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EFFECT OF COMPACTIVE EFFORTS ON DESICCATION – INDUCED VOLUMETRIC SHRINKAGE STRAIN OF SOME COMPACTED TROPICAL SOILS

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Abstract: This paper presents an experimental study of the desiccation-induced volumetric shrinkage strain for two compacted soils classified as A (A-6) and B (A-7-6)according to the Association of American States Highway and Transportation Officials (AASHTO) Classification System and CL according to the Unified Soil Classification System (USCS). The samples were prepared using three compactive efforts of Reduced Proctor (RP), Standard Proctor (SP) and Modified Proctor (MP) at moulding water contents relative to optimum (i.e. -2, 0, +2 and +4%). Samples were extruded from the compaction moulds and allowed to air dry in the laboratory in order to assess the variation of desiccation-induced shrinkage on the material with days and its potentials as a hydraulic barrier in waste containment applications. Results showed that soils compacted using the higher compactive effort showed lower values of volumetric shrinkage strain (VSS) due to the closer packing of soil fabric as a result of higher energy. Similarly, VSS increased with higher moulding water content for specimens compacted on the wet side of the optimum and contain much water as against the specimens compacted on the dry side of the optimum which had less water. At 7 and 14 days cured specimens using the RP compactive effort showed similar features, and up to 2% on the dry side of the optimum for 0 and 21 days cured specimens. The SP compactive effort for 7 and 14 days cured specimens yielded the peak dry densities at 2% on the wet side of optimum and at optimum. The MP compactive effort, the samples compacted at 2% on the wet side of optimum and 2% on the dry side of optimum showed similar behaviours for the hydration periods of 0 to 14 days curing period considering soil sample A. For soil sample B, at 14 and 21 as well as 7 and 21 days cured specimens showed highest dry densities with similar features for, 2% on the wet side of optimum up to the optimum; but changes at 2% on the dry side of optimum for both RP and SP compactive efforts respectively. The predicted models measured adequately the estimation of VSS value using the analysis of variance (ANOVA) and gave good indication of validity.

Keywords: *Volumetric shrinkage strain, desiccation, tropical soil, hydraulic barrier, compaction*

1.0 Introduction

Desiccation cracks which occur due to volume changes resulting from moisture variation are common phenomena in clay soils, and can create pathways for percolation of fluids (Albrecht and Benson, 2001; Rayhani *et al*., 2007; Allaire *et al*., 2009; Taha and Taha, 2012). This phenomenon of “self –healing” can weaken the strength of the soil, causing shrinkage and reduction in crack dimensions during wetting, thus a panacea in waste containment facilities (Mallwitz, 1998; Chertkov, 2000; Tang *et al*., 2011). The resulting loss in pore water leads to shrinkage of the soil mass and subsequently cracking and desiccation as the attractive forces within the clay cause individual clods to form. In some geotechnical applications such as landfills; this could be a serious problem. Therefore, volumetric shrinkage and desiccation cracking of compacted soils used as liners or hydraulic barriers have received much attention by researchers (Kleppe and Olson, 1985; Abu-Hejleh and Znidarcic, 1995; Kodikara *et al*., 2000; Osinubi and Nwaiwu, 2006; Eberemu *et al*., 2011; Moses and Afolayan, 2013).

Compacted soil liners are essential components of engineered landfills which are now widely used in most developed and developing countries to impede or at least minimize the movement of fluid out of the waste disposal facility with a view to ameliorating the menace of groundwater contamination. The landfill sites are normally constructed during the dry season, but wet-dry cycling set up by the tension in the capillary water accounts for the volume changes (Daniel and Wu, 1993; Nwaiwu and Osinubi, 2002; Osinubi *et al*., 2006). Daniel and Wu (1993) as well as Tay *et al*., (2000) suggested that cracking is not likely to occur in compacted liners with less than 4% volumetric shrinkage strain (VSS) during drying. In recent years, there has been an increasing interest in the investigation of the use of various soils either natural or mixed with additives to be used as a hydraulic barrier in landfill (Eberemu *et al*., 2011; Osinubi and Moses, 2011; Daud and Muhammed, 2014).However, certain recommendations have been made regarding the properties of soils to be used as a hydraulic barrier in landfill systems. These are a minimum hydraulic conductivity of 1 x 10^{-9}m/s, Unconfined Compressive strength of 200kN/m^2 and a volumetric shrinkage strain of not greater than 4% (Daniel and Wu, 1993).

