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EFFECTS OF ACHA GRAIN HUSK ASH ON LIME-STABILIZED LATERITIC SOIL

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Abstract: This study assesses the effects of Acha Grain Husk Ash (AHA) on lime stabilized lateritic soil. Preliminary tests were carried out on natural soil sample, for the purposes of identification and classification. The soil sample was classified as A-7-5. Hydrated lime was added to the soil sample at varying proportions of 2, 4, 6, 8 and 10% by weight of soil, thereafter, each of the mixes was subjected to atterberg limits tests to get the optimal amount of lime required, which was 10% lime because it was at this amount of lime that the least value of plasticity index was obtained. The acha husk ash was later added to the lime-treated lateritic soil at proportions of 2, 4, 6, 8 and 10%. Each of the mixes was subjected to compaction, California bearing ratio (CBR), atterberg limits and unconfined compressive strength(UCS) tests. Results from these tests showed general improvement in soil properties, notably, the values of the CBR and UCS increased considerably. It can be concluded that the AHA performs satisfactorily as a cheap complement for lime in stabilizing lateritic soil.
Keywords: Acha grain husk ash, atterberg limits, lateritic soil, lime, soil stabilization

1. INTRODUCTION

According to Sadeeq et al. (2015), geo-technically, soil improvement could be achieved either by modification or stabilization or both. The term modification as defined by Osula (1996) refers to a remarkable improvement of the soil workability and compaction characteristics and to a minor enhancement of the soil mechanical strength using low content stabilizers. The addition of a modifier (cement, lime and bitumen etc.) to a soil to change index properties is called modification. It is aimed at reducing plasticity of the soil to the desired level, short term strength gain, (that is, strength gained immediately after application to about 7 days of compaction). Soil modification may or may not lead to strength increase but leads to the alteration of soil properties to enhance workability as evidence in textural changes that accompany consistency improvements (Joel and Edeh, 2015; Alhassan and Mustapha, 2011).

Ogundipe (2013) defined soil stabilization as the process of blending and mixing materials with a soil to improve certain properties of the soil. The process may include the blending of soils to achieve a desired gradation or the mixing additives that may alter the gradation, texture or plasticity or act as a binder for cementation of the soil.

When a weak soil is encountered on a site and sourcing for alternative may prove economically unwise, to improve the soil by way of stabilizing the available soil to meet the desired objective becomes the viable option (Mustapha, 2005; Osinubi, 1999). The high cost of industrial stabilizers has led to a search for alternative. This, has so far centered on the partial replacement of cement with different materials (Joel, 2010) which can be sourced locally at a very low cost (Bello et al. 2015). These local materials can be classified as either agricultural wastes, such as rice husk ash or industrial wastes (Amu et al, 2011) such as fly ash.

Mechanism of Lime Stabilization

According to Jawad et al. (2014), water absorption is the first activity that takes place when lime (especially quick-lime) is added to the soil. Lime-Soil chemical reaction has two stages. The first stage is known as immediate or short term treatment, which happens within a few hours or days after lime is added. At this stage, three major chemical reactions, namely, cation exchange, flocculation-agglomeration and carbonation take place. The second stage involves several months or years to complete and therefore, it is considered the long-term treatment. Pozzolanic reaction is the main reaction at this stage. The drying of wet soil and the increase in soil workability is attributed to the immediate treatment, the aspect of increase in soil strength and durability is associated with the long-term treatment (Geiman, 2005).

The addition of lime to the soil water system produces calcium ions (Ca^{2+}) and (OH^{-}) in the process of cation exchange, bivalent calcium ions (Ca^{+}) are replace by monovalent cations. The calcium ions link the soil minerals (having negative change) together, thus reducing the repulsive forces and the thickness of the diffused water layer. This layer encapsulates the soil particles, strengthening the bond between the soil particles. The remaining anions (OH^{-}) in the solution are responsible for the increased alkalinity. Upon the reduction in water layer thickness, the soil particles become closer to each other, causing the soil texture to change. This phenomenon is called flocculation-agglomeration. The silica and alumina that exist in the soil minerals become soluble and free from the soil when pH exceeds 12.4. The reaction between the released soluble silica and alumina and calcium ions from lime hydration creates cementitious materials such as Calcium Silicate Hydrates (C-S-H) and Calcium Aluminate Hydrates (C-A-H) (Jawad et al, 2014; Geiman, 2005; Mallela et al., 2004; Locat et al., 1990).

