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Influence of Rice Husk Ash on the Engineering Properties of Soil

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Abstract

The study investigated the effects of rice husk ash (RHA) on the engineering characteristics of soil. The RHA, which was obtained from the combustion of rice husks, an agricultural waste was introduced to stabilize natural soil samples. Laboratory tests such as sieve analysis, compaction, specific gravity, California bearing ratio (CBR) and Atterberg limit tests were conducted on the natural soil samples and soil samples stabilized with 2%, 4%, 6%, 8% and 10% RHA content. The original soil samples were classified as A-1-b (G.I. = 0). The results from the various laboratory tests showed a slight decrease in optimum moisture content (OMC) and an increase in maximum dry density (MDD) of the soil samples between 0% to 2% RHA content and an increase in OMC and decrease in MDD from 2% to 10% RHA content. The results also showed an increase in the CBR of the samples as the ash content increased. For the soil to be used as sub-base material, stabilization with a minimum of 10% RHA and 2% RHA is required for soil sample A and soil sample B respectively. Thus, RHA is recommended for use in the stabilization of natural soils to enhance its performance as pavement material.

1.0 Introduction

Soil is arguably among the most generally used materials in civil engineering constructions. Construction of civil infrastructures cannot be wholly executed without using soil directly or indirectly. Engineering soils are products of the weathering of rocks. Sometimes, they may contain a small quantity of organic matter resulting from decomposed plants and animals. During the process of weathering, the rock particles reduce in size, but the resulting soil still maintains the original composition of the parent material [1]. In the construction of civil infrastructures, soil has several applications such as aggregates in concrete, mortar and soilcrete; a cementitious material; and as a material on which civil infrastructures such as buildings, roads, bridges, etc. are found. For these structures to be stable, the foundation soils must have the basic geotechnical and engineering properties for supporting them. Numerous cases of flexible pavement failures occur in Nigeria due to poor condition of the soils ~~on~~ carrying the pavements. Most cases of highway failures in Nigeria have been attributed to poor geotechnical conditions of either the soils carrying the roads or the soils imported to the site and used in the construction of the roads [2]. This shows that a critical study of the engineering characteristics of the soil on which pavements are found is required for adequate and effective analysis, design and construction of road pavements [3].

When the engineering properties of a given soil proposed to be used as a foundation for a structure are discovered to be inadequate, it will be necessary to subject the soil to a process known as soil stabilization to improve its engineering properties. There has long been a need to enhance the soil's engineering qualities, for instance, numerous methods were employed to improve the soil's quality when the Roman Empire constructed buildings and highways for its inhabitants. Early in the 1960s, soil stabilizations became popular in the United States, and since then, technology and the materials utilized to do so have made major strides. Soil stabilization is said to be the act of treating and improving the characteristics of soil to make the soil more stable and fit for its proposed use [4]. It refers to any physical, chemical, biological, or combination approach used to enhance and modify the characteristics of regular soil in order to serve an engineering goal. Soil stabilization tries to increase soil strength and resistance to water softening by connecting soil particles together, waterproofing the particles, or a combination of the two [5]. There are mainly two major ways by which soil can be stabilized: mechanical method and chemical method. Mechanical stabilization entails physical processes used to modify the physical nature of the native soil such as inducing compaction and improving the gradation of soil particle sizes [6]. Chemical stabilization is achieved by using a stabilizer (cementitious material) to initiate a chemical reaction between the stabilizer and the natural soil particles to improve the engineering characteristics of the natural soil [7]. Over the years, Ordinary Portland Cement (OPC) has been the major traditional material used in chemical soil stabilization method. OPC is very expensive, its manufacturing processes involve the emission of greenhouse gases [8]. Hence, continuous use of OPC as a soil stabilizer results to high cost of construction projects and environmental and health hazards associated with greenhouse gases. Thus, for sustainable and eco-friendly construction, there is need to partially or totally replace OPC as a soil stabilizer.

In Nigeria and other developing countries, agricultural wastes such as rice husks, groundnut shells, sawdust, etc constitute a major environmental challenge. In India alone, about 31 million tons of rice husk is being produced annually [9]. One of the most efficient and environmentally friendly ways of lowering the quantity of Carbon (IV) oxide resulting from the continuous use of OPC in the construction industries is by using agricultural wastes as supplementary cementitious materials, this promotes green and sustainable construction. [10, 11]. About 110 million metric tons of rice husk are generated in the entire world each year, during the processes of production of milled rice, for every 1 ton of rice produced, 22% of rice husk is produced as a bye product, making the overall production of rice husk in the globe enormous [12]. The word "rice husk ash" means the portion of rice husk that has been transformed into ash by the combustion of rice husk at a temperature between 600ºC to 700ºC [9]. Rice husk waste has not been fully and optimally utilized by man and as a result, they are dumped indiscriminately, blocking water ways and causing serious health and environmental hazards [13]. It majorly contains a high amount of silica dioxide which makes it a suitable alternative for cement in soil stabilization and in concrete mixes [14]. Rice husk ash (RHA) contains high proportion of Silica about 85%, thus making it suitable to be used as a pozzolan [15, 16]. As a pozzolan, rice husk ash has the capacity to be used as a soil stabilizer instead of using traditional additives like cement and lime in soil stabilization, hence ensuring sustainability in construction of civil infrastructures [17].

