parts of the sample are dried. The hydrated lime was kept safe in the bag to prevent any contact with moisture and any other external material that can affect its property.

Methods: Preliminary tests (such as natural moisture content, specific gravity, particle size analysis and Atterberg's limits test) were carried out on the soil samples to determine their index properties. Lime which was the main stabilizing material was then thoroughly mixed with the soil samples in 4, 6, 8 and 10% by weight of the soil samples in order to determine the optimum lime requirement of the samples. The geotechnical properties of the lime-stabilized soil samples were thereafter determined. These properties were taken as the control to assess the effects of BLA on the lime-stabilized samples.

RESULTS AND DISCUSSION

The results of the preliminary tests (specific gravity, natural moisture contents, particle size distribution and Atterberg's Limits) and the engineering strength tests (Maximum dry density at optimum moisture content, California bearing ratio and shear strength) are presented and discussed below:

Preliminary test: The summary of the preliminary test results for soil samples A, B, C are shown in Table 3. The natural moisture contents of samples A, B and C are 22.75, 26.60 and 15.32%, respectively. Lambe and Whitman (1979) have discovered that the moisture content of a soil depends largely on void ratio, sample B therefore has the largest void ratio compared to others. The specific gravities of samples A, B and C are 1.85 and 2.77 and 2.77, respectively. Das (2000) stated that most clay minerals have specific gravity that falls within a general range (1.6-2.9). Therefore, the soil samples are halloysites. In the particle size analysis of the samples, less than 35% of the three soil samples passed the 200 mm sieve. The three soil samples were classified using the AASHTO soil classification system as granular materials belonging to A-2 class with significant

Table 4: Summary of Atterberg's limits for lime stabilization

Samples	Lime stabilization (%)	Liquidlimit (LL), (%)	Plasticlimit (PL), (%)	Plasticity index (PI), (%)
A	0	73.22	37.60	35.62
	6	54.16	40.20	13.96
	8	54.16	40.20	13.96
B	0	74.15	22.04	51.61
	4	64.96	44.88	20.10
	6	62.52	52.90	9.62
C	0	45.23	18.36	26.86
	6	46.95	36.75	10.10
	7	52.24	32.64	19.61

Table 5: Unsoaked CBR values for unstabilized and lime stabilized soil

Samples	Unstabilized soil	Lime stabilized soil
A	4	4
B	3	2
C	23	2

Table 6: Summary of Unsoaked CBR Values for varying BLA at optimum lime

Samples	Percentage stabilization	Unsoaked CBR values (%)
A	0% BLA	4
	2% BLA	11
	4% BLA	10
	6% BLA	5
B	0% BLA	2
	2% BLA	10
	4% BLA	8
	6% BLA	5
C	0% BLA	2
	2% BLA	4
	4% BLA	11
	6% BLA	8

constituent materials as silty or clayey gravel and sand with less than 35% passing the 75 mm sieve. They were further classified with their liquid limit and plasticity index as A-2-7 soil with liquid limit greater than 41% and plasticity index greater than 11%. Soils belonging to this class are regarded as good subgrade material based on these consistency limits, however strength parameters are also required to ensure they meet the design criteria as specified for various projects.

The liquid limits, plastic limits and plasticity index of samples A, B and C are shown in Table 3. These values which can be used to predict the swell and shrinkage potential predicts a high swell potential for sample A and B with high plasticity and marginal swell potential for sample C with intermediate plasticity. The summary of the Atterberg's limits for lime stabilized samples A, B and C are presented in Table 4. The optimum lime percentages for stabilization were observed at 8, 6 and 6%, respectively for samples A, B and C. These optimums were used to determine the engineering properties of the stabilized samples prior to the addition of Bamboo leaf ash.

Engineering test: Figure 1-2 shows the effects of BLA addition on the OMC and MDD of the optimum stabilized samples. The addition of the various percentages of BLA

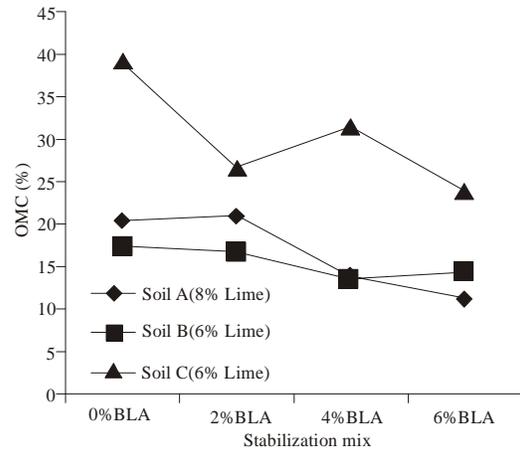


Fig. 1: Variation of maximum dry density with increasing BLA at optimum lime

at optimum lime stabilization caused an increase in MDD from 1318 to 1326 kg/m³ and a decrease in OMC from 33.20 to 30.0%. Whereas in both samples B and C, the addition of BLA at all percentages caused MDD reductions and OMC increases.

