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A Comparative Study of the Basic Strength and Hydraulic Properties of Lateritic Soils Stabilized with Rice Husk Ash and Bagasse Ash

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Authors' contributions

This work was carried out in collaboration between both authors. Author SOO carried out the experiments. Both authors wrote the manuscript. Author OAO presented the final draft. Both authors read and approved the final manuscript.

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ABSTRACT

The strength and hydraulic properties of lateritic soils stabilized with bagasse ash (BA) and rice husk ash (RHA) were examined in this study. The three lateritic soil samples used in the study were obtained from a borrow pit near the main waste dumpsite in Ado Ekiti, Nigeria. The BA and RHA were obtained locally from the burning of fibrous residue of sugar cane and rice husk respectively. Classification of the soils using AASTHO indicates Soil 1 to be Group A-6 soil, Soil 2 to be Group A-2-6 soil and Soil 3 to be Group A-2-7 soil. In general, the optimum moisture content of the stabilized soils increased with increased content of the admixtures-BA and RHA. The maximum dry density of the stabilized soils decreased with increase in the quantity of BA and RHA. Likewise, the saturated hydraulic conductivity of the stabilized soils decreased slightly with increased content of BA and RHA. The values of the minimum hydraulic conductivity of the stabilized soils were of the order of 10^{-4}cm/s, which are higher than the minimum requirement of 10^{-7}cm/s for soil liners in municipal solid waste landfills. The low pozzolanic characteristics of BA and RHA in the stabilized soils were attributed to the low content of CaO needed to produce $CaOH_2$, which is normally needed to produce pozzolanic reaction products in the presence of

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water. The characteristics of the modified soils appeared to be influenced by the change in the soil matrix following mixing. Comparison of individual behaviour of BA and RHA in each stabilized soil showed very similar characteristics. It was concluded that another modifier such as cement that has a high content of CaO should be added to the stabilized soils for the full pozzolanic potentials of BA and RHA to be realised.

Keywords: Lateritic soil; maximum dry density; saturated hydraulic conductivity; rice husk ash; bagasse ash.

1. INTRODUCTION

The increasing population, affluent life styles and development of industrial and commercial activities have resulted in rapid generation of municipal solid waste (MSW) worldwide. It has been forecasted that approximately 2.2 billion tonnes of MSW will be generated globally in 2025 – an increase of about 70% from values in 2012 [1]. Consequently, one of the major problems facing urban communities, especially in the developing countries, at present is poor disposal of MSW. This is not surprising as interaction of waste with the ecosystem cause health hazards such as viral, bacterial and protozoan infections, infectious diarrhoea, salmonellosis and shigellosis [1]. The management of MSW is an intensive service that includes technical expertise, procurement and contract management, budgeting and finance and strong social contract between the service provider and the user-community [1]. These often do not exist in most developing countries as evident in their continuing use for open dumps for waste disposal [1-6]. The consequence has been disastrous! The migration of contaminants in leachate from open dumps has resulted in the pollution of the groundwater bodies [7-12]. However, this can be minimized by placing the waste in engineered containment facilities equipped with bottom liners that drastically reduce the migration of leachate into the immediate environment. The provision of liners, which are typically layers of clay and flexible membrane layer(s), may be unaffordable in developing countries with meagre budget for MSW management. However, the use of a native soil that can minimise the seepage of leachate of emplaced MSW into the surrounding surface water and groundwater bodies may suffice. In situations where adequate clayey deposits are located in proposed landfill sites, any attempt to stabilise the native soil to improve its properties, especially to minimise the hydraulic conductivity, will greatly minimise cost and enhance sustainability.