Pushpakumara~~1~~ and Mendis [18] applied different mixtures of RHA and Lime in treating a parent soil containing a substantial amount of silt and clay. The observations made from their work reveals that when a mixture of 10% RHA and 20% Lime was added to the soil, the unconfined compressive strength and the angle of internal friction increased by 54.05% and 60.48% respectively while the plasticity index reduced by 56.67% after 28 days of mixing with the parent soil. Wibowo, et.al. [13] used a mixture of RHA and cement to stabilize a soil embankment for road subgrade and discovered the existence of a substantial improvement in the load bearing capacity and bearing capacity ratio of the soil. In the works of [15], RHA was used to partially substitute cement in concrete, and their results showed that using RHA in concrete reduces the workability of fresh concrete but increases the compressive strength, splitting and flexural strength of the concrete. RHA was used by [19] to stabilize an expansive soil, they discovered that incorporation of RHA in the soil improved the soil properties by reducing the specific gravity, plastic limit, liquid limit and the plasticity index of the soil, while it increased the CBR of the soil up to 130%. Raja et.al. [20] used a combination of RHA and lime sludge to stabilize soil. Their findings showed that the incorporation of a mixture of RHA and lime sludge in clay soils improved the strength of the soil and reduced the shrinkage and swelling characteristics of the soil. They also observed that a mixture of 10% RHA and 15% lime sludge yields an optimum result in soil stabilization. RHA on its own contains high Silica which reacts with Calcium from the soil minerals in the presence of water to form Calcium Silicate Hydrates which improve soil strength. Thus, its influence on soil properties can be studied independently. RHA has more benefits than traditional stabilizers like lime and cement which include: (i) RHA is very far cheaper than lime and cement. It is readily available in most tropical regions like Nigeria where rice is produced in large quantities. (ii) In most rice producing areas of Nigeria, rice husks are dumped indiscriminately as wastes in landfills constituting environmental hazards. Thus, using it as a soil stabilizer converts waste to money and promotes a safer and cleaner environment. (iii) Production of RHA does not produce greenhouse gases like in the production of cement.

Utilizing agricultural wastes such as RHA in soil stabilization instead of using traditional stabilizing agents like OPC will be highly beneficial because, it promotes environmentally friendly and sustainable pavement construction as well as better waste management system [21]. This will further generate more revenue for rice farmers whose wastes are converted to money, hence encouraging them to produce more rice, enhancing food production. An indebt study on the influence of rice husk ash on the engineering properties of soil will be of great value to engineers involved in the design and construction of highways and other civil infrastructures. Thus, this research seeks to use rice husk ash, an agricultural waste as an alternative to cement in stabilizing the soils around the engineering complex of Federal University of Technology Owerri and studying its effects on the engineering properties of the said soil.

2. Materials and Methods

2.1: Materials

The materials used in this work include soil samples, rice husk ash, water and laboratory apparatus for the various tests carried out.

2.1.1: Soil Sampling

Two trial pits of (1.5m x 1.5m) dimension and 1.5m depth at two different locations were excavated from which samples of the natural soil were collected using a hand trowel and shovel adopting the method of disturbed sampling. Table 1 shows the locations of the trial pits on the earth surface. Soil samples studied in this research were collected from the premises of the School of Engineering complex at Federal University of Technology Owerri, Imo State, Nigeria. The two soil samples were labelled A and B for easy identification. The samples were stored in polyethene bags to prevent loss of moisture and taken to the Civil Engineering laboratory of the Federal University of Technology, Owerri where laboratory analysis was carried out. The coordinates of the trial pits were obtained using a hand-held Global positioning system (GPS) device. The table below shows the different latitudes and longitudes of the trial pits from which the soil samples were collected.

Table 1: The Coordinates of the trial pits

TRIAL PIT.	LATITUDE	LONGITUDE
A	5° 23' 0.17" N	6° 59' 55.04" E
B	5° 22' 59.95" N	6° 59' 54.42" E

2.1.2: Rice husk ash

The rice husks used in this research were obtained from a rice mill located in Ebonyi state. The rice husks were being stacked in heaps near the mill and were gotten from several locations at the heap site. The rice husks were burnt to ashes by placing them on an empty pan of a locally fabricated furnace at a temperature range of 550ºC to 600ºC. After about three days of cooling, the ash was taken to the laboratory where it was sieved using 600-micrometer sieve. The rice husk particles that are finer than 600-micrometer were the RHA specimen used in this work.

2.2: Methods

2.2.1 Soil Stabilization

Chemical stabilization method was adopted in this study. This was achieved by mixing the natural soil samples with (RHA) at proportions of 0%, 2%, 4%, 6%, 8% and 10% weight of the natural soil samples.

2.2.2 Laboratory Analysis

Sieve analysis which determines how the sizes of the various particles are distributed in a given soil mass was conducted on the two soil samples following the procedures in [22]. The following expressions were deducted from the results of the sieve analysis.

$$Coefficient\ of\ Uniformity, C_u = \frac{D_{60}}{D_{10}} \quad (1)$$

$$Coefficient\ of\ Curvature, C_c = \frac{{D_{30}}^2}{D_{10}.D_{60}} \quad (2)$$

F_{10}, F_{40}, F_{200}

Where: D_i is the particle size (mm) corresponding to the ith percentage passing.

