Impact of Rice Husk Ash Based-Geopolymer on Some Geotechnical Properties of Selected Residual Tropical Soils

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ABSTRACT: There is usually a need to enhance the properties of soils with poor geotechnical properties encountered during construction. The utilisation of Rice Husk Ash (RHA) - based geopolymer for improving some properties of two selected tropical soils was investigated. The Atterberg's limits (Liquid limit, LL and plastic limit, PL), compaction properties (maximum dry density, MDD and optimum moisture content, OMC), California bearing ratio (CBR) and unconfined compression strength (UCS) of the un-stabilized and stabilized soils were estimated. The soil samples were stabilized with alkali activated RHA varying from 3 to 15% (in 3% increment). Alkaline activation was achieved by using a mixture of $NaOH_{(aq)}$ and $Na_2SiO_{3(aq)}$ in ratio 1:2. Mineralogy and elemental analysis of the un-stabilized soils, RHA and stabilized soils were obtained using X-Ray diffraction, X-Ray Fluorescence, EDS and SEM. The LL and PI of the stabilized soils decreased with as much as 30 and 40%, respectively, while the CBR and UCS increased as much as 300% and 1500%, respectively. SEM and EDS analysis of the treated soil showed the formation of crystalline hydration products. It is concluded that RHA based geopolymer is a potential environmentally sustainable stabiliser in tropical climatic condition.

KEYWORDS: Subgrade soil, Rice Husk Ash (RHA), geopolymerization, stabilisation, alkaline activation.

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I. INTRODUCTION

In road construction, soils that have low shear strength, low California bearing ratio and high expansivity are not suitable to be used as construction materials, such soils must be improved or removed and replaced with suitable soils before the pavement layers are constructed. Among soil improvement methods, chemical stabilization has been widely used because of its effectiveness (Winterkorn and Pamukcu, 1991). Although ordinary Portland cement (OPC) or lime are widely accepted as soil stabilizers, they have high production and construction cost (Akinwumi et al., 2019; Yalley and Kwan, 2008). In addition to the high production cost, cement production and usage is being discouraged due to its contribution to environmental degradation. Cement production contributes about 8% of greenhouse gases (Andrew, 2018) and carbon emission (Olonade and Mohammed, 2019), hence, it is a key contributor in climate change challenge facing the world. Thus, it is a matter of urgency that sustainable materials with comparative engineering performance to cement are developed and utilized in the construction industry to replace the conventional ordinary Portland cement (OPC).

Furthermore, there is an increase in bio-wastes globally especially in Africa where there is increase in agricultural practices (Olonade and Mohammed, 2019). Among this increasing agricultural practice is rice production. Rice paddy is grown in many countries of the world. Rice husk constitutes 20% of the 800 million tons of paddy produced in the world and 25% of of this husk is obtained as RHA by burning (Singh et al., 2021). Like many other wastes, there is no effective disposal method for rice husk waste generated daily. Most of the time, the husk is left in open space as garbage or disposed by burning thereby causing environmental pollution. The ash generated is discarded as waste, this increases the volume of landfill or the ash is disposed into water ways resulting in water pollution.

RHA is a renewable agricultural waste material littering rice producing communities. RHA recycling requires attention as a sustainable soil stabilizer. Particularly, because of its pozzolanicity. It is a material with high content of SiO_2 and Al_2O_3 (Adeyanju et al., 2020; Moayedi et al., 2019), and thus can be used for alternative binder. However, RHA cannot be utilized alone because it lacks binding properties. The usage of RHA in construction has been explored as additive with effective binders such as cement, lime and calcium chloride

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(Hossain et al., 2021). When compared to traditional binders, the low reaction time and inadequate binding effect but abundance of the rice husk in rice producing community has aroused researchers' curiosity. Rice husk ash contains minerals such as quartz, kaolinite or calcite depending on the burning temperature (Cong and Cheng, 2021; Detphan and Chindaprasirt, 2009).

Geopolymers are inorganic polymers formed by adding alkaline activators to low calcium ashes (such as fly ash and agricultural waste ashes) for purpose of soil stabilisation (Duxson et al., 2007). The alkaline activators often used are Sodium hydroxide (NaOH) or Potassium hydroxide (KOH). In an alkaline condition of NaOH with sodium silicate Na_2SiO_3, a 3D bond structure of Si-O-Al-O is formed (Teing et al., 2019). A discrete molecule of aluminosilicate structures is later generated by polycondensation reaction from the unit of Si-O-Al (Sargent, 2015). The new stable structure formed from polycondensation gives high stability to the stabilized soils.

The use of alkali activated-RHA to stabilize soil for construction is an innovative way of reducing the cost of in-situ soil replacement in road pavement construction and getting our environment free of waste material that is damaging and dangerous to humans (Nassar and Kathirvel, 2023; Tanu and Unnikrishnan, 2022). This is in line with UN sustainable development goals 9 and 11 which is to build resilient infrastructure; make cities and human settlement sustainable.

The aim of this study is to assess the effectiveness of alkaline activated rice husk ash geopolymer in stabilizing two tropical laterites. The objectives are (i) to determine the geotechnical properties of the laterites in their unstabilized states, (ii) determine some geotechnical properties of the stabilized laterite and (iii) compare the results from (i) and (ii). This was achieved by stabilizing the laterites with alkaline activated rice husk ash (RHA). The detailed methodology is provided in section 2. The study was done with a view to providing a potentially environmentally sustainable soil stabilizer for laterites.

