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Geotechnical characteristics of soils stabilized with lime-Rice Husk Ash for road construction in Nigeria Southwestern states

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ABSTRACT

The state of roads in southwestern Nigeria is deplorable. Most of them are not motorable due to pavement failure; this necessitates an investigation into determining the suitability of the underlying soil courses if stabilized with lime-Rice Husk Ash (RHA) mixtures. This investigation used eighteen (18) selected burrow pit soil samples (one from each senatorial district of Southwestern, Nigeria) which are used for road construction. California Bearing Ratio (CBR), compaction, Unconfined Compressive Strength (UCS), and triaxial tests were performed on 6% lime and 0 to 10% RHA mixed soil samples in the laboratory using standard procedures. The additive was also subjected to laboratory test for chemical analysis. The results showed that RHA additive has high silica (Sio2) content and that all strength properties Maximum Dry Density (MDD), CBR, UCS, Cohesion (C), Shear Strength (τ), and angle of internal frictional (ø) increase as RHA content increases and reached the optimum at 4% RHA content, then decrease afterward. The Optimum Moisture Content (OMC) decreases with corresponding increase in RHA content. Almost all of the unsuitable soil samples became suitable for pavement layer materials after stabilization. The mixture of 6% optimum lime and 4% RHA content is recommended for soil improvement, particularly for road construction in Southwestern Nigeria.

Keywords: Rice Husk Ash, Chemical analysis, Lime, Strength properties, Stabilization

1. INTRODUCTION

The state of roads in Southwestern Nigeria remained poor due to faulty design, lack of drainage system, skinny coatings that are easily wear away, overconcentration on road network, use of substandard construction materials, and poor construction techniques among other factors. The excessive use of the road network is majorly due to underdeveloped nature of railways and water ways which could serve as an

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alternative means of transport, absence of an articulated road programme, inadequate funding for road maintenance, and corruption among others (Ighodaro, 2009).

The poor state of roads may be induced by engineering soil problems ranging from heaving to shrinkage of active subsoil underlying a road pavement either at subgrade course or within the road embankment or fill section of the road configuration. The indiscriminate use of soils without fully appreciating their limitation however had resulted in the failure of large number of road pavements in Southwestern Nigeria. Inadequacy in the engineering properties of soils which in some cases made it unsuitable as road construction material can be improved upon, by adding small quantities of lime by weight of soil.

The process of making an unsuitable soil material to be suitable for engineering construction purposes is known as stabilization. When lime is added to soil, the shear strength of the soil increases even in the presence of saturating amount of water. The addition of lime to soil also increases the volumetric stability, bearing capacity, and long-term durability of soil (Kanyi, 2017). The cementation process of soil-lime mixture takes several years to complete and to reach equilibrium state. This reaction involves the lime, alumina, and silica present in the soil in the formation of hydrous calcium aluminates and silicates, which are similar to the reaction products of hydrated cement. The cementation process depends on the amount of available silica.

The strength of a lime-soil mixture usually increases with age until all the free lime is used (Nnochiri, 2018; Jawad et al., 2014). The high cost of the lime used for soil stabilization for road construction, the scarcity of suitable road construction materials, and the environmental hazard posed by agricultural waste materials in third-world countries such as Nigeria prompted this study on the geotechnical characteristics of lime and Rice Husk Ash (RHA) stabilized soils for road construction in southwestern Nigeria. The conversion of Rice Husk waste material into ash and its use with optimal lime stabilized soils will not only help to provide suitable road construction materials but will also help to eliminate the environmental hazard caused by improper agricultural waste disposal.

Rice Husk Ash is a pozzolanic material that contains around 85-90% amorphous silica (Vishwanath et al., 2014). Muntohar, (1999) reported that Rice Husk Ash (RHA) is a potential material for soil improvement, considering its Pozzolanic activity. Figure 1 shows the states in the geopolitical zone of the Southwestern Nigeria which includes Ekiti, Lagos, Ogun, Ondo, Osun and Oyo. The zone is situated on latitudes ranging from 6.214°N to 9.000°N and longitudes 2.681°E to 9.000°E. It was founded in 1967 when the western region of Nigeria was separated into western and Lagos state. Its capital was situated at Ibadan, which was also the ancient region's capital. In 1996 and 1991, two new states (Ekiti and Osun) were created from the old Ondo and Oyo states, respectively (Ayinla, 2013).

2. METHODS

Soil samples, lime, Rice husk and water are the components used for this research work. Samples of soil collected from three different borrow pits along federal roads in senatorial districts of each state in southwestern Nigeria, detailed in Table 1 were used for the research. To prevent moisture loss, samples of soil were immediately placed in polythene bags before being used. The soil samples were taken to the Department of Civil Engineering, the Federal Polytechnic, Ado-Ekiti laboratory. The soil samples were then air-dried, pulverized, and sieved through British Standard (BS) Sieves before being used in other assays.