Location and Geology of Study Area

Akure, Nigeria, being the study area lies within Longitude $7^0$18' N and $7^0$16' N North of the equator and between Latitude 5^0 09' E and 5^0 11.5^0 E of Greenwich meridian. The study area occurred within the pre-cambrian crystalline rocks of the basement complex of southwestern Nigeria. The predominant rock types in the study area are charnockites, granites gneiss and migmatitic rock. In some places in the study, these rocks have undergone deep weathering (Ogunribido, 2011).

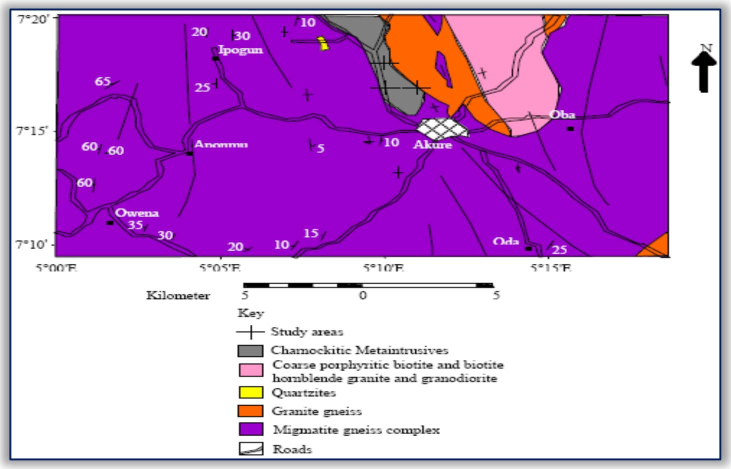

Figure 1: Study Area-Akure, Nigeria. Source: Ademeso (2009)

2. MATERIALS AND METHODS

Materials

Acha Grain Husk Ash (AHA)

Acha is in the form of a small millet and it is often referred to as "Hungarian rice". The crop is commonly grown in some Northern parts of Nigeria. Acha husk is the outer covering of the Acha grain and the husk is removed manually using pestle and mortar. The Acha husk was burnt up to a temperature of 600^{0}C using a kiln. It was allowed to cool. The ash gotten was ground and later sieved through 75µm to obtain fine ash.

Lateritic Soil

The lateritic soil sample was collected in Akure at depths representative of soil stratum and not less than 1metre (1m) below the natural ground level. It was thereafter brought to the Geotechnical Laboratory of the Federal University of Technology, Akure 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 seived with seive no 4 (4.75mm opening) to obtain the final soil samples for the tests. After the drying periods, lumps in the sample were pulverised under minimal pressure.

Water

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

Hydrated lime

This was purchased at a licensed chemical store in Akure.

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 were later subjected to atterberg limits tests, to detect the optimal amount of lime required which was the amount of lime added where the least value of plasticity index was recorded. The Acha grain husk ash (AHA) was added in proportions of 2, 4, 6, 8 and 10% by weight of soil to the lime-treated 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 the fixed optimal amount of required lime and varying proportions of 2, 4, 6, 8 and 10% AHA.

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, tests were performed to determine the proctor compaction properties of soil sample upon stabilization with lime at optimal amount required and the varying amount of AHA (2, 4, 6, 8 and 10%).

— 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 fixed optimal amount of hydrated lime required and varying proportions of 2, 4, 6, 8 and 10% AHA. The needed amount of water was determined from moisture-density relationships for stabilized-soil mixtures was 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).

3.RESULTS AND DISCUSSIONS

Table 1 shows that the percentage that passed through on No. 200 BS sieve was 40.50%, therefore, suggesting that the soil belonged to one of the following groups; A-4, A-5, A-6 and A-7. It is worthy of note that more than 35% of its sample passed through the No 200 sieve, the soil sample therefore fell into the silty or clayey group with generating rating of fair to poor. The liquid limit of the soil is 52.85%, thereby, falling into the A-5 and A-7 groups. The value of the plasticity index is 20.25%, the soil therefore falls into the A-7 group. For soil sample to be classified into the A-7-5 subgroup; plasticity index $\leq \mathrm{LL} - 30; 20.25 \leq 52.85 - 30 = (22.85)$. The soil sample therefore falls into the A-7-5 subgroup (Garber and Hoel, 2009). Furthermore, the specific gravity of the soil sample is 2.58, the soil can be said to belong to the halloysite group, according to Das (2000), soils that possess specific gravity value within the range of 1.69-2.9 are classified as halloysites.