Daniel and Wu (1993), investigated a clayey soil in order to define ranges of water content and dry unit weight at which compacted test specimen would have low hydraulic conductivity, adequate shear strength and minimal shrinkage. According to their findings, an acceptable limiting value of volumetric shrinkage strain to prevent desiccation of these soil was less than or equals to 4%. In a similar work, laboratory tests were carried out by Osinubi and Nwaiwu, (2008) and Kundiri, (2009) using compacted lateritic and Clayey sand soils subjected to drying under room condition. The changes in volume were determined at the 7, 14 and 21 days of the drying process. The results from the experiment showed that volumetric shrinkage strain was influenced most by the clay content, compaction condition, drying process, wetting and drying cycles, soil particle orientation, unit weight, pore fluid and exchangeable ions (Yesiller *et al*., 2000; Osinubi and Kundiri, 2008; Moses and Afolayan, 2013).Albrecht and Benson, (2001) found that cracking could increase the hydraulic conductivity of clay liner material by sometimes as large as three folds due to a larger flow path. Khire *et al*., (1997) showed that compacted clay barrier in earthen covers undergo seasonal changes in water content, even at significant depth, due to seasonal variations in precipitation and evaporation. Field studies have further shown that desiccation can induce severe cracking of unprotected soil liners (Benson and Khire, 1995).The focus of this study is to ascertain the extend of the volumetric shrinkage strain, compaction conditions of the compacted soils with a view to its potentials in waste containment application. A drawback to the land filling method is the induced shrinkage due to loss of moisture which could culminate to severe cracking of the unprotected compacted soil liners unless protected during construction (Benson, 1997; Benson and Khire, 1997).

2.0 Materials and Methods

2.1 Materials

Two soil samples used in this study were fine-grained soils of low plasticity obtained around Polo ground in Maiduguri Metropolitan area, Borno State (latitude 11^{o} 50’ 42’’ N and longitude 13^{o} 9' 36” E). This soil was collected using disturbed sampling method from a depth of 500m and preserved in plastic bags to prevent loss of moisture, then designated as sample A and B.

2.2 Methods

2.2.1 Index Properties and Moisture – Density Characteristics

Laboratory tests were conducted for the determination of the index properties and moisture – density characteristics of the soil samples in accordance with BS 1377 (1990).The three compactive efforts of Reduced Proctor (RP) was determined in accordance with BS 1377 (1990), while the Standard Proctor (SP) and Modified Proctor (MP) were carried out as specified by Head (1992).These samples were classified as A-7-6 and A – 6 according to the Association of American States Highway and Transportation Officials (AASHTO) Classification System (AASHTO, 1986), and CL according to the Unified Soil Classification System (USCS) (ASTM, D2487 1998).Compaction test was carried out to determine the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) on air-dried soil samples passing through sieve size 4.75mm aperture.

2.2.2 Volumetric Shrinkage Strain

The volumetric shrinkage was determined in accordance with BS 1377 (1990). The volumetric shrinkage upon drying was measured by extruding cylindrical specimens, compacted at the three energy levels mentioned above. After extrusion of the cylindrical specimens from the mould, the specimens were air-dried on a table in the laboratory under ambient temperature for a period of 21days. The height and diameter of the compacted soil specimens were measured in triplicate for 0, 7, 14 and 21 days with the aid of a digital vernier calliper. The average diameters and heights were used to compute the volumetric shrinkage strain.

3.0 Results and Discussion

3.1 Chemical Composition and Index Properties

X – Ray florescence was carried out on representative sample to know quantitatively the main oxides of the soil samples. Almost all soils on earth contain some amount of colloidal oxides and hydroxides. The oxides and hydroxides of aluminium, iron and silicon are of greatest interest since they are the ones most frequently encountered. Iron and aluminium oxides coat mineral particles, or cement particles of soils together. The main chemical components of soil samples A and B which was SiO_2, constituted 76.48% and 75.33% respectively, as shown in Table 1.