F_i is the percentage passing the ~~Number. ith~~ sieve number i.

The results of the sieve analysis were presented on Tables (3) and (4) and were used in classifying the soil.

Specific gravity test and Atterberg Limits test which determines the consistency of the soil were conducted on the natural soil samples in accordance with the procedures in [22]. The results were presented on Table (5) and were used in classifying the soil. Compaction test and California Bearing Ratio (CBR) test were conducted on the two natural soil samples (soil samples with 0% Rice husk ash content) to determine their index and physical properties in accordance with procedures enshrined in [23]. Chemical stabilization method was adopted in this study. This was achieved by mixing the natural soil samples with (RHA) at proportions of 0%, 2%, 4%, 6%, 8% and 10% weight of the natural soil samples. Compaction test was conducted on the soil samples adopting the standard Proctor test procedures outlined in [23] and [24] to determine the compaction parameters of the soil samples. The results were presented on Tables (6) and (7) and Figures (1) and (2). The California Bearing Ratio (CBR) test was conducted on the two natural soil samples and on the soil samples stabilized with 2%, 4%, 6%, 8% and 10% RHA content and compacted at optimum moisture content to determine their load bearing capacities. The soaked conditions of the CBR test was adopted for the soil samples, hence the samples were soaked in water for a period 24 hours during the test to mimic the worst conditions of many highways in Southern Nigeria where the roads are subjected to frequent flooding. The results were presented on Table (8) and in Figure (3). The resulting CBR of the samples were related with the recommended CBR for various courses of road pavement by the Nigerian Federal Ministry of Works and Housing Highway Design Manual [25] given in Table 2.

Table 2: Specifications for Road Pavement Courses [25]

Pavement Structural Component	**Minimum Value of Soaked CBR (%)**
Base Course	80
Sub-base	30
Subgrade/Foundation Soil	5 – 11.

3.0 Results

Table 3: Sieve Analysis Test for Soil Sample A

X_1	X_2	X_3	X_4	X_5	X_6
Sieve Nos.	Opening (mm)	weight of soil retained (g).	Percentage weight retained (%).	Cumulative percentage weight (%)	% Finer
5	4	0	0	0	100
10	2	0.4	0.055	0.055	99.95
16	1.18	12.53	1.735	1.79	98.21
30	0.6	213.2	29.53	31.32	68.68
40	0.425	134.11	18.58	49.9	50.1
50	0.3	232.47	32.2	82.1	17.9
100	0.15	59.85	8.29	90.39	9.61
200	0.075	66.1	9.16	99.55	0.45
Pan	0	3.33	0.461	100	0
		721.99	**100**		
$Note: X_4 i = \frac{X_3 i}{721.99} * 100, \quad X_6 i = 100 - X_5 i$					

$$For\ soil\ sample\ A;\ C_c = 1.4788, C_u = 3.2992 \quad (3)$$

Table 4: Sieve Analysis Test for Soil Sample B

X_1	X_2	X_3	X_4	X_5	X_6
Sieve Nos.	Opening (mm)	weight of soil retained (g).	Percentage weight retained (%).	Cumulative percentage weight (%)	% Finer
5	4	0	0.00	0.00	100.00
10	2	0.27	0.04	0.04	99.96
16	1.18	11.65	1.57	1.61	98.39
30	0.6	222.98	29.95	31.56	68.44
40	0.425	141.53	19.00	50.56	49.44
50	0.3	239.24	32.13	82.69	17.31
100	0.15	66.85	8.97	91.66	8.34
200	0.075	58.78	7.89	99.55	0.45
Pan	0	3.26	0.44	100.00	0.00
		744.57	**100**		
$Note: X_4 i = \frac{X_3 i}{721.99} * 100, \quad X_6 i = 100 - X_5 i$					

$$For\ soil\ sample\ B;\ C_c = 1.3102, C_u = 3.9261 \quad (4)$$

Table 5: Properties of the natural soil samples

Soil property	Sample A	Sample B
Specific gravity	2.60	2.20
Liquid limit L.L (%)	37.5	34.5
Plastic limit P.L (%)	22.40	19.16
Plasticity Index P.I. [L.L – P.L] (%)	15.1	15.34
Optimum moisture content (%)	12.25	11.20
Maximum dry density (g/cm3).	1.935	1.945
Coefficient of curvature, Cc.	1.4788	1.3102
Coefficient of uniformity, Cu.	3.2992	3.9261

3.1 Soil Classification using AASHTO method

From the results of sieve analysis and Atterberg Limits tests, For Soil Sample A;

$$F_{10} = 99.95\%, F_{40} = 50\%, F_{200} = 0.45\%, \qquad (5a)$$

$$L.L. = 37.5, P.L. = 22.4, P.I. = 15.1 \qquad (5b)$$

F_{200} = 0.45%, therefore the soil sample is a granular material, it is under either general class A-1 or A-2.
F_{10} = 99.95%, therefore A-1-a class is eliminated
F_{40} = 50%, therefore the soil is **A-1-b**
The Group Index (G.I) is given in AASHTO (1995) as;

$$G.I. = (F_{200} - 35)[0.2 + 0.005(LL - 40)] + 0.01(F_{200} - 15)(PI - 10) \qquad (6)$$