The hydrated lime used in this study was purchased in 25kg bags from a chemical store in Ado-Ekiti, kept cool and dry away from rain and moisture. Rice Husk waste was collected from a farmland at Igbemo-Ekiti, sun dried for an average of 7 days before it was burned at 700°C inside a muffle furnace (5x1-1008 model) at the Civil engineering Department Laboratory, the Federal Polytechnic, Ado-Ekiti. The ash was sieved to a size of 0.425mm, while potable water gotten from the Federal polytechnic Ado-Ekiti was utilized to mix the specimens.

The soil samples were blended together on the ground to obtain representative samples, and then transferred to the laboratory to be eviscerated of harmful element such as roots. The soil samples used in the tests were air-dried broken down into particles with a mortar and pestle, and then sieved to eliminate big particles with a number 10 sieve (2.00mm). The methodologies used for the various tests conformed with the British Standard (BS 1377, 1990). In their natural air-dried form, the soil samples were subjected to classification and engineering tests. Following that, the soil samples were lime stabilized by adding lime at a percentage of 6%. Then at proportions of 2, 4, 6, 8, and 10%, RHA was added to the lime-stabilized soil samples. Chemical analysis of the RHA local additive was performed using the traditional method.

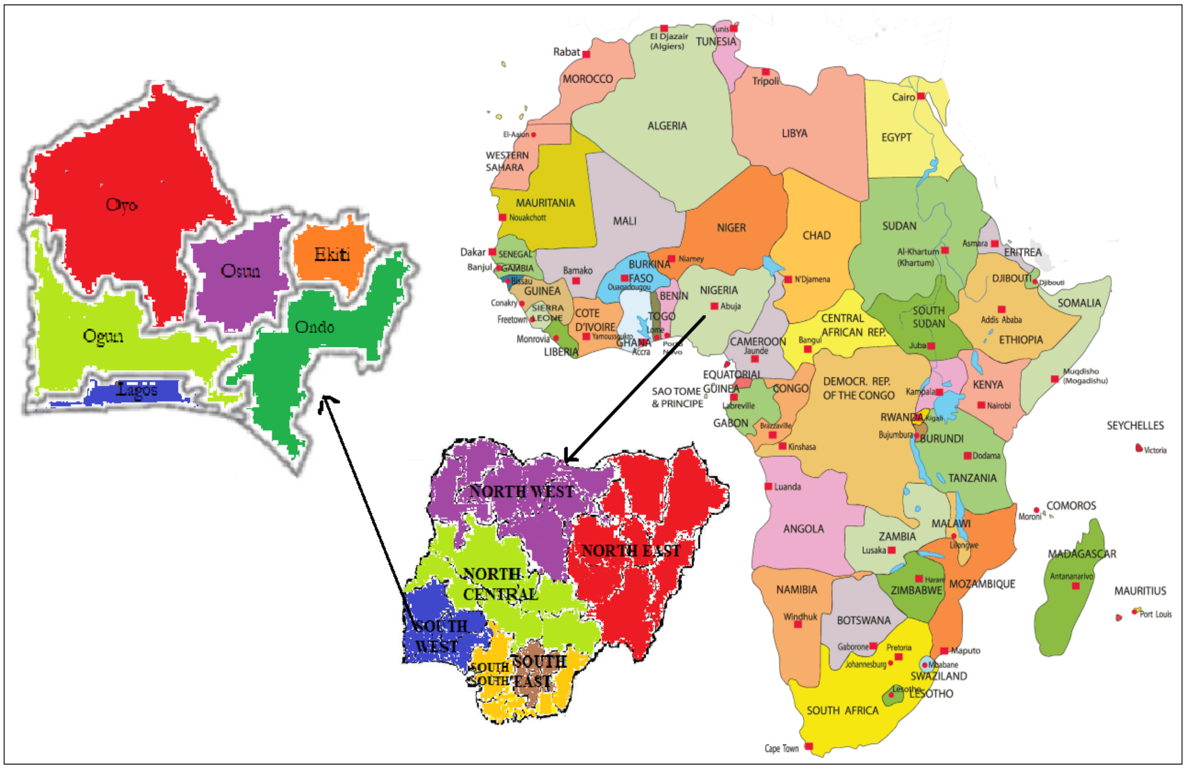

Figure 1 Map showing the case study region

Table 1 Details of the soil samples

S/N	STATE	SAMPLE LABEL	LOCATION (ROAD)	COORDINATES	
				LATITUDE	LONGITUDE
1	EKITI	EK1	Itawure-Aramoko Ekiti	07°32'32"	08°49'27"
		EK2	Ikole-Ijesa isu Ekiti	07°45'28"	05°31'08"
		EK3	Aisegba-Iluomo-oba Ekiti	07°36'38"	05°28'08"
2	ONDO	ON1	Akure-Ogbese	07°56'39"	08°04'57"
		ON2	Owo-Ikare akoko	08°29'11"	08°01'15"
		ON3	Ondo-Ore	07°06'20"	07°54'13"
3	OSUN	OS1	Osogbo-Ikirun	07°47'47"	04°34'16"
		OS2	Ilesa-Ijebu jesa	07°38'32"	04°43'14"
		OS3	Owode-Ode omu	07°33'48"	04°24'00"
4	OYO	OY1	Ogbomoso-Oko	08°31'15"	04°17'12"
		OY2	Igbeti-Ogbomoso	08°44'43"	04°08'17"
		OY3	Ibadan-Fiditi	07°34'21"	03°55'31"
5	OGUN	OG1	Abeokuta-Itori	05°29'28"	08°19'31"
		OG2	Shagamu-Ishara	06°11'05"	08°06'33"
		OG3	Ilaro-Papanlanto	05°32'36"	08°02'07"
6	LAGOS	LA1	Apapa wharf-Apapa expressway	06°27'16"	03°22'05"
		LA2	Lekki-Ajah expressway	06°26'21"	03°31'25"

