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Geotechnical Properties of Lateritic Soil Stabilized with Ground-Nut Husk Ash

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Abstract

This study assesses the geotechnical properties of lateritic soil stabilized with Ground-nut Husk Ash. Preliminary tests were carried out on the natural soil sample for identification and classification purposes, while consistency limits tests were thereafter carried out as well. Engineering property tests such as California Bearing Ratio (CBR), Unconfined Compressive Strength (UCS) and compaction tests were performed on both the natural soil sample and the stabilized lateritic soil, which was stabilized by adding Ground-nut Husk Ash, GHA, in percentages of 2, 4, 6, 8 and 10 by weight of the soil. The results showed that the addition of GHA enhanced the strength of the soil sample. The Maximum Dry Density (MDD) reduced from 1960 kg/m^3 to 1760 kg/m^3 at 10% GHA by weight of soil. The Optimum Moisture Content (OMC) increased from 12.70% to 14.95%, also at 10% GHA by weight of soil. The unsoaked CBR values increased from 24.42% to 72.88% finally, the UCS values increased from 510.25 kN/m^2 to 1186.46 kN/m^2, for both CBR and UCS, the values were at 10% GHA by weight of soil. It was therefore concluded that GHA performs satisfactorily as a cheap stabilizing agent for stabilizing lateritic soil especially for subgrade and sub base purposes in road construction.

Keywords: Geotechnical Properties; Ground-nut husk Ash; Lateritic Soil; Stabilization; Strength Tests.

1. Introduction

Laterites are soil types rich in iron and aluminum that are formed in tropical areas. Most laterites are rusty-red because of the presence of iron oxides. They develop by intensive and long- lasting weathering of the underlying parent rock. Tropical weathering (laterization) is a prolonged process of chemical weathering which produces a wide variety in the thickness, grade, chemistry and ore mineralogy of the resulting soils. The initial products of weathering are essentially kaolinized rocks called saprolites [1]. Lateritic soils are products of tropical weathering with red, reddish- brown or dark brown colour, with or without nodules or concretions and generally (but not exclusively) found below hardened ferruginous crusts. Laterite formation factors include climate (precipitation, leaching, capillary rise and temperature), topography (drainage), vegetation, parent rock (iron rich rocks) and time of these primary factors. However, climate is considered to be the most important factor [2].

Soil stabilization aims at improving soil strength, controlling dust and increasing resistance to softening by water through bonding of the soil particles together thereby water proofing the particles or a combination of the two [3, 4]. The simplest stabilization processes are compaction and drainage (if water drains out of wet soil, it becomes stronger). The other process is by improving the gradation of particle size and further improvement can be achieved by adding binders to weak soils [5].

Soil stabilization can be accomplished by several methods, all these methods fall into two broad categories namely mechanical and chemical stabilization. Mechanical Stabilization is a physical process that involves altering the physical nature of native soil particles by either induced vibrations or compaction or by incorporating other physical properties such as barriers and nailing. Chemical Stabilization involves initiating chemical reactions between

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stabilizers (cementitious material) and soil minerals (pozzolanic materials) to achieve the desired effect of improving the chief properties of a soil that are of interest to engineers namely volume stability, strength, compressibility, permeability and durability [3, 6, 7].

1.1. Alternatives to Cement

About 7% of CO_2 is released into the atmosphere during the cement production [8]. This has negative effects on the ecology and future of human beings one of which is global warming. Research on alternatives to cement has so far centred on the partial replacement of cement with different materials. In advanced countries, partial replacement of cement with pozzolans is well documented.

Reasons for finding alternatives to cement include the following: high cost of production, high energy demand and emission of CO_2 (responsible for global warming). In third world countries, the most common and readily available material that can partially replace cement without economic implication are bio-based materials and agro-based wastes; notable ones are Achahwok ash, Bambara groundnut shell ash, bone ash, groundnut husk ash, rice husk ash and wood ash, dried banana leaves, bagasse, bamboo leaves, some timber species and periwinkle shell ash [9].