Note: When the value of G.I. is a negative number, it is reported as zero.
$G.I. = (0.45 - 35)[0.2 + 0.005(37.5 - 40)] + 0.01(0.45 - 15)(15.1 - 10)$
$= (-34.55)[0.2 + 0.005(-2.5)] + 0.01(-14.55)(5.1) = -34.55(0.1875) + (-0.742)$

$$G.I. = -7.22 \quad \approx 0 \quad (7)$$

Thus, Soil sample A is classified as A-1-b (G.I. 0), (Stone fragments, gravel and sand).
For Soil Sample B

$$F_{10} = 99.964\%, F_{40} = 49.4\%, F_{200} = 0.41\%. \qquad (8a)$$

$$L.L. = 34.5, P.L. = 19.16, P.I. = 15.34 \qquad (8b)$$

F_{200} = 0.41%, therefore the soil sample is a granular material, it is under either general class A-1 or A-2.
F_{10} = 99.964%, therefore A-1-a class is eliminated
F_{40} = 49.4%, therefore the soil is A-1-b.
$G.I. = (0.41 - 35)[0.2 + 0.005(34.5 - 40)] + 0.01(0.41 - 15)(15.34 - 10)$
$= (-34.59)[0.2 + 0.005(-5.5)] + 0.01(-14.59)(5.34) = -34.59(0.1725) + (-0.779) \qquad (9)$

$$G.I. = -6.75 \ \approx 0 \qquad (10)$$

Thus, Soil sample B is classified as A-1-b (**G.I. = 0**), (Stone fragments, gravel and sand).

Table 6: Optimum Moisture Content (OPC) of the soil samples at various percentages of RHA.

Rice Husk Ash (RHA) %	Optimum moisture content (OMC) %	
	Sample A	Sample B
0	12.25	11.2
2	11.2	9.45
4	12.0	11.70
6	12.65	13.91
8	13.40	14.10
10	14.46	16.0

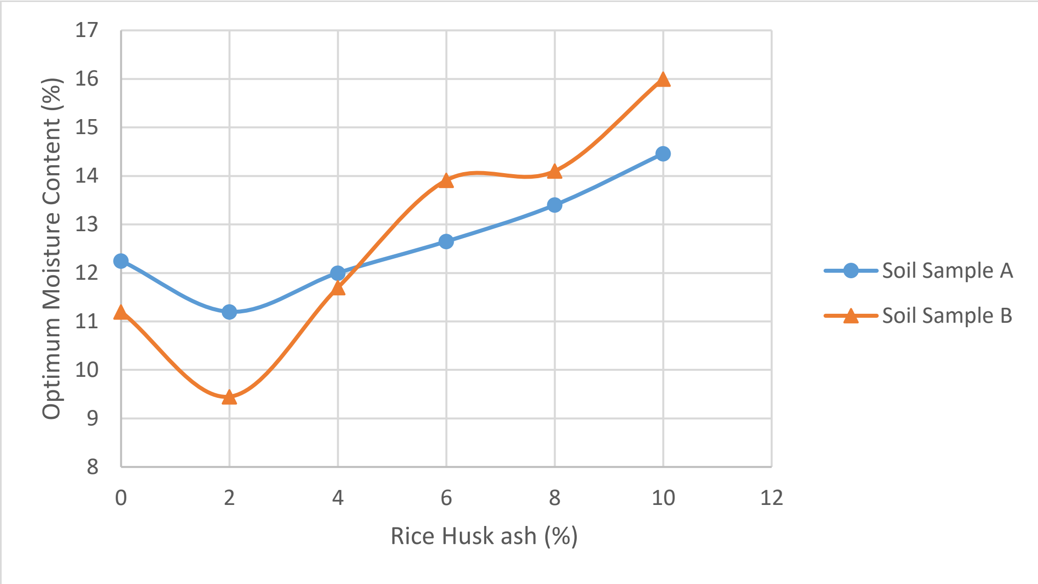

Fig 1: Relationship between OMC and RHA content for soil samples

Table 7: Maximum Dry Density (MDD) of soil samples at various percentages of RHA

Rice Husk Ash (RHA) %	Maximum Dry Density (MDD) g/cm^3	
	Sample A	Sample B
0	1.935	1.95
2	1.980	1.96
4	1.930	1.94
6	1.910	1.87
8	1.860	1.86
10	1.830	1.82

