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EFFECTS OF COCONUT SHELL ASH ON LIME STABILIZED LATERITIC SOIL FOR ROAD CONSTRUCTION

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Abstract: The research was carried out to study the effects of coconut shell ash (CSA) on lime stabilized lateritic soil for road construction. Natural lateritic soil was collected from a burrow pit location in Akure, Nigeria. Preliminary tests such as natural moisture content, specific gravity, particle size distribution and Atterberg limits were carried out on the soil for classification and identification purposes. Engineering tests such as compaction, California bearing ratio and unconfined bearing ratio were also carried out on the natural lateritic soil. The soil sample was mixed with lime in proportions of 2, 4, 6, 8 and 10%, and were each subjected to Atterberg limits tests to determine the optimal quantity of lime, which was the amount of lime with the corresponding least value of plasticity index. The optimal quantity of lime was gradually substituted with appropriate amount of CSA in differentials of 1%. Engineering tests were carried out on the lime-CSA mixtures. The optimal percentage of lime-CSA combination was achieved at a 4% lime + 4% CSA because the highest value of Unsoaked CBR was recorded at this stage. The results in terms of the California Bearing Ratio and Unconfined Compressive Strength, indicate that the 4% lime + 4%CSA combination is higher than the 8% lime stabilization.
Keywords: Coconut shell ash, lateritic soil, lime stabilization, road construction

1. INTRODUCTION

Soil Stabilization

Soil stabilization is the alteration of soils to enhance their physical properties. Stabilization can increase the shear strength of a soil and / or control the shrink-swell properties of a soil, thus, improving the load bearing capacity of a sub grade to support pavements and foundations. Soil stabilization can be utilized on roadways, parking areas, site development projects, airports and many other situations where sub-soils are not suitable for construction. Stabilization can be used to treat a wide range of sub grade materials, varying from expansive clays to granular materials. Stabilization can be accomplished by using a wide range of additives, including lime, fly ash and Portland cement, (www.midstatecompanies.com, 2015).

Lime Stabilization

Lime in the form of quicklime (Calcium Oxide-CaO), hydrated Lime (Calcium hydroxide-$Ca(OH)_2$) or Lime slurry can be used to treat soils. Quicklime is manufactured by chemically transforming Calcium Carbonate (Limestone-$CaCO_3$) into calcium oxide. Hydrated Lime is created when quicklime chemically reacts with water. It is hydrated lime that reacts with clay particles and permanently transforms them into a strong cementitious matrix. Most lime used for soil treatment is 'high calcium' lime, which contains no more than 5% magnesium oxide or hydroxide. Sometimes, 'dolomitic' lime is used for soil treatment. The dolomitic lime contains 35 to 46% magnesium oxide or hydroxide. The dolomitic lime can perform well in stabilization but the magnesium fraction reacts more slowly than the calcium fraction (Lime-treated Soil Construction Manual, 2004). Lime has been discovered to react successfully with medium, moderately fine and fine grained soils causing a decrease in plasticity and swell potential of expansive soils and increase in their workability and strength properties. Research has proven that lime may be an effective stabilizer in soils with clay content as low as 7 percent and in soils with plasticity indices below 10. The National Lime Association recommends a plasticity index of 10 or greater in order for lime to be considered as a potential stabilizer whereas the U. S Army Corps of Engineers recommends a plasticity index of 12 or greater for successful lime stabilization. Based on AASHTO classification, soil types A-4, A-5, A-6, A-7 and some of A-2-6 and A-2-7 are suitable for stabilization with lime (NCHRP Web-Only Document 144, 2009). The lime referred to in this study means the hydrated lime.

Furthermore, the mineralogical properties of the soils will determine their degree of reactivity with lime and the ultimate strength that the stabilized layers will develop. In general, fine grained clay soils (with a minimum of 25 percent passing the No 200 seive and a plasticity index value not greater than 12) are rated as appropriate materials for stabilization. These soils containing significant amount of organic material (greater than about 1 percent) or sulfates (greater than 0.3 percent) may require additional lime and / or special construction procedures. Lime stabilization is pronounced in road pavements. For subgrades (or subbases), lime can permanently stabilize fine-grained soil employed as a subgrade or subbase to create a layer with structural value in the pavement system. The treated soils may be in-place (subgrade) or borrow materials. Subgrade stabilization normally involves in-place 'road-mixing' and generally requires adding 3 to 6 percent lime by weight of the dry soil. For road bases, lime can permanently stabilize submarginal base materials (such as clay-gravels, limestones, cliche) that contain at least 50 percent coarse material retained on a #4 screen. Base stabilization is used for new road construction and reconstruction of worn-out roads and generally requires adding 2 to 4 percent lime by weight of dry soil. In-situ 'road-mixing' is most commonly used for base stabilization, although, off-site 'central mixing' can also be used. Lime is also used to improve the properties of soil / aggregate mixtures in 'full depth recycling' (Lime-treated Soil Construction Manual, 2004).