1.2. Need to Stabilize Laterites

Lateritic soils are generally used for road construction in Nigeria. Lateritic soils in its natural state generally have low bearing capacity and low strength due to high clay content. The strength and stability of lateritic soil containing large amounts of clay cannot be guaranteed under load in the presence of moisture [10]. The use of lateritic soils consisting of high plastic clay content results in cracks in and damage to pavement, roadways, foundations or any civil engineering construction.

The need to improve the strength and durability of lateritic soil in recent times has become imperative, this has geared researchers towards using stabilizing materials that can be sourced locally at a very low cost [11]. These local materials can be classified as either agricultural or industrial wastes [12]. In cases where sourcing for durable soil may prove economically unwise, the viable option is to stabilize the available soil to meet the specified requirements of construction [13, 14].

1.3. Cement Stabilization

According to Jaritngam et al, 2014 [15], cement stabilization involves three processes: cement hydration, cation exchange reaction and pozzolanic reaction carbonation. Cement hydration is a chemical reaction between cement and water whereby calcium hydroxide or hydrated lime $Ca(OH)_2$ is produced. The soil-cement reaction involves the replacement of divalent calcium (Ca^{2+}), absorption of $Ca(OH)_2$ by particles and cementation at inter-particle contacts by the tobemorite gel, which are responsible for strength increases in the treated soil.

Cation exchange reaction involves replacement of univalent sodium (Na+) and hydrogen (H+) ions in the soil with Ca^{2+} from cement. Clay particles continue to absorb $Ca(OH)_2$ until the clay is saturated with it. Such exchange reduces the plasticity, improve workability and shear strength of the soil. The reaction starts immediately upon mixing cement into the soil.

Pozzolanic reaction and carbonation involves the reaction between clay particles and $Ca(OH)_2$ that is produced by cement hydration. This contributes to the long-term strength of the cement paste and pozzolonic materials.

Strength of the stabilized soil increases with time due to pozzolanic reaction. Calcium hydroxide in soil water reacts with the silicates and aluminates (pozzolans) in the soil to form cementing materials or binders, consisting of Calcium Silicate hydrates.

When Portland cement is added to lateritic soil, a soil-cement mixture known as Calcium aluminate silicate hydrate (CASH) is formed. As the pozzolanic reaction progresses, CASH is slowly converted into a well-crystalline phase to form Calcium silicate hydrate (CSH) and Calcium aluminium hydrate (CAH) which hardens with age to form a permanent compound that binds the soil particles. As a result, the shear strength of the stabilized soil is improved.

2. Methods

The materials used for this research work were lateritic soil and Ground-nut Husk Ash, GHA. The disturbed lateritic soil samples were collected from within the campus of the Federal University of Technology, Akure (FUTA), and Nigeria. The lateritic soil was collected at depths representative of the soil stratum and not less than 1.2 m below the natural ground level. It was thereafter brought to the Geotechnical laboratory of the Federal University of Technology, Akure (FUTA) and marked, indicating the soil description, sampling depth and date of sampling. The lateritic soil was air-dried for two weeks to allow for partial elimination of natural water content which may affect the analysis, then sieved with sieve no 4 (4.75 mm opening) to obtain the final soil samples for the tests. After the drying period, lumps in the samples were pulverised under minimal pressure.

The GHA were obtained from a groundnut vendor and later burnt into ashes. It was collected in polythene bags, stored under room temperature until used. Furthermore, the ashes were sieved through BS Sieve 75µm and kept covered before and after use to prevent moisture and contaminations from other materials.

The following tests namely particle size distribution, Atterberg limit, British Standard (BS) compaction, unconfined compressive strength (UCS) and California bearing ratio (CBR) tests were carried out on the unstabilised samples to obtain its index properties in accordance with [16]. Thereafter, compaction unconfined compressive strength and California Bearing Ratio (CBR) tests were carried out on the stabilized samples in accordance with British Standards, 1990 [17].

2.1. Particle Size Distribution Test

The objective of this test is to determine the gradation of the soil to be stabilized. A representative sample of approximately 500g was used for the test after washing and oven-drying. The sample was washed using the BS 200 Sieve and the fraction retained on the sieve was aired-dried and used for sieve analysis. The sieving was carried out by mechanical method using an automatic shaker and set of sieves.