The use of pozzolanic materials for stabilisation purposes abound in the literature [13-18]. The pozzolanic materials being used are usually the abundant waste products from human activities in the locality - in an effort to enhance sustainable living. For instance in Ekiti State, Nigeria, there is abundance of sugar cane straws and rice husks and therefore researches in the State should be geared towards the use of such waste materials. Adequate knowledge of different stabilized soils will enhance better understanding of soil behaviour and replenish the database of soil characteristics. Pozzolans are siliceous and aluminous materials which in themselves possess little or no cementitious value but which in finely divided form and in the presence of water react with calcium hydroxide ($CaOH_{2)}$ at ordinary temperature to form compounds possessing cementitious properties [19]. Bagasse is the fibrous residue obtained from sugar cane after the extraction of sugar juice at sugar cane mills [20]. Bagasse Ash (BA) is the residual obtained from the incineration of bagasse. Rice Husk Ash (RHA) is a carbon neutral product obtained from the combustion of the husk of rice; an agro-industrial waste at a temperature range between 600ºC and 800ºC for about 12-24 hours in excess air. RHA is a pozzolanic material which would react in the presence of moisture to yield cementitious products. In recent times, studies have been carried out on the use of bagasse ash on the improvement of lateritic soil. In recent times, an A-7-6 lateritic soil was treated with 1-4% cement contents and admixed with 2-8% bagasse ash content [21]. Reduction in liquid limit (LL) and plasticity index (PI) was observed while plastic limit (PL) increased. Reduction in the percentage of fines as a result of formation of heavier pseudo-particle with percentage passing BS Sieve No. 200 reduced from 63% to almost zero. They recommended 4-6% of bagasse as optimal value for stabilisation. In the same vein, a study on the influence of compactive effort on bagasse ash with cement treated lateritic soil was carried out by [22]. An increase in optimum moisture content (OMC) and decrease in maximum dry density (MDD) was observed with increase in the percentage of bagasse ash and cement. Some authors stabilized lateritic soil with up to 12% bagasse ash [23]. Their study focused on the effect of up to 12% bagasse ash by weight of dry soil on the geotechnical properties of the deficient lateritic soil. The test specimens were subjected to particle size analysis, compaction, unconfined compressive strength (UCS), California Bearing Ratio (CBR) and durability tests. The compactions were carried out at the energy of the British Standard Light (BSL). The result of the study showed changes in moisture-density relationships resulting in lower maximum dry density(MDD), higher optimum moisture content (OMC), reduction in fine fraction with higher bagasse ash content in the soil stabilizer mixtures.

Similarly, some authors carried out physical, chemical as well as batch adsorption and column tests on foundry sand treated with up to 8% bagasse ash and compacted with British Standard heavy (BSH) energy [24]. Tests results showed trends of chemical sorption by the foundry sand-bagasse ash mixtures in the order sodium, potassium, calcium and magnesium ($Na+> K+> Ca2+> Mg2+$). Higher bagasse ash treatment of foundry sand recorded higher retardation factors and lower diffusion coefficients with an increased sorption of the contaminant species. Conclusively, higher bagasse ash treatment of foundry sand has significant advantages over the untreated foundry sand and will better serve as landfill liner material. Also, a one dimensional laboratory consolidation test was conducted on compacted lateritic soils treated with up to 16% rice husk ash (RHA), to assess its consolidation properties [25]. Specimens were prepared at three different moulding water contents (2% dry of optimum, optimum moisture content and 2% wet of optimum) and compacted using the British Standard Light compactive effort. Pre-consolidation pressure increased with RHA content, it also decreased before increasing with increased moulding water content. Reductions in compression index (Cc) and swell index (Cs) with increased RHA content were recorded. In general, the Cc and Cs decreased before increasing with increased moulding water content. The Atterberg limit results showed improved index properties with an increase in LL, an increase in PL with a resulting decrease in PI. The LL increased from 35% to 42% with increase in RHA content from 0% to 16%. This trend was attributed to the excess RHA quantity requiring more water to mix the soil-RHA mixture. The PL increased from 21% to 31% with increase in RHA content from 0% to 16%. The plasticity index decreased from 15.7% to 10.7% with increase in RHA content from 0 to 16%. The plasticity of a soil decreases as the amount of clay fraction decreases and vice versa [26]. The decrease in plasticity index shows that the engineering properties of the soils were improved.

In this study, the basic strength and hydraulic properties of three different types of lateritic soils stabilized with BA and RHA were analysed. Unlike previous studies, BA and RHA were used to stabilise the same soil independently in order to assess the individual influence of the characteristics of each admixture on the stabilized soil. It is believed that a pragmatic comparison will be achieved using this method as it will eliminate the variance in characteristics of different soils mixed with the admixtures independently. In addition, the potentials of lateritic soil stabilized with bagasse ash (BA) and rice husk ash (RHA) being used as lining materials in landfills was assessed vis-a-vis to minimisation of leachate flow into the immediate environment.

2. MATERIALS AND METHODS

2.1 Materials

The soil samples used in this study were obtained from a borrow pit near the open waste dumpsite being used by Ekiti State Waste Management Board (ESWMB) at Ilokun, Ado Ekiti, Nigeria. Three soil samples were obtained arbitrarily following the extraction of the topsoil at locations at the perimeter of the borrow pit. The borrow pit was previously used to borrow soil materials during the construction of Ado Ekiti-Ifaki Ekiti road. The RHA was obtained from open-air burning of the rice husk obtained from local rice millers in Ire-Ekiti near Ado Ekiti. The farmers in Ire Ekiti are noted in Nigeria for massive rice production. The BA was obtained from open-air burning of the fibrous residue of sugar cane following the extraction of its juice. The sugar cane was sourced from the local sugar farm at Ado Ekiti: The BA and RHA were sieved through the 0.075 mm sieve prior to mixing with the lateritic soils.