		LA3	Oshodi-Agege expressway	06°33'33"	03°20'21"

The soil samples were subjected to engineering strength tests such as the California Bearing Ratio (CBR), Compaction, Unconfined Compressive Strength (UCS), and Triaxial Shear test. Compaction test: This test was performed with the compactive effort of standard Proctor to estimate the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) as specified by the British Standard (BS 1377, 1990). Soil samples weighing 3000g were compacted in three layers with 2.5Kg rammer falling through the height of 300mm in 1000cm3 mold. Each layer of three (3) received twenty-five (25) blows, and moisture content samples were obtained from the top and the bottom of the mold. The dry density was calculated using Equation 1.

$$Dry\ Density = \frac{Bulk\ Density}{1+\frac{moisture\ content}{100}} \qquad (1)$$

California Bearing Ratio (CBR): This is an empirical test for determining subgrade strength established by the California State Highway Department. According to British Standard BS 1377, (1990), soil specimen compacted in a CBR mold of height and diameter of 127mm and 152mm respectively are subjected to CBR test. The specimens were prepared in five (5) layers with a 4.5Kg rammer, each receiving fifty-six (56) blows. The load needed to cause a 49.65mm diameter plunger to penetrate the specimen at a rate of 1.25mm per minute was then calculated. The CBR value was determined from the test results by expressing the corrected values of plunger forces for a specific penetration as a percentage of a standard force. The loads that induced the same penetration on the specimens were compared using the 2.5 and 5.0mm penetration caused by 13.24 and 19.96kN loads respectively. This test was performed following the British Standard's soil test requirements (BS 1377, 1990), and the CBR value in percentage is calculated as expressed in Equation 2.

$$CBR = \frac{Test\ Load\ (kN)}{Standard\ Load\ (kN)} \times 100\% \qquad (2)$$

Unconfined Compressive Strength (UCS): It demonstrates the soil's drainage condition and its ability to sustain compression failure. The UCS specimens were compacted to a height/diameter ratio of 2:1 using the energy of a standard Proctor. The specimens were loaded with a compressive machine of known proofing ring and the load causing failure was divided by the cross-sectional area of the specimen to determine the soil's strength. This test was performed following the BS 1377 [8] soil test requirements and the UCS value was calculated as express in Equation 3.

$$UCS = \frac{Failure\ Load\ (kN)}{Corrected\ Area\ (m^2)} \quad \text{Equation (3)}$$

Triaxial shear test: This is one of the laboratory tests that determine the shear strength of soil. It assesses the cohesiveness (c) and internal friction (ø) of soils, hence, suitable for measuring the shear strength of lateritic soils. The test was performed following the Standard for soil test requirements on remoulded samples compacted to height/diameter ratio of 2:1 (BS 1377, 1990).

3. RESULTS AND DISCUSSION

Chemical composition of RHA

Table 2 summarizes the results of the chemical analysis of the RHA local additive utilized for stabilization. RHA has a high silica oxide (SiO2) content of 79.10%. The total amount of Silica, Aluminum, and ferric oxide was 82.01%.

Table 2 Chemical Composition of RHA

Chemical Composition Parameter	SiO2	Al2O3	Fe2O3	CaO	K2O	MgO	Na2O	MnO	CuO	LoI	U	Sio2 + Al203 + Fe203
RHA %	79.10	1.72	1.19	2.10	2.55	2.20	0.13	0.19	0.12	3.60	7.20	82.01

U- Undetermined

Compaction test

Figures 2 (a and b) show the results of compaction test on lime-stabilized soil samples with RHA additive. For all the lime stabilized soil samples, the optimal maximum dry density (MDD) was achieved at 4% RHA content. At 0% content, the RHA's OMC was optimal (i.e. when the lime used for stabilization of the soil samples is 6% without any additive added). MDD for Ekiti state soil samples ranged from 1828 to 2219Kg/m3, 1909 to 2172Kg/m3 for Ondo state soil samples, 1920 to 2075Kg/m3 for Osun state soil samples, 2050 to 2475Kg/m3 for Oyo state soil samples, 1925 to 2050Kg/m3 for Ogun state soil samples and 1420 to 2056Kg/m3 for Lagos state soil samples.