2.2. Liquid Limit Determination

Soil Sample passing through 425 µm sieve, weighing 200 gr was mixed with water to form a thick homogeneous paste. The paste was collected inside the Casagrande's apparatus cup with a groove created and the number of blows to close it was recorded. The corresponding moisture content was used to indicate the liquid limit.

2.3. Plastic Limit Determination

Soil Sample weighing 200 gr was taken from the material passing the 425 µm test sieve and then mixed with water till it became homogenous and plastic and was able to be shaped into a ball. The ball of soil was rolled on a glass plate until the thread cracked at approximately 3 mm diameter. The corresponding moisture content was used to indicate the plastic limit.

2.4. Compaction Test

Compaction tests were carried out on the air-dried lateritic soil samples which were divided into two groups. The first group was for the control experiment, the second group of lateritic soil had the GHA added in proportions of 2, 4, 6, 8 and 10 % by weight of the dry lateritic soil sample. The maximum dry densities and optimum moisture contents were determined for the soil with and without the additives.

2.5. California Bearing Ratio Test

The CBR value is the resistance to a penetration of 2.5 mm of a standard cylindrical plunger of 50 mm diameter expressed as a percentage of the known resistance of the plunger to 2.5 mm in penetration in crushed aggregate (taken as 13.2 kN). The strength of a subgrade, sub base and base course materials for road construction is expressed in terms of their CBR value [18].

2.6. Unconfined Compressive Strength Test

In this test, the minor principal stress is equal to zero and the deviator stress at failure is called unconfined compressive test [19]. This is the simplest form of shear strength test. It cannot be made for cohesionless soil or on clay and silt which are too soft to stand in the machine without collapsing before the load is applied. [20].

3. Results

Chemical Composition of Ground-nut Husk Ash (GHA):

Table 1. Chemical Composition of Ground-nut Husk Ash [21]

Elemental Oxide	Weight Composition (%)
SiO_2	51.54
Al_2O_3	22.45
Fe_2O_3	2.40
CaO	15.63
MgO	1.20
TiO_2	0.13
MnO	0.05
P_2O_5	0.60
S	0.38
SO_3	0.94
LOI	3.98
others	0.70

Table 1 shows the elemental oxides present in the GHA and their respective weight composition in percentages [21]. Silica- SiO_2 has the highest value with 51.54%, followed by $Al_2 O_3$ with 22.45%. The compound with the third highest value is CaO with 15.63%. According to Egbe-Ngu et al, 2014 [22], the CaO content (15.63%) in GHA shows that it has some self-cementing properties. The total percentage of these three elemental oxides-Fe_2O_3, Al_2O_3 and SiO_2 is found to be more than the minimum 70% specified for pozzolanas [23]. A pozzolana is a siliceous material which by itself does not possess cementitious properties but will in finely divided form and in the presence of water react with calcium hydroxide, $Ca(OH)_2$ to form cementitious compounds [24].

3.1. Preliminary Tests on the Unstabilized Soil Sample

Table 2 shows the properties of the untreated lateritic soil sample. At this state, its natural moisture content was 13.4% and specific gravity was 2.40. This specific gravity value of the soil falls within the range for clay materials as halloysites [25], whose range of specific gravity is 2.0-2.55. Its liquid limit value was 36.50%, plastic limit was 19.30% and plasticity index 17.20%. The soil was further classified as an A-2-6. For the A-2 group, the maximum value for materials passing through the No 200 sieve is 36%, the maximum liquid limit value for A-2-6 group is 40%, and plasticity index is expected to have minimum value of 11% [26]. Compaction test on the unstabilized lateritic soil gave a maximum dry density (MDD) of 1960 kg/m^3 with corresponding optimum moisture content (OMC) of 12.70%, while its California bearing ratio (CBR) and unconfined compressive strength (UCS) were 24.42% and 510.25 kN/m^2 respectively.

Table 2. Properties of the natural lateritic soil

Property	Value
Natural moisture content	13.40%
Specific gravity	2.40
Liquid limit	36.50%
Plastic limit	19.30%
Plasticity index	17.20%
AASHTO classification	A-2-6
Soil type (USCS)	GP
Maximum dry density (MDD)	1960 kg/m^3
Optimum moisture content (OMC)	12.70%
California bearing ratio (CBR)	24.42%
Percentage passing BS Sieve No 200	29.4%
unconfined compressive strength (UCS)	510.25 kN/m^2

3.2. Compaction Tests on Lateritic Soil Containing the Additives

The specific gravity of GHA is 1.85 [27]. This specific gravity value falls within 1.9- 2.4, which is the range of pulverized fuel ash as stipulated in ASTMC-218 [28].