2.2 Methods

The soil mixtures used for the tests comprised air-dried natural lateritic soil samples mixed with 0%, 2%, 4% and 8% RHA and 0%, 2%, 4%, 6% and 8% BA by mass of dry soil respectively. Prior to this, classification tests of the soils were undertaken in accordance with [27]. These were undertaken to determine the particle size distribution, LL and PL of the soil. The compaction tests on the soil mixtures with the RHA and BA were conducted in accordance with [27]. The British Standard (BS) light compaction tests in which the samples were compacted in 3 layers with 25 blows given to each layer with 2.5 kg rammer was used. In the permeability tests, the compaction mould, which already contained the compacted soil-admixture, was used as part of the permeameter in order to eliminate disturbance of the specimens on extrusion from the moulds. The falling head procedure was used for the determination of the saturated hydraulic conductivity of the samples. In carrying out the tests, the specimens were initially saturated in the moulds to expunge any entrapped air. The permeability tests were performed in accordance with the procedures outlined in [27]. The chemical composition of the soil, RHA and BA was determined using X-ray fluorescence spectrometer.

3. RESULTS AND DISCUSSION

3.1 Soil Classification

The properties of the soil samples used in the study are shown in Table 1. According to AASHTO, Soil 1 is classified as Group A-6 soil, Soil 2 is classified as Group A-2-6 soil and Soil 3 is classified as Group A-2-7 soil. Classification using the BS 5930 [28] indicates Soil 1 as very gravelly CLAY (clay of intermediate plasticity), Soil 2 as very clayey SAND (clay of intermediate plasticity) and Soil 3 as very clayey SAND and GRAVEL (clay of intermediate plasticity).

3.2 Chemical Composition of BA and RHA

The chemical composition of BA and RHA is shown in Tables 2 and 3 respectively. The other constituents in BA and RHA are 3.58% and 4.54% respectively.` According to [29], a good pozzolan must have the sum of the percentages of SiO_2, Al_2O_3 and Fe_2O_3 in it greater than 70%. The total percentages of these constituents in BA and RHA are 78.8% and 77.89% respectively. This indicates that the BA and RHA used in this study can be classified as pozzolanic materials.

3.3 Optimum Moisture Content (OMC)

The OMC of the stabilized soils (soil-admixture samples) at various percentages of BA and RHA for Soil 1 is shown in Fig. 1. The OMC in the stabilized soil was achieved when the grains of the both soil and admixture in its structural framework rearranged with the aid of the "mobile" moisture that fully saturated the voids such that the maximum dry density was attained. Generally, there was an increase in OMC with an increase in the percentage of BA and RHA in the stabilized soil. This characteristic trend was also observed when BA was admixed to cement stabilized lateritic soil [22]. The trend can be attributed to increased volume of water needed to saturate the increased finer particles in the framework owing to the increased admixtures, which are finer than the soil particles being replaced. The finer particles increased the specific surface, which needed more water to saturate. Furthermore, the ashes are hygroscopic; therefore, more water will be absorbed by its particles than the soil particles being replaced. As could be seen in Fig. 1, the rate of increase in OMC was greater in the soil stabilized with BA. For instance, the OMC of soil-BA was 3.52% greater than that of soil-RHA at 8% admixture. The reasons for this trend may be attributed to the finer particles of BA relative to RHA that replaced the soil particles. This phenomenon was previously reported [16]. In addition, the configuration of the voids of the soil following mixing with admixtures might have enabled more particles of BA to achieve the maximum dry density. These reasons could also be attributed to the trend of the stabilized soils, as observed in Fig. 2, which is same as in Fig. 1. However, the rate of increase in OMC of the stabilized soil with increased quantity of RHA was slightly higher than that with BA. This could be due to the configuration of the voids in the compacted Soil 3, which enabled slightly more quantity of water in the saturated soil-RHA at MDD. The precise influence of the soil matrix following compaction of the soil-admixture, on individual characteristics of the stabilized soils with BA and RHA would be better understood using a Scanning Electron Microscope (SEM).

