Malaysian Journal of Civil Engineering 30(3):363-377 (2018)

SUITABILITY OF RICE HUSK ASH TREATED BLACK COTTON SOIL FOR WASTE CONTAINMENT APPLICATION

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Abstract: This paper presents an experimental study aimed at assessing the suitability of rice husk ash (RHA) treated black cotton soil as a barrier in Municipal Solid Waste (MSW) containment facility. Laboratory tests were conducted on black cotton soil treated with 5, 10 and 15% RHA at moulding water contents of 2 and 4% on both wet and dry sides of optimum moisture content (OMC) using British Standard Heavy (BSH) compactive effort. Index properties, hydraulic conductivity (k), volumetric shrinkage strain (VSS), and unconfined compressive strength (UCS) tests were conducted on all the samples. The results obtained indicated that the soil was classified as A-7-5(18) according to the American Association of States Highway and Transport Officials (AASHTO) classification system and Silt of high plasticity (MH) in accordance with the Unified Soil Classification System (USCS). It was observed that addition of RHA was accompanied with decrease in the plasticity index from 24 to as low as 3%. An improvement in the moisture-density relationship of the soils showed an increase in Maximum Dry Density (MDD) from 1.46 to 1.52 Mg/m^3 as well as a decrease from 24.5 to 21.2% in OMC. The increase in RHA contents up to 10% brought about an improvement in the strength of the soil specimens by almost 332.4kN/m^2 at 2% on the dry side of OMC. The VSS decreases with increase in RHA content to achieve the minimum shrinkage strain of 4.1% at 5% RHA treatment.

Keywords: *Rice husk ash, black cotton soil, municipal solid waste, containment facility*.

Article history:
Received 27 July 2017
Received in revised form 15 July 2018
Accepted 1 October 2018

1.0 Introduction

Indiscriminate disposal of waste particularly Municipal Solid Waste (MSW) may lead to severe groundwater contamination with resultant health effects which warrants Geo-environmental engineer’s attention. Landfilling of MSW has been and is still the most widely practice and viable alternative means of waste disposal in most developing countries such as Nigeria (Kundiri, 2009; Kundiri *et al.*, 2016**b**). The environmental and health hazards associated with this traditional landfilling system are well known sources of groundwater contamination (Benson, 1999; Ige, 2003; Adewuyi, 2004; Onipede and Bolaji, 2004; Bello, 2010; Kundiri *et al.*, 2017).

In current practice, attempt has been made to counter this problem by use of barrier systems which employed compacted clay liners between the waste and the natural ground to impede migration of leachate and other contaminants into the ground water. Compacted soil liners have been used in recent times as hydraulic barriers in engineered landfills, although the issue of effective waste management has become a serious problem of concern to both environmental protection agencies and environmental professionals.

Compacted soil liners are widely used as hydraulic barriers in landfills and other waste containment facilities in developing countries like Nigeria, to impede migration of leachate into the subsurface groundwater to mitigate health related effects (Daniel and Wu, 1993; Benson *et al.*, 1994; Adewuyi, 2004; Osinubi and Bello, 2010; Umar *et al.*, 2015). This is because the interaction of chemical pollutants with both surface and underground water bodies could pose adverse health effects on their quality (Al-Dakheel *et al.*, 2009). Even though geo-membranes have been considered as the best alternative for liners, they are out of reach of most developing countries for their high price and the need for trained personnel for installation (Avinash *et al.*, 2016). Hence, there is need for economically viable landfill liner that is natural, locally available, and that can be handled in an inexpensive way, and in compliance with the environmental regulations.

The design requirement for compacted soil liners according to (Edil *et al.*, 1992; Daniel and Wu, 1993; Stark and Poeppel, 1994; Wilt and Zeh, 2005; Kundiri, 2009; Osinubi and Bello, 2009; Osinubi and Bello, 2010), include:

- Low hydraulic conductivity to minimize leakage ($k \leq 10^{-9}$ m/s)
- Adequate shear strength to maintain liner stability (a minimum Unconfined Compressive Strength value of 200kN/m^2) and
- Minimum shrinkage strain of $\leq$ 4% to minimize desiccation cracking.