As shown in Figure 1. a decrease in values of MDD from 1960 kg/m^3 at 0% to 1760 kg/m^3 corresponds to increasing percentages of added GHA from 0% to 10% GHA by weight of soil. Also, the values of OMC increased from 12.70% at 0% to 14.95% at 10%. The decrease in values of Maximum Dry Density (MDD) can be attributed to the replacement of soil by the GHA in the mixture which has relatively lower specific density (1.85) compared to that of the soil which is 2.40. It may also be attributed to coating of the soil by the GHA which results to large particles with larger voids with resultant less density. Furthermore, decrease in MDD may be explained by considering the GHA as filler (with lower specific gravity) in the soil voids [29]. Increase in OMC (Figure 2.) is due to the addition of GHA which decreases with the quantity of free silt and clay fraction and coarser materials with larger surface areas were formed, these processes need water to manifest [30] The increase in value of Optimum Moisture Content from 12.70% at 0% to 14.95% at 10% GHA by weight of soil implies that more water is needed to compact the soil-GHA mixtures [31].

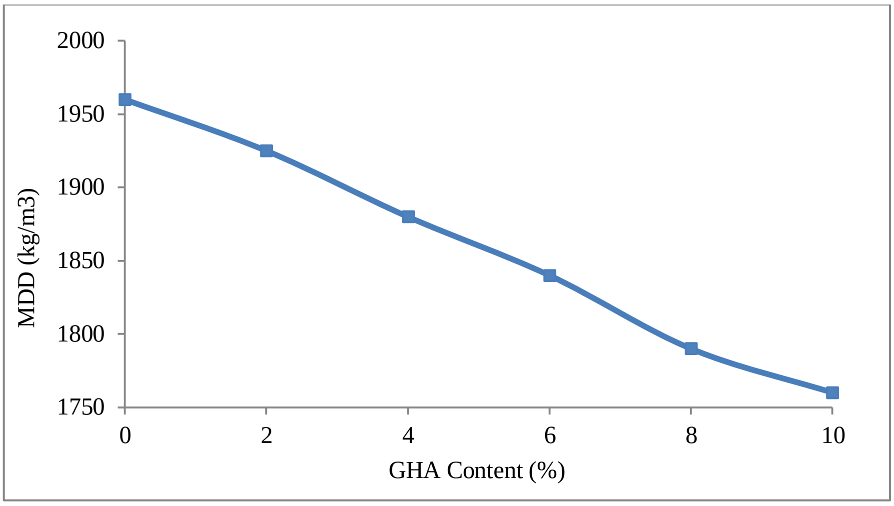