II. MATERIALS AND METHODS/METHODOLOGY/EXPERIMENTAL PROCEDURE.

A. Materials

1) Soil samples

Soils used in this study are typical residual tropical soils collected from two points within Osun State, Southwestern Nigeria. GPS locations of the sampling points are Latitude 7° 30' 47.412"N and Longitude 4° 32' 56.857"E for soil A and Latitude 7°31' 2.705" and Longitude 4° 34' 13.022"E for soil B.

2) Rice husk ash (RHA)

Dried rice husk was obtained directly from National Cereal Research Institute, Badeggi, Nigeria. The rice husk was burnt at a controlled temperature of 750^0C for 210-240 minutes in a muffle furnace as recommended by Olonade and Mohammed (2019). After burning, the ashes were allowed to cool in the furnace before they were removed. The rice husk ash (RHA) ashes were grounded using kitchen blender and then sieved through 75 µm of BS to obtain very fine ash with large surface area needed for binding reaction.

3) Alkali activator (Geopolymer)

High purity sodium hydroxide pellets, $NaOH_{(s)}$ and Sodium silicate solution ($Na_2SiO_{3(aq)}$) were procured from a reputable chemical store. $Na_2SiO_{3(aq)}$ had dark gray colour with high viscosity. These alkali reagents were chosen for the geopolymer because of their proven efficacy in the alkaline activation process in recent studies by Corrêa-Silva et al. (2019); Disu and Kolay (2021); Hwang and Huynh (2015) and Pourakbar et al. (2016). NaOH solution with 10M concentration was produced by dissolving 400 g of $NaOH_{(s)}$ pellets in 1 dm^3 of distilled water. The alkali activator was prepared by mixing $NaOH_{(aq)}$ with $Na_2SiO_{3(aq)}$ using a ratio of 1:2 to obtain 10M. This is according to studies by Corrêa-Silva et al. (2019) and Pourakbar et al. (2016) who established the 10M and ratio 1:2 as the most effective concentration for alkali activation of fly ash. Constant ratio of 0.5 of RHA to alkali activator was also employed in this study to achieve geopolymerization according to Disu and Kolay (2021).

B. Methods

1) Testing program

The testing program for this study are detailed in Table 1. Some baseline properties of the unstabilized/natural soils were determined to serve as basis for comparison and this is test N in Table 1. Soil samples were then thoroughly mixed with different percentages of RHA with or without alkaline activator as detailed in Table 1. The percentage (by dry weight of soil) of the RHA used were 3 -15% (with 3% increment). The first letter in the “Test name” indicate RHA, while the second letter (where applicable) indicate the addition of alkali activator (i.e geopolymer). The only number in the test name indicate the percentage of RHA. Thus, going forward, “R” test refers to test carried out on soil stabilized with only RHA while “RG” test refer to test carried out on soils mixed with both RHA and alkaline activator. Letters A and B can be added at the back to indicate soil A or B. Thus 3R-A indicate test in which only 3% RHA was used to stabilize soil A.

Different properties (such as the Atterberg’s limits, compaction properties, California bearing ratio and unconfined compressive strength) of the natural soil and soil-RHA mixes were determined using standard methods as detailed in the subsequent sections. It should be noted that only the LL and PL of both “R” and “RG” tests were determined while the other properties were determined for only “RG” tests.

2) Index properties of the natural soil Atterberg’s limits determination

The index properties of the residual soils were assessed through natural moisture content, specific gravity, grain size distribution in line with dictates of BS 1377: part 2. The minerals and chemical composition of the soils and RHA were evaluated by X-ray diffraction and X-ray fluorescence, respectively. The Liquid limit (LL) and plastic limit (PL) of the soil samples were determined following the procedures of BS

1377: Part 2. The tests were carried out on the soils finer than sieve 0.425 mm. All the tests in Table 1 were carried out to determine the LL and PL of both soils A and B. The results of the tests were used to classify the soil according to use and its adequacy as road construction material in line with outlines of the American Association of State Highway and Transportation Officials (AASHTO) classification system were evaluated.

Table 1: Testing Program.

S/N	Test	% of RHA	Remarks
1.	N	0	Unstabilized Natural Soil
2.	3R	3	No Alkaline Activator
3.	6R	6	No Alkaline Activator
4.	9R	9	No Alkaline Activator
5.	12R	12	No Alkaline Activator
6.	15R	15	No Alkaline Activator
7.	3RG	3	With Alkaline Activator
8.	6RG	6	With Alkaline Activator
9.	9RG	9	With Alkaline Activator
10.	12RG	12	With Alkaline Activator
11.	15RG	15	With Alkaline Activator

3) Compaction properties

The moisture-density relationships using Standard Proctor Test according to BS 1377-1990 (Part 4) to obtain the optimum moisture content (OMC) and the maximum dry density (MDD) of the natural soils were determined. British Standard light compaction energy of three layers of approximately equal mass with each layer being compacted with 27 blows of 2.5 kg rammer falling through a 300 mm height.

4) California bearing ratio

California bearing ratio (CBR) test was conducted in accordance with BS 1924 (1990) for the natural and geopolymer treated soils. Samples were moulded using British Standard light (BSL) energy level in three layers with each layer receiving 62 blows from the 2.5 kg hammer. Three samples were prepared for every mix design, one was tested after few hours of compaction representing day zero (CBRu-0), and second sample was cured in polythene for 5 days and then immersed in water for 48 hours before testing (CBRs). The third sample was cured for 7 days in polythene before testing (CBRu-7). CBR value was obtained by expressing the loads at penetration of 2.5 mm and 5 mm as a percentage of the standard load.