Table 1: Chemical Composition of the Soil Samples.

Chemical Composition	*Sample A*	*Sample B*
SiO_2	76.48	75.33
Al_2O_3	14.21	13.56
CaO	2.68	3.60
MgO	0.264	0.305
Na_2O	3.63	3.55
K2O	0.46	0.71
Fe_2O_3	0.92	1.04
MnO	0.05	0.04
LOI	0.88	0.21

However, the index properties of the soils were carried out to provide a useful way to identify, classify and assess the engineering properties of the soil. Table 2 shows the index properties of the soil samples, with the specific gravity of the samples being 2.54 and 2.66, while the liquid limit, plastic limit, plasticity index and linear shrinkage of the soil samples ranging from 44 to 50, 25 to 28, 19 to 22, and 19 to 22% respectively.

According to Benson *et al*. (1994), the liquid limit and plasticity index of a soil liner should be at least 20% and ≥ 7% respectively because a low hydraulic conductivity is attributed to higher liquid limits and plasticity indices.

Table 2: Index properties of the soil

Parameters	*Sample A*	*Sample B*
Liquid limit (%)	44	50
Plastic limit (%)	25	28
Plasticity index (%)	19	22
Linear shrinkage (%)	12.1	10.7
Specific gravity	2.54	2.66
Sand (0.06-2mm)	61.20	30.60
Silt (0.002-0.06mm)	16.60	33.70
Clay (<0.002mm)	22.20	35.70
% passing BS No. 200 sieve	5.4	4.1
AASHTO classification	A-6	A-7-6
USCS Classification	CL	CL
Group index	0	0
Activity	0.88	0.62

3.2 Compaction Characteristics

The compactive behaviours of the soil samples are presented in figures 1 and 2. The MP compactive effort gave the highest values of MDD ranging between 1.72 to 1.95 Mg/m^3 which corresponds to OMC values not exceeding 7%.It could be observed that there was an increase in MDD and decrease in OMC with higher compactive effort for both samples. This in agreement with established works (Blotz and Boutwell, 1998; Howard *et al*., 1981).

