Potentials of Coconut Shell and Husk Ash on the Geotechnical Properties of Lateritic Soil for Road Works

Olugbenga O. Amu[*1], Opeyemi S. Owokade[2], Olakanmi I. Shitan[3]

[1] *Senior Lecturer / Civil Engineering Dept., Obafemi Awolowo University, Ile-Ife, Nigeria*

[2,3] *Research Student / Civil Engineering Dept., Obafemi Awolowo University, Ile-Ife, Nigeria*

* Corresponding Author

*E-mail: olugbengaamu@yahoo.com, Tel. No: +234-803-5188-646

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***Abstract*– This paper examined the geotechnical properties of lateritic soils modified with coconut shell and husk ash with a view to obtaining a cheaper and effective road stabilizer. After collecting samples A, B and C from three borrow pits meant for road construction works, we performed preliminary tests on them for identification and classification purposes, followed by the consistency limit tests. We also performed engineering property tests (compaction, California bearing ratio (CBR) and triaxial) both at the stabilized and unstabilized states with the addition of 2, 4, 6, 8 and 10% coconut shell and husk ash (CSHA) contents. The results showed that the soil samples were well graded sand with good to excellent rating as subgrade material for pavement construction. However, the engineering properties of the samples were further improved with the addition of 4% CSHA contents. This caused reductions in the PI of samples A and C from 20.43 to 16.74% and 29.51 to 15.67% respectively and reduction at 2% of CSHA in sample B. We obtained optimum values of maximum dry densities (MDD) and shear strengths at 4% CSHA stabilization. The addition of CSHA increased the values of shear strengths to 136.32, 146.91 and 127.96 kN/m^2 whereas MDD increased to 1939.00, 1749.86 and 2080.25kg/m^3 respectively in samples A, B and C. We therefore concluded that coconut shell and husk ash has a good potential for improving the geotechnical properties of lateritic soils.**

***Index Terms*- Coconut shell ash, geotechnical property, road stabilization, soil improvement**

I. INTRODUCTION

Pavement engineers have long recognized the long term benefits of improving the strength and durability of pavement soil by mixing in a cementitious binder during reconstruction or new construction. Millions of Naira can be saved by soil stabilization in comparison to cutting and replacing the unstable soil material. When included in pavement design, stabilizing the subgrade can reduce the thickness of other pavement layers [1-2]. Laterite which is good for road construction occurs in large quantity in the tropical areas which includes Nigeria. This laterite may contain some amount of clay minerals such that its strength and durability cannot be determined under load, especially in the presence of moisture. Since this type of soil is common in Nigeria, it will be economically wise to improve it to meet the desired properties [1-2]. Over the years, cement and lime have been used to stabilize subgrade materials. These materials have rapidly increased in price due to the sharp increase in the cost of energy since 1970s [3]. This has recently motivated researchers aimed at sourcing possible alternative soil stabilizing materials, especially those that are locally available and less costly. Many local materials which have been used by different researchers include: rice husk ash, sawdust ash, sugarcane ash, all of which are easily obtainable since the parent materials are usually regarded as waste. This study is therefore aimed at investigating the potentials of the coconut shell and husk ash as stabilizer in lateritic soil for road works.

A. Lateritic Soil

The soil name "laterite" was coined from a Latin word "later" meaning brick. Soils under this classification are characterized by forming hard, impenetrable and often irreversible pans when dried. However there is confusion in the use of the term, because a variety of materials with many types of compositions and various origins have been called laterites, ranging from iron cappings found on the plateaux of Southern India to the zonal soils of the humid tropics and from the whole weathered profile beneath a laterite of Buchanan's meaning to the iron-rich breccias and slope wash accumulations. Because of this confusion, most workers now prefer to use the definitions based on hardening, such as "ferric" for iron-rich cemented crusts, "alcrete" or bauxite for aluminium-rich cemented crusts, "calcrete" for calcium carbonate-rich crusts, and "silcrete" for silica rich cemented crusts [4]. Other definitions have been based on the ratios of silica (SiO_2) to sesquioxides (Fe_2O_3, Al_2O_3). In laterites, the ratios are less than 1.33. Those between 1.33 and 2.0 are indicative of laterite soils, and those greater than 2.0 are indicative of non-lateritic soils [5].