As RHA increased, MDD increased and reached the optimum at 4% RHA. Oyo state soil sample OY2 (Igbeti-Igboho Federal Road) had the highest value of 2475Kg/m3 when stabilized with RHA content. Results of the stabilized soils show that the materials are suitable as subgrade materials except that Apapa wharf –Apapa expressway (LA1) which falls below the required density of 1760Kg/m3 as specified by American Association of State Highway and Transportation Officials AASHTO, (1986), but improved to 1798Kg/m3 with 4% RHA.

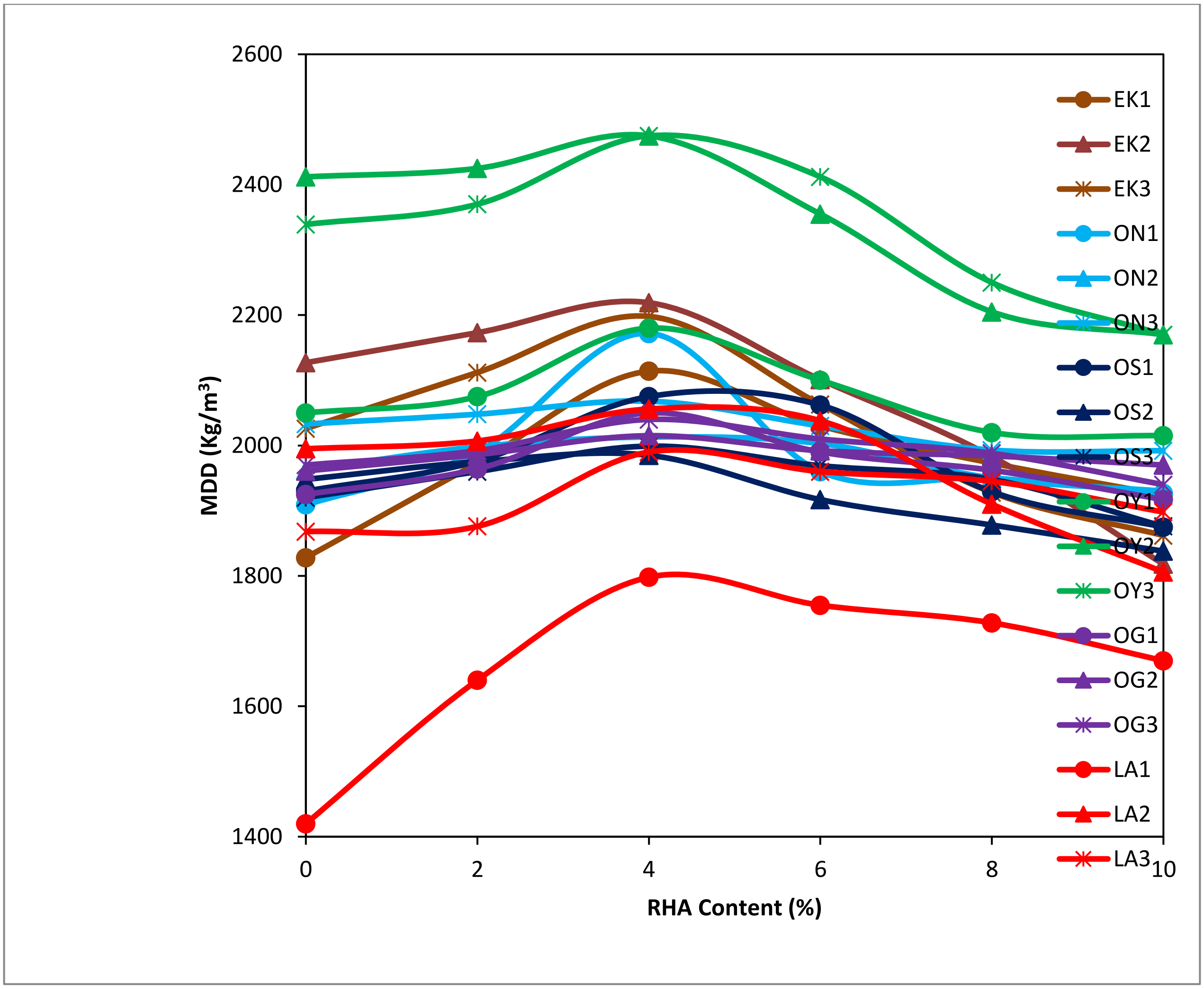

Figure 2a Maximum dry densities of soils stabilized with RHA

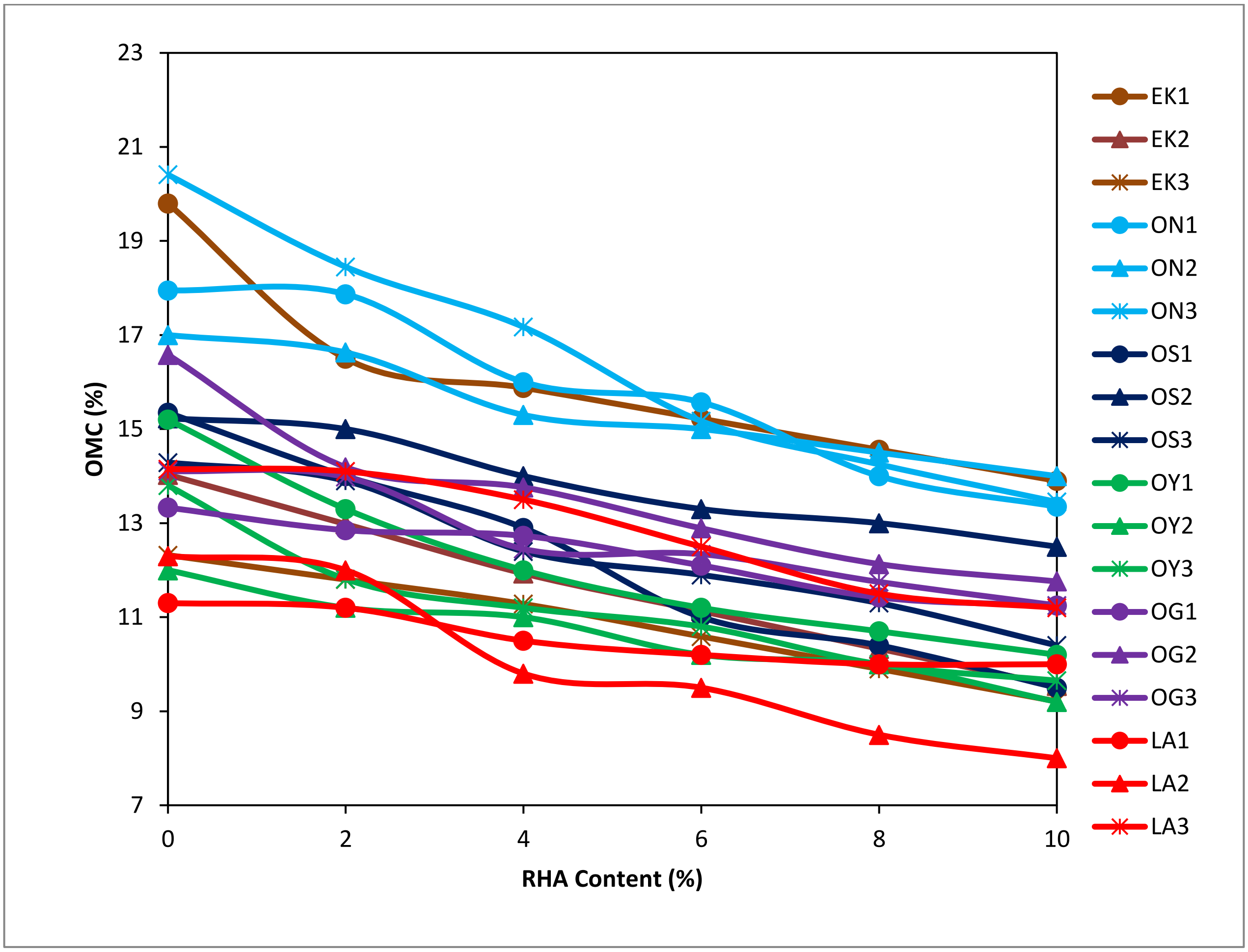

Figure 2b Optimum moisture contents of soils stabilized with RHA

CBR test

Generally, it was observed from Figures 3 (a and b) that there was increase in CBR (both soaked and unsoaked) as RHA content increases and reached the optimum at 4% of the additive content. The 0% values correspond to the optimum values obtained when the soil samples were stabilized with 6% lime content alone. The soaked CBR values of Ekiti State soil samples ranged