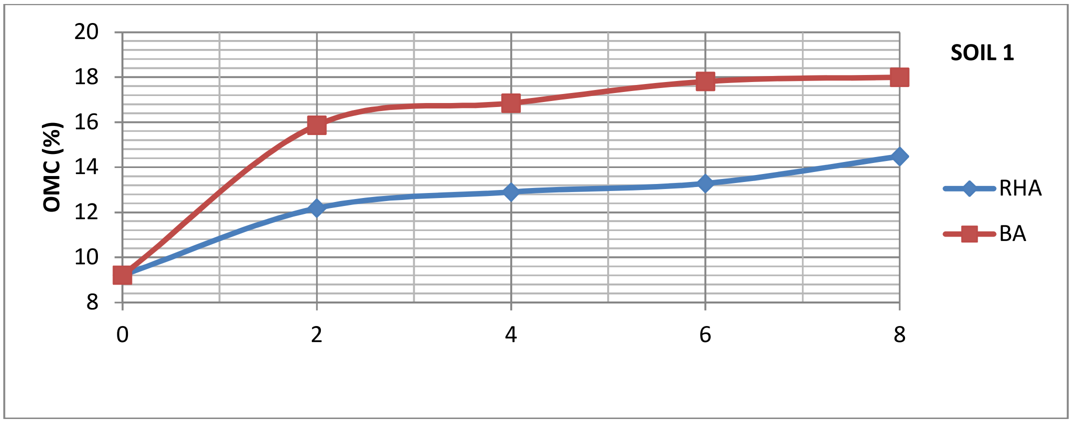

Fig. 1. The OMC of the stabilized soil at various percentages of BA and RHA - Soil 1

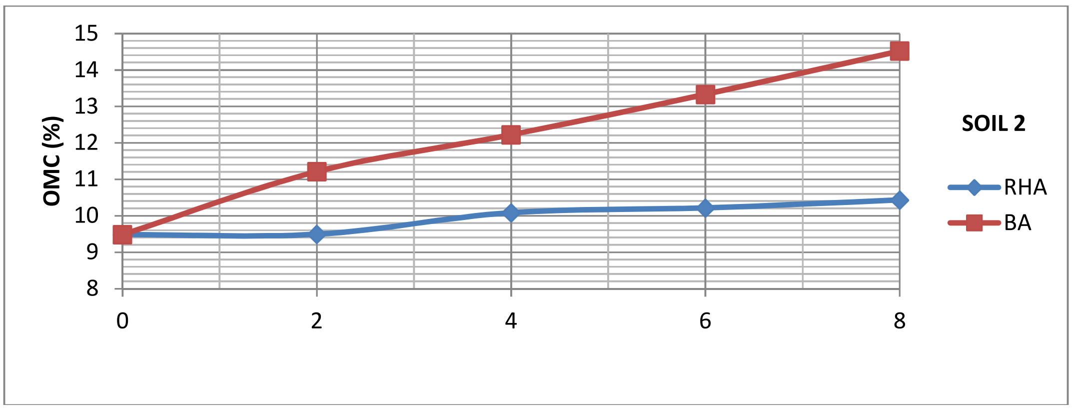

Fig. 2. The OMC of the stabilized soil at various percentages of BA and RHA - Soil 2

Table 1. Soil properties

Properties	Values		
	Soil 1	**Soil 2**	**Soil 3**
Liquid limit	38.2	38.8	41.85
Plastic limit (%)	20.61	24.17	25.26
Plastic Index (%)	17.59	14.64	16.59
Gravel content (%)	32.36	23.55	36.10
Sand content (%)	29.22	49.05	35.86
Silt/Clay content (%)	38.42	27.40	28.04
Maximum dry density (kg/m^3)	1969	2009	2077
Optimum moisture content (%)	9.21	9.48	10.76
Saturated Hydraulic conductivity (m/s)	5.40E-04	8.63E-04	8.00E-04
Classification according to BS 5930 [28].	very gravelly CLAY (clay of intermediate plasticity)	very clayey SAND (clay of intermediate plasticity)	very clayey SAND and GRAVEL (clay of intermediate plasticity)
AASTHO classification	A-6	A-2-6	A-2-7
Colour	Reddish Brown	Reddish Brown	Reddish Brown