Table 1: Summary of the preliminary tests results

Property	Amount
Natural Moisture Content (%)	19.85
Percentage passing Sieve No. 200	40.50
Specific gravity	2.58
Liquid limit (%)	52.85
Plastic limit (%)	32.60
Plasticity Index (%)	20.25
Unsoaked CBR (%)	9.5
Soaked CBR (%)	5.5
Optimum Moisture Content (%)	14.45
Maximum Dry Density (kg/m^3)	1650
Unconfined Compressive Strength (kN/m^2)	190
AASHTO Classification	A-7-5
USCS Classification	CH

In Table 2, chemical composition of AHA presents a conclusion that the AHA is non-pozzolanic and has the same active chemical constituents and properties as that of the hydrated lime, such as CaO, SiO_2, Al_2O_3, Fe_2O_3, MgO. According to ASTM C618 (1978), if the total sum of SiO_2, Al_2O_3 and Fe_2O_3 of a material is equal or greater than 70%, the material can be said to be pozzolanic. The sum total of SiO_2, Al_2O_3 and Fe_2O_3 of the AHA equal 48.36%, therefore, the AHA is non-pozzolanic. Specific gravity of AHA is found to be 2.12 (Joel, 2010).

Table 2: shows chemical composition of the acha grain husk ash and hydrated lime used for the study. Source: Joel (2010)

Elemental Oxide	AHA (Weight %)*	Hydrated Lime (Weight %)
SiO_2	40.46	1.71
Al_2O_3	5.50	0.72
Fe_2O_3	2.40	0.05
CaO	0.84	68.12
MgO	0.08	1.38
SO_3	-	-
K_2O	0.24	0.06
Na_2O	0.22	0.03
P_2O_5	-	-

Table 3, presents the results of the effects of lime on soil properties, with increasing addition of lime to soil, values of liquid limit and plasticity index reduced. The least value of plasticity index-13% was recorded at 10% lime content. Therefore, the optimum lime requirement was 10%, further addition of the AHA was done to the soil sample which was treated with 10% lime.

Table 3: effects of lime on soil properties

Lime (%)	LL (%)	PL (%)	PI (%)	MDD (kg/m^3)	OMC (%)	Unsoaked CBR (%)	Soaked CBR (%)
0	52.25	32.60	20.25	1650	14.45	9.5	5.5
2	49.85	30.95	18.90	1625	15.50	20.65	11.35
4	47.40	30.00	17.40	1605	16.80	35.75	23.65
6	44.80	29.00	15.80	1584	18.00	60.80	46.70
8	42.30	27.90	14.40	1568	19.30	56.88	44.40
10	40.20	27.20	13.00	1549	21.24	54.45	40.40

Effect on Compaction Characteristics

The variations of Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) with stabilizer contents are shown in table 3, figures 2 and 3. Table 3 shows that with the addition of lime to the natural soil sample, increase in the value of OMC as lime was increasingly added to the natural soil sample. OMC value increased from 14.45% at 0% lime to 21.24% at 10% lime. Figure 2 shows that the optimum moisture content (OMC) increased with increase in amount of AHA added to the lime-treated soil. The increments in OMC with increase in AHA may be attributed to the amount of water required in the system to sufficiently lubricate all the particles in the soil-lime and AHA mixture (Okafor and Okonkwo, 2009). OMC therefore continuously increased with increase in AHA. Also, values of MDD decreased from 1650 kN/m^3 at 0% lime to 1549 kN/m^3 at 10% lime (table 3). Figure 3 indicates that Maximum Dry Density (MDD) decreases with increase in Acha Husk Ash (AHA) content, MDD decreased from 1549 kg/m^3 at 0% AHA by weight of soil to 1480 kg/m^3 at 10% AHA. According to Okonkwo (2015), this, may be attributed to the partial replacement of soil with higher specific gravity (2.58) by AHA with lower specific gravity (2.12). Also, it may be due to the reaction between lime, AHA and fine fractions of the soil in which they form clusters that occupied larger spaces and invariably increasing their volume with decreasing the maximum dry density (MDD).