5) Unconfined compression strength

Strength tests were performed on soil - RHA - geopolymer mixtures to determine unconfined compressive strength (UCS) according to BS 1377; 1990 Part 7. Specimens were prepared at their respective optimum moisture content; fresh samples were tested few hours after moulding representing zero-day strength (UCS-0). Another set of samples were cured for 7, 14 and 28 days in air tight polythene before testing (UCS-7 etc). The last set of samples for each mix were put in the oven at 70^0C for 24 h (i.e thermally cured), retrieved from oven and then kept in room temperature until 7th, 14th and 28th days before testing to obtain UCS-7T etc. This thermal curing aimed to study elevated temperature influence on the soil-geopolymer mixes i.e. RG tests.

III. RESULTS AND DISCUSSION

A. Properties of the Natural Soils

Some properties of both Soil A and B in their natural states are presented in Table 2. These soils are susceptible to water content changes. Both soils have more than 50% fines content which implies their unsuitability as road construction material according to Federal Ministry of works and Housing (2013). Quartz is identified as the major soil mineral in the residual soil samples with 67% in soil A and 68% in soil B. The peaks of Quartz can also be seen in the XRD diffractogram for both soils A and B in Figures 1(a) and (b), respectively. Other mineral compositions of the soils determined through XRD are also presented in Table 2.

The soils in their natural states have liquid limit (LL) of 59.3% and 50% for soil A and B respectively. According to Adeboje et al. (2017), liquid limits above 35% show high plasticity indicating that the soil is susceptible to shrinkage or cracking. Thus, both the soil samples require treatment before they can be considered suitable for road construction.

The unsoaked and soaked CBR (CBR and CBR_s) of both natural soil samples are presented in Table 2. The soaked and unsoaked CBR for both soil samples in their natural states are low. According to Federal Ministry of works and Housing (2013), soil A is classified as subgrade soil S1 and soil B as class S2 subgrade. Soils with a CBR_s less than 3% are described as a low strength soil that require special treatment before being used as pavement construction layer (Federal Ministry of works and Housing, 2013). Pavement built with Low strength soil such as soil A is required to have 250 mm thickness, while a thickness of 350 mm is required for a pavement built with soil B. High thicknesses such as these would result in high cost of construction.

Table 2: Physical Properties and Chemical Composition of Natural Soil Samples.

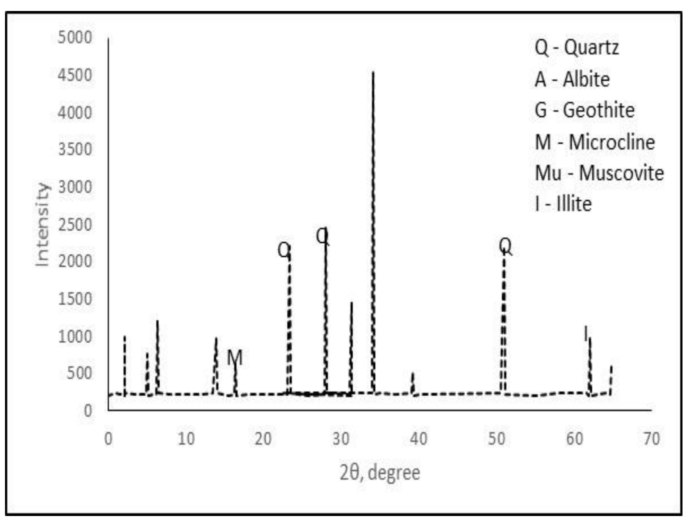
	Values	
	Soil A	Soil B
Physical Properties		
Natural Moisture Content (%)	30.53	27.03
Specific Gravity (Gs)	2.61	2.64
Colour	Reddish brown	Yellowish brown
pH	8.0	7.6
Liquid Limit LL (%)	59.3	50
Plastic Limit PL (%)	25.59	31.82
Plasticity Index PI (%)	33.71	18.18
Soil passing 75 µm sieve (%)	84.2	67.4
AASHTO classification	A-7-6	A-7-6
USCS Classification	CH	CL
Group Index (GI)	31	12
Optimum Moisture Content, OMC (%)	34	21
Maximum Dry Density, MDD (Mg/m^3)	1.46	1.62
California Bearing Ratio, CBR (%)	2.36	7.16
Soaked CBR, CBR_s (%)	1.13	6.01
Unconfined compressive strength, UCS (kN/m^2)	112.28	130.05
Minerals Composition (%)		
Quartz	67.08	68.4
Albite	6.19	6.3
Goethite	4.99	4.76
Microcline	3.28	3.02
Muscovite	7.41	7.54
Smectite	5.95	5.87
Illite	5.09	4.14

B. Properties of Rice Husk Ash

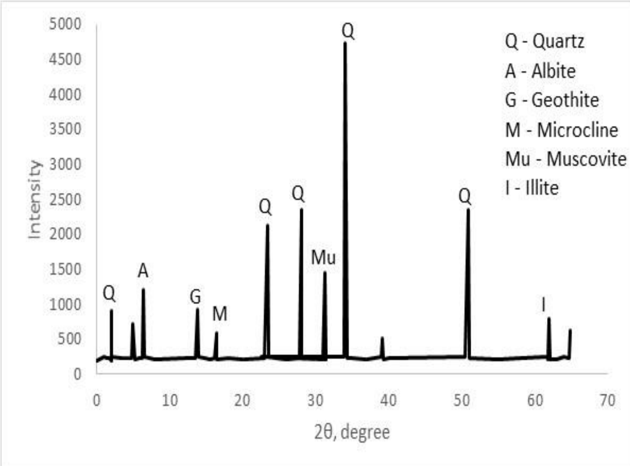
Rice Husk Ash (RHA) had a grey colour after burning. The specific gravity was evaluated as 2.29. Table 3 shows the oxides composition of the RHA while Figure 1c shows the RHA diffractogram. The results show that SiO_2+Al_2O_3+Fe_2O_3 of the ash is 83.64% which is more that 70% and the LOI is greater than 6%. These properties classify the RHA as a class F fly ash according to Bhatt et al. (2019), this implies that an activator is required for the RHA to be used for improving soil properties

Table 3: Chemical Composition of Rice Husk Ash.