RHA is one of the major Agricultural wastes found abundantly. The burning of rice husk generates about 20-23% of its weight as ash. The RHA is a pozzolanic material due to its high amorphous silica content (Mehta, 1986; ASTM C 168, ASTM 1997; Della *et al.*, 2002). The objective of this paper is to determine the suitability of Rice Husk Ash treated Black Cotton Soil when compacted with Modified Proctor (MP) compactive effort as a barrier in waste containment facilities.

2.0 Materials and Methods

2.1 Materials

2.1.1 Black-cotton soil

The soil sample used for this study was obtained from Baure village (latitude 10^0 16’N and longitude11^0 21’E) in Yamaltu-Deba Local Government Area of Gombe state, using the method of disturbed sampling and collected at depth of 0.5 to 1.0m. The materials were preserved in polythene bags to avert moisture loss, and transported to the Soil mechanics Laboratory of Abubakar Tafawa Balewa University, Bauchi.

2.1.2 Rice Husk Ash

Rice husks were obtained from rice mill in Yelwa area of Bauchi, and burnt using controlled furnace of Abubakar Tafawa Balewa University, Bauchi; to produce the RHA which was sieved through BS Sieve No 200 (75 µm).

2.1.3 Water:

Portable drinking water was used for the purpose of the laboratory tests.

2.2 Methods

Laboratory tests were conducted for the determination of the index properties of the natural soil and soil – RHA mixtures samples in accordance with BS 1377 (1990). Compaction test was conducted using Modified Proctor (MP) method as specified by Head (1992) to determine the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) on the air-dried soil samples passing through 4.75mm sieve size.
Volumetric Shrinkage Strain (VSS), Hydraulic conductivity and Unconfined Compressive Strength (UCS) tests were also conducted in accordance with BS 1377 (1990) on the RHA treated Black Cotton Soil (BCS). The specimens were prepared by mixing the soil with 0, 5, 10, and 15% RHA at four different moisture contents of 2 and 4% on the dry and wet sides of the optimum moisture contents using the MP compactive effort.

3.0 Results and Discussion

3.1 Oxide Compositions and Engineering Properties

The results of the oxide composition and loss on ignition (LOI) were obtained using X-ray fluorescence (XRF) for both the black cotton soil (BCS) and Rice Husk Ash (RHA) as presented in Tables 1 and 2 respectively.

Table 1: Oxide Composition of Black Cotton Soil

Oxide	*Concentration (%)*
CaO	0.53
Sio_2	31.05
Al_2O_3	18.21
Fe_2O_3	4.74
MnO	0.38
TiO_2	2.34
LOI	< 50

Table 2: Oxide Composition of Rice Husk Ash

Oxide	*Concentration (%)*
CaO	1.58
Sio_2	67.3
Al_2O_3	4.96
Fe_2O_3	0.95
MgO	0.53
LOI	< 25

The main oxides of the BCS sample and the RHA are Silicon dioxide (SiO2) and Aluminium (III) Oxide and were 31.05 and 18.021 % as well as 67.3 and 4.96 % respectively. The cations are exchangeable with another group of different cations having the same total charge in the RHA, thus stabilizing and improving the properties of the BCS, as observed by (Baig *et al*., 1999; Rathan *et al*., 2016; Alhassan and Alhaji, 2017).

The Engineering properties of both the natural and treated soil samples vital for the determination of index properties and classification of the soil are summarized in Table 3.

Table 3: Engineering Properties of Soil.

Properties	*Rice Husk Ash (%)*			
	0	*5*	*10*	*15*
Liquid Limit, **(%)**	62	62	62	65
Plastic Limit, **(%)**	38	45	57	59
Plasticity Index, **(%)**	24	17	8	3
% Sand (0.06-2mm)	15	15	15	15
% Silt (0.002-0.06mm)	74.8	74.8	74.8	74.8
% Clay (<0.002mm)	10.2	10.2	10.2	10.2
% Passing BS Sieve NO. 200 (75µm)	85	83	81	84
AASHTO Classification	A-7-5	A-7-5	A-7-5	A-7-5
Group Index	18	15	12	12
USCS Classification	MH	MH	MH	MH
Activity	2.35	1.67	0.78	0.29
Specific Gravity	2.62	2.63	2.65	2.68
Maximum Dry Density (Mg/m^3):	1.46	1.53	1.52	1.38
Optimum Moisture Content (%):	24.5	22.3	21.2	24.6

