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INVESTIGATING THE SUITABILITY OF COCONUT HUSK ASH AS A ROAD SOIL STABILIZER

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ABSTRACT

There is a pressing need to locate cheaper alternatives to traditional stabilizers such as Portland cement and lime which will reduce the cost of stabilized roads and make the practice of treating local soil materials very attractive to road development agencies in poor countries of the underdeveloped world, where deficient soils are often used without treatment, the consequence of which is premature deterioration of roads. This paper presents a study that was conducted to investigate the suitability of coconut husk ash (CHA), a waste product from crop plants, as a road soil stabilizer. The oxide composition of CHA was determined to establish its suitability as a pozzolanic material. It was then mixed with a lateritic soil (classified as A-2-6(1) using the AASHTO system of soil classification) in varying proportions, ranging from 0–20% by dry weight of soil at increments of 2%. The physical and strength properties of each of the soil-CHA blends was then determined in the laboratory. The results show that oxides of K_2O, SiO_2, Cl, CaO, P_2O_5, MgO and Al_2O_3 constitute 92% of CHA, indicating that it is a pozzolanic material. The optimum moisture content (OMC) of the soil increased, while its maximum dry density (MDD) decreased, with increasing CHA content. The CBR and UCS of the mixes increased with CHA content up to 8%, but decreased with a further increase in CHA content. However, the increase in the strength of the soil obtained at the optimum CHA content was not significant enough to warrant its usage as a lone stabilizer for sub-base and base materials, but it can be used for subgrade stabilization. For sub-base and base stabilization, CHA should be admixed with conventional stabilizers for improved performance.

Keywords: California bearing ratio; Coconut husk ash; Compaction characteristics; Lateritic soil; Pozzolanic material; Unconfined compressive strength

1. INTRODUCTION

Soils are routinely used for pavement layer construction in developing nations of the tropics, where good quality aggregates are not readily available in all locations as a result of the intensive weathering in the region. In Nigeria, for instance, there is hardly any road project that does not employ lateritic soils for sub-base, or for both sub-base and base, construction. This heavy application of lateritic soils in road construction derives from their widespread availability in the country.

However, many soils in their natural state do not possess the requisite engineering properties that qualify them to be used for pavement layer construction (Chittaranjan et al., 2011; Chhachhia & Mital, 2015). This deficiency renders soils wholly or partially incapable of meeting construction

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requirements. In the event that the local soil fails to meet the requirements of construction, the options available to the road engineer are to source good quality materials from where they are available and transport them over long distances, or to use soil stabilization techniques to improve or modify the properties of the local soil to bring it to the standard required for pavement layer materials. The first option is often uneconomical, as hauling materials over long distances adds considerably to the final construction cost (Ekeocha & Agwuncha, 2014). Soil stabilization provides cheap materials for the construction of low-cost roads, given that unsuitable locally available materials can be improved and used effectively (Pundir & Prakash, 2015).

The most common and widely used soil stabilizers, known as traditional stabilizers, are Portland cement, lime and bitumen (Roy, 2014; Barasa et al., 2015). However, over-dependence on these industrially manufactured traditional soil stabilizers has resulted in an increase in the construction cost of stabilized soil roads (Oriola & Moses, 2010; Roy, 2014; Zahra et al., 2015). Moreover, the industrial process of the production of cement and lime is associated with hazardous greenhouse gas emissions that threaten the environment (Rahman et al., 2014). Therefore, there is a pressing need to locate cheaper and environmentally friendly alternatives to traditional stabilizers, which will reduce the cost of stabilized roads and make the practice of treating local soil materials very attractive to road development agencies in poor countries such as Nigeria.

In a bid to address the challenges that have been thrown up by total dependence on industrially produced soil stabilizers and the associated hike in cost of construction of stabilized soil roads, researchers over the years have been busy searching for suitable alternatives that can replace cement and lime, partially or wholly, as soil stabilizers. Successes have been recorded in the area of partial replacement of cement and lime with pozzolanic materials, some of which were obtained from plant ashes. These successes have been reported in the works of Basha et al. (2005); Aparna (2014); and Barasa et al. (2015).