Oxides	**%**
SiO_2	78.56
Al_2O_3	4.11
Fe_2O_3	0.97
CaO	0.27
MgO	0.31
SO_3	0.50
K_2O	1.60
Na_2O	0.03
P_2O_5	0.57
LOI	9.51
TOTAL	**96.44**



(a)



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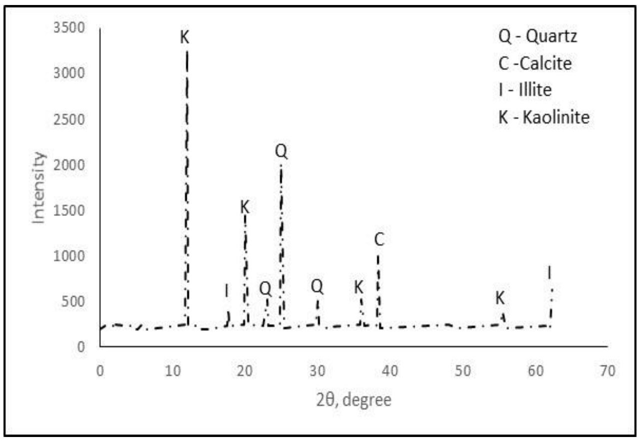

(c)

Figure 1: Diffractogram of soil A, B and Rice husk ash

C. Effect of geopolymer on pH of soil samples

The pH variation of both soils A and B for RG tests are presented in Figure 2. The findings showed that with the addition of geopolymer, the pH values of both soil samples significantly increased more than the initial unstabilized soils' pH values. Similar results were obtained by Etim et al. (2017).

According to Vogel and Kasper (2002), high pH is associated with low dissolved metals and high metal concentration in the soil. Sargent (2015) stated that the pH of stabilized soil must not be less than 10.5 for pozzolanic reaction to occur. Ekpo et al. (2020) also stated that high alkaline medium is required for pozzolanic reaction for the formation of Si-O-Al stable bond in geopolymerization process. Thus, the pH in the treated soils can facilitate pozzolanic reaction required for increased strength.

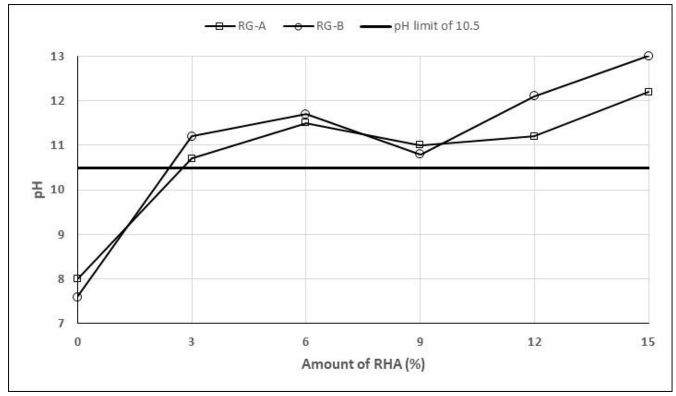

Figure 2: Effect of geopolymerization on the pH of the soils.

D. Effect of RHA on the Atterberg's Limits of the Soils

1) Liquid limit

The effect of RHA on the liquid limit (LL) of both soil samples are shown in Figure 3. It was seen that there is reduction in LL of both soils A and B in both test R and RG such that most of the treated soils have changed from high to low plasticity soils. The most reduction are recorded in test RG. When comparing the LL of treated soil with the natural untreated soil, the highest reduction (20%) for R tests was recorded in both 9R-A and 15R-B while that of RG test was recorded in test 15RG-A (30%) and 6RG-B (40%). This implies that geopolymerization caused a further decrease in the LL of both soil samples. The addition of alkali activator possibly caused the release of cations into the pore water, leading to increase of electrolyte concentration of the pore water thereby decreasing the thickness of the diffuse double layer held on to the soil leading to a lower liquid limit (Osinubi et al., 2015). This result is in agreement with that of Amadi (2010); Ayodele et al. (2023) and Ramesh et al., (2013).

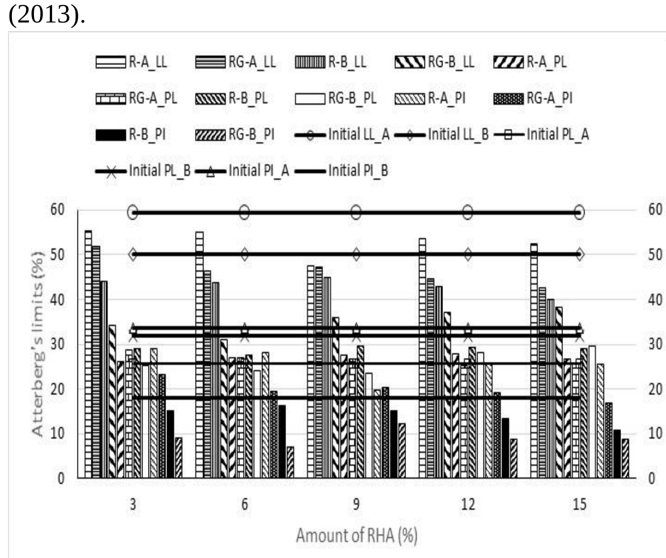

Figure 3: Atterberg's limits of RHA and geopolymer treated soils.