The soil was classified as A-7-5 using the American Association of States Highway and Transportation Officials (AASHTO 1986) soil classification system and Silt of high plasticity (MH) using the Unified Soil Classification System (USCS) (ASTM, 1992). Physical inspection showed that the soil is dark grey in color and has an activity value of 2.35 which is indicative of active Montmorillonite. The activity decreases to 1.67 and subsequently to 0.29 with increase of 5 to 15% in RHA content. The value of the specific gravity of the soil was observed to be 2.62 which also indicated the prevalence of montmorillonite minerals (Das, 2005). It increases to 2.68 gradually with increase of 5 to 15 % RHA, the liquid limit maintained a constant value of 62% up to 10% RHA blend, but with further increase to 15 %, the liquid limit also increases to 65%. This could be due to the reduction in the diffused double layer as well as incomplete dilution of the clay content of the mix. The subsequent increase in the liquid limit could be attributed to the increase in RHA which introduced more pozzolanic substances from the ash. This requires more amount of water to complete the hydration process (Rahman, 1986; Osula, 1991; Akinyele *et al.*, 2015).

3.2 Compaction Characteristics

Maximum Dry Density (MDD) of 1.53 Mg/m^3 was obtained with the corresponding Optimum Moisture Content (OMC) of 24.6 %, it increases with increase in RHA content, as the OMC reduces; which signifies that the RHA has occupied the void within the soil matrix and resulted to the flocculation of the soil particle due to ions exchange. These results are no doubt in agreement with earlier studies by (Eberemu, 2011**a**; Kundiri and Kundiri,2002; Osinubi and Stephen, 2007; Oriola and Moses, 2010; Kundiri *et al.*, 2016**a**). The trends of the moisture – density relationships are presented in figure 1.

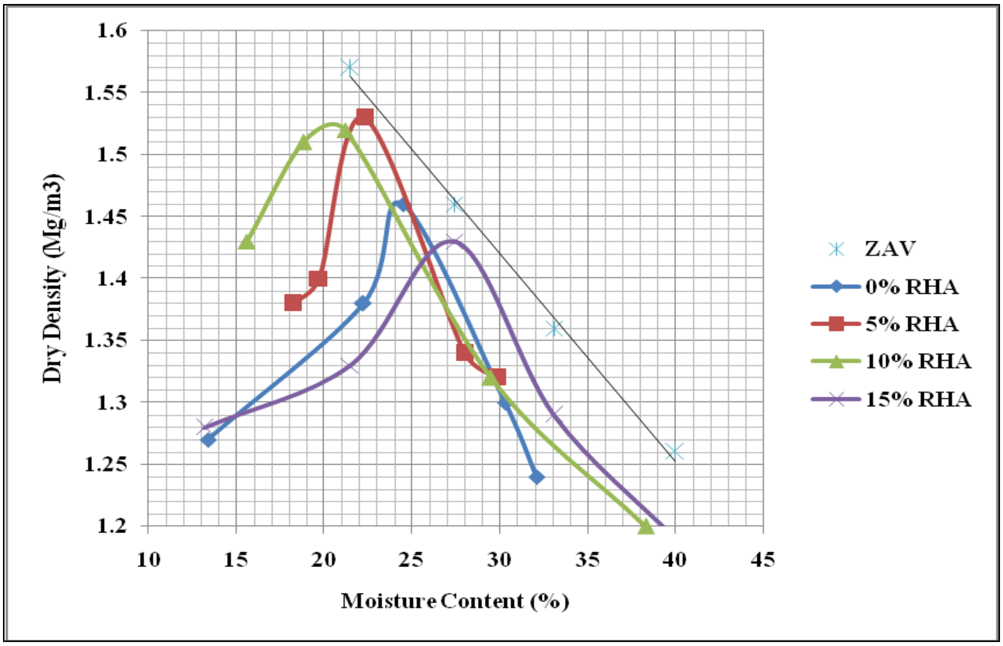

Figure 1: Moisture – Density relationship for natural and treated soils using MP compactive effort.

It could be inferred that 5 % RHA yielded the highest MDD, followed by 10 % RHA, with 15 % RHA being the least. This can be attributed to the replacement of soil by RHA in the mixture which absorbs more moisture up to an optimum RHA content of 5 – 7 %, and then there is slight decrease in MDD due to incomplete hydration process at 10 and 15 % of the RHA mixture.

