Sustainability in Road Construction: Using Bamboo Straw Ash to Improve the Index Properties of Lateritic Soil

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Abstract

In a bid to improve sustainability in road construction and reduce the cost of road construction, there is a need for a green alternative. This research improved the geotechnical properties of tropical lateritic soil using Bamboo Straw Ash (BSA). The lateritic soil was stabilized with increasing percentage of BSA at 0%, 2%, 4%, 6%, 8%, 10%, and 12%. The index properties, Compaction (Maximum moisture content, Maximum dry Density), CBR, of the soil samples with BSA were evaluated. Response Surface Analysis was used to model the mathematical relationship between the atterberg limit and the CBR of the BSA stabilized soil sample. The plasticity index of the unstabilized soil sample was 14.01 upon the addition of 16% BSA, the plasticity index reduced to 10.73 which showed an improvement in the soil index properties. The CBR increased from 26.38% to 30.2% at 0% and 8% respectively which signifies an improved strength. From the Respons Surface Analysis, the highest plasticity index achievable with BSA stabilization is 27.18. The model equation showed that the plasticity index and plasticity limit have a positive relationship with the CBR. Ultimately, the use of BSA provides a cost-effective and green alternative to lateritic soil stabilization in road construction.

Keywords: Bamboo straw ash, soil stabilization, strength properties, compaction, Pavement material

1. Introduction

The soil is an important material in highway construction but it is also the major cause of pavement failures. Although pavements fail from the top, pavement systems generally start to deteriorate from the bottom (subgrade), which often determines the service life of a road (Hijab, 2012). These failures are mostly due to the use of soil with insufficient strength to carry traffic wheel load applied on it. Improvement is therefore necessary in such cases, this leads to the concept called soil stabilization.

Soil stabilization is any treatment whether technical or compactive, applied to improve the engineering properties of the soil (strength, waterproofing, durability etc.). Stabilization of soil is employed when it is more economical to overcome a deficiency in a readily available material than to bring in one that fully complies with the requirements of the specification for the soil (Ola, 1975). There are various chemical materials that have been used in the past for this process. Lime and cement are the oldest stabilizers used. These materials have proven to be though efficient but expensive and unsustainable hence the necessity to find partial or total replacements for them. With the

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waste to wealth initiative and the nation's alertness to economic resource management, biomass waste has been reported to be suitable for such replacements. These include Rice Husk Ash (Chungsangunsit et al, 2007), Bamboo Leaf Ash (Dwiveldi et al, 2006), Palm Fruit Ash (Olonode, 2010), Locust Bean Pod Ash (Adama and Jimoh, 2011), Cement Cassava Peel Ash (Salau et al, 2012), Corn Husk Ash (Adesanya and Raheem, 2009) and Corn Cob Ash (Akinwumi and Aidomojie, 2015), (Yinusa and Jimoh, 2014). Bamboo has a very long history with human kind. Bamboo chips were used to record history in ancient China. 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. However bamboo straw may constitute a nuisance with no economic benefit in areas where the need for its eradication is important. This research provides another economic and engineering usage for bamboo straw ash in road construction. This is in an attempt to improve the strength of pavement interlayer material and also reduce the cost of road construction.

2. Methodology
2.1 Materials
        The Bamboo straws were obtained locally from a shed situated in Sabon Gari local government area in Kawo, Kaduna state. The Bamboo straws were collected, air-dried and burnt at a controlled temperature. The ash was collected in sacks and transported to the soil mechanics research laboratory in the Kaduna Polytechnic. The ash was then passed through the BS No 200 sieve (75µm) to meet the requirements of ASTM class N pozzolans (ASTM D4318-10e1) as reported by Head in (1994). The chemical analysis of the bamboo straw ash was carried out using Flame Photometer and the Atomic Absorption Spectrophotometer (Pye-Unicam Model SP 1900). Portable water from Kaduna Polytechnic was used all through the research.

