International Journal of Civil Engineering, Construction and Estate Management, 11 (2), 39-69, 2023

Print ISSN: 2055-6578(Print),

Online ISSN: 2055-6586(online)

Website: https://www.eajournals.org/

Publication of the European Centre for Research Training and Development -UK

A Comparative Study on the Stabilization of Soft Soil Using Agricultural Wastes (Baggase Ash (BA) And Rice Husk Ash (RHA)

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doi: https://doi.org/10.37745/ijcecem.14/vol11n22969 Published June 25, 2023

Citation: Vincent A.C. and Ikebude C.F. (2023) A Comparative Study on the Stabilization of Soft Soil Using Agricultural Wastes (Baggase Ash (BA) And Rice Husk Ash (RHA), *International Journal of Civil Engineering, Construction and Estate Management*, 11 (2), 29-69

ABSTRACT: *Soft soils are expansive soils, also referred to as tropical clay. Soft soil may cause instability to foundations thereby reducing their service life, this necessitates the adoption of a suitable soil stabilization method in order to improve the engineering properties of soft soils. This research work aims at comparing the strength properties of soft soil stabilized using two different agricultural wastes-Bagasse Ash (BA) and Rice Husk Ash (RHA). The studies were conducted to determine the properties of the natural and treated soft soils, the oxide composition of BA and RHA and the evaluation of the effect of BA and RHA (0, 2, 4, 6, 8, 10 and 12 % by dry weight of the soil) on the index and strength properties of soft soil, the determination of strength characteristics (proctor compaction , unconfined compressive strength (UCS), and California bearing ratio, (CBR) under soaked and unsoaked conditions) of soft soil with BA and RHA mixtures, the optimum blend of both BA and RHA needed for the stabilization of clay soil, the comparison of BA and RHA as stabilizing agents on the performance of clay soil. From the test results, it was observed of the natural moisture content of the clay soil was to be 18.02%, indicating that the soil material is a relatively high water holding material with very low porosity and specific gravities of 2.66. The maximum dry density (MDD) of BA treated soil increased with higher BA content to an optimum BA content lying between 8-10% of dry clay soil and MDD of RHA treated soil continuously decreased with addition of RHA to the clay soil. OMC of BA and RHA treated soils continuously increase, the BA treated clay soil increase with increase in BA content with a possible percentage increment of 11.20% and RHA treated clay soil increases continuously with addition of RHA to a percentage increment of 16.2%. BA content leads to a consequent increase in CBR to an optimum value of 9%. The optimum value of RHA content was obtained as 10% with a maximum CBR value of 28.72%. BA treated clay soil increase both CBR and UCS to percentage increment change of 630% and 91.41% respectively while percentage increments of 619.8% and 85.23% were recorded for RHA treated clay soil. BA thus improved the strength properties better in comparison to RHA although in smaller optimum percentage addition.*

KEY WORDS: Soft Soil; BA; RHA; Stabilisation; OMC; MDD; UCS; CBR; optimum blend

INTRODUCTION

The stability of structures founded on soil depends to a large extent on the interaction of the said soil with water. Some soils of the tropics (e.g., soft soil), absorb large amount of water during the rainy seasons and do not allow easy passage of such water. This consequently results in a large volume increase which drastically reduces during the dry season. This phenomenon has substantial effect on structures founded on such soils. Also, road bases built with soils that are not easily drained are affected by the development of pore water pressures which causes the formation of potholes and, eventually, the total failure of such roads. In an attempt to minimize these effects, such soils are subjected to treatments aimed at either disallowing water into them allowing easy passage (drainage) of water to prevent pore water build up (Alhassan, 2008).

Soft soils are expansive soils also referred to as tropical clay. They are so named because of their suitability for growing cotton. Soft soils have varying colours ranging from light grey to dark grey and black. The mineralogy of this soil is dominated by the presence of montmorillonite which is characterized by large volume change from wet to dry seasons and vice versa. Deposits of soft soil in the field show a general pattern of cracks during the dry season of the year. Cracks measuring 70 mm wide and over 1 m deep have been observed and may extend up to 3m or more in case of deep deposits (Adeniji, 1991). These soils are poor materials to employ for highway or airfield construction because they contain high percentages of plastic clay. In areas where they occur, usually there are no suitable natural gravels or aggregates and most deposits cover significantly large areas that avoiding them is not possible.

Although poor and undesirable for engineering purposes, its properties could be improved to meet standard specification by stabilization processes. Stabilization of the soil with chemical admixtures is a common method of reducing the swell – shrink tendencies of the soil and also makes the soil less plastic (Ola, 1983; Balogun, 1991; Osinubi, 1995; 1999). In traditional practices, stabilizers such as cement, lime, and bitumen, alone or in combination, are used as additives to stabilize soils. However, there is a variety of non-traditional soil stabilization/modification additives available from the commercial sector such as polymer emulsions, acids, lignin derivatives, enzymes, tree resin emulsions, and silicates. To achieve stability, the additive must be incorporated with the soil (Newman and Tingle, 2004).

Researchers (Ola, 1983, Balogun, 1990, Osinubi, 1995, 1999, Osinubi and Medubi, 1998) reported that appreciable improvements in the geotechnical properties of soft soil were observed when treated with lime, as well as lime admixed with cement. The need to reduce the rising cost of soil stabilizers and overdependence on industrially manufactured soil improving additives (cement, lime, etc.), has led to intense global research towards economic utilization of wastes for engineering purposes (Oriola and Moses, 2010).

Research works (Mohammedbhai and Baguant, 1990; Osinubi, 1997; Osinubi and Stephen, 2005; Osinubiet al., 2009) in the field of geotechnical engineering focus on the search for cheaper and locally available materials for use in stabilization. A large percentage of such materials are agricultural wastes that produce cementituous compounds on addition of moisture. These studies tried to match the need for safe and environmental disposal of waste, for the society, and the engineer's need for better and cost effective construction materials (Collins and Ciesiellski, 1993).

This research will seek to compare the strength properties of soft soil stabilized using two different agricultural wastes; baggase ash (BA) and rice husk ash (RHA)

MATERIALS AND METHOD

All materials for this study was sourced from areas located in the Port Harcourt City environment. These sourced materials were prepared according to their respective appropriate standards or codes of practice.

Clay soil

The soil sample used in this study was obtained at Eagle Island, Obio-Akpo Local Government Area of Rivers State. Clay soil was obtained using the following procedures;

- The soil sample was collected as a disturbed sample, excavated from a depth not less than 1.0 m so as to avoid any organic material.
- The soil sample was packaged in sealed plastic bags for use in laboratory.
- The collected soil sample was then air-dried and pulverized into particles passing BS No. 4 (4.75 mm)

Admixtures:

Admixtures used here are; baggase ash (BA) and rice husk ash (RHA). In this project, agricultural waste materials were used to stabilize clay soil. The portion of the admixtures passing through British Standard No. 200 sieve to obtain finer particles, was used for experimental purposes.

Water

Portable water free of dirt and organic matter with pH value of close to 7 was used for experimental purposes. The drinking tap water was entirely satisfactory and it satisfied the requirement of BS 3148 throughout the experimental phase of the project.

Experimental Equipment:

The major equipment that used for this study are hereby outlined;

i. 50mm (diameter) x 150mm (Height) cylindrical moulds
ii. Universal Strength Testing Machine (4207D, Chandler Eng. USA) which meets the requirements of BS 1881; 115 (1983)

METHODOLOGY

Main Experimental Test

Natural Moisture Content

The natural moisture content of the clay soil as obtained from the site was determined in accordance with BS 1377 (1990). Three weighing containers were cleaned and weighed to the nearest 0.01g (m_1). Freshly collected soil sample was crumbled and placed loosely in the containers and the containers plus samples were weighed together to the nearest 0.01g asm2. The containers were then placed in the oven and dried to a constant weight at 105 -110oC for 24 hours. The containers and the samples were then removed and weighed dry to the nearest0.01g asm3. The natural moisture content (as collected from the site) is calculated by Equation (3.1).

$$w = \frac{m_2 - m_3}{m_3 - m_1} \text{ x } 100 \qquad (3.1)$$

where,
w = moisture content in percentage.
m_1 = wt of container
m_2 = wt of container and sample,
m_3 = wt of container and oven dried sample.