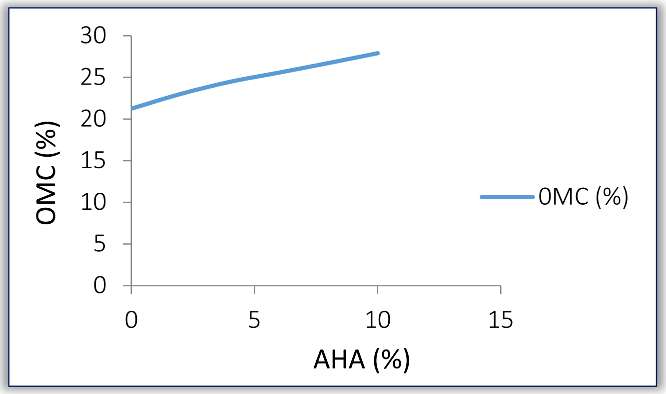

Figure 2: Effects of AHA on OMC of lime-treated lateritic soil

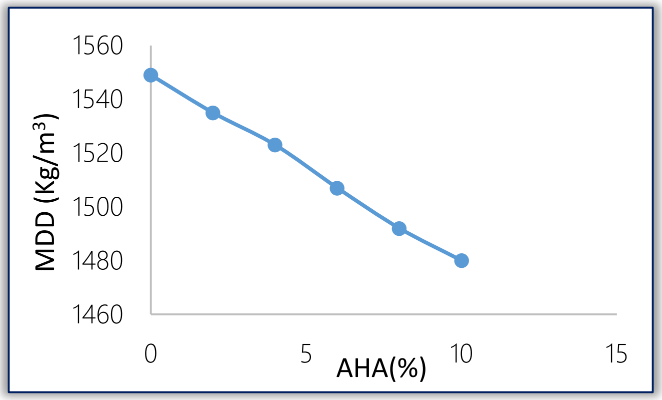

Figure 3: Effects of AHA on MDD of lime-treated lateritic soil

California Bearing Ratio

Figure 4 shows values of unsoaked CBR increased from 54.45% at 0% AHA to maximum value of 68.70% at 6% AHA, while soaked CBR increased from 40.40% at 0% AHA to 52.75% at 6% AHA by weight of soil. In both cases, the values started falling at 8% AHA. The increase in values of California Bearing Ratio (CBR) upon the addition of AHA may be attributed to the presence of adequate amounts of calcium required for the formation of Calcium silicate hydrate (CSH) and Calcium aluminate hydrate (CAH), which are the major compounds responsible for strength gain (Sadeeq et al., 2015). The reduction in CBR values at 8% AHA may be due to excess AHA and lime that was not mobilized in the reaction, therefore, reducing bond in the lime-AHA-soil (Ogunribido, 2011).

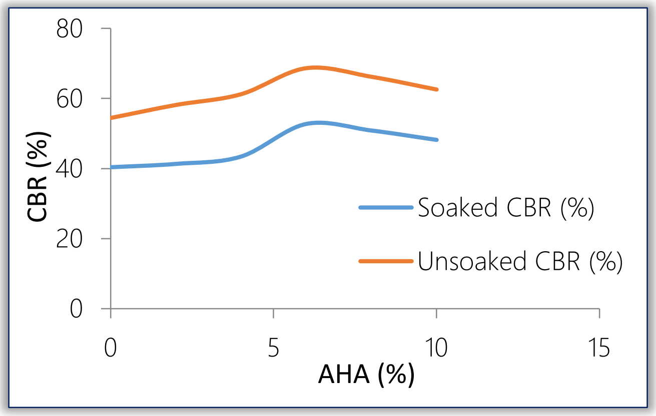

Figure 4. Effect of AHA on CBR of Lime-treated Lateritic Soil

Atterberg limits

From table 3, the addition of lime to the lateritic soil sample resulted to the decrease in the values of liquid limit and plasticity indices of the soil sample. The trend observed with the lime can be attributed to agglomeration of fine clay particles into coarse, friable particles by a base exchange with the calcium cations from lime displacing sodium or hydrogen ions, with a subsequent dewatering of the clay fraction of the laterite, referred to as cation exchange reaction (Joel and Edeh, 2015). According to Osinubi (1995), the reduction in the plasticity is attributed to the change in soil nature (granular nature after flocculation and agglomeration) and the modified soil as crumbly as silt soil, which is characterized by low surface area and low liquid limit because of the plastic nature of the lime. In figure 5; the addition of AHA to the lime-treated lateritic soil sample further reduced the liquid limit values and its plasticity index values. This, may be attributed to the higher release of Ca^{2+} and Si^{2+} cations with increased lime+AHA (Iorliam et al. 2012).

The addition of the AHA to the lime-treated soil reduced the plasticity index which is an indication of improvement of soil properties (Basha et al. 2005; Iorliam et al. 2013).

Unconfined Compressive Strength

Unconfined compressive strength (UCS) is the test commonly used for the determination of the needed amount of additive to be used in stabilization of soil (Ogunribido, 2011). From table 4, the Unconfined Compressive Strength (UCS) values increased as more percentages of lime were being added till it got to maximum values of 272, 320 and 379 kN/m^2 for 7, 14 and 28 days at 6% lime from natural state of 190 kN/m^2. On reaching these peak values, the UCS started decreasing till it got to 248, 280 and 345 kN/m^2 at 10% lime content for 7, 14 and 28 days respectively.