from 31.85% (0% RHA) to 35.88% (4% RHA); while unsoaked CBR values ranged from 27.46% (0% RHA) to 32.48% (4% RHA). Ondo State soil samples ranged from 4.25(0% RHA) to 5.89% (4% RHA), while unsoaked CBR values ranged from 5.68% (0% RHA) to 8.02% (4% RHA). The soaked CBR values of Osun State soil samples ranged from 7.77% (0% RHA) to 24.55% (4% RHA), while unsoaked CBR values ranged from 5.78% (0% RHA) to 12.27% (4% RHA).

Oyo State soil samples have soaked CBR values ranged from 11.00% (0% RHA) to 59.48% (4% RHA); while unsoaked CBR values ranged from 8.10% (0% RHA) to 43.62% (4% RHA). The soaked CBR values of Ogun State soil samples ranged from 11.11% (0% RHA) to 26.00% (4% RHA); while unsoaked CBR values ranged from 6.51% (0% RHA) to 18.87% (4% RHA). The soaked CBR values of Lagos State soil samples ranged from 4.11% (0% RHA) to 7.77% (4% RHA), while unsoaked CBR values ranged from 6.13% (0% RHA) to 8.02% (4% RHA). Oyo state soil sample OY2 (Igbeti- Igboho Federal Road) has the highest values of 59.48% and 43.62% for both soaked and unsoaked CBR respectively when stabilized with RHA content.