2.2 Test and Methods
The moisture content was carried out according to ASTM D 2216 - Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures). The Particle size distribution test was carried out in accordance with BS1377 (1990). The atterberg limit and strength index test was carried out in accordance with (BS 1990b) part 4.

3. Results and Discussion
3.1 Oxide Composition and Seive Analysis
        The basic oxides contained in the soil samples indicate the presence of Fe_2O_3, Al_2O_3 and SiO_2 (Table 2). This from literature have been shown to be the major oxides which indicate lateritic soils but their various quantities in the soil vary, due to laterization (Ola, 1983, Akinwumi, 2015). The chemical composition of the Bamboo straw ash showed that the material is pozzolanic in nature and have the attributes of improving the strength of soil as seen in Table 3.1.

Table 3.1: Chemical Composition of the Soil Sample and Bamboo Straw Ash

Composition (%)	Kaduna Lateritic soils	Bamboo straw ash (BSA)
SiO_2	34.60	33.85
SO_3	-	4.94
K_2O		34.70
Na_2O		9.70
CaO	0.25	8.13
MgO	0.56	0.46
TiO_2		0.16
MnO		0.21
Fe_2O_3	2.20	1.95
Cl		4.61
Al_2O_3	25.80	
Mn_2O_5	0.20	

The Particle size distribution of the soil sample is as seen in figure 3.1. The result of the AASHTO soil classification showed that the soil is A-7-6 soil. It is yellowish brown in colour. This colouration may be due to the percentage of iron oxide content in the soil. The particle size analysis of the sample was seen to have a high percentage of clay and is rated as fair-poor material for a subgrade (Nigeria Specification for Bridges and Road Design, 1997) hence the need for soil stabilization or soil replacement is required.
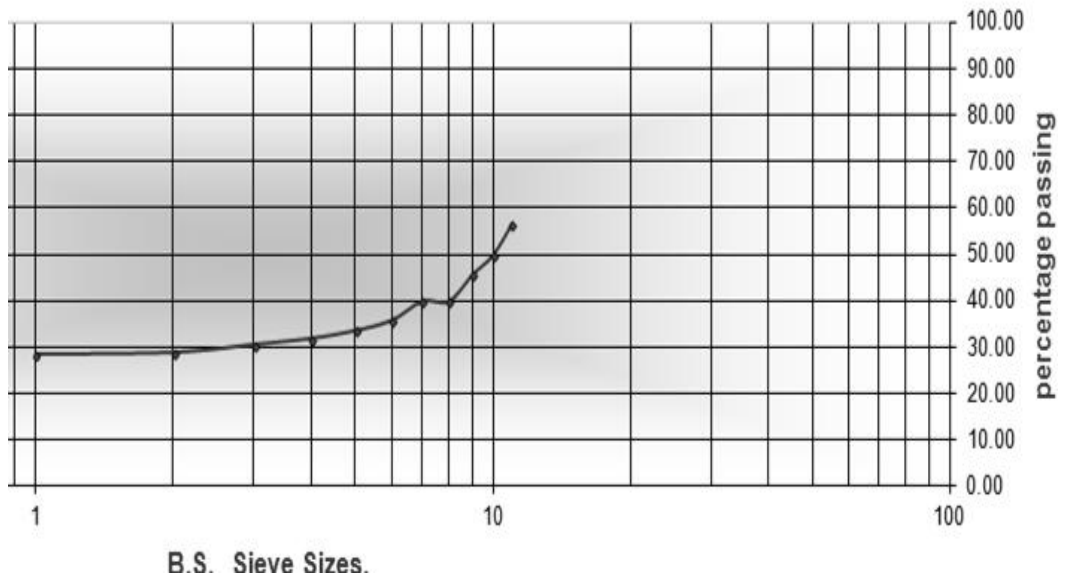

Figure 3.1: Sieve Analysis of the Soil Sample

3.2 Geotechnical Properties of the Unstabilized Soil Sample

The preliminary assessment of the soil sample is as indicated in Table 3.2. The atterberg limit of the soil in the form of liquid limit, plastic limit, and the plasticity index was 42, 27.99 and 14.01 (Table 3.4). These properties according to the requirement of Nigeria Bridges and Road design manual is good as an embankment or as a subgrade material. Therefore, there is a need for the improvement of the geotechnical properties of the soil to make it suitable as a sub-base and base material. Accordingly, the CBR value of 26.38 is an indication of the strength index of the soil, the result showed that the soil satisfies the criteria for an embankment or subgrade material.