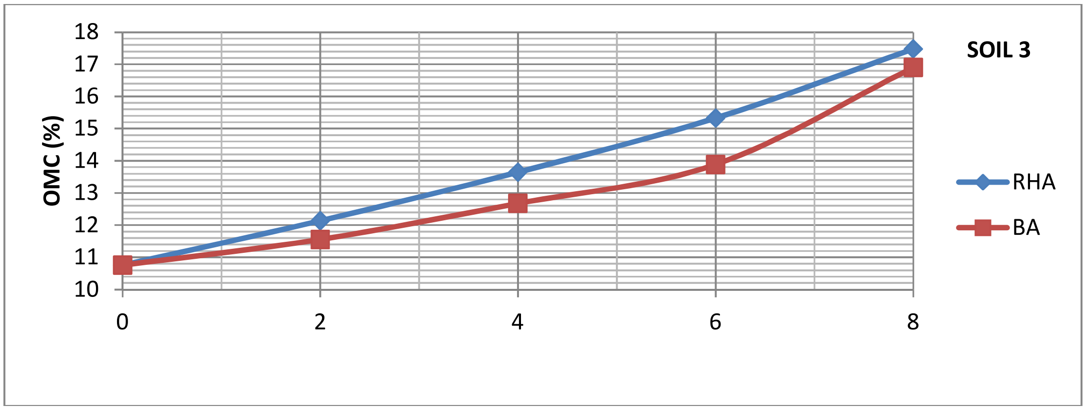

Fig. 3. The OMC of the stabilized soil at various percentages of BA and RHA - Soil 3

Table 2. Chemical composition of bagasse ash (BA)

Chemical constituent	Composition (%)
SiO_2	67.29
Al_2O_3	7.55
Fe_2O_3	3.96
MgO	2.85
CaO	3.69
Na_2O	0.57
K_2O	4.09
LOI (Loss of Ignition)	6.42

Table 3. Chemical composition of rice husk ash (RHA)

Chemical constituent	Composition (%)
SiO_2	70.68
Al_2O_3	5.18
Fe_2O_3	2.03
MgO	1.28
CaO	2.82
LOI (Loss of Ignition)	13.47

3.4 Maximum Dry Density (MDD)

The MDD of the stabilized soils at various percentages of BA and RHA is shown in Figs. 4-6. Pozzolanic materials will only exhibit cementitious properties when its fine particles react with $CaOH_2$ in the presence of water to form calcium silicate hydrates (C-S-H) and calcium aluminate hydrates (C-A-H). As could be seen in Tables 2 and 3, the quantities of CaO in BA and RHA are 3.69% and 2.82% respectively. As these quantities are small, the quantity of cementitious products formed in the soil-admixture would be small. As observed for most cementitious admixture with soil, the strength of the pozzolanic reaction products is usually weak at the initial stages, but increases with time [30]. There was a general decrease in the MDD with increased quantity of admixture to Soils 1, 2 and 3. This characteristic trend was also exhibited when BA was admixed to cement stabilized lateritic soil [22]. The reasons for this trend may include: (i) the specific gravities of BA (2.17) and RHA (2.14) were lower than that of the soil grains (2.6) being replaced; (ii) the increased water content in stabilized soil as seen in Figs. 4-6 would result in overall lower density; (iii) the pozzolanic reaction products formed will be lighter and weaker than the soil particles being replaced. From Figs. 4-6, a comparative study of the individual trend of MDD of the soil-admixture with various percentages of BA and RHA could be made individually for Soil 1, Soil 2 and Soil 3. The rate of decrease in MDD with increasing content of admixture was less in the soil-RHA, as compared to soil-BA for Soil 1, as shown in Fig. 4. For instance, the MDD of soil-RHA was $58kg/m^3$ greater than that of soil-BA at 8% admixture. This could be owing to slightly more pozzolanic reaction hydrates of soil-BA being formed in Soil 1, as compared to soil-RHA, thus resulting in lower MDD. As discussed earlier, the bonding in pozzolanic reaction products(C-S-H and C-A-H) are weak at the initial stage of formation-the time when these tests are conducted. This characteristic trend has also been reported [19]. The same reason could be adduced to the relatively decrease in rate of soil-BA with increased quantity of BA, shown in Figs. 5 and 6.

3.5 Saturated Hydraulic Conductivity

The saturated hydraulic conductivity of the stabilized soils at various amounts of admixtures of BA and RHA is shown in Figs. 7-9.