3.3 Volumetric Shrinkage Strain

The shrinkage is mainly as a result of loss of moisture due to evaporation, as the surface dehydrates and drying proceeds from the surface as it goes deeper downwards until it affects the entire specimen (Khire *et al*., 1997; Tang *et al*., 2010; Eberemu, 2011). The cracking is not likely to occur in compacted soil liners with volumetric shrinkage strain (VSS) of less than 4 % upon drying (Daniel and Wu, 1993; Osinubi and Kundiri, 2007). The specimens compacted at higher moulding water contents shrank more resulting in high VSS, which conformed to similar findings by researchers such as (Daniel and Wu, 1993; Albrecht and Benson, 2001; Osinubi and Eberemu, 2010). In general, decrease in the VSS was observed with increase in RHA contents up to 10 %; followed by a slight increase with addition of 15 % RHA. This could be attributed to the pozzolanic input of the RHA treatment which reduces the fine-grained soils (Liman, 2009).

The variations of VSS with moulding water content relative to the optimum for both natural and treated soils are shown in Figure 2.

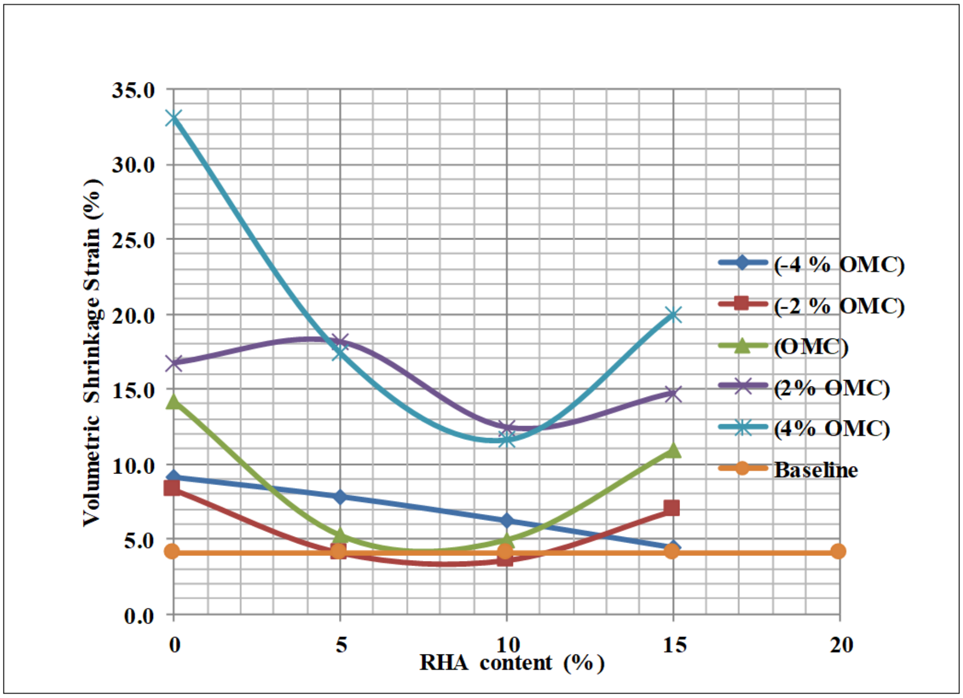

Figure 2: Variation of VSS with RHA treatments at different moisture contents using MP compactive effort.

It was observed that at 5 and 10 % RHA, a higher value of VSS occurs at 2 % on wet side of OMC. 2 % dry sides of OMC satisfied the VSS requirement of $\leq$ 4 % as confirmed by (Kundiri *et al.*, 2016**a)**

3.4 Hydraulic Conductivity

Hydraulic conductivity is the key parameter affecting the performance of containment facilities (Daniel, 1987; Daniel and Benson, 1990). Generally, there are notable increases of hydraulic conductivity values with addition of RHA; these increases indicate that RHA content has filled the air voids present in the black cotton soil. After the addition of RHA, specimens on wet side of optimum moulding water content have lower hydraulic conductivity than those on the dry side of the optimum. This could be due to the de-flocculation of the soil particles structures thereby reducing the voids (Eberemu, 2011**b**). The hydraulic conductivity also changes with the change in moulding water content. Soils compacted on the dry side of optimum water content tend to have relatively high hydraulic conductivity values, whereas soils compacted on the wet side of optimum water content tend to have lower hydraulic conductivity values.
Moreover, increasing water content results in the re-orientation of clay particles and reduction in the size of inter particle pores (Benson and Trast, 1995).