Table 1: Chemical Composition of Coconut Shell Ash

Elemental Oxide	Weight (%)
K_2O	0.83
Na_2O	0.95
CaO	4.98
MgO	1.89
Al_2O_3	24.12
P_2O_5	0.32
SO_3	0.71
SiO_2	37.97
Fe_2O_3	15.48
MnO	0.81
LOI	11.94

Source: Utser and Taku (2012)

Coconut

According to Coconut Research Centre (2015), coconut has its scientific name as Cocos nucifera. Early Spanish explorers called it 'coco', which means 'monkey face' because the three indententations (eyes) on the hairy nut resembles the head and face of a monkey. Nucifera means 'nut-bearing'. Coconut palm trees grow abundantly along the coastline of countries within 15^0 of the equator. They prosper in sandy, saline soil and in tropical climates. A healthy coconut tree will produce approximately 120 watermelon-sized husks per year, each with a coconut imbedded inside. There are three components of the Cocos nucifera that can be used for fuel: the husk, the coconut shell and the coconut oil that is in the white coconut 'meat' or copra as it is normally called. In light of the foregoing, the coconut tree is a very abundant, renewable resource of energy. When coconut is harvested, the husks are removed, thereby leaving the shell and the copra. Large quantities of the shells can be obtained in places where coconut meat is used for food processing. Both the shells and the husks are regarded as waste materials. These materials are burnt into ashes in a furnace at a very high temperature to produce the coconut shell and husk ash (Amu et al., 2011).

2. MATERIALS AND METHODS

Materials

This research was conducted at the Geotechnical Laboratory of the Federal University of Technology, Akure. The materials used were Lateritic soil, Lime, Coconut Shell Ash (CSA), and Potable water.

The lateritic soil samples were obtained from an existing borrow pit in Akure, Nigeria. The tags indicating dates of extraction of the lateritic soil sample, depths of extraction from the borrow pit and the location were affixed to the sacks containing the lateritic soil sample. The samples were kept in the sack and left in the laboratory to enable the samples to be properly air-dried for a minimum of two weeks. The samples were kept away from water and sunlight contacts during the drying process and even drying of the samples was ensured.

The hydrated lime was purchased in 25 Kg bags from a licensed chemical store. The hydrated lime ($Ca(OH)_2$) was also kept away from moisture and any external material that could alter its original property.

Coconut shells were obtained from the store of a local coconut ointment dealer in Akure. The shells were well dried to eliminate moisture and burnt in the open air for three hours and allowed to cool. The burnt ash was ground and seived through a BS Sieve (75 microns) to get the required fine ash.

Potable water was obtained from the running taps in the laboratory.

Methods

The preliminary tests were carried out on the natural lateritic soil sample for the purpose of identification and classification, thereafter, the engineering tests such as California bearing ratio tests, unconfined compressive strength tests and compaction tests were performed on the natural soil sample. Hydrated lime was added to the soil sample in proportions of 2, 4, 6, 8 and 10% and was later subjected to Atterberg limits tests, to detect the optimal amount of lime required which is the amount of lime added where the least value of plasticity index is recorded. The coconut shell ash was added in differentials of 1% in descending order while lime was added in differentials of 1% in ascending order. The corresponding sum of both proportions by percentage of dry weight of soil must equal the optimal amount of lime in percentage by weight of soil, thereafter, each of the mixes was subjected to the following tests: Compaction, California Bearing Ratio (CBR), Atterberg Limits and Unconfined Compressive Strength tests.