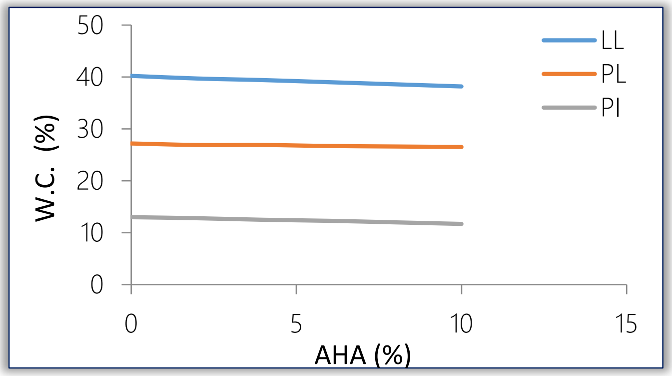

Figure 5. Effect of AHA on Atterberg limits of Lime-treated Lateritic Soil

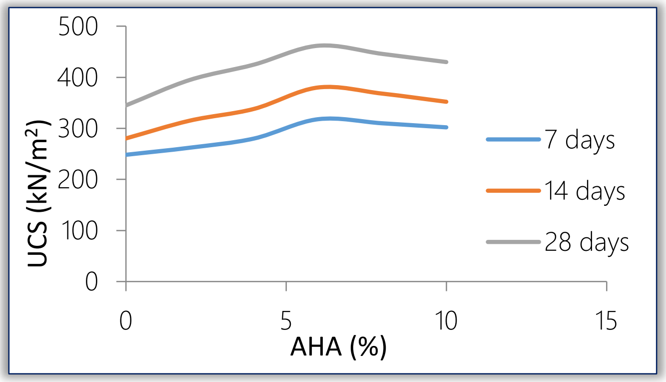

Figure 6. Effect of AHA on UCS of lime-treated lateritic soil

Figure 6 shows that with the increased addition of AHA, UCS values increased from 248, 280 and 345 kN/m^2 at 0% AHA at 7, 14 and 28 days to peak values of 318, 380 and 462 kN/m^2 respectively all at 6% AHA, before declining in values at 8% and 10% AHA. The resultant increase in values of Unconfined Compressive Strength (UCS) upon the addition of AHA may be attributed to the formation of cementitious compounds between the CaOH present in the soil and AHA and the pozzolans present in AHA. The decrease in UCS values after the addition of 6% AHA may be due to the excess AHA introduced to the soil and therefore forming weak bonds between the soil and the cementitious compounds formed (Fattah et al. 2013).

Table 4. Effect of lime on unconfined compressive strength properties of lateritic soil

Lime (%)	7 days (kN/m^2)	14 days (kN/m^2)	28 days (kN/m^2)
0	190	190	190
2	210	259	300
4	238	280	346
6	272	320	379
8	260	296	358
10	248	280	345

4. CONCLUSIONS

The lateritic soil is classified as A-7-5 using AASHTO classification system and CL using the USCS. Therefore, the soil passes for a poor soil.

The optimal amount of lime required is 10%, because at 10% lime the least value of plasticity index was recorded. The addition of Acha grain husk ash (AHA) further reduced the plasticity index values from 13% at 0% AHA to the least value of 11.70% at 10% AHA, thus, enhancing the soil engineering properties.

The maximum dry density (MDD) and optimum dry density (OMC) of lime-treated soil increased and decreased respectively with the addition of the AHA.

Upon the addition of AHA to the lime-treated soil, the values of unsoaked and soaked CBR improved remarkably, from 54.45% (unsoaked CBR) and 40.40% (soaked CBR) to highest value of 68.70% (unsoaked CBR) and 52.75% (soaked CBR) at 6% AHA.

The addition of AHA to the lime-treated soil improved the unconfined compressive strength (UCS) values to peak values at 6% GCHA. UCS values also increased with curing ages of 7, 14 and 28 days.

It can therefore be concluded that the Acha husk ash can serve as cheap complement for lime in soil stabilization.

Acknowledgement

The Authors hereby seize this opportunity to appreciate Engr. Moses Tanimola and the Technical team of the Geotechnical Laboratory of the Federal University of Technology, Akure, Nigeria, for the support given while this research lasted.

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ISSN 1584 - 2665 (printed version); ISSN 2601 - 2332 (online); ISSN-L 1584 - 2665