Specific Gravity

The specific gravities of the clay soil, baggase ash and rice husk ash were determined using a density bottle according to BS 1377(1990). The empty density bottle and the stopper were weighed to the nearest 0.001g (m_1).The oven dried soil was transferred into the density bottle, and the bottle plus content and the cover were weighed as m2.Waterwas then added just enough to cover the soil, the solution is gently stirred to remove any air bubble. The bottle was then completely filled up and covered. The covered bottle was then wiped dry and the whole weighed to the nearest 0.001g(as m_3). The bottle was subsequently emptied and filled completely with water, wiped dry and weighed to the nearest 0.001g (m_4). The specific gravity was then calculated using Equation (3.2). The procedure was repeated to obtain three values of specific gravity from which theaverage specific gravity was determined.

$$Gs = \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_2)} \qquad (3.2)$$

Particle Size Distribution Analysis of Clay Soil

Particle size analysis of clay soil was carried out in accordance with BS 1377 (2016). Wet sieving was conducted by measuring 200 g of the soil sample and soaking it for 24 hours. The sample was then washed through BS No 200 sieve. The particles retained were then dried in an oven for 24hours and dry sieving was carried out on the dried sample to obtain the particle size distribution. The mixture that passed through sieve No 200was poured into a 1000 ml measuring cylinder then 25 ml of sodiumhexametaphosphate (commercial grade) was added and stirred thoroughly, then hydrometer was immersed gently and readings were taken at intervals stipulated by BS 1377; 2016 Part 2.

Atterberg limits of soils

The Atterberg limits tests included the determination of liquid and plastic limits, and plasticity index of the natural soil sample. They were also conducted in accordance with Test 1(A) BS 1377 (1990) Part 2.

Liquid limit:

Liquid limit is the minimum moisture content at which the soil will flow under its own weight. In this test, 200 g of the sample passing sieve 425 µm was placed on a clean glass plate. Water was added little by little as it was mixed, using palette knife or spatula to form a homogeneous paste. A proportion of the paste was placed in Casagrande apparatus and leveled parallel to the base of the chip and divided by drawing the grooving tool through the paste along diameter passing the centre of the hinge. The crank was turned to lift-drop the cup at the rate of 2 revs per second, noting the number of blows (falls) that would make the bottom two parts of the groove come together. A sample of it was taken and its moisture content determined. This test was repeated for well-spaced moisture content starting from the drier to wetter state. The determined moisture contents were plotted against corresponding number of blows on a semi-logarithmic paper and liquid limit was determined at the moisture content corresponding to 25 blows.

***Plastic limit*:**

Plastic limit is the minimum water content at which a soil will just begin to crumble when rolled into a thread approximately3mm in diameter. Some 20 g of the air-dried natural soil passing sieve with 425µmaperture was put on a flat glass plate and mixed thoroughly enough to be shaped into a small ball. Liquid content for this test was slightly less than the one for liquid limit test. The ball was then moulded between fingers and then rolled on the glass plate with palm of hand into thread of about 3mm diameter until when the thread crumbles by shearing. The crumbled threads were immediately put in weighing pan for moisture content determination.

Plasticity Index

Plasticity Index of the natural soil sample was derived from the already determined values of liquid limit and plastic limit using Equation (3.3)

$$PI = LL - PL \qquad (3.3)$$

where,

PI = Plastic Index
LL= Liquid Limit
PL = plastic Limit

The Minitab software was used for the RSM design and analysis in this study.

Linear shrinkage of soils

The test was conducted in accordance with Test 5 BS 1377 (1990). It involves the mixing of about 125g of soil, passing the BS No. 40 sieve (425µm), with water in order to obtain a homogenous paste. Water mixed with the soil sample was in the same amount as the moisture content corresponding to the liquid limit. (The water added to the natural soil corresponded to the moisture content at liquid limit). The paste was then placed in the shrinkage mould and vibrated gently in order to expel air pockets from the mixture. The soil was then leveled by spatula and air dried at 60oC. Initially, the soil shrank clear of the mould. Subsequent drying to a constant weight was made at 105–110 oC in an oven in order to complete the shrinkage. On cooling, the length of the sample was measured with a ruler and the linear shrinkage was calculated using Equation (3.4).

$$\text{Linear Shrinkage} = \frac{(\text{Initial length} - \text{dried length})}{\text{Initial length}} \text{ X } 100\% \qquad (3.4)$$

Compaction Test

Standard Proctor compaction test of the untreated lateritic soil was carried out in accordance to BS 1377. The essence of this test is to obtain the optimum moisture content (OMC) and the maximum dry density (MDD).The test was carried out on an air dried soil sample (20kg). Untreated lateritic soil was passed through sieve no. 4 (4.75mm) to remove larger particles that may hamper the compaction process. Proctor mould of 100mm internal diameter with a rammer of 2.5kg was used for this test. Before commencement of the test proper, the weight of the mould together with the base plate was measured and tagged (M1). An initial water content of 10% was added to the untreated soil and thoroughly mixed. The soil was then compacted in the mould in three layers using the 2.5kg rammer with each layer given 25 blows. A straight edge was used to trim the top of the mould and the compacted specimen demoulded. The weight of the mould plus base plate plus compacted soil was measured and tagged (M2) and the bulk density calculated in accordance to Equation (3.5). A small portion of the compacted sample was collected from the top and bottom respectively for moisture content determination. The dry density was then calculated using Equation (3.6). This procedure was repeated for water additions of two percent increments until the dry weight of the soil begins to reduce.

$$\mathrm{p} = \frac{M_2 - M_1}{Volume\ of\ mould} \qquad (3.5)$$

$$\mathrm{p}_d = \frac{\mathrm{p}}{1+w} \qquad (3.6)$$

Where; p is the bulk density; p_d is the dry density and w is the moisture content

California Bearing Ratio (CBR)

The CBR test was carried out as specified by BS 1990. The test was carried out in a laboratory with air dried soil sample with a predetermined natural moisture contents. The soil broken into the specified size was allowed to pass through 2mm BS sieve and mixed thoroughly with a specified percentage of water obtained from mix design. The wet soil is filled into the mould attached with the collar in 3 layers. Each layer is given 56 blows for a standard rammer of 2.5kg dropping freely from a height of 300mm.The sample was then trimmed to the mould level and the spatula was used to scrape the level surface of the mould and weighed together with the base plate to obtain the weight of the soil sample. The moulds containing the compacted specimen with the base plate in position were subjected to surcharge weights as required. A load was applied to it, firing the plunger to penetrate the sample. The force on the plunger was read at every penetration of 0.25mm dial gauge reading after the first was completed, the mould was removed. The mean moisture content to top and bottom was obtained. The readings were recorded and plotted and the CBR calculated using Equation (3.7).

$$\text{CBR} = \frac{\text{Applied force}}{\text{standard value}} \text{ X } 100\% \tag{3.7}$$

Where the applied force is calculated using Equation (3.8)

$$\text{Applied force} = \frac{\text{plunger reading x proving ring factor}}{1000} \tag{3.8}$$

Where; the standard value = 1370Kg for 2.5mm penetration and 2055Kg for 5mm penetration

Unconfined Compressive Strength Test

One of the predominant convenient immediate tests on saturated fine soil is the unconfined compressive test. It is a special case of triaxal test in which lateral pressure is zero. The test thus, becomes extremely simplified. It is used in the field because of its simplicity and undisturbed sample can be tested easily. Readings of the vertical loads and the deformations are taken till the specimen fails. Since the specimen bulges during the test, some correction the cross sectional area for various stress has to be applied. The maximum compressive stress at the failure is noted.

The test was repeated for stabilized soil of 5, 10, 15, 20, 25 and 30% of both admixtures with their respective OMC.