» Atterberg limits test

The Atterberg limits tests were carried out in accordance with the British Standard Methods-BS 1377 (1990). The lateritic soil sample was sieved through 0.425mm. Materials that were retained on the sieve was discarded and not used for the test. The soil sample was oven-dried for at least 2 hours before the test. For the stabilized specimens; the tests were carried out on the soils mixed with lime alone and on soils with mixed varying amount of hydrated lime (in ascending order) and varying proportions of CSA (in descending order), the addition of each corresponding proportions of lime and CSA must be equal to the optimal amount of lime used in percentage by weight of dry soil.

» Compaction Characteristics

The proctor standard compaction method was adopted for this study. The test was carried out according to BS 1377 (1990), with the purpose of determining the maximum dry density (MDD) and the optimum moisture content (OMC) of the soils. The soil mixtures (with or without additives) were thoroughly mixed with various moisture content and allowed to equilibrate for 24 hours before compaction. The first aspect of the compaction test involved determining the compaction properties of the natural soil sample. At the second stage, mixing varying amount of hydrated lime (in ascending order) and varying proportions of CSA (in descending order), the addition of each corresponding proportions of lime and CSA must be equal to the optimal amount of lime used in percentage by weight of dry soil. Tests were performed to determine the proctor compaction properties of soil sample mixed with lime.

» California bearing ratio (CBR)

The BS 1924 (1990) stipulates the procedures to follow in carrying out this test. This, was however modified in conformity with the recommendation of the Nigerian General Specification, Federal Ministry of Works and Housing (1997), which stipulates that specimens be cured for six days unsoaked, immersed in water for 24 hours and allowed to drain for 15 minutes before testing.

» Unconfined Compressive Strength (UCS)

The BS 1924 (1990) stipulates the procedure for carrying out this test and was adopted for the natural soil sample. For the stabilized soil mixtures, specimen were prepared by carefully and completely mixing dry quantities of pulverized soil with the varying amount of hydrated lime (in ascending order) and varying proportions of CSA (in descending order), the addition of each corresponding proportions of lime and CSA must be equal to the optimal amount of lime used in percentage by weight of dry soil. The needed amount of water was determined from moisture-density relationships for stabilized-soil mixtures were subsequently added to the mixture. For each of the mix, three specimens were prepared as stipulated by the Nigerian General Specification, Federal Ministry of Works and Housing (1997).

Table 2: Summary of preliminary results

Property	Values
Percentage passing BS No 200 sieve (%)	55
Natural Moisture Content	13.6
Specific gravity	2.36
AASHTO classification	A-7-6
Liquid limit (%)	49.4
Plastic Limit (%)	13.3
Plasticity Index	36.1
Maximum Dry Density (Kg/m^3)	1398
Optimum Moisture Content (%)	17.42
California Bearing Ratio (%)	7.9
Unconfined Compressive Strength (kN/m^2)	57.30

3. RESULTS AND DISCUSSIONS

Preliminary results

The results of the preliminary tests (specific gravity, natural moisture content, particle size distribution and Atterberg limits) and the engineering tests (Compaction- Maximum Dry Density (MDD) and

Optimum Moisture Content (OMC), California Bearing Ratio and Unconfined Compressive Strength (UCS) are presented and discussed below:

From table 2, the natural moisture content of the soil sample is 13.6. According to Amu and Babajide (2011), moisture content of a soil depends on the void ratio. The specific gravity of the soil sample is 2.36. Classification of the soil according to Amadi et al., (2015), it stipulates that for a soil sample to be classified as A-7-6, the percentage passing BS No 200 sieve must be more than 35%, for this soil sample, it is 55%. The minimum value for liquid limit for the A-7-6 category is 40%, the soil sample has a liquid limit of 49.4%. According to Garber and Hoel, (2009), plasticity index of A-7-6 subgroup > LL -30, therefore, 36.1 > 19.4 from the foregoing, the soil rightly belongs to the A-7-6 subgroup.

Engineering Tests

From table 3, the plasticity index of the natural soil was 36.1% with a liquid limit of 49.4% and plastic limit of 13.3% indicating that the clay is of high plasticity in nature. According Amu et al., (2005), high plasticity is an indicator for swelling potential, clay is susceptible to large volume changes if PI is greater than or equal to 30%. The addition of lime at 8% reduced the PI from the highest value at 36.1% to lowest PI value of 12.2%, thus, 8% lime is the optimal amount for lime stabilization.