2) Plastic limit

The plastic limits of the treated soils fluctuate in an irregular manner as presented in Figure 4. Both RHA and geopolymerization generally increased the PL of soil A with a maximum increase of 9% in 12R-A test and 12% in 3RG-B test. When comparing R and RG tests, it was found that geopolymerization caused a decrease of up to 9% in the PL. The PL of soil B, on the other hand, generally decreased after stabilization with maximum decrease of 14% in 6R-B and 26% in 9RG-B tests. Geopolymerization further reduced the PL with maximum of 20% in 9RG-B. The general effect in R-A tests is increase There was an increase of about 12% in the PL of treated soil A, whereas, the PL of treated soil B reduced with about a maximum of 35%. The pattern observed for soil A is in agreement with that of Amadi (2010), Okunade (2010) and Sargent et al. (2013) who observed increased PL with increased fly ash content. Whereas the decrease pattern observed in B is in agreement with Ayodele et al. (2023). The increase in geopolymer causes changes in the physical and chemical properties of the soils.

3) Plasticity Index

There is a general reduction in the PI of the treated soils A and B as presented in Figure 5. The reduction is about 40, 50, 40 and 60% in tests 9R-A, 15RG-A, 15R-B, and 6RG-B, respectively. The results further show that geopolymerization caused further decrease in the PI with maximum reduction of about 35 and 56% in soil A and B, respectively. This reduced PI is required for the soil to be suitable as a road construction material.

4) Statistical Analysis of the Atterberg's Limits of Treated Soils

The statistical significance of the effect of RHA and geopolymerization on the Atterberg's limits of the soil samples was evaluated using a two-way analysis of variance (ANOVA). The results of the analysis show that. The P values (at 95% confidence level) indicate that the addition of RHA and geopolymer are significant factors affecting the Atterberg's limits for both soil samples except for the PI of soil B. Considering the fact that geopolymerization has a positive effect on the plasticity results, the other geotechnical properties were determined for alkaline activated RHA stabilized soils i.e RG tests.

E. Compaction Properties of the Treated Soils

The variation of maximum dry density (MDD) and optimum moisture content (OMC) of the treated soils are shown in Figure 4. Generally, the MDD values decreased with increasing RHA content. The decrease in MDD values is probably as a result of the RHA particles which has a lower specific gravity replacing the soil particles which has a higher specific gravity. However, the OMC showed a corresponding increase with increase in RHA percentage for both soils. The increased OMC is, however, more pronounced in soil B. The increase in OMC in both soils could probably be due to the increase in fines of RHA with larger surface areas that required more water to react (Santos et al., 2011). This result is in agreement with that of Ayodele et al. (2023) who worked on fly ash stabilized laterite. Additionally, the increase in moisture is probably the result of hygroscopic nature of the alkali, in which all sodium hydroxide attracts moist air, causing hydration.

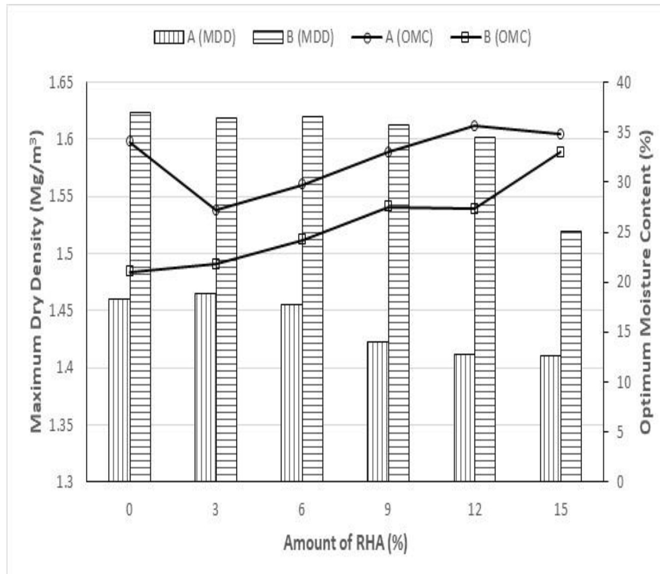

Figure 4: Moisture-Density parameters of treated soils.

F. California Bearing Ratio of Treated Soils

It is common practise to design base and sub-base materials for pavement using the CBR value of a compacted soil as an indicator of soil strength and bearing capacity. It is also one of the most often employed tests for determining the durability of stabilised soils. Figure 5 illustrates the changes in the CBR of both soil samples as RHA increased from 0 to 15%. Geopolymerization caused significant increase in the soaked and unsoaked CBR of both soil samples. It can be seen that the highest increase was recorded for the soaked condition (i.e. CBRs). The highest increase in CBRs of almost 800% and 240% were recorded for soils A and B, respectively at 15% RHA. These results show that soaking has a beneficial effect on the CBR of the soil as also reported by Turkane and Chouksey (2022). These results are in agreement with that of Adeyanju et al. (2020) and Corrêa-Silva et al. (2019). It is noteworthy that geopolymerization has more positive effect on soil A which has a higher plasticity than soil B. Increasing the curing period also improved the CBR as seen for CBRu-7.