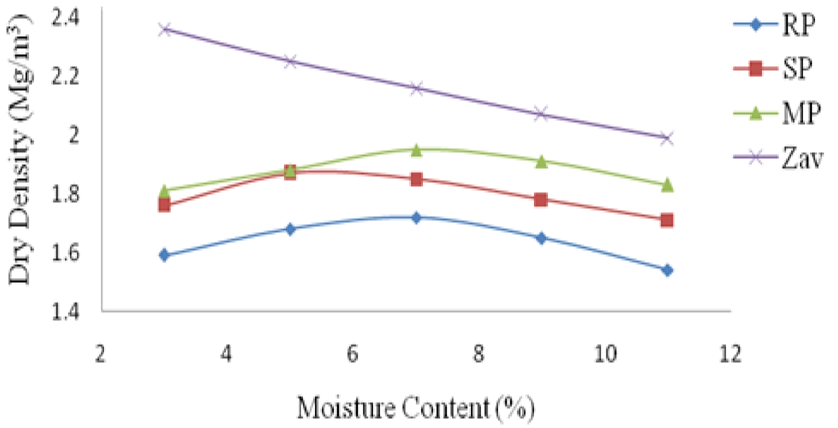

Figure 1: Variation of compactive efforts with moisture content for sample A

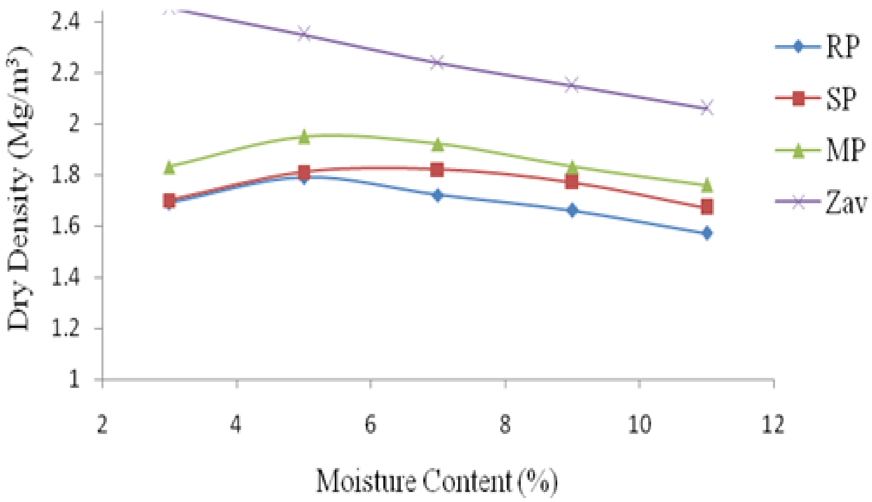

Figure 2: Variation of compactive efforts with moisture content for Sample B

3.3 Volumetric Shrinkage Strain

The shrinkage is mainly due to water loss by evaporation, as the drying proceeds from the surface; it goes deeper downwards making the dehydrated surface layer to shrink (Khire *et al*., 1997; Tang *et al*., 2011; Eberemu, 2011). Daniel and Wu (1993) suggested that cracking is not likely to occur in compacted soil liners with volumetric shrinkage strain (VSS) of less than 4% upon drying. The variations of volumetric shrinkage strain with moulding water content relative to the optimum using the RP, SP and MP compactive efforts for both soil samples as shown in Figures 3 and 4. For sample A the range of volumetric shrinkage strain from 2.6 - 6.2%, 2.8 – 6.8% and 2.5 – 4.2% were observed for RP, SP and MP compactive efforts respectively. On the other hand, sample B shown volumetric shrinkage strain ranging from 2.6 – 4.2%, 2.3 – 4.2% and 2.8- 4% using the RP, SP and MP compactive efforts respectively. It could be inferred that all the soils compacted using the higher compactive effort showed lower volumetric shrinkage strain due to closer packing of soil fabric as a result of higher energy, this agreed with earlier findings by (Daniel and Wu, 1993; Albrecht and Benson, 2001; Tang *et al*., 2011).

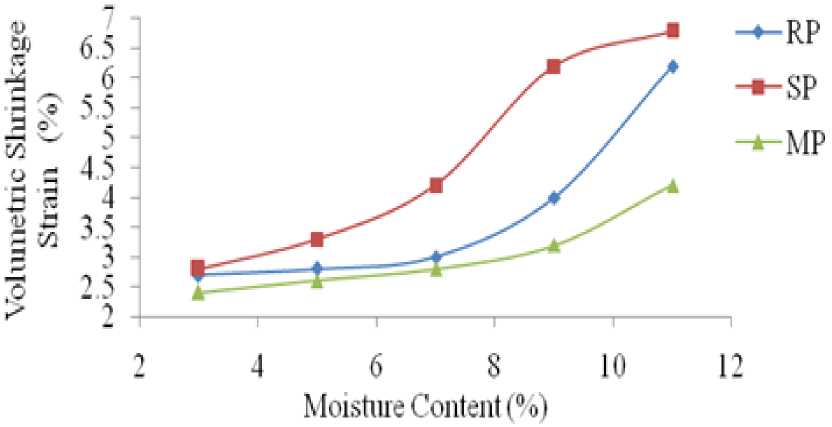

Figure 3: Variation of volumetric shrinkage with moisture content for sample A

Generally**,** the VSS increased with higher moulding water content for specimens compacted on the wet side of the optimum and contain much water as against the specimens compacted on the dry side of the optimum which had less water.

