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GEOTECHNICAL PROPERTIES OF LATERITIC SOIL STABILIZED WITH THE ASHES OF OIL PALM FRONDS

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ABSTRACT

This study assesses the geotechnical properties of lateritic soil stabilized with the ashes of oil palm fronds. These properties are then compared with those of the same soil stabilized with cement to determine how well the ashes perform since cement is considered to be the best stabilizer. Laboratory tests such as specific gravity, moisture content, Atterberg limits, particle size distribution, compaction, unconfined compressive strength (UCS) and California bearing ratio (CBR) tests were first carried out to determine the basic properties of the lateritic soil (without the stabilizers). Based on the results of these tests, the soil was classified according to AASHTO soil classification system as an A-7-5 soil which is a poor soil. Hence, the need for stabilization. Thereafter, strength tests such as California bearing ratio (CBR), unconfined compressive strength (UCS) and compaction tests were performed on the soil to which the ashes and cement were added in percentages of 2, 4, 6, 8 and 10 by weight of the lateritic soil. The compaction test showed that the highest maximum dry densities (MDD) were recorded in the case of the oil palm frond ash (OPFA) and cement at 4% (MDD = 2.02kg/m^3) and 6% (MDD = 2.40kg/m^3) respectively. The highest CBR values obtained were 32.6% and 87.32% at 4% OPFA content and 6% cement content respectively.The unconfined compressive strengths (UCS) of the soil were highest at 4% OPFA content (234.86kN/m^2) and 6% cement content (588.32kN/m^2). The chemical tests performed on the OPFA and the cement showed that the highest oxide component were SiO_2 (33.67%) and CaO (60.83%) respectively.

KEYWORDS

Geotechnical, stabilized, Atterberg limits, California bearing ratio, unconfine compressive strength, compaction.

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 [2]. 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.

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 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].

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 the third world countries, the most common and readily available materials 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, bagass, bamboo leaves, some timber species and periwinkle shell ash [8].

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 [9]. 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 [10]. These local materials can be classified as either agricultural or industrial wastes [11]. 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 [12, 13].

Cement Stabilization

The addition of cement to a material, in the presence of moisture, produces hydrated calcium aluminate and silicate gels, which crystallize and bond the material particles together. Most of the strength of a cement- stabilized material comes from the physical strength of the matrix of hydrated cement. A chemical reaction also takes place between the material and lime which is released as the cement hydrates, leading to increased soil strength. The solubilities of Silica and Alumina are greatly increased in the stabilised clay soils to form calcium silicate gel which coats and binds lumps of clay together and occupies the pores in the soil [14].

MATERIALS AND METHODS

The materials used for this research work were lateritic soil, oil palm fronds ash and ordinary portland cement. The disturbed lateritic soil samples were collected from within the campus of the Federal University of Technology, Akure (FUTA), Nigeria. The lateritic soil was collected at depths representative of the soil stratum and not less than 1.2m 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 which may affect the analysis, then sieved with sieve no 4(4.75mm opening) to obtain the final soil samples for the tests. After the drying period, lumps in the samples were pulverised under minimal pressure.

Fresh oil palm fronds were obtained from a large abandoned farmland at the phase II site of the Federal University, Oye-Ekiti. The broom-stick part of the fronds were removed, the fronds were spread on the ground and air-dried to facilitate easy burning. The fronds were burnt into ashes and 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. Figure 1 shows a sample of the oil palm frond ash.