RESULTS AND DISCUSSION

Presentation of Results

Results obtained from experimental procedures in this study are hereby presented in details in the forms of tables and figures where necessary. Actual discussions on the effects of the two admixtures on the properties of the stabilized clay were also done.

Results for the Natural moisture content of untreated clay soil test

The natural moisture content test results of the untreated clay soil sample is presented in Table 4.1. The moisture content of the soil was then determined with the aid of Equation (3.1).The natural moisture content of the untreated clay soil was then determined as 18.02%, representing the average of the natural moisture content values shown in Tables 4.1. This is an indication that the soil material is a relatively high water holding material with low porosity.

Table 4.1. Natural Moisture Content Result of Untreated Clay Soil

S/N	Test no Observations	1	2	3
1	Mass of container alone(m_1)	39.67	39.58	39.93
2	Mass of container + wet soil (m_2)	132.52	132.03	132.02
3	Mass of container + oven dry soil (m_3)	118.29	117.88	118.04
5	$m_3 - m_1$	78.62	78.3	78.11
6	$m_2 - m_3$	14.23	14.15	13.98
7	Applying Equation (3.1), w	18.10	18.07	17.90

Results for the Specific Gravity of Materials Test

The specific gravity test result of the soil sample is presented in Table 4.2. The specific gravity was determined using Equation (3.2). Specific gravity value of the soil sample was obtained as 2.66 which represent the average of the three specific gravity values displayed in Table 4.2. The specific gravity is a property that indicates how dense a soil material can be and how many voids it may contain. In general, the specific gravity of soils tends to fall between 2.60-2.90, with coarser soils generally having lower specific gravities than finer soils. Specific gravity value of 2.66 is an indication of test properly done and representative of a fine grain material. Also from Table 4.3 and Table 4.4, the specific gravities of BA and RHA were obtained as 2.25 and 2.13 respectively.

Table 4.2. Specific Gravity Result of Untreated Clay Soil

S/N	Test no Observations	1	2	3
1	Mass of density bottle alone(m_1)	27.65	27.55	27.50
2	Mass of density bottle + oven dry soil (m_2)	53.06	53.49	53.50
3	Mass of density bottle + oven dry soil + distilled water (m_3)	96.17	96.68	96.27
4	Mass of density bottle + distilled water (m_4)	80.36	80.36	80.17
5	m_3-m_2	43.11	43.19	42.77

6	m_4-m_1	52.71	52.81	52.67
7	$(m_4-m_1)-(m_3-m_2)$	9.60	9.62	9.9
8	m_2-m_1	25.41	25.94	26
9	Applying Equation (3.2), G_s	2.65	2.70	2.63

Table 4.3. Specific Gravity Result of Bagasse Ash (BA)

S/N	Test no Observations	1	2	3
1	Mass of density bottle alone(m_1)	27.65	27.55	27.50
2	Mass of density bottle + oven dry BA(m_2)	56.18	56.32	56.37
	Mass of density bottle + oven dry BA + distilled water (m_3)	96.21	96.25	96.22
4	Mass of density bottle + distilled water (m_4)	80.36	80.36	80.17
5	m_3-m_2	40.03	39.93	39.85
6	m_4-m_1	52.71	52.81	52.67
7	$(m_4-m_1)-(m_3-m_2)$	12.68	12.88	12.82
8	m_2-m_1	28.53	28.77	28.87
9	Applying Equation (3.2), G_s	2.25	2.23	2.25

Table 4.4. Specific Gravity Result of Rice Husk Ash (RHA)

S/N	Test no Observations	1	2	3
1	Mass of density bottle alone(m_1)	27.65	27.55	27.50
2	Mass of density bottle + oven dry RHA(m_2)	57.45	57.57	57.38
3	Mass of density bottle + oven dry RHA + distilled water (m_3)	96.19	96.14	96.23
4	Mass of density bottle + distilled water (m_4)	80.36	80.36	80.17
5	m_3-m_2	38.74	38.57	38.85
6	m_4-m_1	52.71	52.81	52.67
7	(m_4-m_1)-(m_3-m_2)	13.97	14.24	13.82
8	m_2-m_1	29.8	30.02	29.88
9	Applying Equation (3.2), G_s	2.13	2.11	2.16

Results for Particle Size Distribution of Soil Test Results

The sieve analysis test results for the untreated clay soil is displayed in Table 4.5. This data is used in gradation and particle size distribution of soils. Data from Table 4.5 was used in producing the particle size distribution curves presented in Figure 4.1. Figure 4.1 reveals that the soil material is basically composed of clay and silt material particles with over 80% passing 75 µm sieve. The silt content of soil sample A is about 38% with 60% clayey content representing the basic material of the soil material. Fine sand particles constitute about 2% of the total soil mass.

Table 4.5: Sieve Analysis Test Result of Clay Soil

Sieve Sizes (mm)	Percentage Passing
1.18	100
0.6	100
0.3	100
0.212	100
0.15	98.1
0.063	97.1
0.0512	96.2
0.0233	94
0.0136	90
0.0096	87
0.0068	80
0.0048	71
0.0034	60
0.0028	54
0.0024	40
0.0014	5

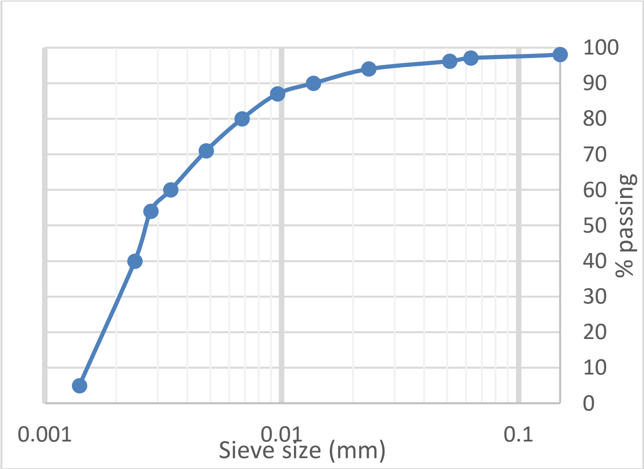


Figure 4.1. Particle Size Distribution Curve of untreated clay soil

Results Used for Atterberg Limit of untreated soil test

The Atterberg limit of the untreated soil test results such as liquid limit, plastic limit and plasticity index test results are presented and analyzed in this sub section.

Table 4.6 presents the liquid limit test result for the untreated soil sample. The liquid limit of the soil is that water content corresponding to 25Nos. blows. The moisture or water content obtained as per Tables 4.6 were plotted against the Number of blows involved in the experiment. The moisture content corresponding to 25 blows was taken as the soil's liquid limit. This liquid limit values of soil sample as revealed by Figure4.2 is37.75%. The liquid limit of a soil which is one indication of the soil consistency, is the minimum moisture content at which a soil, though still in its liquid state, still has a small resistance against flow.

The plastic limit is another measure of soil consistency. It is the moisture content at the boundary between the plastic and semisolid states of consistency. The plastic limit of the untreated clay soil is obtained as the average moisture content of the moisture content values displayed in Table 4.7. The plastic limit of soil was deduced as 17.36%.

The plasticity index of the soil sample was determined using Equation (3.3). 20.39% was obtained as the plasticity index of soil sample. This value of plasticity index indicate a material with high plastic characteristics suggesting the presence of clay and fines particles.