Table 3.2: Geotechnical Properties of the Unstabilized Soil Sample

Properties	Quantity/description
Natural Moisture Content (%)	14.02
Liquid Limit (%)	42.00
Plastic Limit (%)	27.99
Plastic Index (%)	14.01
AASHTO Soil Classification System	A-7-6
Group index	1
Maximum Dry Unit Weight	1.81
Optimum Moisture Content (%)	15.18
CBR (%)	26.38

3.3 Atterberg Limit of the Stabilized Soil Sample

The atterberg limit of the stabilized soil indicates that as the percentage of BSA increases the plasticity index of the soil reduces. The reduction in the plasticity index indicates an improvement in the soil index properties. The plasticity index of the unstabilized soil sample was 14.01 upon the addition of 16% BSA, the index reduces to 10.73 which showed an improvement in the soil index properties as indicated by Whitlow, (1995).
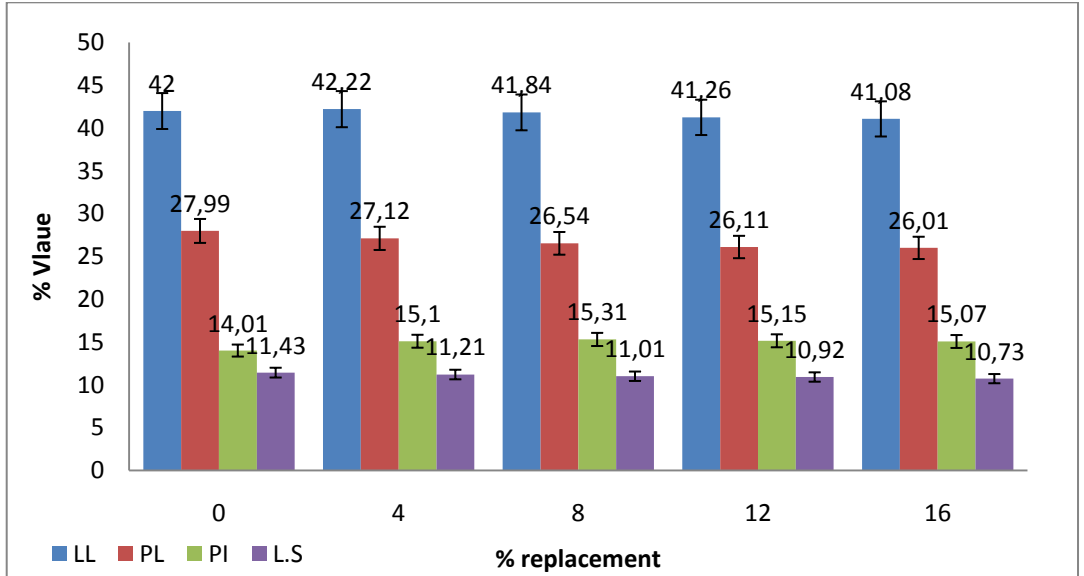
Figure 3.2: Atterberg limit of the Stabilized soil sample