Figure 1. Measured MDD values as a function of the added GHA values

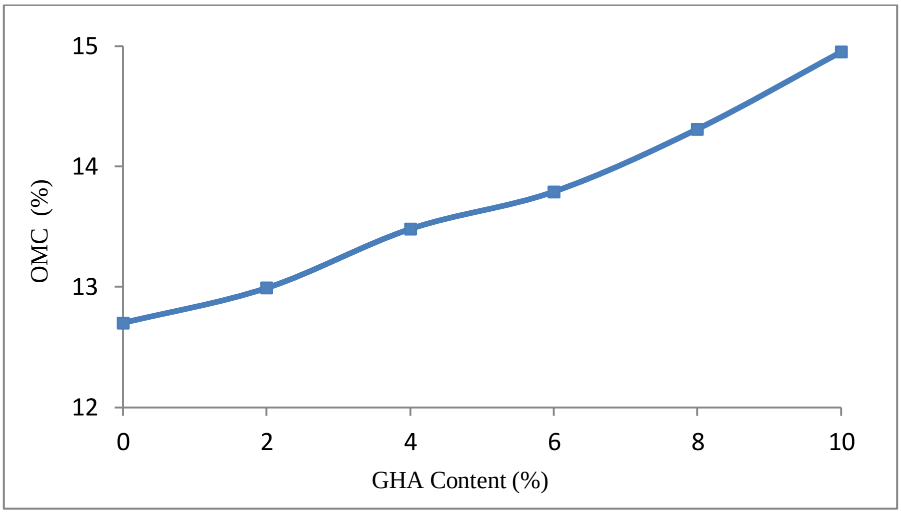

Figure 2. Measured OMC values as a function of the added GHA values

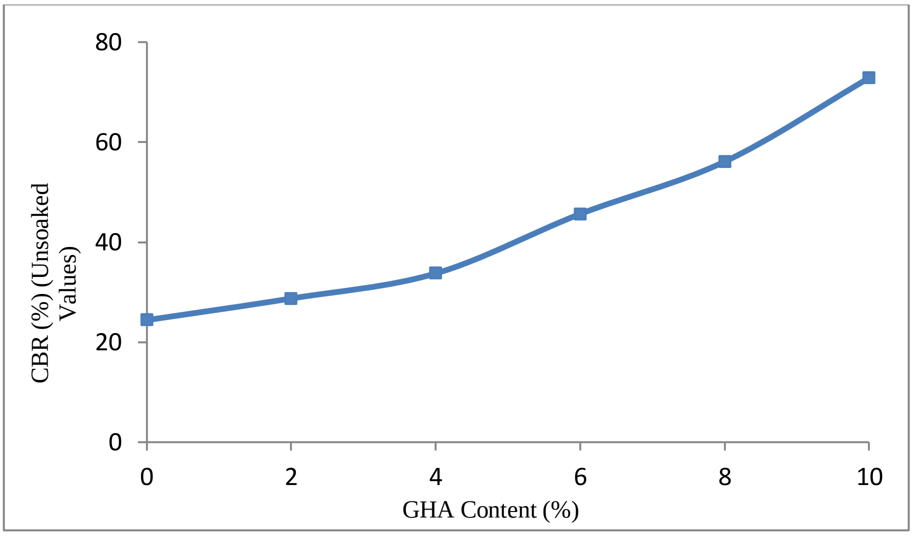

Figure 3. Measured CBR values as a function of added GHA values.

As shown in Figure 3. the CBR value increases from 24.42% at 0% GHA to 72.88% at 10% GHA by weight of soil. Such increase may be due to the gradual formation of cementitious compounds in the soil by the reaction between the GHA and some amounts of Calcium hydroxide present in soil, [32]. The results therefore showed that the strength of samples in terms of their samples greatly improved with GHA stabilization.

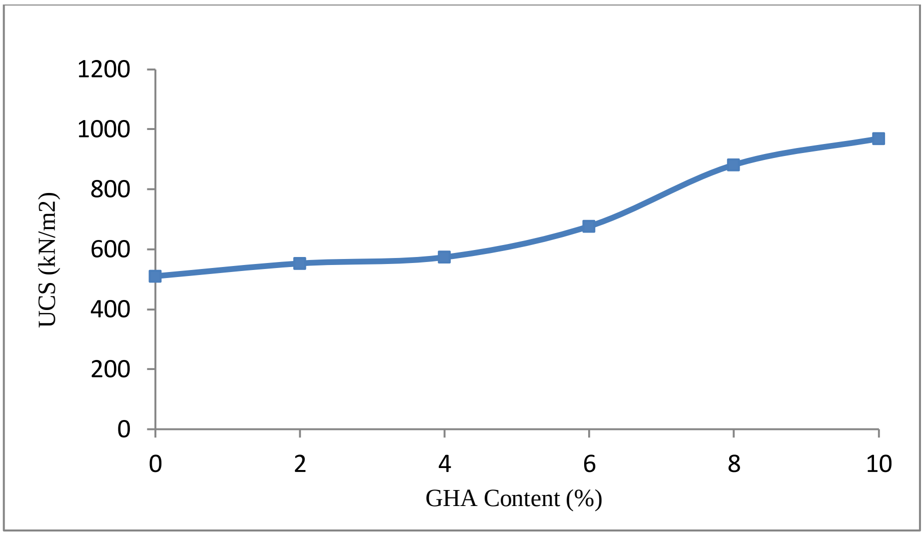

Figure 4. Measured UCS values as a function of the added GHA values

Figure 4. shows that the increase in UCS value increases from 510.25 kN/m^2 at 0% GHA to the range of 968.82-1186.46 kN/m^2 at 10% GHA on the 28th day, the maximum value was attained after 28 days, i.e. after the formation of cementitious compounds between the Calcium hydroxide present in the soil and GHA and the pozzolans present in GHA [33].