The maximum permissible value of 1 x 10 $^{-9}$ m/s were obtained for almost all the moulding water and RHA contents except for 15% RHA contents on the dry side of the optimum moulding water contents (-4 and -2%). This could be as a result of the RHA content displacing the clay contents and fines in the specimen, thus making specimen incapable of satisfying the specified values of the hydraulic conductivity (Benson et. al., 1994). Better result was achieved using higher compactive efforts with RHA contents up to 10 %, which agreed with an earlier research work by (Osinubi and Eberemu, 2009). The relationship between hydraulic conductivity and RHA contents is shown in Figure 3.

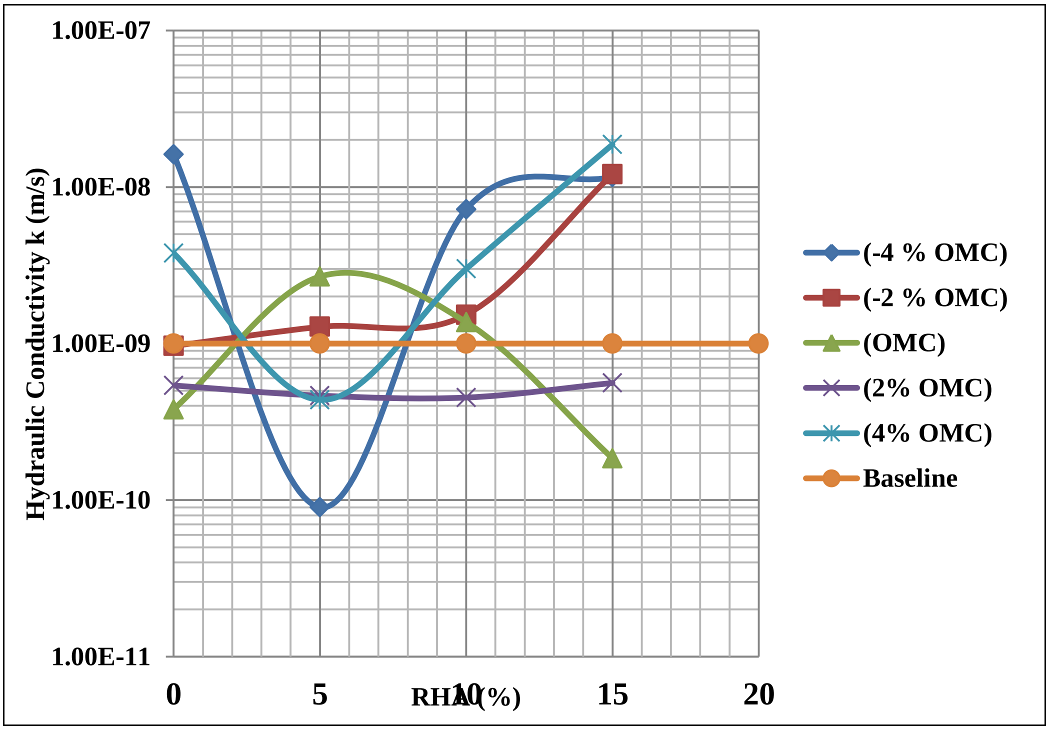

Figure 3: Variation of Hydraulic conductivity with RHA treatments at different moisture contents using MP compactive effort

3.5 Unconfined Compressive Strength

The UCS values of the untreated Black Cotton Soil decreases with increase in moulding water content. As the moulding water content increases, the electrolyte concentration reduces, leading to an increase in diffused double layer expansion; thus, the distance between the alumina – silicate unit layers thereby increase. The specified minimum

UCS values were not achieved in the case of the untreated black cotton soil samples. Although, the trend of the untreated black cotton soil is in conformity with earlier research works by (Daniel and Wu, 1993; Taha and Kabir, 2003; Ijimdiya, 2011).