When the grading of lateritic gravel is close to a mechanically stable particle size distribution, the material performs satisfactorily both as unstabilized base and or subbase in light trafficked gravel roads [6]. A satisfactory performance of laterite pavements has generally been reported on laterite gravels that posses adequate strength, not over-compacted, and are provided with adequate drainage. Weakly indurated gravels have a tendency to break down during compaction and under repeated traffic loading, resulting in the increase of fines. The situation may be worsened by water due to its softening effect on the soil and to the strength reduction it causes. This leads to pavement distress and partially to failure. Many laterites contain a proportion of quartz.

The most common materials used in the construction or rehabilitation of the rural access roads are lateritic soils. This is because: (a) they are the most common naturally-occurring materials, (b) in the tropics weathering is intense, and hence there is lack of good quality crushed aggregate, (c) long haulage distances and the associated high costs involved in the transportation of good quality aggregates, make the utilization of laterite gravels economically attractive. The wide spread evidence of the deterioration of laterite roads in Nigeria, and probably other developing tropical countries emphasize the need for careful assessment of lateritic gravel to be used for road construction. Geotechnical properties of lateritic soils are influenced by the degree of weathering, the amount of sesquioxides and degree of desiccation in the soil, the clay-size content and the clay mineralogy, the mica content, and the position of the soil in the laterite profile. A critical assessment of the above factors may give a basis to predict the behaviour of a given laterite soil in the field. A proper understanding of the geotechnical properties of soil is required in the selection of suitable base for highway construction.

B. Soil Stabilization

Stabilization may be defined as any process by which a soil material is improved and made more stable. Soil stabilization is the treatment of natural soil to improve its engineering properties. Soil stabilization occurs when lime is added to a reactive soil to generate long-term strength gain through a pozzolanic reaction. This reaction produces stable calcium silicate hydrates and calcium aluminate hydrates as the calcium from the lime reacts with the aluminates and silicates solubilized from the clay. The full-term pozzolanic reaction can continue for a very long period of time, even decades, as long as enough lime is present and the pH remain high (above 10). As a result, lime treatment can produce high and long-lasting strength gains. The key to pozzolanic reactivity and stabilization is a reactive soil, a good mix design protocol, and reliable construction practices [7]. The goals of stabilization are therefore to improve the soil strength, to improve the bearing capacity and durability under adverse moisture and stress condition, and to improve the volume stability of a soil mass. There is the tendency for laterite gravels to be gap-graded with depleted sand-fraction, to contain a variable quantity of fines, and to have coarse particles of variable strength which break down, limits their usefulness as pavement materials; especially on roads with heavy traffic and adverse moisture conditions. To improve these deficiencies, and consequently to improve on their field performance characteristics, they need to be stabilized. There are three purposes for soil stabilization. The first one is strength improvement. This increases the strength of the existing soil to enhance its load-bearing capacity. The second purpose is for dust control. This is done to eliminate or alleviate dust generated by the operation of equipment and aircraft during dry weather or in arid climates. The third purpose is soil waterproofing, which is done to preserve the natural or constructed strength of a soil by preventing the entry of surface water. Basically, two methods are employed in the stabilization of lateritic soils, these are: mechanical stabilization and chemical stabilization.

C. Source of Coconut Shell and Husk Ash

Cocos Nucifera trees, otherwise known as coconut palm trees, grow abundantly along the coast line of countries within 15^{o} 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 constituents 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 usually called. Thus, the coconut tree is a very abundant, renewable resource of energy. When coconuts are harvested, the husks are removed, thereby leaving the shell and the copra. Plate 1 shows the coconut with the husk being removed whereas plate 2 shows the different layers of the coconut fruit. These husks are considered as waste materials and are usually dumped into refuse bin. When consumers buy the coconut, they buy it with the shell and when it is to be consumed it is broken and the shell is removed. Large quantities of the shells can be obtained in places where coconut meat is used in food processing. The husk and the shell are both regarded as waste materials. These materials are then burnt into ashes in a furnace at a very high temperature to produce the coconut shell and husk ash. The coconut shell when dried contains cellulose, lignin, pentosans and ash in varying percentage. Table 1 shows the percentage composition of the shell whereas Table 2 shows the constituent in the coconut shell ash.