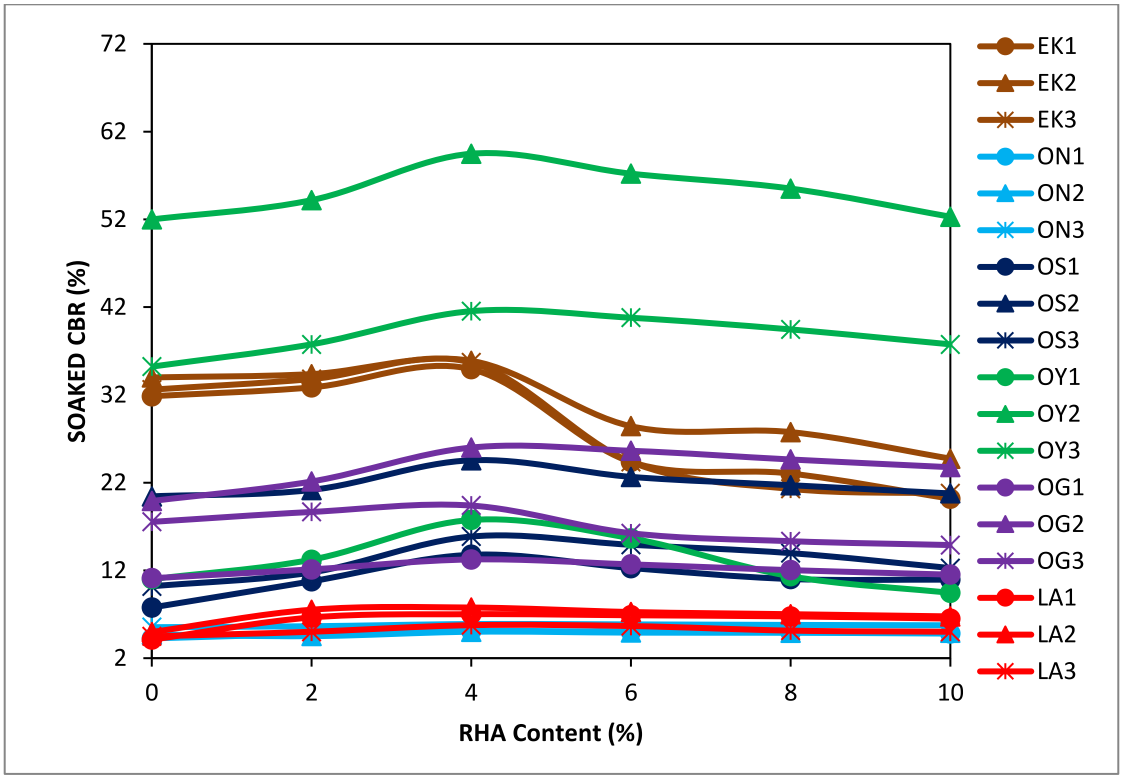

Figure 3a California bearing ratio of soils stabilized with RHA in soaked state

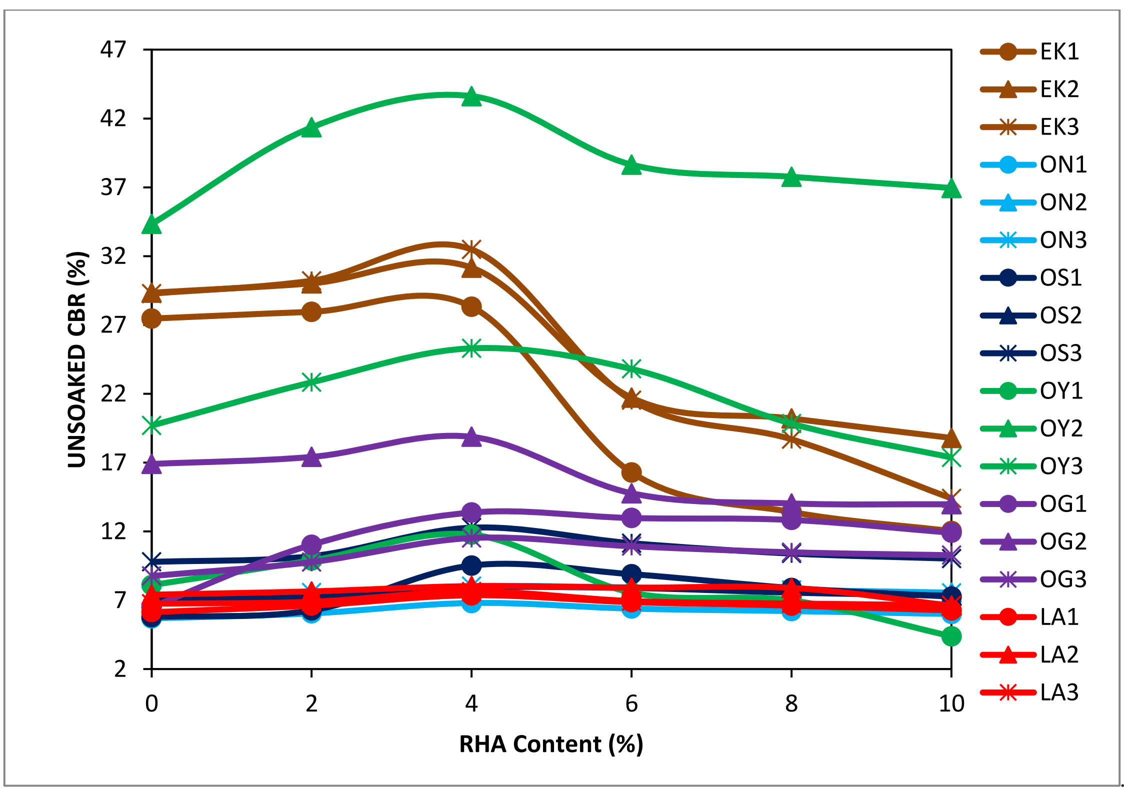

Figure 3b California bearing ratio of soils stabilized with RHA in unsoaked state