The knowledge that traditional stabilizers generally rely on pozzolanic reactions and cation exchange to modify and/or stabilize soils (Little & Nair, 2009) and the successes recorded in the use of known pozzolanic materials like fly ash for soil stabilization have prompted investigations into the feasibility of using plant ashes as soil additives, considering that the ashes have been classified as pozzolans. According to Chmeisse (1992), plant ashes have high silica content and can be made to be pozzolanic by suitable treatment.

In recent years considerable research has gone into identifying agricultural wastes whose ashes produce good pozzolans and which are available in exploitable quantity (Tsado et al., 2014). Locally available agricultural wastes that have received serious attention from researchers include: Rice Husk Ash, Groundnut Shell Ash, Sugarcane Bagasse Ash, Sugarcane Straw Ash, Coconut Shell Ash, Corn-cob Ash, Coco Pod Ash, Locust Bean Ash, Palm Kernel Shell Ash, Saw Dust Ash etc.

Investigation of the suitability of ash remains of agricultural wastes to completely take the place of cement and lime as road soil stabilizers has received the focus of many researchers in Nigeria and other underdeveloped countries in recent years. The use of agricultural waste products as soil stabilizers will help to solve two very important engineering problems: reducing cost of road construction and managing environmental waste. Agricultural waste products are viable sources of environmental pollution. Recycling and putting them to productive use will help to sanitize the environment.

This paper presents a study that was carried out to determine the possibility of stabilizing road soils with the ash remains of coconut husks. Coconut husk is the outermost layer of the coconut fruit that houses the coconut seed. Farmers harvest coconut for the seed, while the husk and the shell are usually discarded as waste. Coconut husks, like many other agricultural waste products, are found dumped indiscriminately in areas where coconut is harvested, posing serious environmental sanitation challenges. The scope of the study involved the determination of the compaction and strength characteristics (in terms of CBR and UCS) of different combinations of lateritic soil and coconut husk ash. The scope also covered the determination of chemical composition of CHA and the index properties of the lateritic soil.

2. MATERIALS AND METHODS

2.1. Materials

Materials used in this study included lateritic soil and coconut husks ash (CHA). The lateritic soil was obtained in a disturbed state from an existing borrow pit located at Ikpayongu, a settlement on the outskirts of Makurdi town in Nigeria. The soil was dried under the sun after which it was sieved through a 20 mm aperture BS sieve to remove particles greater than 20 mm.

CHA was obtained by collecting and burning dried coconut husks. Coconut husks were collected from rural communities in Tarkaa and Konshisha Local Government Areas of Benue State, Nigeria, where they are dumped as wastes. The husks were dried to enhance combustion and then ashed in a furnace at a temperature of about 700^{o}C for three hours. The ash remains were allowed to cool slowly, after which they were collected and stored in a moisture-proof polythene bag. Figure1(a) shows a pile of coconut husks, while Figure 1(b) shows the ash remains of the burnt coconut husks.

(a)

(b)

Figure 1 Material samples of: (a) Coconut husks; (b) Coconut husk ash

2.2. Tests and Test Methods

A laboratory experimental program was undertaken as a primary source of data for this study. The experimental program was aimed at investigating the properties of different blends of lateritic soil and coconut husk ash, including compaction characteristics and strength properties (measured in terms of CBR and UCS). The laboratory testing program also involved the determination of chemical composition of CHA and the index properties of the lateritic soil. The following laboratory tests were performed:

1. Particle size analysis test.
2. Liquid limit test.
3. Plastic limit test
4. Specific gravity test
5. Compaction test
6. California bearing ratio (CBR) test
7. Unconfined compression test.
8. Chemical composition analysis