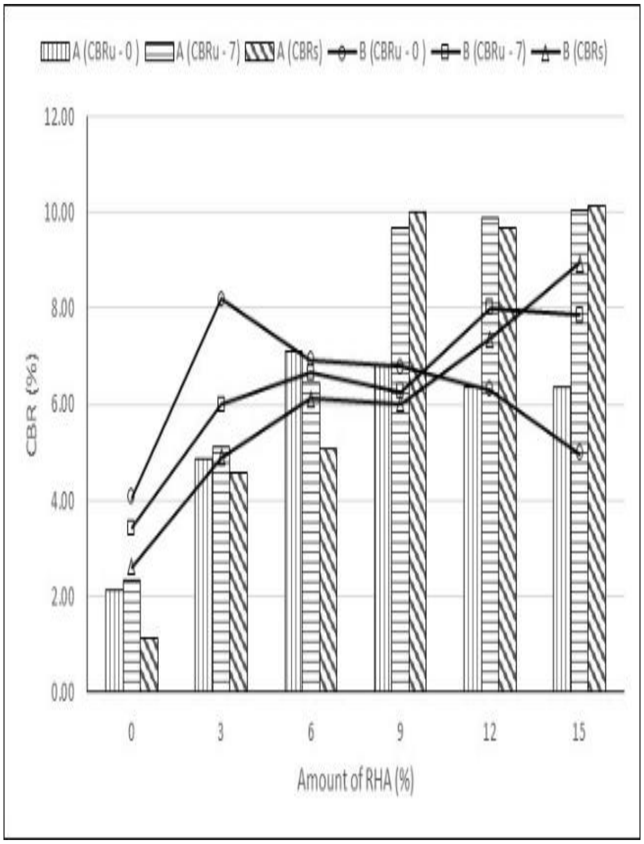

Figure 5: Effect of RHA (%) on California Bearing Ratio.

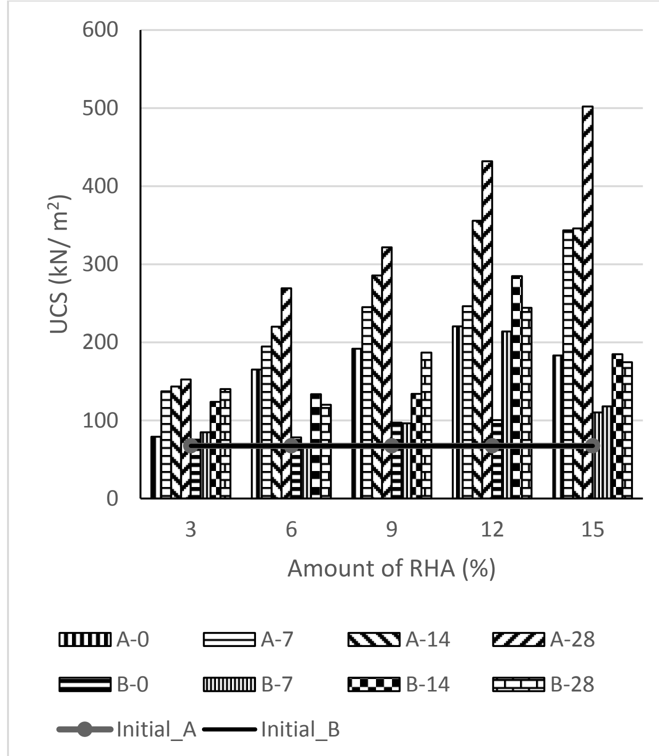

Figure 6a: Effect of geopolymerization at different curing ages on unconfined compression strength of polythene cured soils A and B.

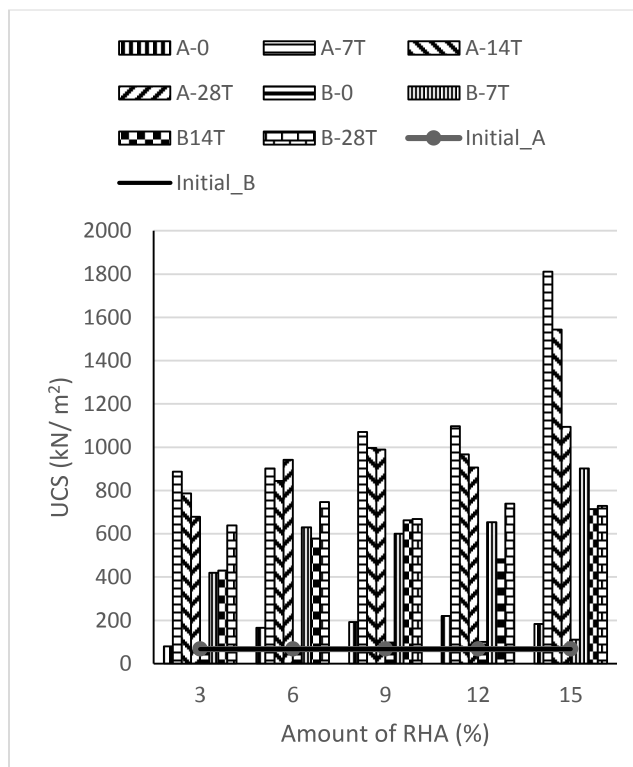

Figure 6b: Effect of geopolymerization at different curing ages on unconfined compression strength of thermally cured soils A and B.