Plate 1. Coconut with the husk being removed

Plate 2. Different parts of the coconut fruit

TABLE 1
COCONUT SHELL COMPOUND (DRY BASIS)

Compound	**Percent**
Cellulose	33.61
Lignin	36.51
Pentosans	29.27
Ash	0.61

TABLE 2
COCONUT SHELL ASH COMPOUND

Compound	**Percent**
K_2O	45.01
Na_2O	15.42
CaO	6.26
MgO	1.32
$Fe_2O_3 + Al_2O_3$	1.39
P_2O_5	4.64
SO_3	5.75
SiO_2	4.64

II. MATERIALS AND METHODS

A. *Materials and Preparations*

Lateritic soil samples, coconut shell and husk ash and water were used for this study. The lateritic soil samples were obtained from three different borrow pits meant for road construction works. This was meant to serve as reference guide for the soil samples after pavement construction. These borrow pits were located in Osogbo, Ile-Ife and Ibadan, Nigeria. The soil samples were obtained at average depths of 4m to obtain true representative samples of the soils used for the road construction. The natural moisture contents of the samples were immediately determined on getting to the laboratory and the samples were kept safe and dry in jute bags in the Geotechnics laboratory of the Department of Civil Engineering, Obafemi Awolowo University, Ile-Ife. Marks were placed on them to indicate soil descriptions, sampling depths and dates of sampling. The samples were spread on different matting to facilitate air drying. All the clods and lumps in the samples were broken down and well pulverized before running classification test on them. The coconut shells and the husk were obtained from a market waste dump. They were subsequently spread on matting and allowed to properly dry to facilitate proper combustion during burning. The coconut shells and the husk were burnt separately in a metal drum. The ashes formed were allowed to cool down before sieving through 4.75mm BS sieve. The ashes were therefore stored in airtight containers to prevent moisture loss and any form of contamination. The portable water available in the laboratory was used for the study.

B. *Methods*

Preliminary tests (natural moisture content, specific gravity, particle size analysis and Atterberg's limits) were performed on the three soil samples for classification and identification purposes. Coconut shell and husk ash (CSHA) was added to each of the soil samples in 2, 4, 6, 8 and 10% by weight of the samples. Atterberg's limits and engineering property tests (compaction, California bearing ratio (CBR), undrained triaxial) were also performed on the samples. The effects of the coconut shell and husk ash as stabilizing agent on the 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 from the preliminary test (natural moisture content, specific gravity, particle size analysis and Atterberg's limits) as well as the engineering property tests (compaction, California bearing ratio (CBR), undrained triaxial) are discussed below.

A. *Preliminary Tests*

The natural moisture contents of samples A, B, C are 21.31, 12.01 and 22.22% respectively. The summary of the preliminary test is given in Table 3. This shows that sample C has the highest natural moisture content. In reference [8], the performance of lateritic soil may be influenced by the climate, hydrological regime of the area in which the road is to be constructed and the topography. These factors might be responsible for the variation in the natural moisture contents of the three soil samples.

The specific gravities of samples A, B and C are 2.31, 2.56 and 2.81 respectively. This is a measure of the weight of the aggregate to the weight of an equal volume of water. The results showed that soil samples A and B contained majorly quartz mineral whereas sample C is montmorillonitic in nature [9]. Reference [8] stated that many laterites contain a proportion of quartz which is a determinant in the strength of soil. Therefore, samples A and B have significant strength indices than sample C.