UCS test

In general, Unconfined Compressive Strength (UCS) test values rose and reached their peak at 4% RHA content. Figure 4 shows the results of UCS testing on lime-stabilized soil samples with RHA addition. For Ekiti, Ondo, Osun, Oyo, Ogun and Lagos state soil samples, the UCS values ranged from 464.1 to 1096.5kN/m2, 218.4 to 381.6kN/m2, 253.0 to 880.1kN/m2, 126.0 to 521.4kN/m2, 174.0 to 655.5kN/m2 and 292.3 to 390.4kN/m2. Ekiti State soil sample (Ado-Itawure Federal Road) had a maximum value of 1096.5kN/m2 when stabilized with RHA content.

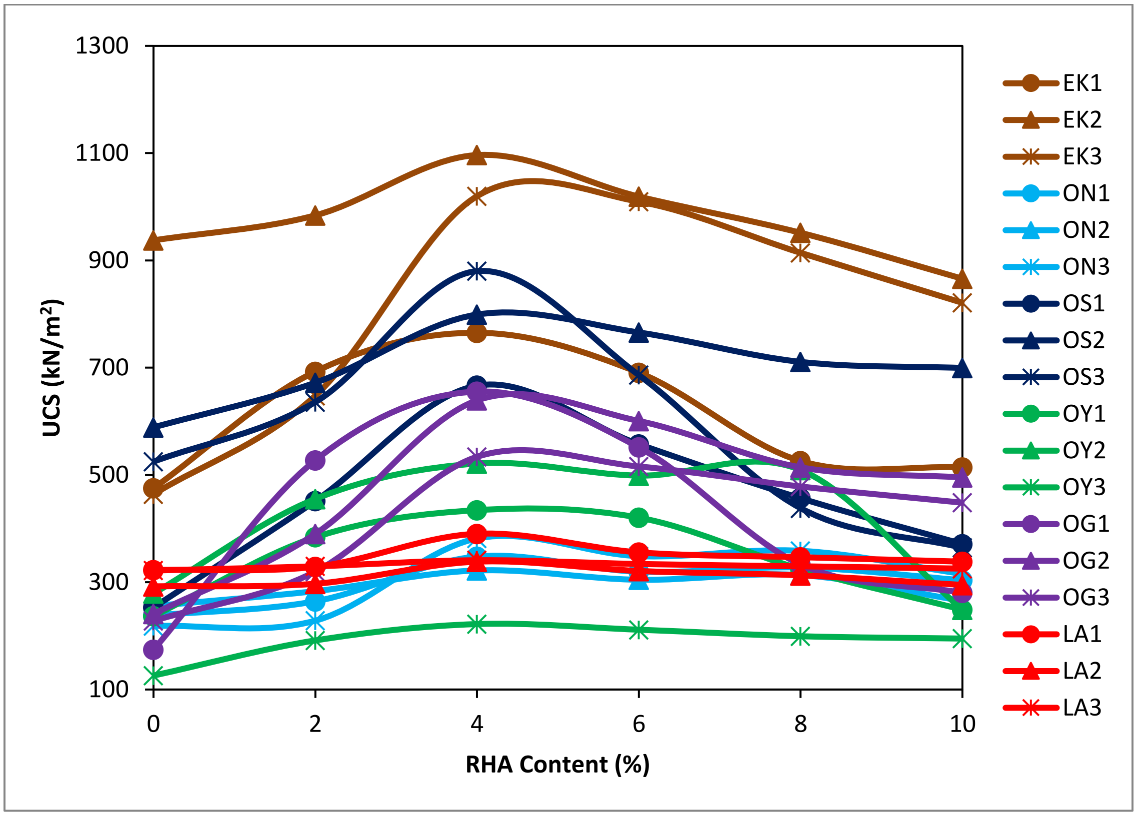

Figure 4 Unconfined compressive strength results of soils stabilized with RHA

Triaxial test

Triaxial compression test was performed on optimum lime stabilized soil samples with RHA additive. The cohesion(C), angle of internal friction (ø), and shear strength (τ) values of the triaxial tests on the 6% lime stabilized soil samples with 0-10% additive content improved in general and they achieved the optimum at 6% RHA content. The C, ø and τ values ranged from 80 to 140kN/m2, 20 to 26° and 153.25 to 213.94kN/m2 respectively for Ekiti state soil samples; from 108 to 130kN/m2, 20 to 31°, and 186.71 to 262.52kN/m2 respectively for Ondo state soil samples; from 34.00 to 98.00kN/m2, 15 to 260 and 94.11 to 155.00kN/m2 respectively for Osun state soil samples; from 87 to 126KN/m2, 12 to 15° and 122.61 to 172.77kN/m2 respectively for Oyo state soil samples; from 99.00 to 114.00kN/m2, 8 to 12° and 135.94 to 161.36kN/m2 for Ogun state soil samples and 8 to 122kN/m2, 22 to 43° and 91.98 to 254.97kN/m2 for Lagos state soil samples.