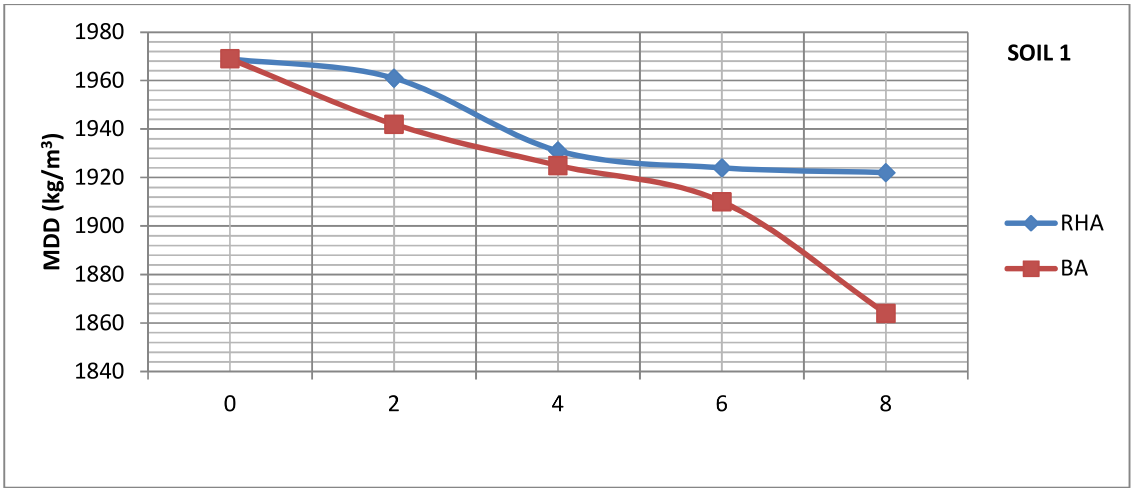

Fig. 4. The MDD of the stabilized soil at various percentages of BA and RHA - Soil 1

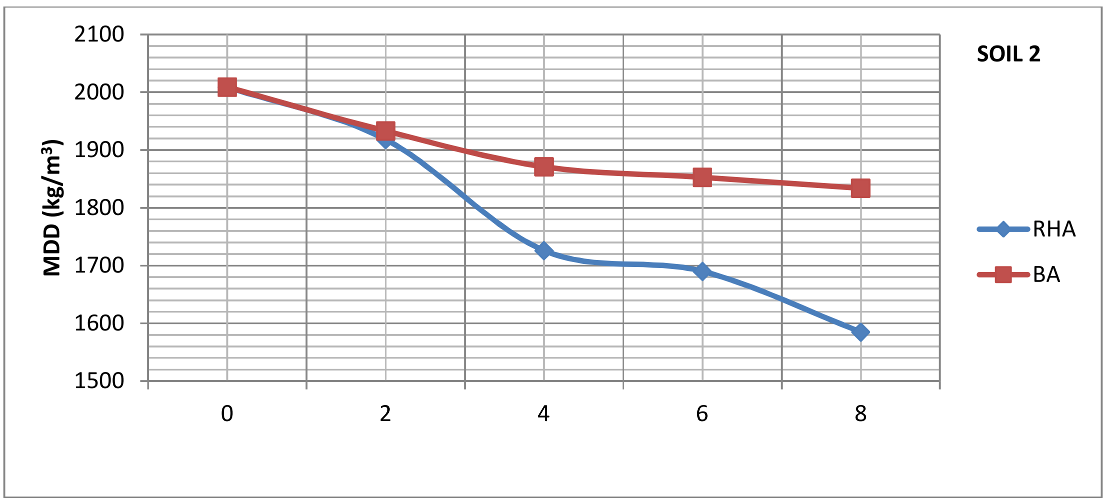

Fig. 5. The MDD of the stabilized soil at various percentages of BA and RHA - Soil 2

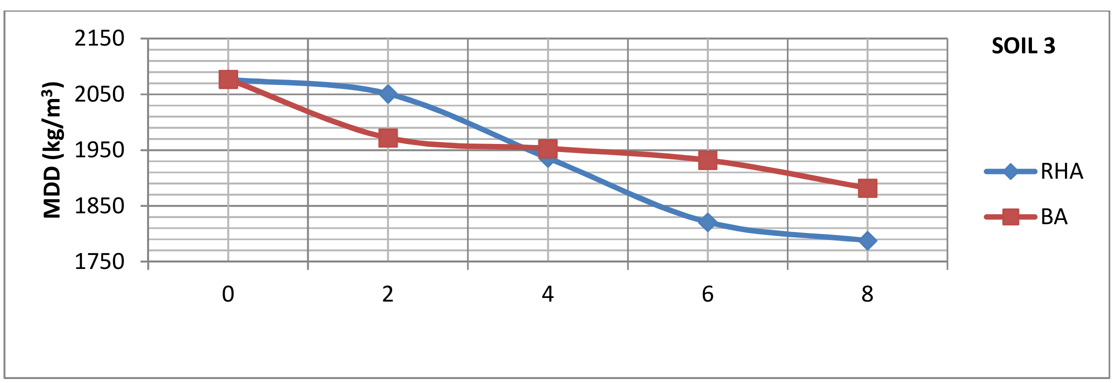

Fig. 6 The MDD of the stabilized soil at various percentages of BA and RHA - Soil 3