TABLE 3
SUMMARY OF THE PRELIMINARY TEST OF THE SOIL SAMPLES

Sample	Natural Moisture Content (%)	Specific Gravity	Liquid Limit (%)	Plastic Limit (%)	Plastic Index (%)
A	21.31	2.31	45.75	25.32	20.43
B	12.01	2.56	49.00	28.80	20.20
C	22.22	2.81	62.40	32.89	29.51

The results of the sieve analysis showed that less than 35% of the three samples pass the sieve number 200 (75µm sieve). This indicates that all the samples are within the granular material family. Under the AASHTO classification system, they fell within the range of A1 to A3 soils. This implies that they are fairly good for road construction.

The results obtained from Atterberg's limits test are very essential for the classification of soil samples for pavement construction. The variations of the Atterberg's limits with the addition of CSHA in the three samples are shown in Figures 1-3. The liquid limit (LL), plastic limits (PL) and the plastic index (PI) for the natural soil samples are 45.75, 25.32 and 20.43% respectively for sample A, whereas sample B are 49.00, 28.80 and 20.20% respectively and 62.40, 32.89 and 29.51% respectively for sample C. According to reference [10], liquid limit between 35% and 50% indicates intermediate plasticity, between 50% and 70% high plasticity and between 70% and 90% very high plasticity. This indicates that samples A and B have intermediate plasticity whereas sample C has a high plasticity. The addition of 4, 2 and 4% of CSHA caused PI values to reduce in samples A, B and C respectively.

B. Engineering Tests

Table 4 shows the summary of the compaction test results. The MDD increased from 1649.00 to 1939.00kg/m^3, 1467.77 to 1749.86kg/m^3 and 1350.67 to 2080.25kg/m^3 respectively in samples A, B and C, all at 4% CSHA content. The optimum moisture contents (OMC) also reduced correspondingly in all the samples with the addition of CSHA. An increase in MDD is a good indication of improvement in soil property, whereas a reduction in OMC enhances the workability of a good soil.