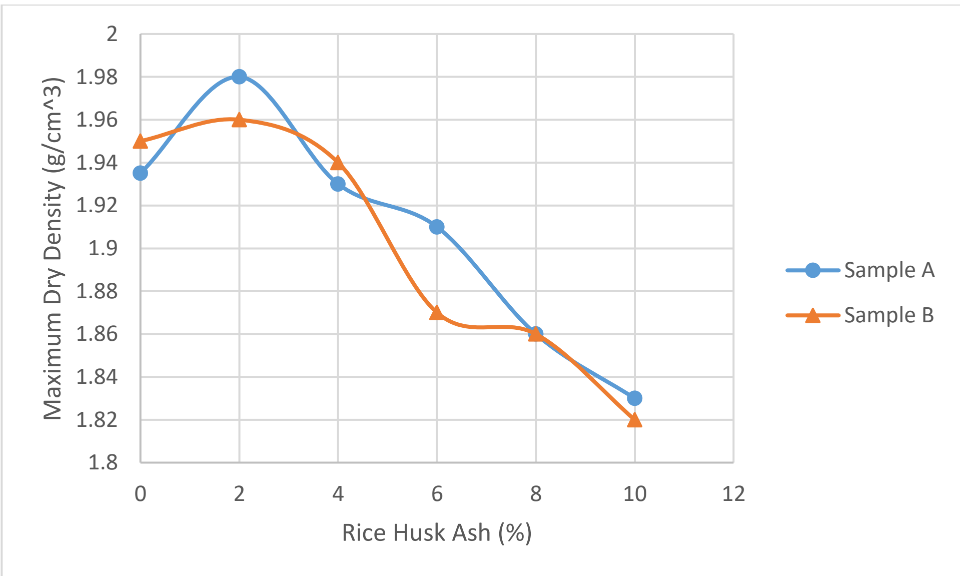

Fig 2: Relationship between MDD and RHA content for the soil samples

Table 8: CBR of soil samples at different amount of RHA content and their recommended uses in accordance with [25].

Rice Husk Ash (RHA) %	CBR (%)			
	Sample A	Recommended use [21]	Sample B	Recommended use [25]
0	6.65	Subgrade	28.78	Subgrade
2	10.56	Subgrade	30.3	Subgrade/Sub-Base
4	12.46	Subgrade	30.4	Subgrade/Sub-Base
6	17.32	Subgrade	32.3	Subgrade/Sub-Base
8	28.15	Subgrade	41.4	Subgrade/Sub-Base
10	29.25	Subgrade/Sub-Base	44.4	Subgrade/Sub-Base

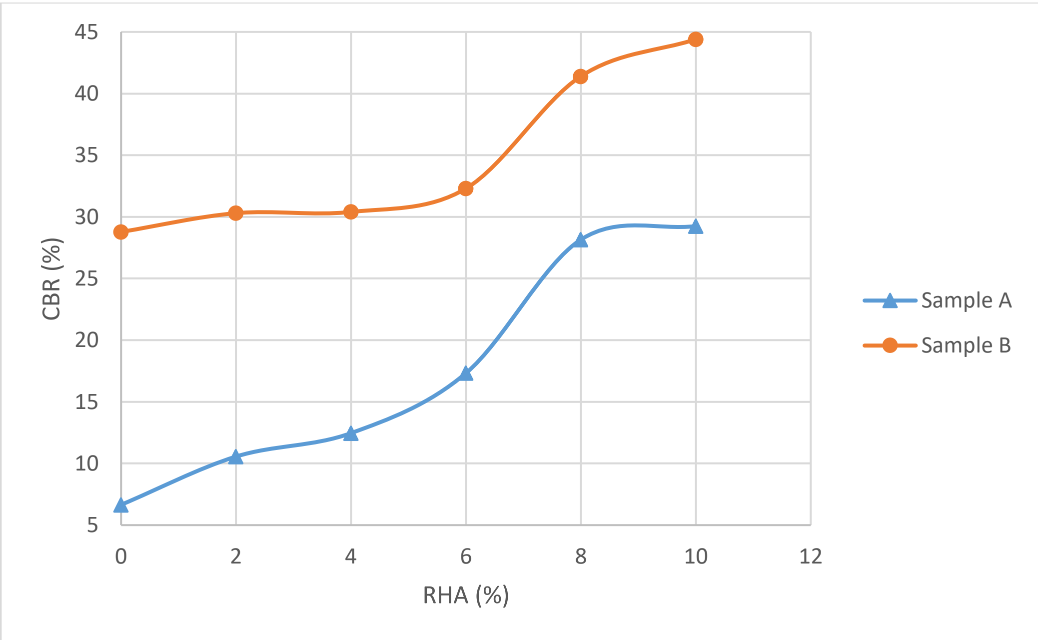

Fig 3: Relationship between CBR and RHA content for the soil samples

4.0 Discussion

4.1 Discussions on Soil Classification

From Tables (4), (5) and (6) and Equations (7) and (8), both soil samples are classified as; A-1-b (G.I**.** = **0**), (Stone fragments, gravel and sand). This class is excellent material for subgrade in road work.

4.2 Compaction Characteristics.

The changes in OMC at different percentages of RHA for soil samples A and B are presented in Figure 1 and Table 6. From the results, it was detected that the OMC for soil samples A and B slightly decreased from 12.25% to 11.20% and from 11.20% to 9.40% between 0% and 2% RHA content. Between 2% and 10% RHA content, it is observed that the OMC for soil sample A increased from 11.20% to 14.46% while the OMC for soil sample B increased from 9.40% to 16.0%. The slight decrease in optimum moisture content between 0% and 2% rice husk ash content occurred as a result of the soil samples being mixed with excess water during the compaction test. The increase in optimum moisture content as expected between 2% and 10% RHA content occurred because, the presence of RHA in the mix lowers the amount of free silt and clay fraction in the mixture which results to creation of more coarse materials possessing greater surface areas in the soil - RHA mixture, hence requiring more water to compact the mixture. Thus, more water is needed to compact the soil-RHA mixtures when being used as road pavement material.