There is an improvement in the UCS values of BCS treated with RHA up to 10 %, resulting to an increased in strength of up to 332.4 kN/m^2 at 10 % RHA treatment using 2 % on the dry side of optimum moulding water content. With 15 % RHA treatment, maximum UCS value of 195.8 kN/m^2 was obtained which is slightly below the specified minimum UCS value of 200 kN/m^2. This trend is attributed to the incomplete hydration reaction of the RHA due to insufficient water. The minimum specified value of 200 kN/m^2 was obtained at 4 % on the dry side of optimum moisture content with RHA treatments of 5 to 10 % RHA. The variation of the UCS with RHA contents is shown in Figure 4.

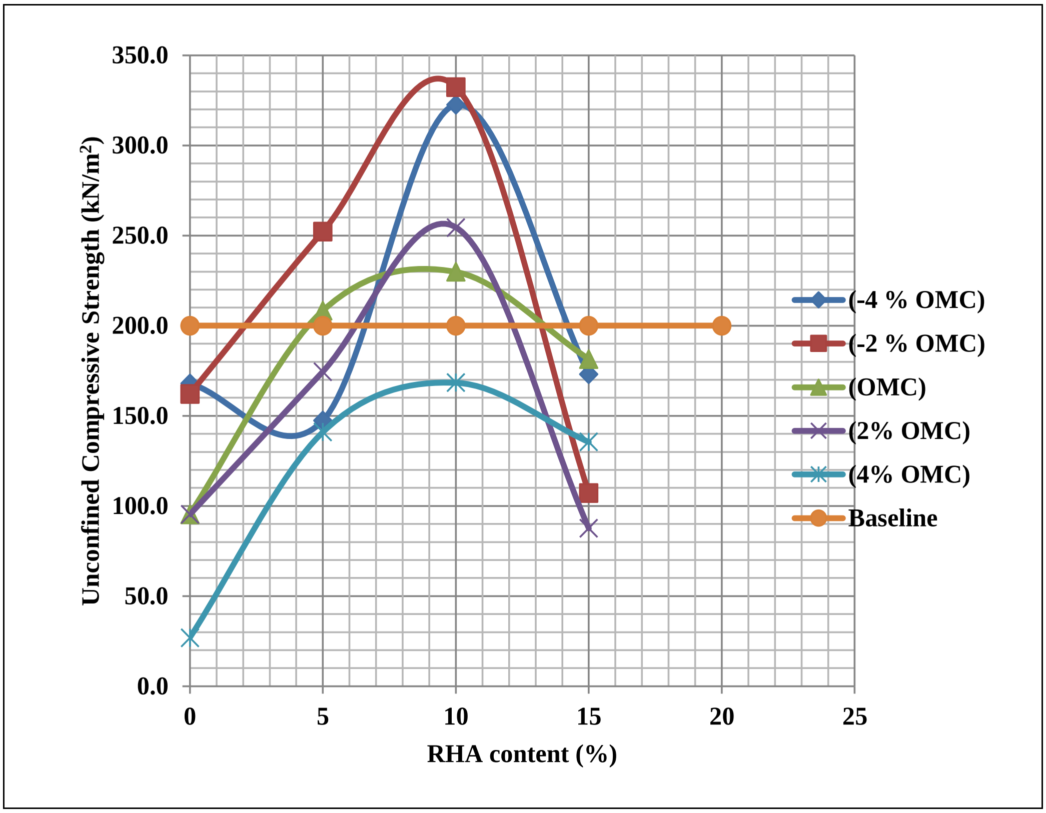

Figure 4: Variation of UCS with RHA treatments at different moisture contents using MP compactive effort.

3.6 Delineation of Acceptable Zone Criteria

Design of containment facilities notably Liners and covers systems involves the satisfaction of several parameters such as VSS, UCS and Hydraulic conductivity to obtain an acceptable zone that define the level of convergence of these parameters as prescribed by (Daniel and Benson, 1990). The delineation of the three design parameters using compaction plane was carried out as shown in Figures 5, 6 and 7; with the overall acceptable zone presented in Figure 8.