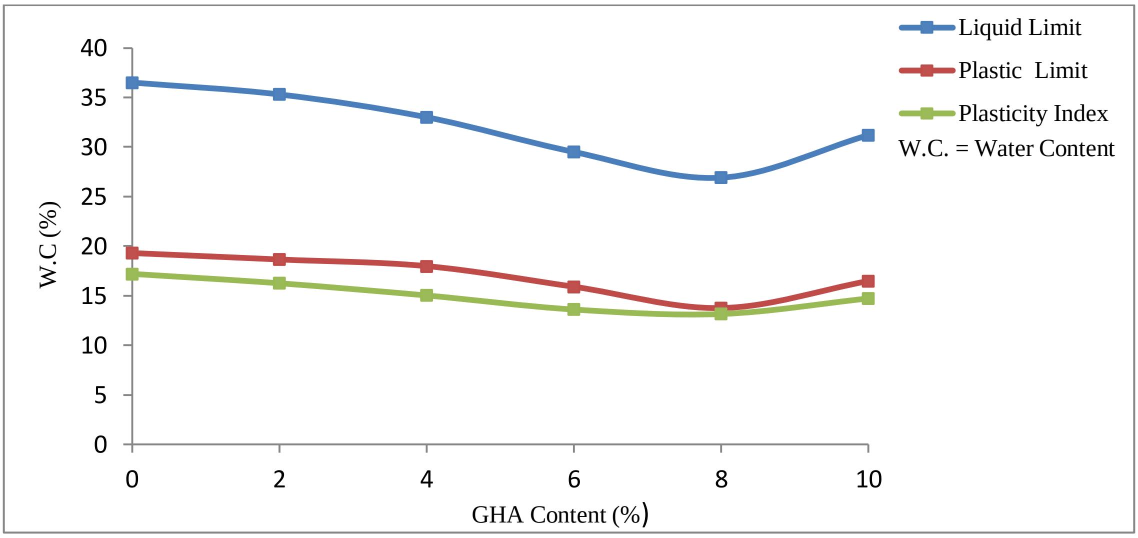

Figure 5. Measured Atterberg limits as a function of added GHA values

As shown in Figure 5. the Liquid Limit (LL) reduces from 36.50% at 0% to 31.20% at 10% GHA by weight of soil, while Plastic Limit (PL) value reduces from 19.30 % at 0% to 16.48% at 10%. As a consequence, Plasticity Index (PI) value reduces from 17.20% at 0% to 16.48% at 10%. The reduction of LL and PI values with GHA value indicates a reduction in compressibility and swelling characteristics. The observed trend indicates improvement in the lateritic soil upon the addition of GHA [34]. Decrease in LL and PL values may be attributed to the replacement of the soil fines with GHA, which has less affinity for water, [35].

4. Conclusion

From the results of the investigation carried out in this study, the following conclusions can be drawn:

- The lateritic soil is classified under the A-2-6 group.
- Liquid Limit and Plasticity Index values reduced considerable from 36.50% to 31.20% and from 19.30% to 16.48% both with the addition of 10% GHA by weight of soil.
- The treatment of the lateritic soil resulted to the general decrease in Maximum Dry Density (MDD) and increase in Optimum Moisture Content (OMC) with the addition of GHA.
- The unsoaked CBR values increased with the addition of GHA to the lateritic soil sample to an optimum value

of 72.88% at 10% GHA by weight of soil.

- The UCS values increased with the addition of GHA to the lateritic soil sample to an optimum value of 1186.46 kN/m^2 at 10% GHA by weight of soil.

As a consequence, we could state that the Ground nut Husk Ash performs satisfactorily as a cheap agent for stabilizing lateritic soil especially for sub grade and sub base purposes in road construction.

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