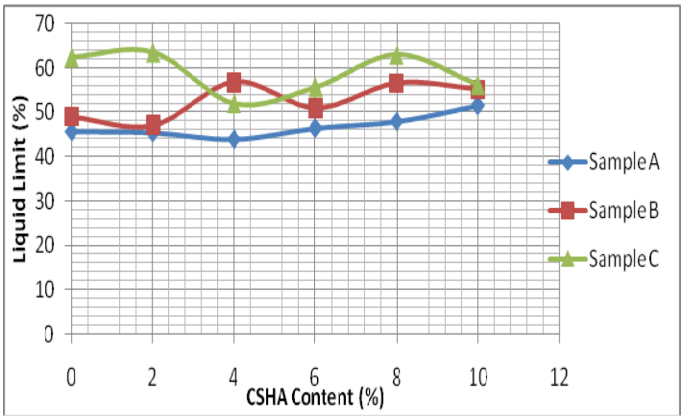

Fig. 1. Variation of liquid limit with CSHA content for the three soil samples

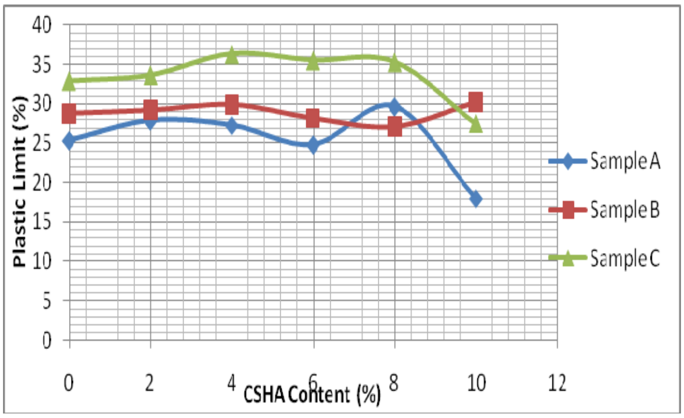

Fig. 2. Variation of plastic limit with CSHA content for the three soil samples

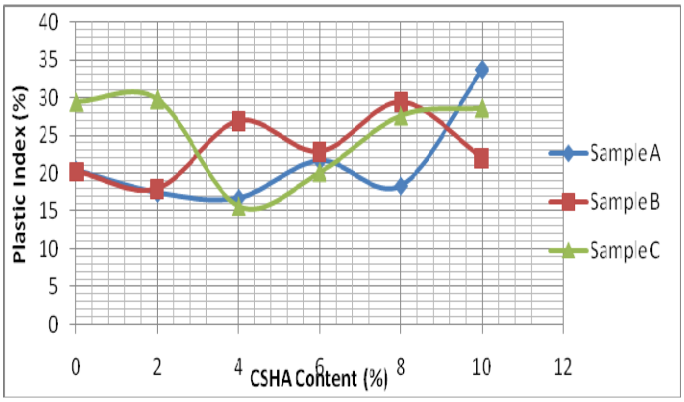

Fig. 3. Variation of plasticity index with CSHA for the three soil samples

TABLE 4
SUMMARY OF COMPACTION TEST RESULTS

Sample	Percentage Stabilization	Optimum Moisture Content (OMC) (%)	Maximum Dry Density (MDD) (kg/m^3)
A	0%	24.56	1649.00
	2% CSHA	16.50	1824.00
	4% CSHA	8.39	1939.00
	6% CSHA	9.33	1872.00
	8% CSHA	11.83	1842.00
B	0%	19.10	1467.77
	2% CSHA	18.75	1710.77
	4% CSHA	18.60	1749.86
	6% CSHA	17.11	1690.51
	8% CSHA	20.61	1656.00
C	0%	21.06	1350.67
	2% CSHA	19.50	1772.92
	4% CSHA	18.05	2080.25
	6% CSHA	21.00	1738.23
	8% CSHA	20.49	1556.62

Triaxial test is the most common and versatile test used to determine the stress-strain properties of the soil. Table 5 shows the summary of the unconsolidated undrained triaxial test results. The optimum shear strengths were obtained at 4% CSHA for all the samples. Shear strengths of samples A, B and C increased to 136.32kN/m^2, 146.91kN/m^2 and 127.96kN/m^2 respectively at 4% CSHA contents.

The results of the California Bearing Ratio (CBR) test are summarized in Table 6. The unsoaked CBR values of soil samples B and C increased gradually as the percentages of CSHA increased. The CBR tests were only possible on samples B and C due to a faulty CBR machine. The CBR values in sample C reached a maximum value of 23.05% at 8% CSHA stabilization, whereas the maximum value of 5.85% was obtained at 8% addition of CSHA in sample B. However, the minimum value of unsoaked CBR for subgrade is 10% [11]. Therefore sample B will not be adequate as a subgrade material.

TABLE 5
SUMMARY OF UNDRAINED TRIAXIAL TEST RESULTS

Sample	CSHA Content	Deviator Stress (kN/m^2)	Cohesion (kN/m^2)	Angle of Internal friction (ϕ)	Shear Stress τ
	0%	87.115	24.41	13	44.52
	4%	170.82	37.7	30	136.32
A	6%	83.497	19.5	17	45.02
	0%	154.372	67.25	10	94.47
B	4%	208.497	40.68	27	146.91
	6%	163.141	73.5	7	93.53
	0%	156.286	25.5	27	105.13
C	4%	167.857	42.43	27	127.96
	6%	122.91	42.43	20	87.17

TABLE 6
SUMMARY OF CBR TEST RESULTS

Sample	Percentage Stabilization	Unsoaked CBR (%)
	0%	1.14
B	2%CSHA	1.90
	4% CSHA	3.55
	6% CSHA	4.15
	8% CSHA	5.85
	0%	4.15
C	2%CSHA	7.60
	4% CSHA	8.95
	6% CSHA	16.75
	8% CSHA	23.05

IV. CONCLUSION

The plastic index of each sample reduced with the addition of various percentages of CSHA, indicating a reduction in swelling potential and hence an increase in strength properties. The samples gained higher unit weights with the addition of CSHA, the shear strengths of all samples increased respectively at 4% CSHA and that the CBR values increased gradually with increased percentages of CSHA. It was therefore concluded that coconut shell and the husk ash can effectively stabilize lateritic soil samples for road works.

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