The changes in the Maximum Dry Density (MDD) as the rice husk ash content changes for soil samples A and B are reported in figure 3 and Table 5. From the results shown, it was observed that the MDD of the soil samples increased between 0% and 2% RHA content from 1.935 g/cm3 to 1.980 g/cm3 for soil sample A and from 1.945 g/cm3 to 1.970 g/cm3 for soil sample B. Between 2% and 10% RHA content, the MDD decreased from 1.98g/cm3 to 1.83g/cm3 for soil sample A and from 1.970 g/cm3 to 1.820 g/cm3 for soil sample B. As stated earlier, the little increase of the MDD between 0% and 2% RHA content was not expected and it occurred as a result of the fact that the soil samples had excess moisture content during the compaction test. The decrease of the MDD of the soil samples between 2% and 10% RHA content occurred because of the interactions between the soil particles and the RHA. The ash particles being finer forms a coating around the soil particles resulting in larger particles, thus creating more voids within the soil – RHA mixture, leading to reduction in the maximum dry density. At lower content of RHA (0% – 2%), RHA particles being smaller than the soil particles fills the interparticle voids of the soil, resulting to better packing, more dense structure and thus increase in MDD. Also RHA at lower percentages promotes cementation of soil particles, improving compaction and producing higher MDD. RHA in the presence of water undergoes pozzolanic reaction producing additional cementitious material leading to increased MDD. However, at higher RHA content (>2%), the finer nature of the RHA particles reduces the packing efficiency of the soil, RHA particles being very light in weight acts as filler materials which do not promote better compaction, thus leading to reduced MDD. Also at higher content of RHA, the particles acting as filler materials disrupts the optimal packing arrangement of the structure, leading to higher void ratios and lower MDD. Moreso, RHA has higher water absorption capacity, thus, at higher content the RHA-soil mixture absorbs more water which can hinder proper compaction, leading to reduced MDD. At lower content of RHA (0% – 2%), RHA particles being smaller than the soil particles fills the interparticle voids of the soil, resulting to better packing, more dense structure and requiring less moisture to achieve the same level of compaction. Also, lower contents of RHA in soil reduces plasticity, promotes the cementation of soil particles, thus reducing the OMC. However, higher RHA content (>2%) in the soil leads to increased void spaces, increased water absorption and reduced compaction efficiency, leading to an increase in OMC.

4.3 Strength Characteristics

The California Bearing Ratio (CBR) test is a major test required in the design of road pavement materials. It is used in determining the load bearing capacity and the compacted strength of road pavement materials. The relationship between the CBR and RHA content for the soil samples is reported in Figure 3 and Table 8. It is discovered from the result that the CBR for soil sample A increased from 6.65% to 29.82% and the CBR for soil sample B increased from 28.78% to 44.40% with an increase in RHA content from 0% to10% respectively. The consistent rise in CBR of the soil samples was brought about by a continual formation of cementitious compound synthesis within the soil resulting from the reaction between the RHA and calcium hydroxide (CaOH) in the soil samples. In Tables 8, following the minimum requirements of [25] for various courses of flexible pavement, presented in Table 2, it was discovered that the two natural soil samples (0% RHA) are suitable for subgrade material in road construction. Soil sample A stabilized with 2% to 8% RHA are all recommended for Subgrade course in construction of flexible pavements. Soil sample A requires to be stabilized with at least 10% RHA before it can serve as a Sub-base material. For soil sample B, at least 2% RHA stabilization is required before it becomes suitable to be used as a Sub-base material. From the relationship between CBR values and RHA content given in Fig. 3, of all the percentages of RHA content studied in this work, 10% yielded the highest CBR for both Soil Samples A and B, thus, 10% is adjudged to be the optimal value**.** Also From Fig. 3, there is inconsistency in the increase in the CBR values as the RHA content increases. This was caused by the following: (a) Since the soil samples were manually mixed with the RHA, there was inconsistency in the distribution of RHA particles in the soil leading to local variations in stabilization and inconsistent increase in CBR values (b) From the results of the sieve analysis, the soil samples used in this research are sandy soils and thus does not bind well, resulting in less noticeable increase in CBR values. (c) The samples were collected from a forested area which contains organic matters in form of roots of trees, this also hinders bonding and prevents sharp increase in CBR values as RHA increases.

In general, the result from this present study agrees with the works of Guleria, Thakur & Gautam, [26]. In their work they used a mixture of 5% to 15% of rice husk ash (RHA) by weight and lime Sludge to stabilize natural soil. Their results showed decrease in MDD and increase in OMC as the ash content increased from 5% to 15%, which is in line with results of the present study. Also, in the works of Lakshmi et.al [27], where a mixture of 5% to 15% of RHA and 4% Lime sludge was used to stabilize Clayey – Sandy soil, the CBR increased from 5% to 12% RHA content and then started decreasing after 12% RHA content in the soil. Also, in the works of Gunjagi et.al [28], where a mixture of 5% to 20% of RHA and 8% Lime sludge was used to stabilize Black Cotton soil, the CBR increased from 5% up to about 14% RHA content and then started decreasing after 14% RHA content in the soil. These results are in line with the results of the present study which showed an increase in CBR when soil samples were stabilized with 0% to 10% of

RHA by mass. Also, in the work Tuhin et.al., [29], 5%, 10%, 15%, 20% and 25% of RHA were used to stabilize natural soil sample, their results showed a decrease in MDD and increase in OMC between as the ash content increases from 5% to 25%. This result also is in line with the present study.