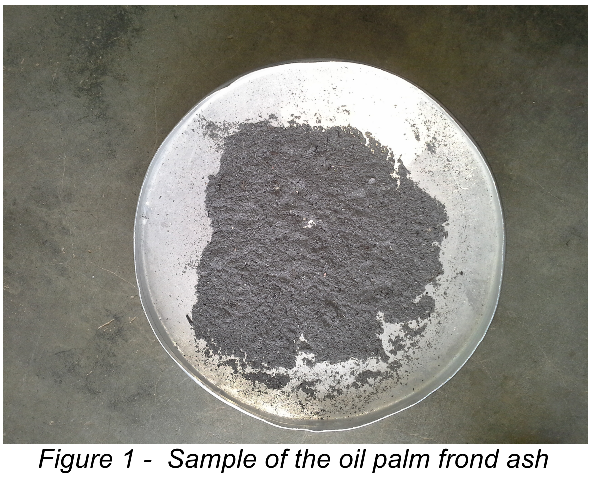

Figure 1 - Sample of the oil palm frond ash

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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 basic properties. Thereafter, compaction, unconfined compressive strength and California Bearing Ratio (CBR) tests were carried out on the stabilized samples in accordance with British Standard Methods of testing soil for Civil Engineering purposes [15, 16]. In addition, the chemical composition of the ordinary portland cement and the ashes of the oil palm fronds were determined through chemical analysis. Chemical analysis of the fine powdered ashes and cement was carried out at the central laboratory of the Federal University of Technology, Akure using the x-ray diffraction and SEM techniques.

DISCUSSION OF RESULTS

Chemical Analysis of the OPFA and OPC

The chemical analysis carried out on the oil palm frond ash (OPFA) and ordinary Portland cement revealed the oxide components as shown in *Table 1*.

Table 1 - Chemical composition of the oil palm frond ashes (OPFA) and ordinary Portland Cement (OPC)

Components (oxides)	OPFA (%)	OPC (%)
CaO	28.66	60.83
ZnO	0.89	NIL
MgO	3.97	3.02
P_2O_5	3.99	NIL
SiO_3	5.59	NIL
Al_2O_3	14.79	6.47
Fe_2O_3	4.51	2.79
SiO_2	33.67	20.05
K_2O	3.41	0.51
Na_2O	0.52	O.48
SO_3	NIL	0.35
TiO_2	NIL	0.38

Table 1 shows that the OPC contains a high amount of CaO (60.83%) which aids in the stabilization process and invariably makes cement a very effective stabilizer. On the addition of water to cement, major cementitious products like calcium silicate hydrates and calcium aluminium hydrates are produced which provide the bond between the soil particles. On the other hand, the OPFA can be regarded as a pozzolana since it contains an appreciable amount of SiO_2 (20.05%). 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 [17]. The OPFA aptly qualifies as a pozzolana since the percentage sum of its SiO_2, Al_2O_3 and Fe_2O_3 components (52.97%) exceeds the minimum requirement of 50% [18].

Preliminary tests on the unstabilized soil sample

The tests carried out on the lateritic soil sample without the additives gave its natural moisture content as 13.4% and specific gravity as 2.40. The soil was classified as a silt-clay soil since the percentage passing the sieve no. 200 was than 35%. Based on its liquid limit of 45.5% and plasticity index 14.5%, the soil was further clasified as an A-7-5 "fair to poor soil" [19] which cannot be used in road construction without treatment. Hence, the need for stabilization. *Table 2* shows a summary of the properties of the natural lateritic soil used in this study. Compaction test on the soil gave a maximum dry density (MDD) of 1.94kg/m^3 with corresponding optimum moisture content (OMC) of 10.7%, while its California bearing ratio (CBR) and unconfine compressive strength (UCS) were 10.42% and 209.18kN/m^2 respectively.

Table 2 - Properties of the natural lateritic soil

Property	Value
Natural moisture content	13.4%
Specific gravity	2.40
Liquid limit	45.5%
Plastic limit	31.0%
Plasticity index	14.5%
AASHTO classification	A-7-5
Soil type	Silt-Clay
Maximum dry density (MDD)	1.94kg/m^3
Optimum moisture content (OMC)	10.7%
California bearing ratio (CBR)	10.42%
unconfine compressive strength (UCS)	209.18kN/m^2

Compaction test on the lateritic soil containing the additives

Table 3 shows the compaction properties of the soil containing the additives. In the case of the soil with OPFA, the MDD improved from the initial value of 1.94kg/m^3 for the natural soil to 1.98kg/m^3 at 2% OPFA content and this further increases to 2.02kg/m^3 (the highest value) when the OPFA content was increased to 4%. Thereafter, the MDD drops all through up to 10% OPFA content. This drop can be attributed to the fact that the specific gravity of the soil had been lowered on addition of the OPFA.

In the case of the lateritic soil containing the ordinary Portland cement (OPC), the MDD initially drops from the original value of 1.94 for the natural soil to 1.85 at 2% cement content after which it increases to 1.91 at 4% cement content (which is still lower than that of the natural soil).

The highest MDD (2.40) is reached at 6% cement content after which it drops at 8% and 10% cement contents.