Table 5 shows the summary of unsoaked CBR values for the natural and lime-stabilized soil. The unsoaked CBR values for the natural soil was 4% for sample A, 3% for sample B and 23% for sample C. When stabilized with optimum lime, the values were reduced in the samples and substantially in sample C from 23 to 2% which can be attributed to the high water content utilized during compaction. These values do not represent the in-situ or working condition strength of the soil. Curing of the samples will however increase the strength of the stabilized soil (Jha and Gill, 2006).

Table 6 shows the summary of the result of unsoaked CBR test for lime stabilized samples at varying BLA contents. The addition of 2, 4 and 6% BLA increased the unsoaked CBR values to 11, 10, and 5% in sample A; 10, 8 and 5% for sample B; 4, 11 and 8% for sample C. This shows that BLA has the ability to complement lime in increasing the strength properties of lateritic soils to a range suitable for subgrades.

Table 7 shows the summary of shear strength results for the natural and lime stabilized samples while

Table 7: Summary of Shear strength for unstabilized and lime stabilized soil

Sample	Percentage lime	Cohesion, c (kN/m ²)	Internal friction angle (φ)	Average deviator stress, σ ₁ - σ ₂ (kN/m ²)	Shear stress τ = c + (σ ₁ - σ ₂) tanφ (kN/m ²)
A	0 %	5.91	18	43.78	20.14
	8 %	34.08	6	76.90	42.16
B	0 %	16.37	14	57.16	30.62
	6 %	41.31	1	94.85	42.96
C	0 %	43.61	20	46.61	60.57
	6 %	25.28	38	220.40	197.48

Table 8: Variation of shear strength with BLA addition at optimum lime

Sample	Bamboo leaf Ash (%)	Cohesion, c (kN/m ²)	Internal friction angle (φ)	Average deviator stress, σ ₁ - σ ₂ (kN/m ²)	Shear stress τ = c + (σ ₁ - σ ₂) tanφ (kN/m ²)
A	0 % BLA	34.08	6	76.90	42.16
	2 % BLA	58.10	40	406.22	398.96
	4 % BLA	71.31	11	191.54	108.54
	6 % BLA	61.82	29	345.62	253.40
B	0 % BLA	41.31	1	94.85	42.96
	2 % BLA	28.32	21	100.14	127.975
	4 % BLA	60.73	17	177.527	146.844
	6 % BLA	60.51	2	150.998	127.152
C	0 % BLA	25.28	38	220.40	197.48
	2 % BLA	54.45	59	187.14	365.90
	4 % BLA	1.873	41	106.19	94.18

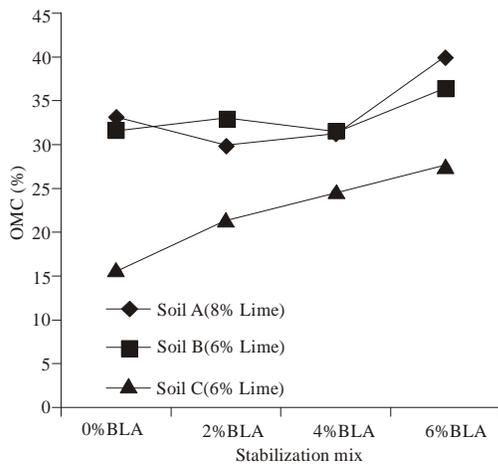


Fig. 2: Variation of optimum moisture content with increasing BLA at optimum lime

Table 8 shows the shear strengths variation with the addition of BLA at optimum lime stabilization. The introduction of BLA caused a further substantial increase in the shear strengths of the samples above those obtained at optimum lime stabilization as seen in Table 7. The values increased from 42.16 to 398.96kN/m², 42.96 to 146.84 kN/m², and 197.48 to 365.90kN/m², respectively for samples A, B and C.

Reductions in shear strengths were observed at 4% BLA for samples A and C while sample B experienced an increase. The triaxial test is one of the most reliable methods now available for the determination of shear parameters of soil samples. An increase in the shear

strength of a soil is an indicator of improvement in the strength of the soil and also shows an improved workability for construction works (Das, 1990). The increase with the addition of BLA to the stabilized samples further confirms the improvement earlier shown in their geotechnical properties.

CONCLUSION

Based on the results of this study, which showed a substantial improvement on the strength properties of the lime stabilized samples. It was therefore concluded that Bamboo Leaf Ash (BLA) is a good complement for lime stabilization in lateritic soils.

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AUTHOR'S CONTRIBUTION

Dr. Olugbenga O. AMU developed the concept and designed experiments, supervised the acquisition of data, analysis and interpretation of data and also prepared and approved the version published. Babajide, S.S. was the research assistant. He was involved in developing the concept and designed experiments, acquisition of data, analysis and interpretation of data for the version published.