Ekiti state soil sample (Ado- Ilawure Federal Road) has the highest value of 140kN/m2 (cohesion) when stabilized with RHA content, Lagos State soil sample LA2 (Lekki- Ajah Federal Road) has the highest value of 430 (angle of internal friction) while Ondo State soil sample ON3 (Ondo- Ore Federal Road) has the highest value of 262.52kN/m2 (shear strength) when stabilized with RHA content. The result of shear strength of the stabilized soil samples is as shown in (Figure 5).

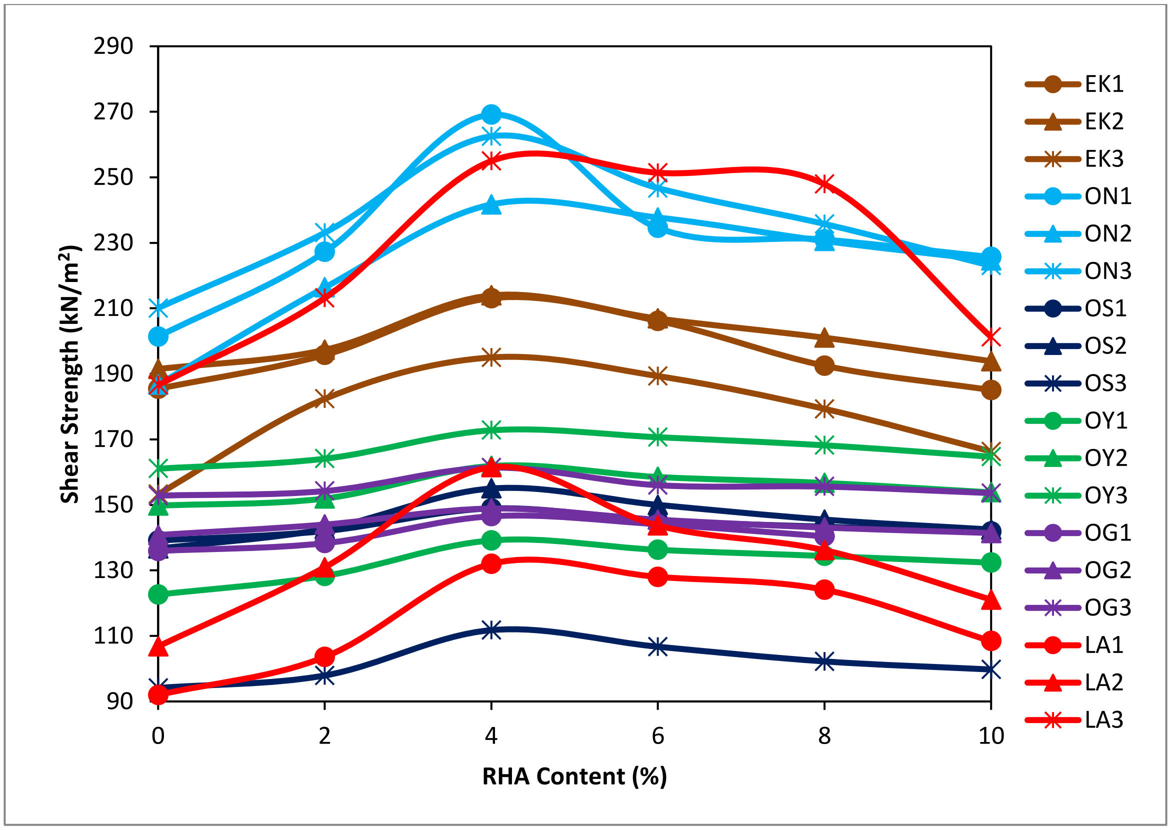

Figure 5 Shear strength of soils stabilized with RHA

4. CONCLUSION

The investigation came to the following conclusions:

RHA has a high silica (SiO2) content.

Except for OMC, all the strength attributes increase as RHA increases up to 4% RHA content and then decreases afterward.

The results indicate that the soils could effectively be stabilized using lime and Rice Husk Ash (RHA) additive. A blend of 6% lime and 4% RHA is suggested for soil improvement, particularly in Southwestern Nigeria.

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Author Contributions

The study was carried out by Dr SO Faluyi under the supervision of Prof OO Amu, in the laboratory headed by Engr JS Adekanmi.

Informed consent

Not applicable.

Ethical approval

Not applicable.

Conflicts of interests

The authors declare that there are no conflicts of interests.

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Data and materials availability
All data associated with this study are present in the paper.

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