Table 4.6. Liquid Limit of Untreated Soil

	Liquid Limit (%)		
Container No.	1	2	3
No. of Blows	36	24	12
Wet sample + Container (mt + mc)	234	237	235
Dry sample + Container (md + mc)	183	184	182
Water (mw= mt - md)	51	53	53
Container, mc	46	45	47
Dry soil, md	137	139	135
Moisture Content, w= (mw/md)*100	37.23	38.13	39.26

Table 4.7. Plastic Limit of Soil

Container No.	1	2	3
Wet sample + Container ($m_t + m_c$)	72	74	71
Dry sample + Container ($m_d + m_c$)	67.5	69.2	66.7
Water ($m_w= m_t - m_d$)	4.5	4.8	4.3
Container, m_C	42	41	42
Dry soil, W_d	25.5	28.2	24.7
Moisture Content, $w= (m_w/m_d)*100$	17.65	17.02	17.41

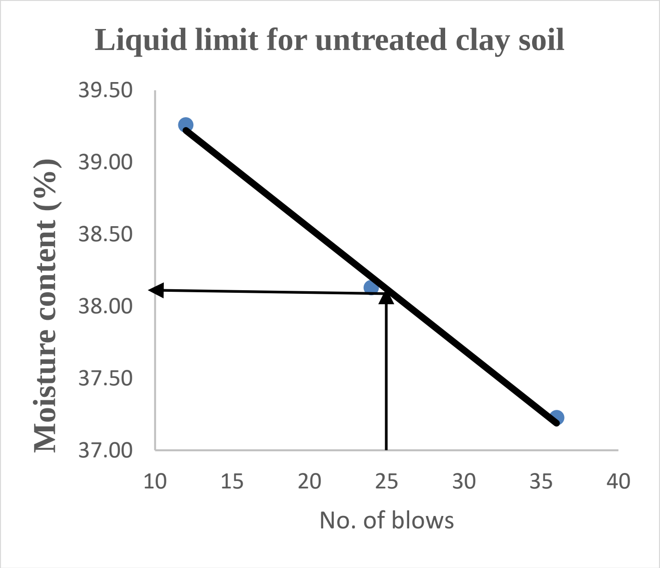


Figure 4.2. Liquid Limit Determination of Untreated Soil Sample

Linear Shrinkage Result of Untreated Clay Soil

The linear shrinkage test result is displayed in Table 4.8. On application of Equation (3.4), the linear shrinkages of the soil sample was obtained as 38%. This value (linear shrinkage) is used here to represent the maximum shrinkage to be experienced by the soil sample in the presence of water such that it could possibly offer shear resistance

Table 4.8. Linear Shrinkage Result of Untreated Clay Soil

Parameter	Value (cm)
Initial length	15.00
Dried length	9.30

Standard proctor compaction test result of untreated clay soil presentation and analysis

Table 4.9 present the summarized compaction test results for the untreated soil sample. The optimum moisture content (OMC) and maximum dry density (MDD) were obtained from this test. The optimum moisture content for untreated soil sample was obtained from the compaction curve (Figures 4.3) as 14.2%. 1.72g/cm3 was recorded as the maximum dry density of the soil sample.

Table 4.9. Compaction Test Results of Untreated Soil Sample

Moisture content (%)	10	13	17	19
Dry density (g/cm3)	1.63	1.71	1.69	1.61

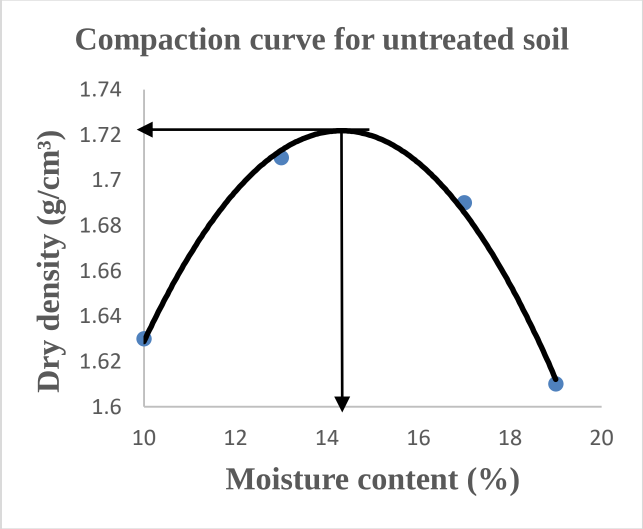


Figure 4.3. Dry Density vs Moisture Content for Untreated Soil

CBR Result for Untreated Clay Soil

The CBR value was deduced from the penetration test results shown in Table 4.10. The CBR value was determined with the help of the load penetration curve and application of Equation (3.7) and/or Equation (3.8). Figure 4.4 gives the Load penetration curve for the untreated soil sample using the data displayed in Table 4.10. The CBR of a soil material is usually calculated at penetration 2.5mm or penetration 5mm according to Equation (3.7). The CBR value of the untreated soil was obtained as 3.99%.

Table 4.10. Penetration Test Results

Pen (mm)	***0***	***0.5***	***1***	***1.5***	***2***	***2.5***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
Load(Kg)	***0***	***12.23***	***20.39***	***29.56***	***37.72***	***46.89***	***55.05***	***69.32***	***82.57***	***94.80***	***111.11***	***126.40***	***141.69***	***161.06***

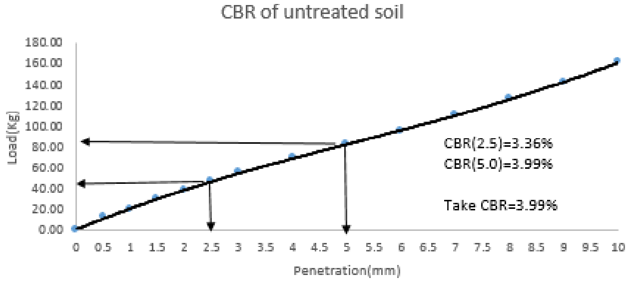


Figure 4.4. Load Penetration Curve of Untreated Soil for CBR Determination

UCS at 7 Days Result for Untreated ClaySsoil

The UCS test result for the unmodified lateritic soil is presented in Table 4.11. The initial length of the specimen, l0 was 116mm and initial area, A_0 was 2642mm^2. The maximum axial or compressive stress is 163kPa which is an indication of the unconfined compressive strength of the untreated clay soil. Figure

4.5 shows the compressive stress- strain curve for the unmodified lateritic from which the maximum compressive stress can be clearly seen as 163kPa

Table 4.11. UCS at 7days Test Result for Unmodified Lateritic Soil

Compression Δl (mm)	Strain $\varepsilon = \Delta l/l_0$	Force F (N)	Corrected Area (mm2), $A = A_0/1-\varepsilon$	Compressive Stress (kPa), $\sigma 1 = 1000F/A$
0	0.00000	0	2642	0
0.042	0.00036	44	2643	17
0.107	0.00092	109	2644	41
0.215	0.00185	181	2647	68
0.325	0.00280	235	2649	89
0.403	0.00347	267	2651	101
0.513	0.00442	294	2654	111
0.626	0.00540	347	2656	131
0.703	0.00606	385	2658	145
0.787	0.00678	412	2660	155
0.834	0.00719	433	2661	163

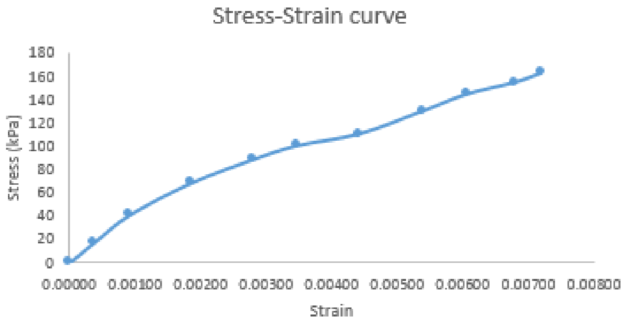


Figure 4.5. Stress-Strain Curve for Untreated Clay Soil

4.1.9 Atterberg Limit Test Result for Studying the Effect of Admixtures on Index Properties of Treated Clay Soil

Table 4.12 presents a summary of the plasticity test results to investigate the effect of the admixtures on the index properties of treated clay soil.