G. *Unconfined Compressive Strength of Treated Soils*

The unconfined compressive strengths (UCS) of the treated soils are presented in Figure 6. The UCS of the treated soils increased considerably both for polythene and thermally cured conditions. The UCS improvement due to increase in RHA must have resulted from the pozzolanic reaction between the activated alkali and the pozzolanic RHA to form secondary cementitious materials. Although, thermal curing resulted in a much higher UCS with percent increase of up to 2600 and 1200% in soils A and B, respectively. Microfabric alterations and the creation of cementitious compounds are responsible for strength development which resulted in the increase in UCS values according to Negi et al. (2013).

Similarly, the rise in UCS with curing time can be attributed to hydration reactions of the soil–RHA and alkali mixtures induced by the high pH of the mix induced by the alkali activator, as well as a time-dependent gain in strength as postulated by Teing et al. (2019). As observed in the Figure 6a, geopolymer stabilized soil at high temperature exhibited greater compressive strength than polythene-cured specimens. This can be as a result of heat, which expedited the production of strong Si-O-Al bonds. This result show that there could be additional increase in the UCS of compacted stabilized soil under elevated temperature that is common in the tropics.

H. Micro-Structural Analysis of Geopolymer-stabilized Soils

Figures 7 (a) and (b) illustrate the scanning electron microscopy (SEM) of natural soil A and 15% RHA-geopolymer-treated soil (i.e. 15RG) for a better understanding of the chemical reaction or mechanism of stabilization process. The treated soil in 15RG tests exhibited the optimal strength for both CBR and UCS. Figure 7(a) depicts the loose texture of untreated soil where the size of the particles varies from small to large and there are multiple voids and visible cracks. In contrast, Figure 7 (b) demonstrates that the discrete soil particles in the stabilized material appear to be tightly bound and dense, with the void appearing to be filled. The observed blended particles can be ascribed to the ability of activated alkali, NaOH/$NaSiO_3$, to dissolve RHA and soil particles (Disu and Kolay, 2021). The SEM micrograph and EDX data of stabilized soil reveal the formation of cementitious gels. This is the result of hydration and pozzolanic reactions in the pores of the soil, which reduced the pore space through binding.

Figures 8(a) and 8(b) show the energy – dispersive X-ray spectroscopy (EDS) elemental analysis of natural soil A and the optimally treated soil A (i.e. 15RG). The results show the expected production of new compounds as a result of the physicochemical changes occurring within the soil–RHA-alkali mixes. In all the spot analyses done on both natural and optimally treated soils, Si, Al, and Fe are the dominant elements. However, Si was observed to increase in percentage in the treated soil sample. This increment may be due to silica content of added RHA. Additional elemental residues of Ca and Pb were identified in the treated soil scanned after the curing period.

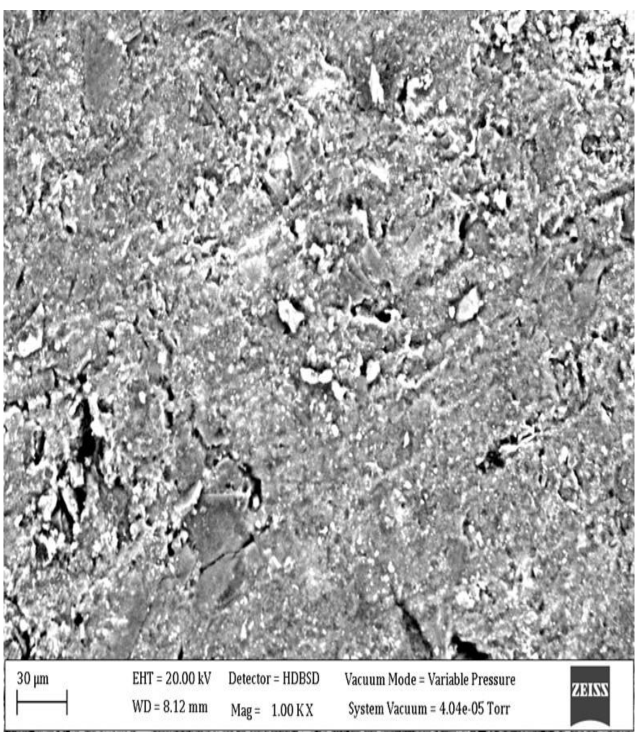

Fig 9(a) Natural Soil A.