5. Conclusion

It was revealed by this study that the natural soil samples studied were classified using AASHTO method as; A-1-b (G.I. = 0), (Stone fragments, gravel and sand). This class is described by AASHTO as an excellent material for subgrade in road work. Incorporation of Rice Husk Ash (RHA) in the natural soil samples greatly influenced the compaction and strength parameters of the natural soil samples. Incorporation of RHA in the natural soil samples reduces the MDD of the samples and increases the optimum moisture content of the sample. The implication of this is that when soil – RHA mixture is used in road pavement construction, more water is required during compaction to achieve the required maximum dry density. Hence, in Southern Nigeria where heavy rainfall is experienced in most part of the year which makes it very difficult to achieve a good dry density during soil compaction due to excess moisture in the soil. During this period, most earthworks are suspended due to the challenges of achieving sufficient dry density. In such cases, the soil – RHA mixture is recommended as subgrade and subbase material in order to achieve better compaction. It was equally discovered that Rice Husk Ash increases the CBR of the natural soil sample thereby increasing its strength and load bearing capacity. The two natural soil samples met the CBR requirements for use as subgrade material in flexible pavement. Soil samples A stabilized with 2% to 8% RHA all met the requirements for subgrade while stabilization with at least 10% RHA is required for soil sample A to be used as Sub-base material. Stabilization with at least 2% RHA is required for soil sample B to be used as Sub-base material. Thus, rice husk ash is recommended as a good stabilizing agent for improving the characteristics of natural soil as a road pavement material. Since the laboratory results showed that RHA improves soil properties when used as a stabilizer, it will equally perform well when used in actual road projects as a stabilizer.

The laboratory results showed that 10% RHA in soil greatly improves its strength, thus enhancing its long-term durability. Using RHA as a soil stabilizer in road construction will largely reduce the environmental issues created by indiscriminate dumping of rice husks in landfills. It will equally create wealth for rice farmers and encourage rice farming leading to massive food production. It will equally reduce the over-dependency on Ordinary Portland Cement as a soil stabilizer which causes much environmental and health hazards.

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References

[1] Budhu M. Soil Mechanics Fundamentals, Imperial Version. John Wiley & Sons Ltd., United Kingdom, 2015.
[2] Yakubu J. A., Daku S. S., Gusikit R. B., Emmanuel E. D. & Mangai M. C. "Causes of failure of Nigerian roads: A review". World Journal of Advanced Engineering Technology and Sciences. 08(02): 217–223, 2023. https://doi.org/10.30574/wjaets.2023.8.2.0079.
[3] Onyelowe, K. C., Jalal, F. E., Onyia, M. E., Onuoha, I. C., & Alaneme, G. U. "Application of Gene Expression Programming to Evaluate Strength Characteristics of Hydrated-Lime-Activated Rice Husk Ash-Treated Expansive Soil". Applied Computational Intelligence and Soft Computing. 1 – 17, 2021. https://doi.org/10.1155/2021/6686347
[4] Ming X. Geotechnical Engineering Design. John Wiley & Sons Ltd., United Kingdom, 2015.
[5] Braja M. D. Principles of Foundations Engineering, S.I. 7th Edition. Cengage Learning, USA, 2007.
[6] Knappett J. A. & Craig R. F. Craig's Soil Mechanics, Eight Edition. Spon Press, Tailor & Francis New York. 2012.
[7] Babu B. M., Ravali G., Saikiran C., Reddy B. A. and Kumar P. R. "Soil Stabilization by Using Rice Husk Ash". Journal of Engineering Sciences. 14(02): 529 – 540, 2023. DOI:10.15433.JES.2023.V14I2.43P.61.
[8] Adedokun, S. I, Oluremi, J. R., Mark, D. O., Anifowose, M. A., and Lawal, A. R. "Effects of Substitution of Cement with Ground Granulated Slag on Concrete produced with different Water-Cement Ratios", Nigerian Journal of Technology, 43(3), pp. 400 – 410, 2024. https://doi.org/10.4314/njt.v43i3.1
[9] Charyulu S. V., Akhila C., Vineetha C., and Akanksha A. "Stabilization of Soil using Rice Husk Ash (RHA) and Cement". E3S Web of Conferences. 391, 01201 (2023). https://doi.org/10.1051/e3sconf/202339101201
[10] Endale S.A., Taffese,W.Z., Vo, D.-H., Yehualaw M.D. "Rice Husk Ash in Concrete". Sustainability. 15 (137): 1 – 26, 2023. https://doi.org/10.3390/su15010137.
[11] Buenaflor K. E., Celerinos P. J. S., Del Castillo C. J. P., Gala J. M. R., Sumatra K. A. "Effects of Sugarcane Bagasse Ash as Partial Replacement of Cement in the Compressive Strength and Light Transmissibility of Litracon Blocks". Research on Engineering Structures and Materials. 10(3): 973-994, 2024. http://dx.doi.org/10.17515/resm2024.66ma1102rs
[12] Rana V. and Sonthwal V. K. "Improving the Engineering Properties of Soil Using Sisal Fibre with Rice Husk Ash". International Journal for Research in Applied Science & Engineering Technology (IJRASET). 10 (5): 1194 – 1199, 2022. https://doi.org/10.22214/ijraset.2022.42464.
[13] Wibowo D., Ramadhan D., Endaryanta, Prayuda H. "Soil Stabilization Using Rice Husk Ash and Cement for Pavement Subgrade Materials". Revista de la Construcción. Journal of Construction. 22(1): 192-202, 2023. https://doi.org/10.7764/RDLC.22.1.192.