Table 4.12. Atterberg Limit Test Result of Treated Clay Soil

% replacement	BA treated soil			RHA treated soil		
	Liquid limit (LL)	Plastic limit (PL)	Plasticity index (PI)	Liquid limit (LL)	Plastic limit (PL)	Plasticity index (PI)
0	37.75	17.36	20.39	37.75	17.36	20.39
2	35.24	17.11	18.13	36.18	17.4	18.78
4	33.81	16.89	16.92	35.06	17.42	17.64
6	31.54	16.78	14.76	32.49	17.46	15.03
8	28.39	16.52	11.87	30.98	17.46	13.52
10	27.99	16.38	11.61	28.37	17.48	10.89
12	27.43	16.21	11.22	28.01	17.47	10.54

Analyzing the Effect of Bagasse Ash (BA) on the Index Properties of Treated Clay Soil

Data in Table 4.12 is pictorially represented in Figure 4.6 for BA treated clay soil. All Atterberg limits can be seen to reduce with introduction of bagasse ash. The liquid limit decreases continuously as the bagasse content increases. Also, the plastic limit recorded a slight continuous decrease as the bagasse ash content is increased. Consequently, the plasticity index of the treated clay soil continuously decreased. Although the consistency limits reduces with bagasse ash content, this reduction rate is reduced as the bagasse ash content is increased. While the liquid limit recorded a percentage reduction of 27.34% (reduced from 37.75% to 27.43 % at 12% bagasse ash content), the plastic limit recorded a percentage reduction rate of 6.6% (reduced from 17.36% to 16.21%). The percentage reduction rate for plasticity index is determined to be 45% (reduced from 20.39% to 11.22%). This indicates a reduction in plasticity of clay soil from high (untreated) to low plasticity characteristics, signifying improvement in the properties or performance of the clay soil for usage in foundational applications.

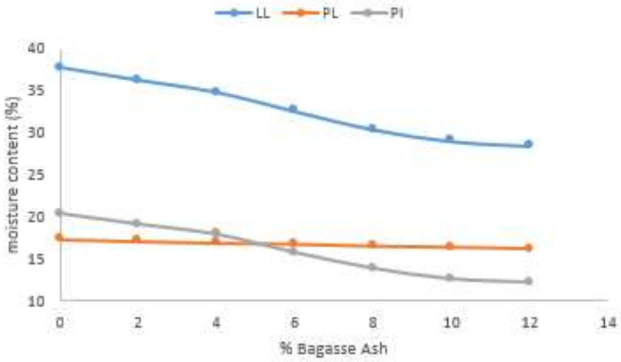


Figure 4.6. Atterberg Limits Variation with BA Content

Analyzing the Effect of Rice Husk Ash (RHA) on the Index Properties of Treated Clay Soil

Figure 4.7 was produced using the rice husk ash treated clay soil data in Table 4.12. The liquid limit of the RHA treated clay soil decreases with increase in RHA content. This reduction amounts to a percentage reduction in liquid limit of 25.8% (reduced from 37.75% to 28.01%). Inverse is the case for plastic limit.

The plastic limit of the RHA treated clay soil increases steadily as the RHA content increased to a percentage addition of 10% afterwhich a reduction in plastic limit was noticed at 12% RHA addition. The plasticity index was consequently reduced from 20.39% to 10.54% (a percentage reduction of 48.33%). This reduction in plasticity index translates to a reduction in plasticity of the clay soil which invariably translates to improvement in clay soil performance. It was also noticed here that improvement in clay soil plasticity reduces as the percentage increment in RHA increases.

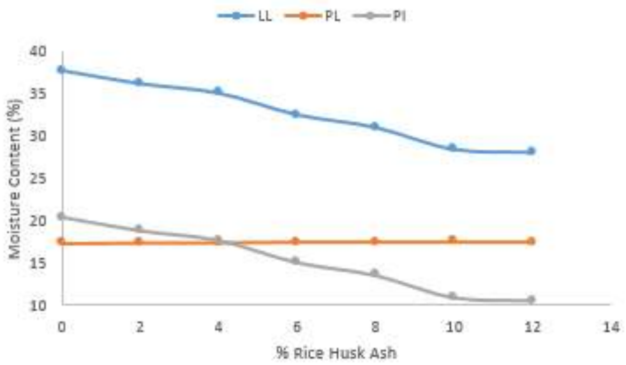


Figure 4.7. Atterberg Limits Variation with RHA Content

Compaction Test Result for Studying the Effect of on Compaction Properties of Admixtures Treated Clay Soil

Analyzing the Effect of Bagasse Ash (BA) on the Compaction Properties of Treated Clay Soil

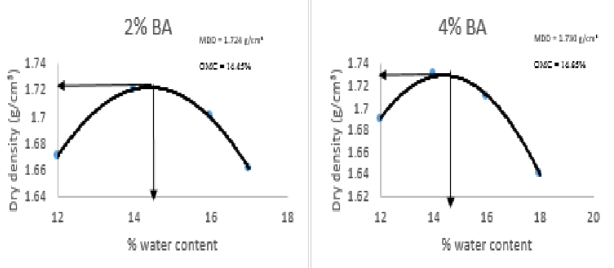
Figure 4.8 presents the optimum moisture contents and the maximum dry densities of clay soil treated with different percentages of bagasse ash. A summarized version of Figure 4.8 is presented in Table 4.13.The variation of compaction characteristics with bagasse ash content is presented in Figure 4.9. The OMC continuously increases as the BA content increased. This increment is from 14.20% to 15.80% at 12% BA content. This is an increment of about 11.27%. OMC increment tends to get smaller as the percentage BA content is increased as can be observed in Figure 4.9 and Table 4.13. While the OMC continuously increases with BA content, the MDD increases to a certain percentage lying between 8-10% BA content before it started decreasing. This is an indication that the optimum BA content lies between 8-10% of dry clay soil.

Analyzing the Effect of Rice Husk Ash (RHA) on the Compaction Properties of Treated Clay Soil

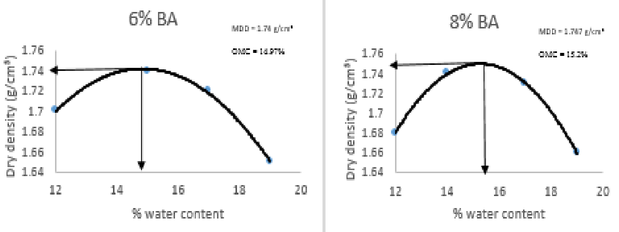
Figure 4.10 presents the optimum moisture contents and the maximum dry densities of clay soil treated with different percentages of RHA. A summarized version of Figure 4.10 is presented in Table 4.14 which is then represented pictorially in Figure 4.11. The OMC of RHA treated clay soil also increased as the RHA content increases (Figure 4.11). This increment is from 14.2% at 0% RHA content to 16.5% at 12% RHA content. With this, a percentage increment of 16.2% was recorded for the OMC. While the OMC increased continuously with RHA content, the MDD decreased continuously as the RHA content was increased with a percentage reduction of almost 39%. The MDD reduced from 1.72% at 0% RHA to 1.653% at 12% RHA addition.

Table 4.13. Summarized Compaction Test Result of BA Treated Clay Soil

% replacement	BA treated soil	
	Optimum moisture content (OMC), %	Maximum dry density (MDD), g/cc
0	14.20	1.72
2	14.45	1.724
4	14.65	1.730
6	14.97	1.740
8	15.20	1.747
10	15.60	1.730
12	15.80	1.724



(a) 2% BA (b) 4% BA



(e) 6% BA (f) 8% BA

(g) 10% BA (h) 12% BA

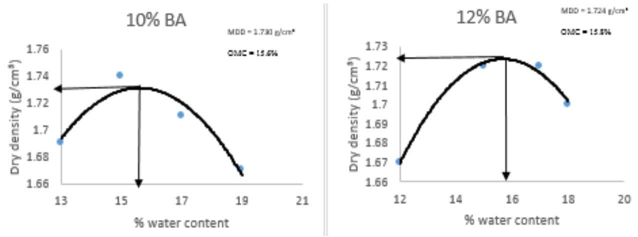
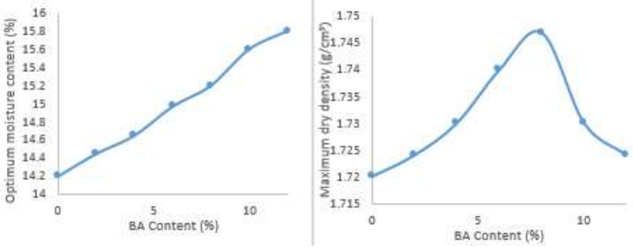