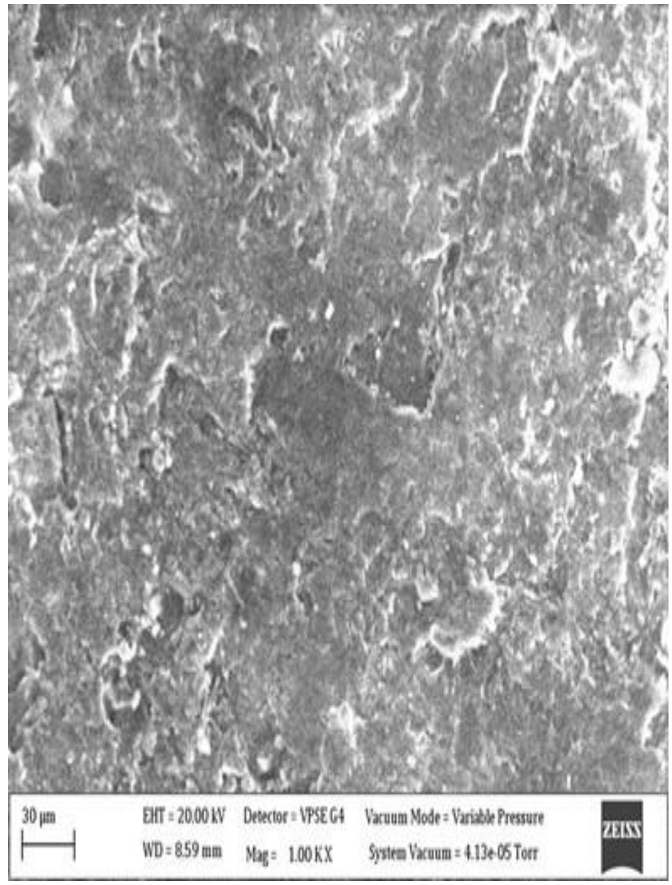

Fig 9b: 15% RHA-geopolymer + Soil A.

Energy-dispersive X-ray spectroscopy (EDS)

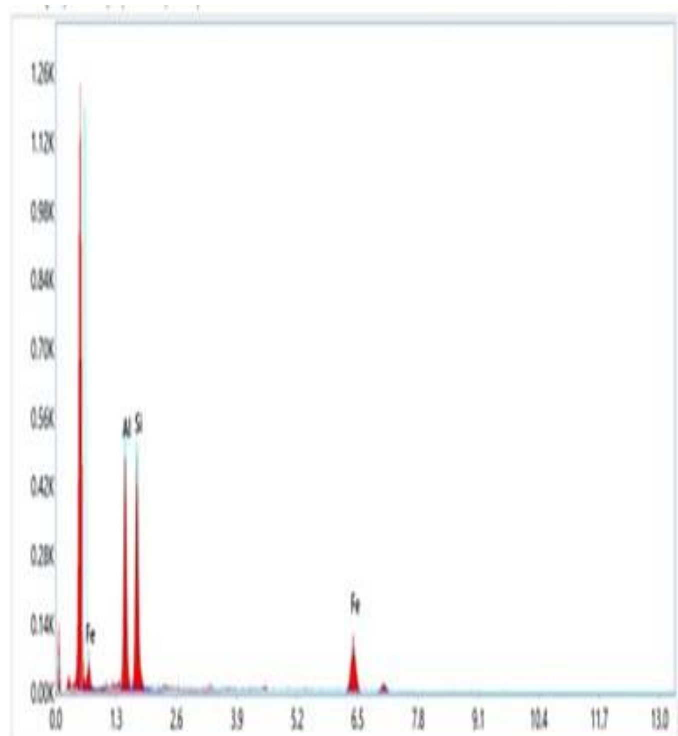

Figure 10a: Natural A

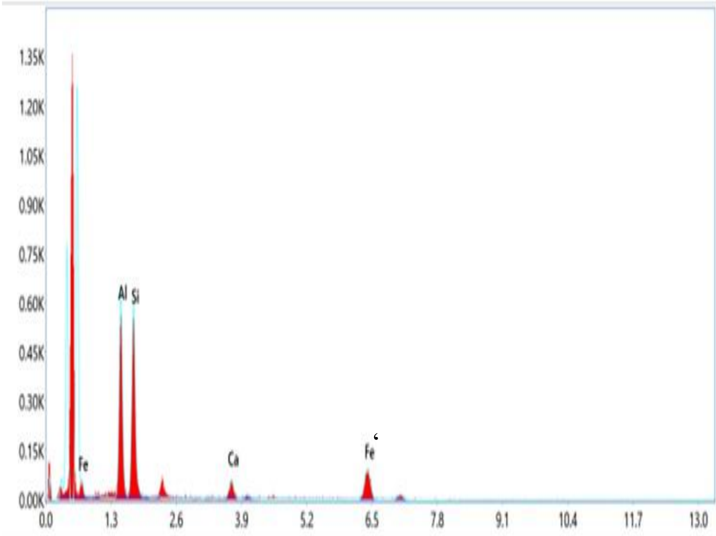

Figure 10b: 15% A

IV. CONCLUSION

The study investigated the effects of different percentages of Rice Husk Ash (RHA) and geopolymerization (alkaline activation) on the Atterberg's limits, soaked and unsoaked California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) of two laterite soils at different curing ages. The soil samples used for UCS determination were both polythene and thermally cured. Laboratory analysis using standard methods were employed. The results showed that both soils samples were fine grained and classified as clay/silt soils and thus require stabilization. The study revealed that while geopolymerization has a significant effect on the Atterberg's limits and CBR of both soil sample, it has more positive effect on soil A which has a higher plasticity than soil B. Soaking also improve the CBR of both stabilized soil samples. Thermal curing was also found to be more beneficial in increasing the UCS, this imply that there could be increase in the strength properties of a compacted stabilised soil under elevated temperature common in the tropics. EDS elemental analysis confirmed the presence of crystalline hydration products in the RHA-geopolymer treated soil; The blended phase observed in SEM micrographs are manifestations of crystalline hydration products formed in the process of stabilization. This is assumed to be the primary component contributing to strength improvement. This study concluded that the use of RHA geopolymer has promises in the stabilization of tropical laterites.

AUTHOR CONTRIBUTIONS

A. L. Ayodele: Conceptualization, Project administration, formal analysis, Supervision, Writing – review & editing, Visualisation. **I. K. Ajibola:** Data curation, investigation, Methodology, Resources, Writing – original draft. **A. B Fajobi:** Conceptualization, Methodology, Resources and Validation

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