3.4 Strength Index

Stabilization of lateritic soil sample with 0%-6% BSA is as represented in figure 3.3. The result indicates a slight decrease in the maximum dry density (MDD) during compaction. Then, with the addition of 8% BSA, there was an increase in the MDD. The final addition of 16% lime indicated a decrease in MDD.
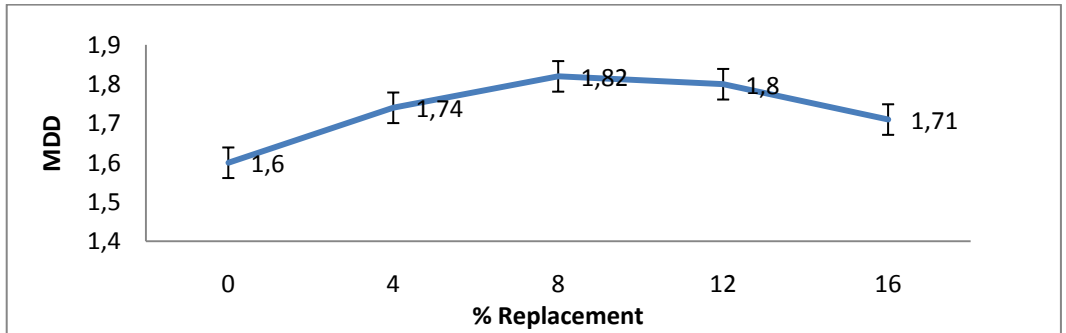

Figure 3.3: Maximun Dry Density of the Stabilized sample

The Optimum moisture content, on the other hand, indicated an increase between 8%-12% BSA and then from 12-16%, there was a decrease in OMC.
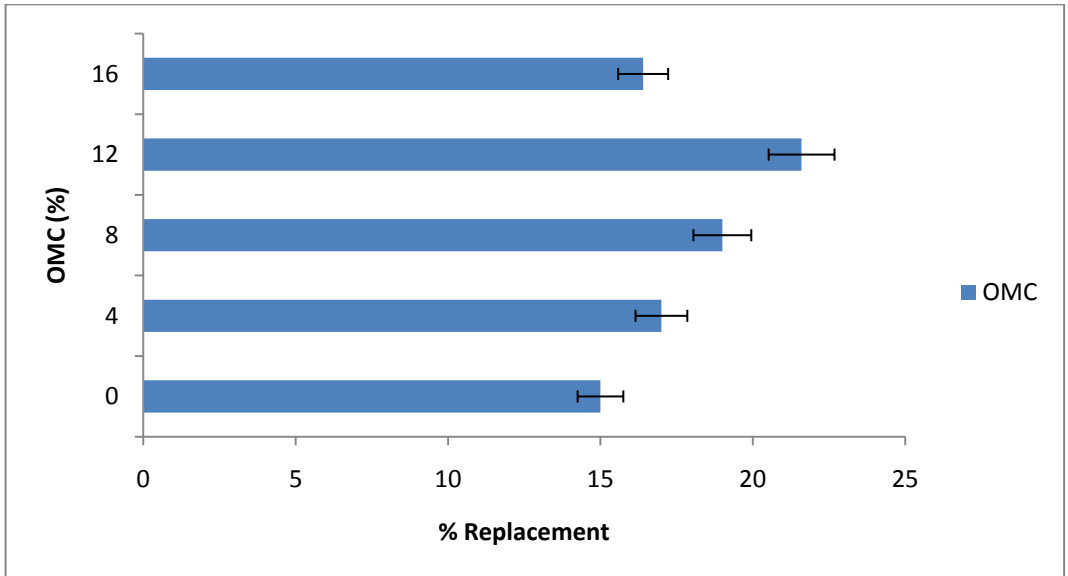
Figure 3.4: Optimum Moisture Content of the Stabilized Sample

3.5 CBR

The CBR value of the stabilized soil is as shown in Figure 3.5. From the figure, the CBR increased from 26.38% to 30.2% at 0% and 8% respectively. This is an indication of improved strength. The improved strength is as a result of the structural modification of the soil structure based on the pozzolanic properties of the BSA.