Figure 4.8. OMC and MDD for the Different BA Content



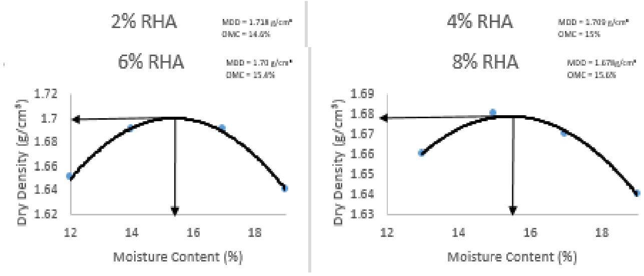
(a) OMC Vs BA (b) MDD Vs BA

Figure 4.9. Variation of Compaction Properties with Bagasse Ash Content

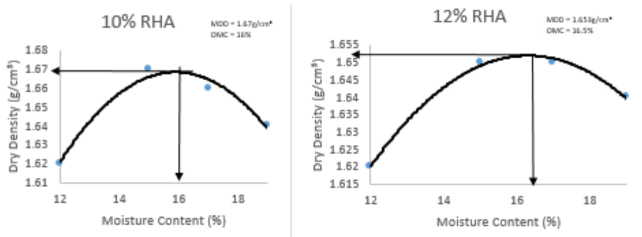
Table 4.14. Summarized Compaction Test Result of RHA Treated Clay Soil

% Replace-ment	*RHA Treated Soil*	
	Optimum Moisture Content (OMC), %	***Maximum Dry Density (MDD), g/cc***
0	***14.2***	***1.72***
2	***14.6***	***1.718***
4	***15***	***1.709***
6	***15.4***	***1.7***
8	***15.6***	***1.678***
10	***16***	***1.67***
12	***16.5***	***1.653***

(a) 2% RHA (b) 4% RHA



(a) 4% RHA (b) 6% RHA



(a) 4% RHA (b) 6% RHA

Figure 4.10. OMC and MDD for the Different RHA Content

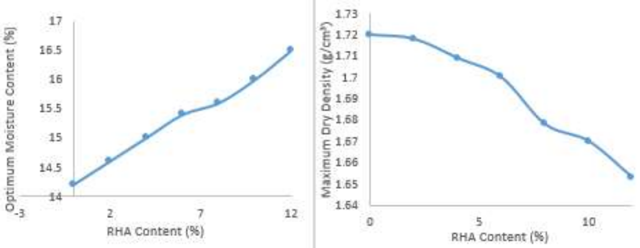


Figure 4.11. Variation of Compaction Properties with Rice Husk Ash Content

4.1.11 CBR Test Result for Studying the Effect of Admixtures on the CBR of Treated Clay Soil

Table 4.12 presents a summary of the plasticity test results to investigate the effect of the admixtures on the index properties of treated clay soil.

Analyzing the Effect of Bagasse Ash (BA) on the CBR of Treated Clay Soil

BA shows improvement on the CBR property of the treated clay soil. Data in Table 4.15 which is pictorially represented by Figure 4.12 presents the variation of CBR with percentage addition of BA content. The CBR of BA treated clay soil increased from 3.99% to an optimum percentage before reduction in CBR was noticed. This optimum seem to lie between 8-10% of BA as indicated in Figure

4.12 showing an optimum BA content of about 9% with a maximum CBR value of 29.5%, signaling a percentage increment of almost 64%. Beyond the optimum BA content, the CBR of BA treated soil started reducing.

Analyzing the Effect of Rice Husk Ash (RHA) on the CBR of Treated Clay Soil

RHA also produced similar trend as the BA. The CBR of the treated clay soil increases to an optimal RHA value before it started decreasing. The optimal RHA content is obtained as 10%. That is, the CBR of RHA treated clay soil increases as the RHA content was increased to about 10%. Beyond 10%, the CBR took a reverse turn. 28.72% was observed as the highest CBR value at the optimal RHA content of 10% leading to a percentage increment in CBR of about 620%.

Table 4.15. Summarized CBR Test Result of Treated Clay Soil

% Replacement	CBR (%) BA Treated Soil	CBR (%) RHA Treated Soil
0	3.99	3.99
2	9.78	9.92
4	18.91	16.84
6	24.62	22.08
8	29.13	27.75
10	29.05	28.72
12	24.86	28.16

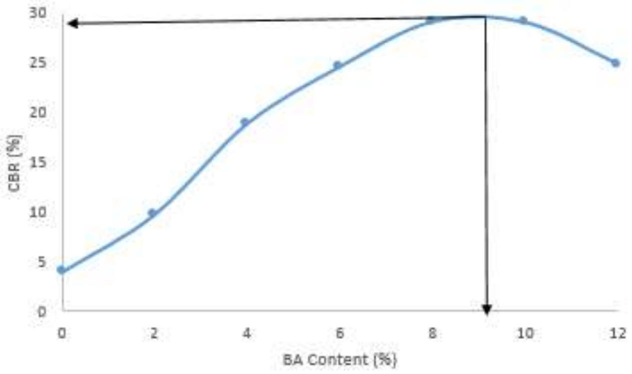


Figure 4.12. Variation of CBR with Bagasse Ash Content

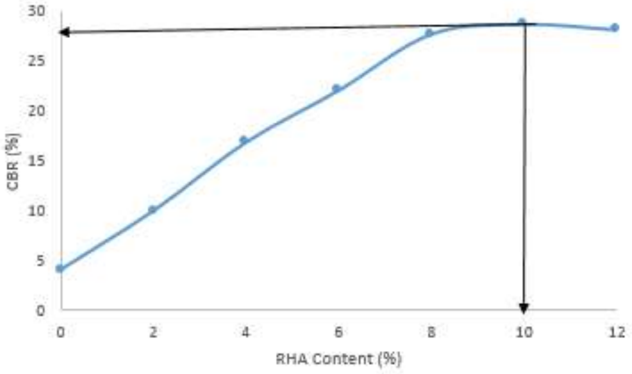


Figure 4.13. Variation of CBR with Rice Husk Ash Content

UCS Test Result for Studying the Effect of Admixtures on the UCS of Treated Clay Soil

Table 4.12 presents a summary of the plasticity test results to investigate the effect of the admixtures on the index properties of treated clay soil.

Analyzing the Effect of Bagasse Ash (BA) on the UCS of Treated Clay Soil

As can be observed from Table 4.12 and Figure 4.14, 7day UCS strength of clay soil increases as the BA content increases to an optimum value. The optimum value lies between 8 and 10% as shown in Table 4.12. From Figure 4.14 showing variation of UCS with BA content, this optimum BA content is approximately 8.2%. Beyond this optimum point, the UCS decreases with further addition of BA. At the optimum content of 8.2%, the maximum UCS is obtained as 314kPa. Therefore, there is a percentage increase in strength of approximately 93%.

Analyzing the Effect of Rice Husk Ash (RHA) on the UCS of Treated Clay Soil

RHA improved the UCS of the treated clay soil to a maximum value. As the RHA content increases, the UCS also increased. This optimum value as can be observed from Figure 4.15 showing the variation of UCS with RHA content, as 10%. Beyond 10% RHA addition, a reverse was observed and the UCS values started decreasing. The UCS of RHA treated soil increased from 163kPa at 0% RHA to 302kPa at 10% RHA addition. This amounts to a percentage increase in UCS of 85.3%.