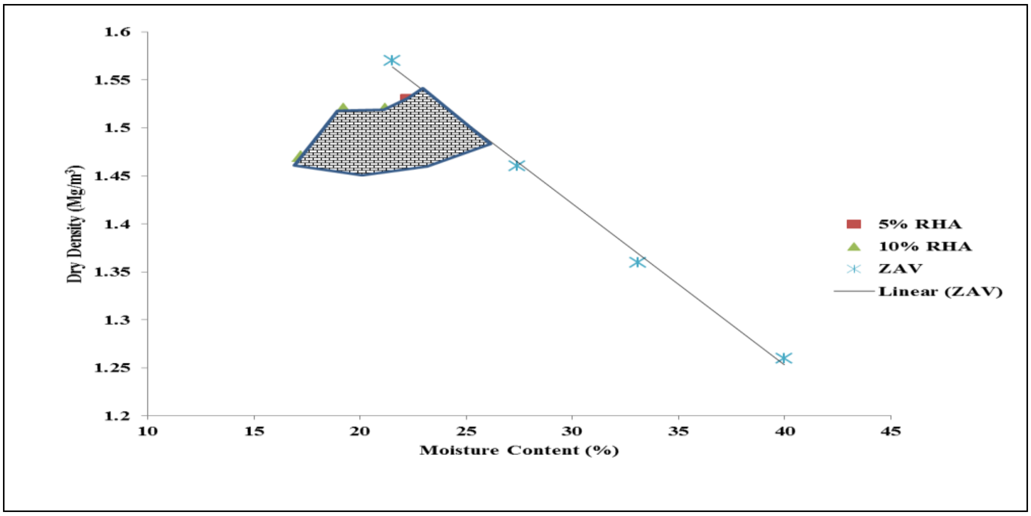

Figure 5: Acceptable zone for UCS of RHA treated BCS using MP compactive effort.

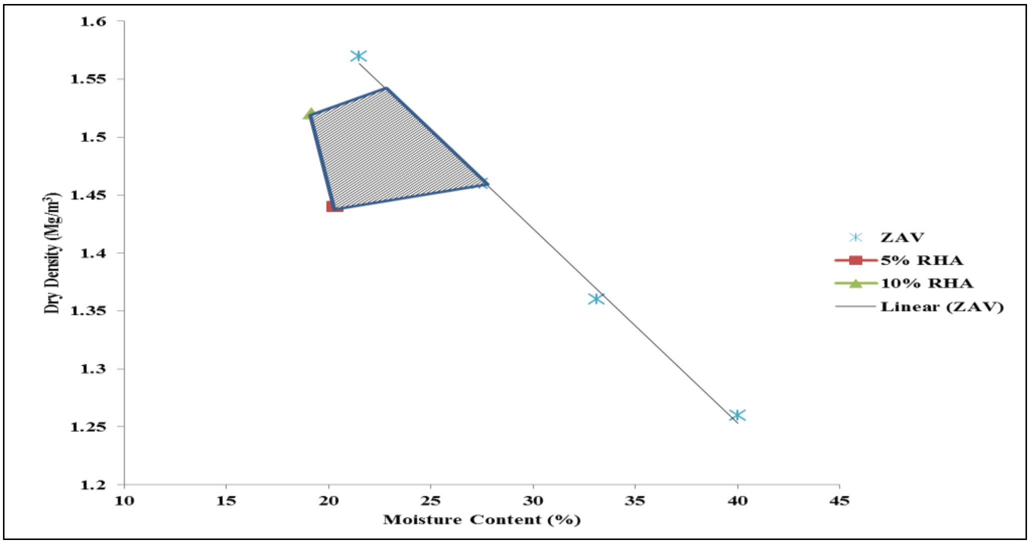

Figure 6: Acceptable zone for VSS of RHA treated BCS using MP compactive effort.