Chemical analysis of the CHA was carried out to determine its oxide composition in order to establish a basis for its identification and classification as a pozzolanic material. Chemical composition of CHA was determined by means of X-ray fluorescence spectroscopy. The index properties (including particle size distribution, Atterberg limits and specific gravity) of the natural soil were determined. CHA was then mixed with the lateritic soil in varying proportions, ranging from 0–20% by dry mass of soil, at increments of 2% as shown in table 1. Each blend of soil and CHA was subjected to compaction test, California Bearing Ratio (CBR) test, and unconfined compression test. Sample preparation and test procedures were performed in accordance with BS 1377 (1990), Parts 1, 2, 4, and 7. Samples containing zero CHA (that is, the natural soil) were used as a control.

Table 1 Soil - CHA Mixtures

Sample No.	Proportion of CHA	Mix Ratio (by dry mass of soil)
1	0%	100% LS + 0% CHA
2	2%	98% LS + 2% CHA
3	4%	96% LS + 4% CHA
4	6%	94% LS + 6% CHA
5	8%	92% LS + 8% CHA
6	10%	90% LS + 10% CHA
7	12%	88% LS + 12% CHA
8	16%	84% LS + 16% CHA
9	20%	80% LS + 20% CHA

LS = Lateritic Soil. CHA = Coconut Husk Ash.

3. RESULTS

3.1. Chemical Composition of the Coconut Husk Ash (CHA)

Table 2 shows the results of the chemical composition analysis of the CHA.

Table 2 Chemical Composition of CHA

Chemical Compound	Concentration (%)
Na_2O	0.300
MgO	5.463
Al_2O_3	1.947
SiO_2	17.863
P_2O_5	8.121
SO_3	3.453
Cl	12.010
K_2O	36.542
CaO	10.405
TiO_2	0.066
Cr_2O_3	0.004
Mn_2O_3	0.085
Fe_2O_3	1.198
ZnO	0.124
SrO	0.059
Loss on Ignition (LOI)	2.36

3.2. Physical Properties of the Lateritic Soil

A summary of the geotechnical properties of the lateritic soil in its natural state is presented in Table 3. The grading curve of the raw soil is shown in Figure 2.

Table 3 Summary of the physical properties of the lateritic soil

Property	Quantity/Description
Specific Gravity	2.83
Gravel Particles	60%
Sand Particles	12%
Fines	28%
Liquid Limit	32%
Plastic Limit	13
Plasticity Index	19%
Classification (AASHTO)	A-2-6
OMC	13.8%
Maximum Dry Density	1.99 g/cm^3
CBR (Unsoaked/Soaked)	16%/13%
UCS (Unsoaked/Soaked)	102/90

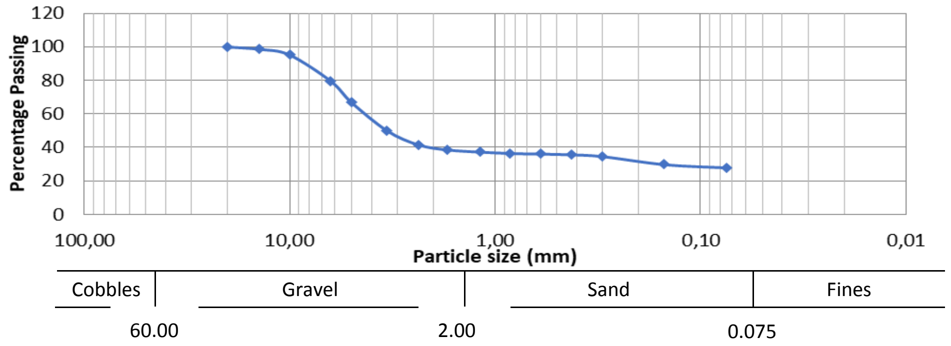

Figure 2 Particle size distribution curve of the lateritic soil

3.3. Compaction Characteristics of the Soil – CHA Mixtures

Table 3 presents the results of the compaction test for the various soil – CHA mixes. Figure 3 shows the variations in optimum moisture content (OMC) and maximum dry density (MDD) of the soil with CHA content.