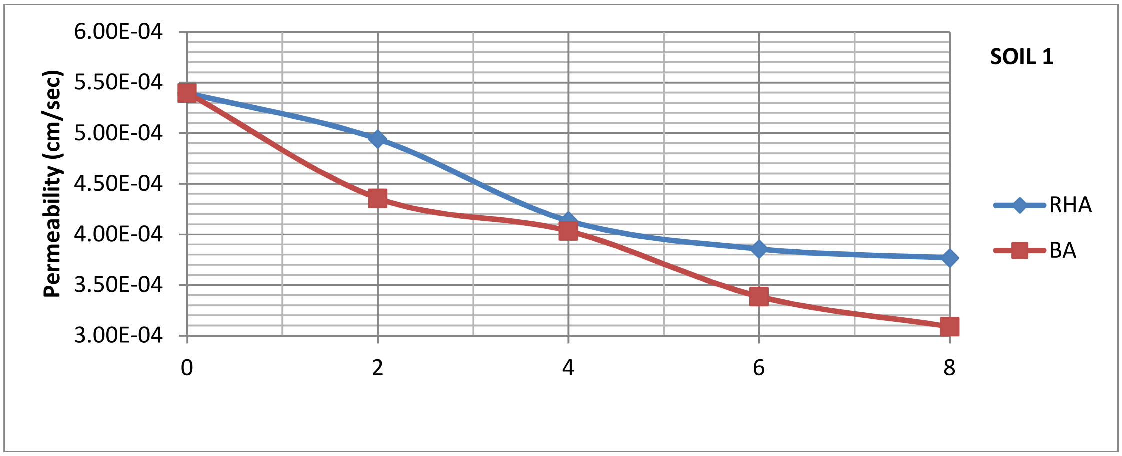

Fig. 7 The saturated hydraulic conductivity of the stabilized soil at various percentages of BA and RHA - Soil 1

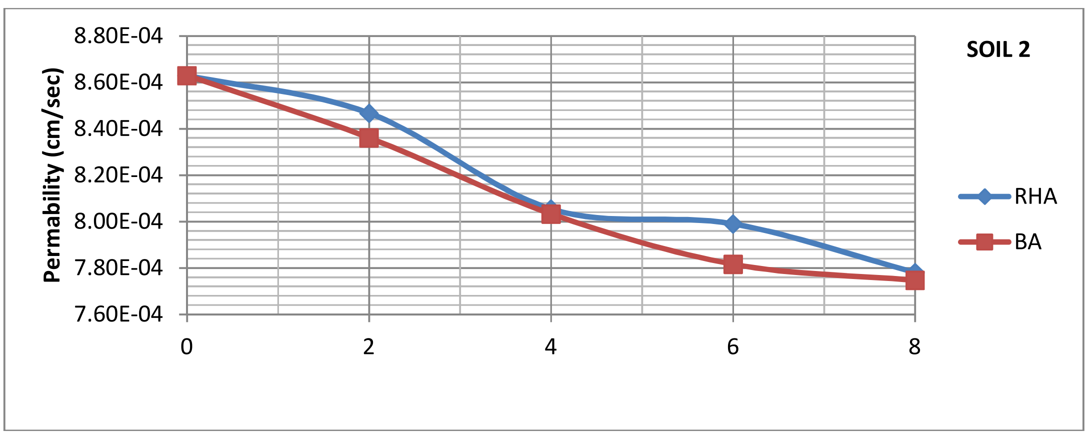

Fig. 8 The saturated hydraulic conductivity of the stabilized soil at various percentages of BA and RHA - Soil 2