Table 4.12. Summarized UCS Test Result of Treated Clay Soil

% Replacement	UCS (kPa)	
	BA Treated Soil	**RHA Treated Soil**
0	163	163
2	202	197
4	243	239
6	265	274
8	312	289
10	299	302
12	287	291

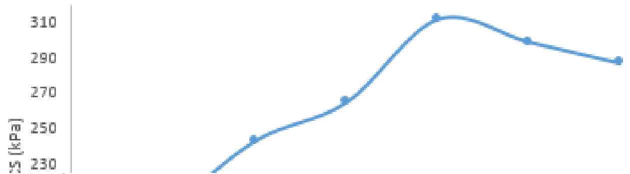


Figure 4.14. Variation of UCS with Bagasse Ash Content

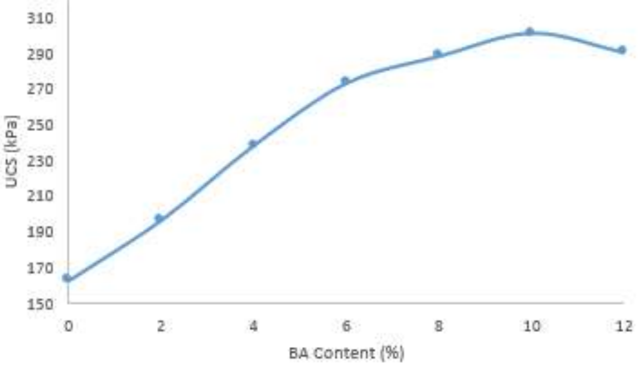


Figure 4.15. Variation of UCS with Rice Husk Ash Content

4.1.13 Comparative Analysis of the Effect of BA and RHA on Index Properties of Treated Clay Soi

Figure 4.16 presents the variation of change in liquid limit and plasticity index as affected by BA and RHA introduction to clay soil. The change or reduction in liquid limit of the clay soil can be seen to be affected more by BA in comparison to RHA. That is to say that BA has a higher influence on the liquid limit of soft clay at the initial admixture addition. Although the change in liquid limit of BA treated clay soil is increase more in comparison to RHA treated clay soil, it seem to converge as the content of the admixtures increases. As can be observed from Figure 4.16, the increase in the change in liquid limit tends to converge when the admixture content gets to 10% and beyond. For the plasticity index, similar observation was discovered as the BA treated soil has a higher initial impact on the plasticity of the treated clay soil in comparison to the RHA treated clay soil. As the admixture content increases, the gap tends to narrow until a reversal is observed at admixture content just before 10%. This is an indication that the optimum content of RHA is farther as compared to the BA optimum content, although, the BA might perform better overall.

Comparative Analysis of the Effect of BA and RHA on Compaction Properties of Treated Clay Soil

The variation of change in compaction characteristics with admixture content is presented in Figure 4.17. The change in optimum moisture content is higher in RHA treated soil than BA treated soil for every percentage admixture content. This is to say, that RHA has a higher influence on the amount of water required for maximum performance of treated clay soil. More water is needed for easy compaction of RHA treated soil as compared to BA treated clay soil. For the change in maximum dry density, while there is a corresponding increase in the change of MDD to a maximum value as BA increases, there is a continuous decrease in the change of MDD for RHA treated clay soil.

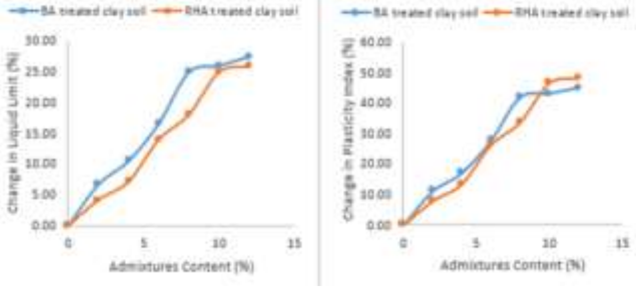


Figure 4.16. Variation of Change in Atterberg Limit with Admixture Content

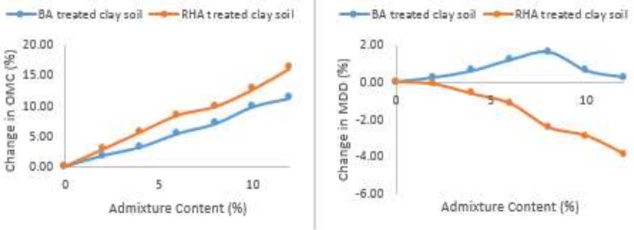
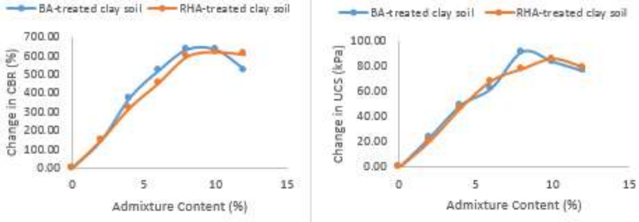


Figure 4.17. Variation of Change in Compaction Characteristics with Admixture Content

Comparative Analysis of the Effect of BA and RHA on Strength Properties of Treated Clay Soil

Figure 4.18 presents the variation of change in strength properties as affected by BA and RHA introduction to treated clay soil. The change or reduction in CBR of the clay soil can be seen to be influenced more by BA in comparison to RHA to a certain percentage increment, after which the reversal becomes the case. That is to say that BA has a higher influence on the CBR of soft clay at the initial admixture addition. Although the change in CBR of BA treated clay soil is increased more in comparison to RHA treated clay soil, it seem to converge at percentage content just above 10% beyond which a reversal in the curve is noticed. For the UCS, similar observation was discovered as the BA treated soil has a higher initial impact on the strength of the treated clay soil in comparison to the RHA treated clay soil. As the admixture content increases, the gap tends to narrow until a reversal is observed at admixture content just before 10%. This is an indication that the optimum content of RHA is farther as compared to the BA optimum content, although, the BA might perform better overall. Furthermore, BA treated clay soil increase both CBR and UCS to percentage increment change of 630% and 91.41% respectively while percentage increments of 619.8% and 85.23% were recorded for UCS. From the above, BA improved the strength properties better in comparison to RHA albeit in smaller optimum percentage addition.



(a) Change in CBR (b) Change in UCS

Figure 4.18. Variation of Change in Strength Properties with Admixture Content

DISCUSSION OF FINDINGS

Soil Classification

From the analysis of the natural moisture content of the clay soil, the natural moisture content was determined to be 18.02%, indicating that the soil material is a relatively high water holding material with very low porosity. This is a fundamental characteristic of cohesive soils. Analysis of the specific gravity result of the soil further cemented the claim of having the right material for this study. Fine grained soils tend to have specific gravities in the bracket of 2.60-2.90. Specific gravities of 2.66as obtained for the clay soil is an indication of test properly done and representative of a fine grained material.

The particle size distribution analysis for the soil reveal that the soil material is basically composed of clay and silt particles. The silt content of soil sample is about 38% with 60% clayey content representing the basic material of the soil material. Fine sand particles constitute about 2% of the total soil mass. Using the USCS method of soil classification (ASTM D2487, 2017), the soil material is basically composed of clayey and silty materials with high plasticity.

The Atterberg characteristics of the soil such as liquid limit, plastic limit and plasticity index test were obtained as 37.75%, 17.36% and 20.39% respectively. This value of plasticity index indicates a material with high plastic characteristics suggesting the heavy presence of clay. Using the AASHTO classification system, the soils were therefore classified as A-7-6 soil materials.

Effect of Admixtures on Index Properties of Treated Clay Soil

Increase in bagasse ash content, subsequently lead to decrease in the Atterberg limit of the soft clay soil. This decrease can be associated with the agglomeration and flocculation of the clay particles as a result of ions' exchange at the surface of the clay particles. This observed trend is in agreement with those of Salahudeen and Akiije (2014) and Ramzi et al. (2001). Venkaramuthyalu et al. (2012) and Ramzi et al. (2001) reported that the reduction in plasticity index with chemical treatment could be attributed to the depressed double layer thickness due to cation exchange by potassium, calcium and ferric ions.

Increase in RHA content, leads to continuous reduction in liquid limit, increment in plastic limit to about 10% RHA content and reduction in the plasticity index of the RHA treated clay soil. The general decrease in liquid limit at all soil-rice husk ash combination is attributed to the fact that the rice husk ash reaction forms compounds possessing cementitious properties calcium silicate cement with soil particles. This trend conforms to findings of Muntohar and Hantoro (2000) and Mohammed et al. (2013) who found that the liquid limit reduces with increasing lime and rice husk ash combinations.