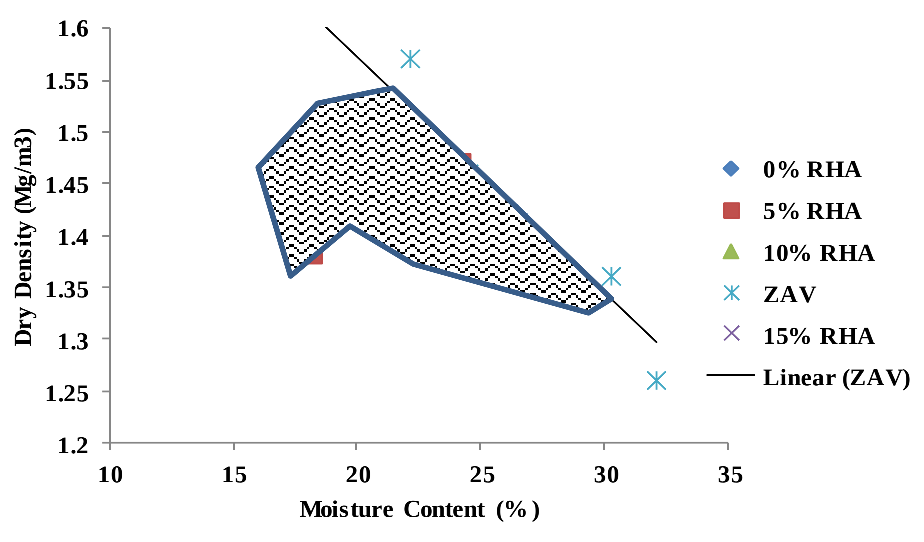

Figure 7: Acceptable zone for Hydraulic conductivity of RHA treated BCS using MP compactive effort.

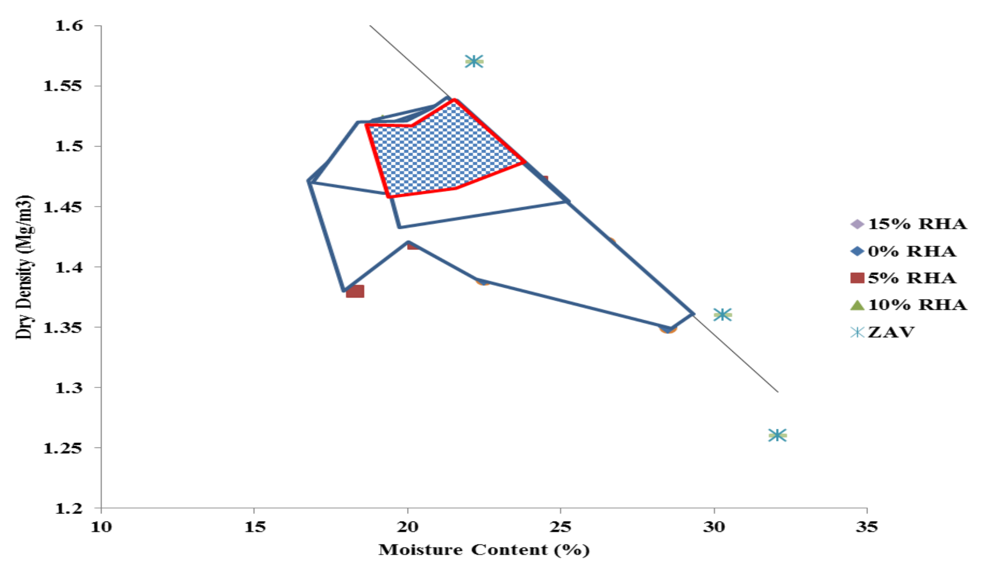

Figure 8: Overall acceptable zone for the design parameters of RHA treated BCS using MP compactive effort.

4.0 Conclusion

(1) The soil was classified as A-7-5(18) according to AASHTO classification system and MH in accordance with USCS classification system. The general properties of the natural untreated soil do not satisfy the requirements based on the three most important parametric design criteria for containment facilities.

(2) The addition of RHA led to decrease in the plasticity index from 24% to as low as 3% with subsequent reduction in swell characteristics from medium to low.

(3) Addition of RHA also resulted to improvement in the index properties of the soil; with an increase in MDD from 1.41 to 1.53 Mg/m^3 and decrease in OMC from 28.8 to 18%.

(4) The increase in RHA contents up to 10% brought about an improvement in the strength of the soil specimens to 332.4kN/m^2 at 2% of optimum moisture content. This improvement is mostly on the dry sides of the optimum than on the wet sides.

(5) The VSS decreases with increase in RHA content to achieve the minimum shrinkage strain of 4.1% at 5% RHA treatment.

(6) The maximum permissible value of 1 x 10 $^{-9}$ m/s was achieved with almost all the moulding water contents and RHA treatment, but at higher values on the wet sides of the optimum than on the dry sides.

(7) The total acceptable zone was achieved as a guide for suitability criteria.

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