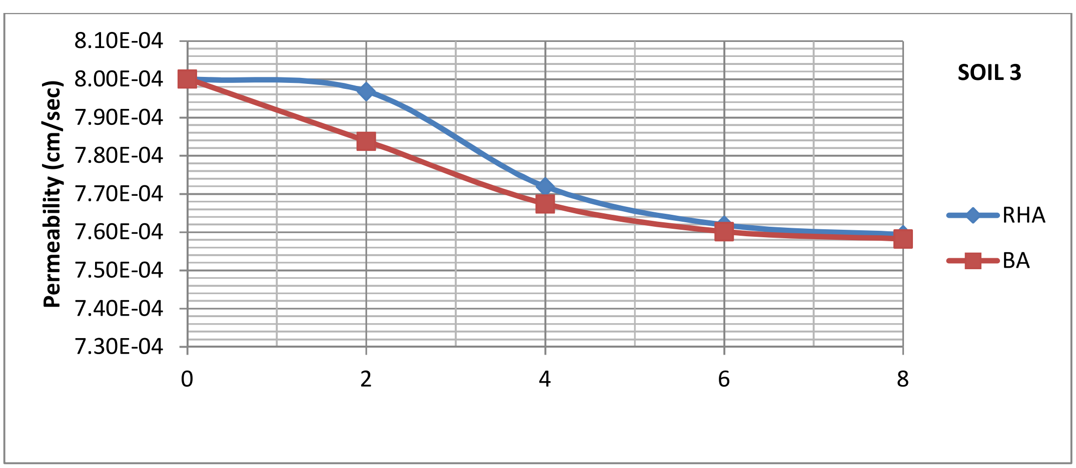

Fig. 9 The saturated hydraulic conductivity of the stabilized soil at various percentages of BA and RHA - Soil 3

In general, the saturated hydraulic conductivity of the stabilized soils decreased with increased quantity of admixture in it. This characteristic trend has also been reported for stabilized tropical clay [25]. Some of the reasons attributed to this include: (i) the filling of the pores in the stabilized soils with finer particles of the admixture-BA and RHA, which caused a refining of the pore structure, thereby reducing the permeability of the entire soil-admixture; (ii) the clogging of the pores in the stabilized soil by the products of the pozzolanic reaction, thereby reducing the flow of water through the soil-admixture. The pozzolanic reaction hydrates formed in the soil-admixture will be minimal owing to the small quantity of $CaOH_2$ available for the hydration, however, the amount of C-S-H and C-A-H formed will still influence the physical and hydraulic characteristics of the soil-admixture slightly, as evidence in this study. A comparative analysis of the influence of incremental addition of admixtures of the stabilized soils (Soil 1, Soil 2 and Soil 3) shows that the rate of decrease in saturated hydraulic conductivity was higher in soil-BA, as shown in Figs. 7-9. For instance, the saturated hydraulic conductivity of soil-BA was 6.8E-5 m/s lower than that of soil-RHA at 8% admixture in Soil 1, as shown in Fig. 7.This could be owing to relative finess of BA which enabled more pores in the pore structure to be filled, thus reducing the permeability of the entire stabilized soils. Ordinarily, slightly more pozzolanic hydrates would be expected to be formed in the soil-BA composite, owing to the slightly higher content of CaO in BA, thus reducing its saturated hydraulic conductivity. However, this is dependent on the moisture conditions, which is required to convert CaO to $CaOH_2$. In addition, temperature and the chemical composition of the native soil would influence the formation of pozzolanic reaction hydrates and thus an exact postulation cannot be made until tests using a SEM are undertaken to the soil-admixture composites. The values of the saturated hydraulic conductivity of the stabilized soils are in the order of 10^{-4}cm/s, which is greater than the minimum requirement of 10^{-7}cm/s for soil liners used in municipal solid waste (MSW) landfills [31]. It is therefore evident that lateritic soils stabilized with BA and RHA alone cannot be used as bottom liners for a MSW landfills. This is owing to the small quantity of pozzolanic reaction hydrates formed as a result of the small quantity of $CaOH_2$ in the soil-admixture reaction with moisture. This deficiency can be overcome by adding another admixture that has a high content of CaO. Probably the best admixture to be used for such purpose is cement, which has CaO content of more than 60% [16] and is readily available worldwide.

4. CONCLUSION

It has been found out in this study that the OMC of lateritic soils stabilized with BA and RHA increased with the amount of the admixtures added. The MDD of the stabilized lateritic soils decreased with the amount of the BA and RHA added. In the same vein, the hydraulic conductivity of the stabilized soils decreased with the amount of the admixtures added. The values of the hydraulic conductivity of the stabilized soil is of the order of 10^2 greater than the minimum recommended for use as soil liners in a MSW landfill. In order for soils stabilized with BA and RHA to be used as a liner, another admixture such as cement which has a high content of CaO that will produce adequate $CaOH_2$, in the presence of water is required. With this, high content of pozzolanic binders-C-S-H and C-A-H that will enable BA and RHA to exhibit full pozzolanic characteristics in the stabilized soils will be achieved. The characteristics of BA and RHA in stabilized soils appear similar although BA appears finer than RHA. The configuration of the stabilized soil appears to be the factor responsible for the slight difference in the behaviour of BA and RHA stabilized with the same soil. It is believed that this could be better understood using a SEM.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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