Table 3: Atterberg Limit tests results for the lime stabilization

% Lime by weight	LL (%)	PL (%)	PI (%)
0	49.4	13.3	36.1
2	46.8	14.5	32.3
4	43.5	16.2	27.3
6	40.2	19.9	20.3
8	35.1	22.9	12.2
10	33.9	15.7	18.2

From table 4, it is also observed that the PI values reduced with the reduction of CSA in the mixture. The PI value at optimal mixture was as a result of 4% lime + 4% CSA, which was 14.3%. From the foregoing, there is the indication that the addition of CSA enhances the soil properties by reducing the PI (Fattah et al., 2013)

Table 4: Atterberg Limit tests results for CSA- Lime stabilization

% Lime by weight	% CSA by weight	LL (%)	PL (%)	PI (%)
1	7	59.1	28.0	31.1
2	6	65.3	37.3	28.0
3	5	55.5	34.9	20.6
4	4	51.4	37.1	14.3
5	3	53.8	36.7	17.1
6	2	54.7	36.4	18.3
7	1	52.6	35.7	16.9

» **Compaction test**

From table 5, the natural soil sample had maximum dry density (MDD) of 1398 Kg/ m³ and optimum moisture content (OMC) of 17.42%, the addition of 8% lime reduced the MDD to 1374 Kg/ m³ and increased the OMC to 23.24%, while the addition of 4% lime + 4% CSA increased the MDD to 1387 Kg/m³ and increased the OMC to 25.35%. According to Amu et al, (2011), increase in MDD with lime content is indicative of improvement in soil properties. It may also be due to a decrease in surface area of the clay fraction of the lateritic soil arising from the substitution of the lateritic soil with lime (Manasseh and Joseph, 2015).

Table 5: Compaction tests results

% Additive by weight	MDD (Kg/m³)	OMC (%)
0%	1398	17.42
8% lime	1374	23.24
4% lime+ 4% CSA	1387	25.35

» **California Bearing Ratio**

California bearing ratio is one of the common tests widely used in the design of base and subbase material for pavement and can be used to evaluate the strength of the stabilized soils (Ogunribido, 2011). From table 6, the unsoaked value of the soil sample is 7.9%, while the lime-stabilized CBR is 31.76% at 8% lime which is just fair enough a value for use as a sub grade material (Amadi et al., 2015). The addition of 4% lime + 4% CSA gave a CBR value of 49.70% which is adequate enough for use as sub base, by Nigerian Specifications for road construction (Federal Ministry of Works and Housing, 1997).

Table 6: CBR values for Unsoaked condition

% Additive by weight	Unsoaked CBR values (%)
0%	7.90
4% lime + 4% CSA	49.70
8% lime	31.76

» **Unconfined Compressive Strength**

The unconfined compressive strength (UCS) test is a special type of unconsolidated-undrained test that is commonly used for clay specimens where the confining pressure (σ_3) is zero and the major principal stress (σ_1) is the unconfined compressive strength (q_u) (Bello et al., 2015). Unconfined compressive strength is also the test for the determination of the required amount of additives to be used in the stabilization of the soil (Ogunribido, 2011). From table 7, the unconfined compressive strength value for the natural clay soil was 57.30 kN/m², the addition of 8% lime raised this value to 198 kN/m². The addition of 4% lime + 4% CSA further increased the value to 242.89 KN/m². The resultant increase in values of Unconfined Compressive Strength (UCS) upon the addition of CSA may be attributed to the formation of cementitious compounds between the CaOH present in the soil and CSA and the pozzolans present in CSA.(Fattah et al., 2013).

Table 7: Unconfined Compressive Strength values

% Additive by weight	UCS values (kN/m²)
0%	57.30
4% lime +4% CSA	242.89
8% lime	198.00

4. CONCLUSION

The tests were carried out in accordance with BS 1377 (1990) and BS 1924 (1990). This study reveals that the combination of lime-CSA yields better results than lime alone in stabilizing such a poor soil.
The CSA cannot effectively be used alone in stabilizing poor soils but could still be used with lime to achieve adequate strength in terms of California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS).
The results in terms of the California Bearing Ratio and Unconfined Compressive Strength, indicate that the 4% lime + 4% CSA combination is higher than the 8% lime stabilization.
Coconut Shell Ash (CSA) can therefore serve as a cheap compliment for lime in soil stabilization.

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