However, at percentages higher that 8% the CBR value reduced. At 8% CBR value recorded was good enough for subbase material. Based on the General Specification for roads and bridges design manual, the soil is suitable for subbase and base material.
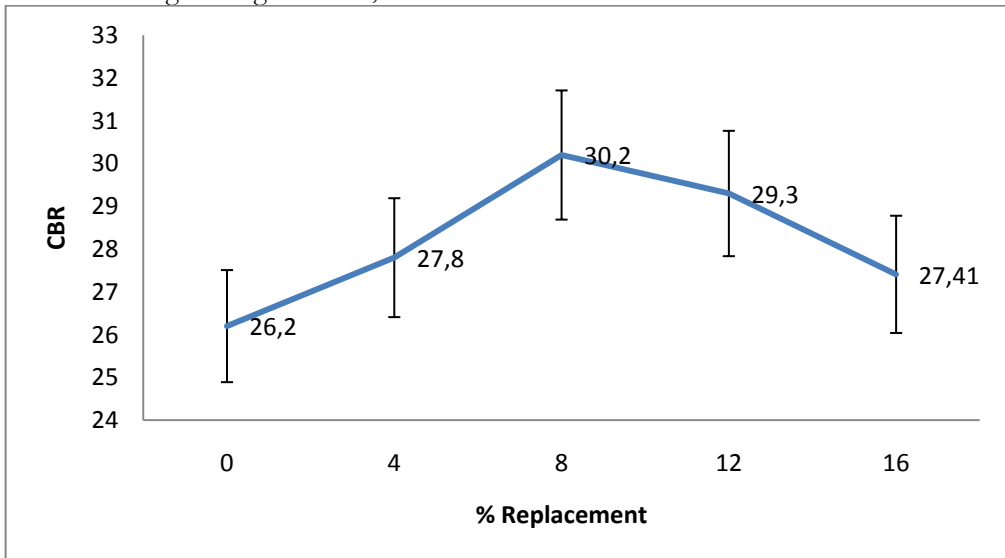

Figure 3.5: CBR value of the stabilized sample

3.6 Modelling the Relationship between the Index Properties

Equation 1 shows the relationship between the strength index (CBR) and the atterberg limit. From the equation, plasticity index and plasticity limit have a positive relationship with the CBR. This means that the higher the PI and PL the higher the CBR of the soil when stabilized with BSA. However, LL had a negative relationship with the CBR of the oil when stabilized with BSA. The R2 value of 0.87 signifies the robustness of the model developed as seen in Table 3.3.

$$CBR = 118.25 + 4.53P.I + 3.39PL - 5.96 L.L - - - - - - Equation\ 1$$

Std. Dev.	0.24398	R-Squared	0.993827
Mean	28.268	Adj R-Squared	0.875306
C.V.	0.863095	Pred R-Squared	N/A
PRESS	N/A	Adeq Precision	16.36395

3.6.1 Response Surface Analysis of the Index Properties

The response surface analysis of the index properties is as seen in Figure 3.6 and 3.7. The result of the analysis showed that the stabilization of A-7-6 soil with BSA index properties is been altered based on the percentage of BSA added. From the analysis, the highest plasticity index achievable with BSA stabilization is 27.18. The highest liquid limit achievable with BSA stabilization is 41.08 as seen in figure 3.6 and 3.7. This to a very large extent will aid researchers, engineers and highway engineers on the optimum index property expected using BSA in the stabilization of lateritic soil.
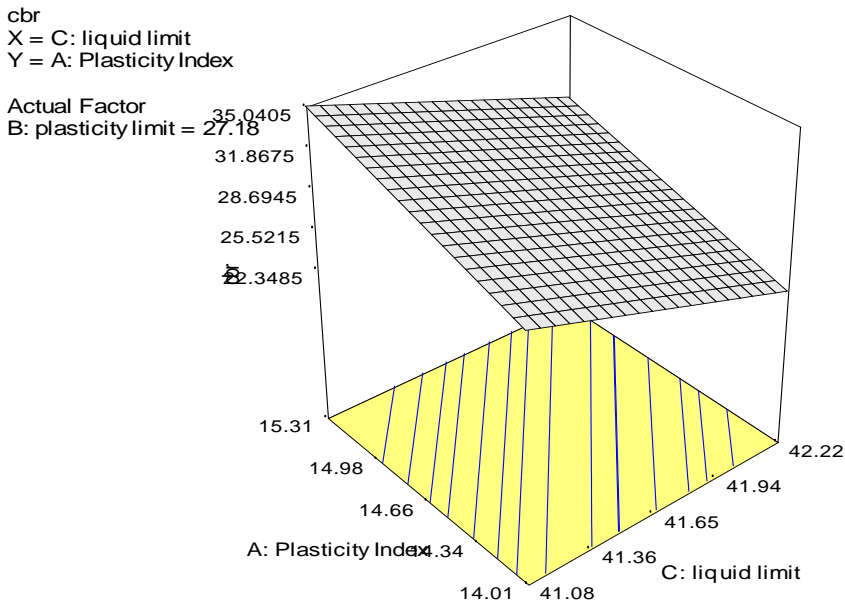
DESIGN-EXPERT Plot