Table 4 Compaction characteristics of the soil – CHA mixes

CHA Content	0%	2%	4%	6%	8%	10%	12%	16%	20%
OMC (%)	13.8	16.4	15.2	16.6	15.0	16.2	16.0	19.0	21.0
MDD (g/cm^3)	1.990	1.912	1.900	1.884	1.920	1.880	1.884	1.864	1.804

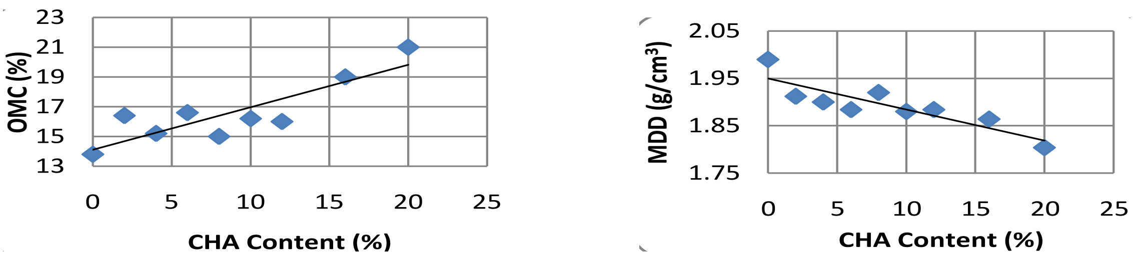

Figure 3 Variation in OMC and MDD with CHA content

3.4. Strength Properties of the Soil – CHA Mixtures

The strength of the soil was measured in terms of CBR and UCS. The results of the CBR and UCS tests performed on the soil samples containing different amounts of CHA are presented in Table 4, for both the un-soaked and soaked conditions.

Table 4 Results of the CBR and UCS tests for the various mixes of soil – CHA

CHA Content	Results of CBR Test		Results of UCS Test	
	Un-soaked CBR (%)	Soaked CBR (%)	Un-soaked UCS (kN/m^2)	Soaked UCS (kN/m^2)
0%	16	13	102	90
2%	19	10	111	93
4%	18	12	127	97
6%	21	16	190	100
8%	23	20	206	131
10%	20	17	128	125
12%	18	14	122	108
16%	12	11	105	94
20%	11	6	88	82

4. DISCUSSION

The chemical compounds that were significantly present in the CHA included Potassium oxide (37%), Silicon dioxide (18%), Chlorine (12%), Calcium oxide (10%), Phosphorus pentoxide (8%), Magnesium oxide (5%), and Aluminium (III) oxide (2%), which together total 92%. These chemical compounds are usually present in materials that are classified as pozzolans (ASTM C618, 2014), indicating, therefore, that CHA is a pozzolanic material.

The grading curve in Figure 2 shows that the lateritic soil consists of 60% gravel, 12% sand and 28% fine materials, indicating that it is a granular material with a deficiency of sand particles. This shows that the soil is gap-graded, which is a common tendency in lateritic soils (Oluyemi-Ayibiowu & Adeyeri, 2006).

The results of the Atterberg limits tests indicate that the soil has a liquid limit of 32%, plastic limit of 13% and plasticity index of 19%. The soil plots above the A-line in the low plastic clay zone on the Plasticity Chart, indicating that it contains clay particles of low plasticity. Based on these index properties, the soil was classified as A-2-6(1) using the ASSHTO system of soil classification.

For all combinations of the soil and CHA, OMC increased and MDD decreased with increasing CHA content, as shown in Figure 3. This variation of OMC and MDD with CHA content conforms with findings of other researchers in similar investigations (see Ako & Yusuf, 2016; Chhchhia & Mital, 2015; Amu et al., 2011).