Effect of Admixtures on the Compaction Properties of Treated Clay Soil

The MDD increased with higher BA content to an optimum BA content lying between 8-10% of dry clay soil. This increase in MDD could be attributed to BA occupying the voids within the soil matrix as well as the flocculation and agglomeration of the clay particles due to exchange of ions (Osinubi, 2000; Oriola and Moses, 2010; Salahudeen et al., 2014). The trend is in agreement with the findings reported by Lees et al. (1982), Ola (1991), Iorliam et al. (2012), Salahudeen and Akiije (2014) and Salahudeen et al. (2014). The subsequent decrease in MDD beyond the optimum point can be attributed to the replacement of soil by the BA in the mixture which has relatively lower specific gravity compared to that of the soil (Ola 1975; Osinubi and Katte 1997). It may also be attributed to coating of the soil by the BA which result to large particles with larger voids and hence less density (Osula, 1991). For the OMC, a continuous increment was noticed as the BA content increases with a possible percentage increment of 11.20%. This trend is in conformity with results reported by Ola (1978), Gidigasu (1976) and Osinubi (1999). An explanation for this trend was the increased demand for water commensurate with the higher amount of BA required for its hydration reaction and dissociation needed for cation exchange reaction.

OMC of RHA treated clay soil increases continuously with addition of RHA to a percentage increment of 16.2%. This trend can also be attributed to the increase in demand needed for water commensurate with higher amount of RHA required for the hydration reaction and dissociation needed for cation exchange reaction. Addition of RHA decreases the quantity of free silt leading to formation of clay fraction and coarser materials with larger surface areas (these processes need water to take place). MDD continuously decreased with addition of RHA to the clay soil. This decrease in MDD can be attributed to the replacement of soil by the RHA in the mixture. RHA has a lower specific gravity compared to that of the soil. It may also be attributed to coating of the soil by the RHA which result to large particles with larger voids and hence less density (Osula, 1991). The decrease in the MDD may also be explained by considering the RHA as filler (with lower specific gravity) in the soil voids.

Effect of Admixtures on the CBR of Treated Clay Soil

Increase in BA content leads to a consequent increase in CBR of BA treated soft soil. This increment is continuous to an optimal value lying between 8-10%, which from Figure 4.12, is 9% precisely. This increase could be due 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 (Salahudeen and Akiije, 2014). For the soil–BA mixtures with 5 %BA content and above, the soaked CBR met the value recommended by Gidigasu and Dogbey (1980), who stated that minimum CBR value of 20%-30% is required for sub-bases when compacted at OMC.

Same trend was noticed for the CBR of RHA treated clay soil. The optimum value of RHA content was obtained as 10% with a maximum CBR value of 28.72%. This increase can also 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 (Salahudeen and Akiije, 2014). For the soil–RHA mixtures with 6 % RHA content and above, the soaked CBR met the value recommended by Gidigasu and Dogbey (1980), who stated that minimum CBR value of 20%-30% is required for sub-bases when compacted at OMC.

Effect of Admixtures on the UCS of Treated Clay Soil

The 7day UCS of clay soil is improved with addition of BA. As the BA content increased, the UCS increases to a maximum value after which, it started reducing. This increment rose to a percentage of 93% upon BA addition. The increase in the UCS may be attributed to the formation of cementitious compounds between the CaOH present in the soil and BA and the pozzolans present in the BA. The subsequent decrease in the UCS values after the addition of 8.2% BA may be due to the excess BA introduced to the soil and therefore forming weak bonds between the soil and the cementitious compounds formed. These results are compatible with the findings of Yadu et al. (2011) who studied stabilization of black cotton soil with industrial wastes.

RHA also improve the UCS of treated clay soil to a percentage increment in strength (UCS) of 85.3%. Beyond the optimum percentage addition of RHA of 10%, the UCS starts decreasing. As in the case of BA, this increase in the UCS can be attributed to the formation of cementitious compounds between the CaOH present in the soil and RHA and the pozzolans present in the RHA. The subsequent decrease in the UCS values after the addition of 10% RHA may be due to the excess RHA introduced to the soil, therefore forming weak bonds between the soil and the cementitious compounds formed.

Comparing bagasse ash (BA) and rice husk ash (RHA) on modification process

The change or reduction in liquid limit of the clay soil is being affected more by BA in comparison to RHA. That is to say that BA has a higher influence on the liquid limit of soft clay at the initial admixture addition. Although the change in liquid limit of BA treated clay soil is increase more in comparison to RHA treated clay soil, it seem to converge as the content of the admixtures increases. The reason for a greater effect of BA on the plasticity properties of clay soil in comparison to RHA can be attributed to higher agglomeration and flocculation of the clay particles as a result of ions' exchange at the surface due to the higher content of silica present in BA. The subsequent convergence can be due to higher values of BA and RHA contents rendering initial advantage of BA in terms of silica content irrelevant.

The change in optimum moisture content is higher in RHA treated soil than BA treated soil for every percentage admixture content. This is to say, that RHA has a higher influence on the amount of water required for maximum performance of treated clay soil. More water is needed for easy compaction of RHA treated soil as compared to BA treated clay soil. The difference in performance here can be attributed to the higher surface area of RHA in comparison to BA. Thus, more RHA is required to coat a particular clay sample in comparison to that required for BA treated sample (this process require more water for completion). For the change in maximum dry density, while there is a corresponding increase in the change of MDD to a maximum value as BA increases, there is a continuous decrease in the change of MDD for RHA treated clay soil. This can be attributed to the difference in specific gravities/densities of both substances. BA has a higher density/specific gravity in comparison to RHA. Hence, the difference in MDD percentage changes.

The change or reduction in CBR of the clay soil can be seen to be influenced more by BA in comparison to RHA to a certain percentage increment, after which the reversal becomes the case. That is to say that BA has a higher influence on the CBR of soft clay at the initial admixture addition. Although the change in CBR of BA treated clay soil is increased more in comparison to RHA treated clay soil, it seem to converge at percentage content just above 10% beyond which a reversal in the curve is noticed. For the UCS, similar observation was discovered as the BA treated soil has a higher initial impact on the strength of the treated clay soil in comparison to the RHA treated clay soil. As the admixture content increases, the gap tends to narrow until a reversal is observed at admixture content just before 10%. Furthermore, BA treated clay soil increase both CBR and UCS to percentage increment change of 630% and 91.41% respectively while percentage increments of 619.8% and 85.23% were recorded for RHA treated clay soil.

CONCLUSION AND RECOMMENDATION

Conclusions

Based on the findings, the following significant conclusions have been made;

a. Based on USCS criteria, the soil material is basically composed of clayey and silty materials with high plasticity characteristics. Using the AASHTO classification system, the soilis classified as A-7-6 soil material.

b. Increase in admixture content (BA and RHA) leads to decrease in all Atterberg limit of the soft clay soil except for plastic limit where there is generally a slight increase as RHA content increases.

c. Increase in admixture content leads to a consequent increase in CBR of treated soft soil. This increment is continuous to an optimum value which lies between 8-10% for BA content and exactly 10% for RHA content.

d. The soil–BA mixtures with 5 %BA content and above, the soaked CBR met the recommended value of 20%-30% required for sub-bases. The CBR soil–RHA mixtures met the recommended minimum soaked CBR value of 20%-30% with 6 % RHA content and above.

e. The 7day UCS of clay soil is improved with addition of both admixtures to the optimum admixture percentage addition.

f. In comparing both BA and RHA in the clay soil treatment process, although both substances increase strength properties of clay soil, the BA treatment process recorded a percentage increment change of 630% and 91.41% for CBR and UCS respectively while percentage increments of 619.8% and

85.23% were recorded for RHA treatment process. BA thus improved the strength properties better in comparison to RHA albeit in smaller optimum percentage addition.

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