[14] Adedokun, S. I., Ganiyu, A. A., Adebajo, G. O., and Ogundele, A. S. "Comparative Effects of Selected Wastes on the Indices and Strength Properties of Laterite Soil", Nigerian Journal of Technology, 43(3), pp. 428 – 435, 2024. https://doi.org/10.4314/njt.v43i3.4

[15] Hasan N.M.S., Sobuz M.H.R., Khan M.M.H., Mim N.J., Meraz M.M., Datta S.D., Rana M.J., Saha A., Akid A.S.M., Mehedi M.T., Houda M. and Sutan N. M. "Integration of Rice Husk Ash as Supplementary Cementitious Material in the Production of Sustainable High-Strength Concrete". Materials. 15(8171): 1 – 26, 2022. https://doi.org/10.3390/ma15228171

[16] Bheel N., Abro A.W., Shar I. A., Dayo A. A., Shaikh S., Shaikh Z. H. Use of Rice Husk Ash as Cementitious Material in Concrete. Engineering, Technology & Applied Science Research. 2019; 9 (3): 4209-4212. https://doi.org/10.48084/etasr.2746.

[17] Osanyinlokun, O. E., Fapohunda, C. A., and Olaniyan, O. M. "Compressive, Bending and Shear Properties of Reinforced Concrete Beams containing Sawdust Ash as Partial Replacement of Cement", Nigerian Journal of Technology, 43(1), pp. 2 – 13, 2024. https://doi.org/10.4314/njt.v43i1.2

[18] Pushpakumara B. H. J. and Mendis W. S. W. "Suitability of Rice Husk Ash (RHA) with Lime as a Soil Stabilizer in Geotechnical Applications". International Journal of Geo Engineering. 13(4): 1 – 12, 2022. https://doi.org/10.1186/s40703-021-00169-w

[19] Daryati and Ramadhan M. A. "Improvement of Expansive Soils Stabilized with Rice Husk Ash (RHA)". Journal of Physics.: Conference Series. (2020); 1625 012006. doi:10.1088/1742-6596/1625/1/012006

[20] Raja K., Venkatachalam S., Vishnuvardhan K., Siva R. K. R., Tamil V. S. & Vetriselvan N. "A Review on Soil Stabilization using Rice Husk Ash and Lime Sludge". Materials today: Proceedings. 65(2): 1205 – 1212, 2022. https://doi.org/10.1016/j.matpr.2022.04.178.

[21] Eziefula U. G., Nwosu O. U., Udoha C. L., Ibearugbulem O. M., and Onyechere I. C. "Strength Properties of Concrete Containing Palm Bunch Ash–Calcined Anthill Clay". International Review of Applied Sciences and Engineering. 15(2024): 1 – 10, 2024. DOI:10.1556/1848.2024.00905

[22] BS 1377: Part 2: 1990. Soils for Civil Engineering Purposes; Classification Tests. British Standards Institution. 1990. London.

[23] BS 1377: Part 4: 1990. Soils for Civil Engineering Purposes; Compaction Related Tests. British Standards Institution. 1990. London.

[24] Ishibashi I. and Hazarika H. Soil Mechanics Fundamentals. CRC press, Tailor and Francis group. New York. 2014.

[25] Federal ministry of works highway manual part 1: Design, Volume III: Pavements and Materials Design, 2013.

[26] Guleria, A.; Thakur, S.; Gautam, C.P. Stabilization of Mohali Soil Using RHA and Lime Sludge; Jaypee University of Information Technology: Waknaghat, India, 2017.

[27] Lakshmi, S.M.; Geetha, S.; Selvakumar, M.; Susanna, K.D. Strength Enhancement of Clayey Sand Subgrade Using Lime and Rice Husk Ash. Mater. Today Proc. **2021**, 46, 7430–7435. DOI:10.1016/j.matpr.2021.01.039

[28] Gunjagi, M.D.;Wadar, R.; Patil, A.; Gurme, S.; Nalang, A.; Kamble, M. To Study the Effect of Lime and Rice Husk Ash on CBR Parameters of Black Cotton Soil. Int. Res. J. Eng. Technol. **2019**, 6. 195 – 198. https://www.irjet.net/archives/V6/i4/IRJET-V6I444.pdf

[29] Tuhin M.T.H., Hassan M. M., Julfikar M.S.A., Farooq M. S. M. Stabilization Of Soil By Rice Husk Ash. Proceedings of 2nd International Conference On Research and Innovation in Civil Engineering (ICRICE 2020)ÐSBN: 978-984-3- 8047-7. 2019.