cbr
X = C: liquid limit
Y = A: Plasticity Index

Actual Factor
B: plasticity limit = 27.18

35.0405
31.8675
28.6945
25.5215
22.3485

15.31
14.98
14.66
14.34
14.01

A: Plasticity Index

42.22
41.94
41.65
41.36
41.08

C: liquid limit

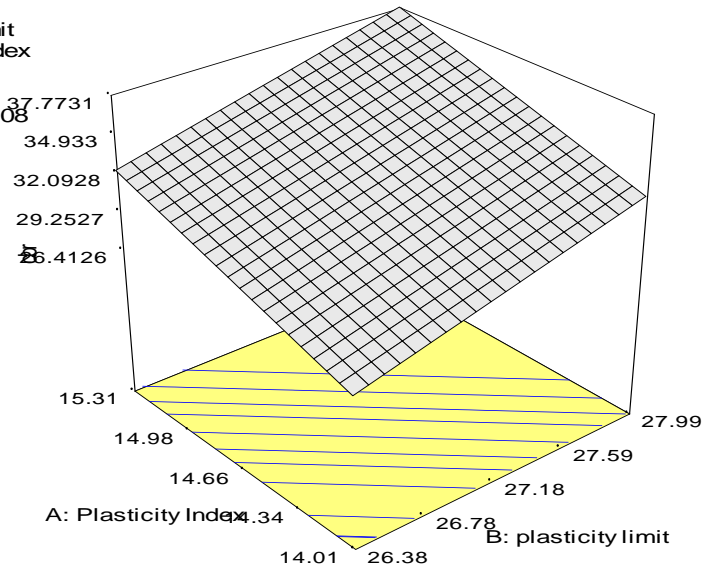*Figure 3.6: Response Surface View of Plasticity Index Versus Plasticity limit*

Figure 3.7: Response Surface View of Plasticity Index Versus Plasticity limit

Conclusion

This experimental research assessed the utilization of Bambo straw Ash in the stabilization of tropical lateritic soil from Kaduna, Northern Nigeria. This was done with special focus on the index properties. Therefore, plasticity limit, liquid limit and plasticity index properties of the soil was assessed. The strength index of the soil was also espoused. The result of the experimental research showed that:

i. The atterberg limit of the soil in the form of liquid limit, plastic limit, and the plasticity index was 42, 27.99 and 14.01
ii. The plasticity index of the unstabilized soil sample was 14.01 upon the addition of 16% BSA, the plasticity index reduced to 10.73 which showed an improvement in the soil index properties
iii. The highest liquid limit achievable with BSA stabilization is 41.08
iv. From the analysis, the highest plasticity index achievable with BSA stabilization is 27.18
v. The model equation showed that the plasticity index and plasticity limit have a positive relationship with the CBR. This means that the higher the PI and PL the higher the CBR of the soil when stabilized with BSA.
vi. However, LL had a negative relationship with the CBR of the oil when stabilized with BSA.

Recommendation for Future Research

Future research should focus on the effect of Bamboo Straw ash on both lime and cement stabilized soil, which the authors are already working on.

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