The increase in OMC was because the fine CHA particles have large surface areas that require additional water for wetting. Replacing fractions of the coarse soil with the fine CHA, therefore, produced a mixture with high water demand, hence the increase in OMC. The positive aspect of the increase in OMC with CHA content is that it can enhance the workability of CHA-treated soils. On the other hand, the increased OMC may also cause an increase in the porosity of CHA-treated soils, thereby resulting in a reduction in strength.

The decrease in MDD of the CHA-treated soils was due to the partial replacement of the comparatively heavy soil with lightweight CHA. CHA has less specific gravity (2.23) compared to that of the soil (2.83). Therefore, adding CHA to the soil disproportionately increased the volume of the soil relative to its mass, hence the decrease of the dry density of the soil with increasing CHA content.

The CBR value of the soil increased with CHA content up to a maximum of 8% CHA, beyond which the CBR value decreased with further increases in CHA content in both un-soaked and soaked conditions. The optimum CHA content of 8% increased the un-soaked and soaked CBR values of the soil by 44 and 54% respectively. The drop in the value of CBR at CHA contents higher than 8% was due to the increase in compressibility caused by an increase in the porosity of the soil. The addition of CHA to the soil increased its porosity; as such, with higher contents of CHA, the increased porosity became significant enough to undermine the strength of the soil.

The variation of UCS with CHA content follows the same trend as that of the CBR. Samples containing 8% CHA had the highest UCS in both un-soaked and soaked conditions. The un-soaked UCS increased from 102 kN/m^2 at 0% CHA content to a maximum of 206 kN/m^2 at 8% CHA content, representing an increase of 102%. The soaked UCS increased by 46% from 90 to 131 kN/m^2. High CHA contents caused the loss of inter-particle friction as a result of increased porosity and reduced density, hence the fall in the value of UCS at CHA contents higher than 8%.

Result of the strength tests discussed above also agree with the findings of other researchers including Adama and Jimoh (2012), Saleh and Srividhya (2015), Adetoro and Adam (2015), and many other researchers.

4.1. Suitability of CHA as a Lone Soil Stabilizer

The results of the strength tests performed on the CHA-treated soil samples were compared with standard specifications provided by the Nigerian Highway Manual (2013) for pavement layer materials. It was discovered that while CHA significantly increased the strength of the soil, the CBR value of the treated soil still did not meet the minimum 30% that is specified for granular sub-base materials. The UCS value also fell short of the minimum 0.75–1.5 MP_a specified for cemented sub-base materials. This indicates that as a lone additive CHA is only suitable for subgrade stabilization, but is unsuitable for the stabilization of sub-base and base materials. This limitation of CHA can be attributed to the low concentration of calcium oxide (10%) in CHA, which was unable to produce the necessary amount of free calcium ions that are required for the pozzolanic reaction that results in the formation of cementing materials that enhance the strength of the stabilized material to take place.

5. CONCLUSION

Based on the results of the study, the following conclusions can be drawn: (1) The lateritic soil in its natural state is weak and unsuitable for pavement layer construction; (2) CHA can be classified as a pozzolanic material; (3) CHA altered the compaction characteristics of the soil. The OMC of the CHA-treated soil increased with CHA content, while the MDD decreased with an increase in the CHA content of the soil. This trend is similar to that established for soil stabilization projects involving pozzolanic materials; (4) CHA also produced measurable effects on the strength characteristics of the soil measured in terms of CBR and UCS. The CBR and UCS values of the CHA-treated soil increased with CHA content up to a maximum of 8% CHA, beyond which the values decreased with an increase in CHA. The optimum CHA content was therefore found to be 8% of the soil’s dry mass; and (5) CHA, as a lone additive, can be used to improve the strength of subgrade materials. If admixed with conventional stabilizers (such as Portland cement and lime), it can be used for the improvement of sub-base and base soil materials.

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