Table 3 - Compaction properties of the lateritic soil containing the additives

Additives (%)	Soil with OPFA		Soil with OPC	
	MDD (kg/m^3)	OMC (%)	MDD (kg/m^3)	OMC (%)
2	1.98	11.3	1.85	18.6
4	2.02	11.2	1.91	17.3
6	1.99	13.4	2.40	15.7
8	1.87	14.15	1.96	17.9
10	1.86	16.60	2.30	19.1

California bearing ratio (CBR) test on the lateritic soil containing the additives

Table 4 shows the unsoaked CBR of the soil containing the additives. In the case of the soil containing OPFA, the CBR increases from 10.42% for the natural soil to 31.06% at 2% OPFA content and to the highest value of 32.6% at 4% OPFA content. Thereafter, the CBR falls throughout up to 10% OPFA content.

In the case of the soil containing the OPC, the CBR increases from 10.42% for the natural soil to 57.62% at 2% OPC content, drops to 45.74% at 4% cement content, increases again to the highest value of 87.32% at 6% cement content, drops again to 78.32% at 8% cement content and finally increases to 80.41% at 10% cement content.

Table 4 - CBR (unsoaked) of the lateritic soil containing the additives

% of additives	unsoaked CBR (%) values	
	Soil with OPFA	Soil with OPC
2	31.06	57.62
4	32.6	45.74
6	21.19	87.32
8	19.29	78.32
10	9.52	80.41

Table 5 shows the soaked CBR of the soil containing the additives. In the case of the soil containing OPFA, the CBR increases from 10.42% for the natural soil to 15.41% at 2% OPFA content and to the highest value of 17.33% at 4% OPFA content. Thereafter, the CBR falls throughout up to 10% OPFA content.

In the case of the soil containing the OPC, the CBR increases from 10.42% for the natural soil to 42.63% at 2% OPC content, drops to 33.78% at 4% cement content, increases again to the highest value of 74.62% at 6% cement content, drops again to 64.35% at 8% cement content and finally increases to 69.48% at 10% cement content.

Table 5 - CBR (soaked) of the lateritic soil containing the additives

% of additives	soaked CBR (%) values	
	Soil with OPFA	Soil with OPC
2	15.41	42.63
4	17.33	33.78
6	13.26	74.62
8	8.12	64.35
10	6.44	69.48

Unconfined compressive strength (UCS) test on the lateritic soil containing the additives

Table 6 shows the UCS of the soil containing the additives. In the case of the soil containing OPFA, the UCS increases from 209.18kN/m^2 for the natural soil to 226.73kN/m^2 at 2% OPFA content and further on to the highest value of 234.86kN/m^2 at 4% OPFA content. Thereafter, the UCS drops to 216.32kN/m^2 at 6% OPFA content, increases again to 227.85kN/m^2 at 8% OPFA content and finally drops to 198.44 at 10% OPFA content..

In the case of the soil containing the OPC, the UCS increases from 209.18kN/m^2 for the natural soil to 542.52kN/m^2 at 2% OPC content, drops to 430.86 kN/m^2 at 4% OPC content , increases again to 588.32kN/m^2 at 6% OPC content, drops again to 574.46kN/m^2 at 8% OPC content and finally increases to 575.22kN/m^2 at 10% OPC content.

Table 6 - UCS of the lateritic soil containing the additives

% of additives	Unconfirmed compressive strength (kN/m^2)	
	Soil with OPFA	Soil with OPC
2%	226.73	542.52
4%	234.86	430.86
6%	216.32	588.32
8%	227.85	574.46
10%	198.44	575.22

CONCLUSION

Based on the chemical test, the oil palm frond ash can be classified as a pozzolanic material because the percentage sum of its SiO_2, Al_2O_3 and Fe_2O_3 components (52.97%) exceeds the minimum requirement of 50%.

The compaction, California bearing ratio (CBR) and unconfined compressive strength tests indicated that the highest values were obtained at 4% OPFA and at 6% OPC content. These represent the optimum values for the OPFA and OPC to be used as stabilizers in the lateritic soil.

It can be inferred from the tests that even though cement proved to be a better stabilizer, the OPFA could be used as an alternative if added in the right quantity. The oil palm fronds provide a readily available, easily sourced and affordable material that can be used to produce the OPFA stabilizer.

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