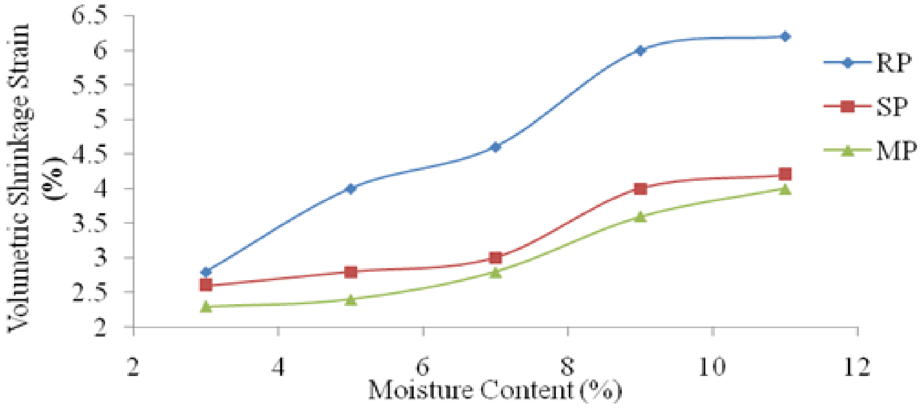

Figure 4: Variation of volumetric shrinkage with moisture content for sample B

This result is in agreement with the findings of (Osinubi and Nwaiwu, 2006; Chaosheng 2011; Moses and Afolayan, 2013; Taha and Taha, 2012). However, the moulding water content at 2% relative to optimum on the wet side of optimum water content is applicable to liners that are nearly saturated after construction as reported by (Kundiri, 2009).

3.3.1 Effect of Dry Density on Compaction Water Contents

The effect of dry density on compaction water contents was dependent on the compactive efforts, and the hydration periods which lasted for a period of 21 days. For the specimens prepared at the RP compactive effort, the dry density which is related to the soil mass; generally decreased with higher hydration periods as depicted in figures 5 to 10.

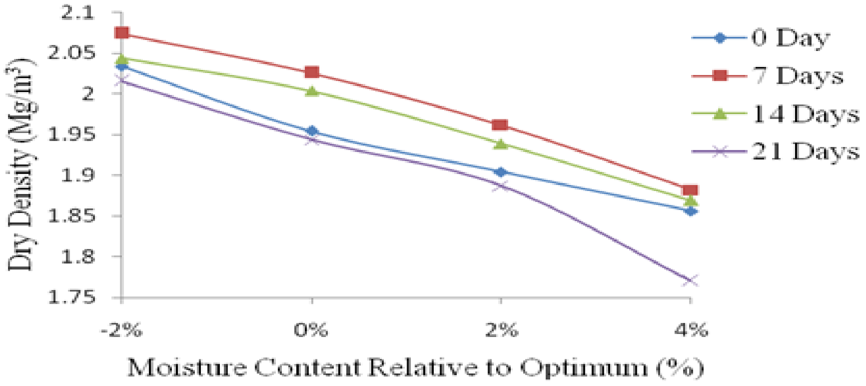

Figure 5: Variation of dry density with Moisture Content relative to optimum for Sample A using the RP compactive effort

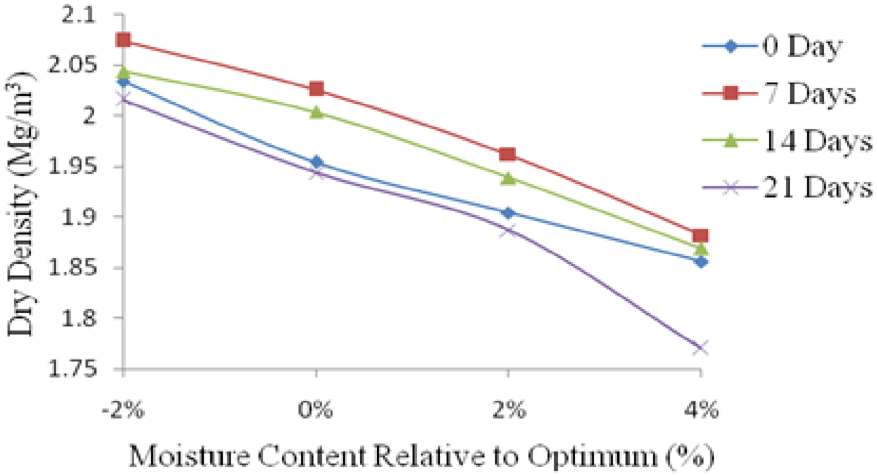

Figure 6: Variation of dry density with Moisture Content relative to optimum for Sample B using the RP compactive effort

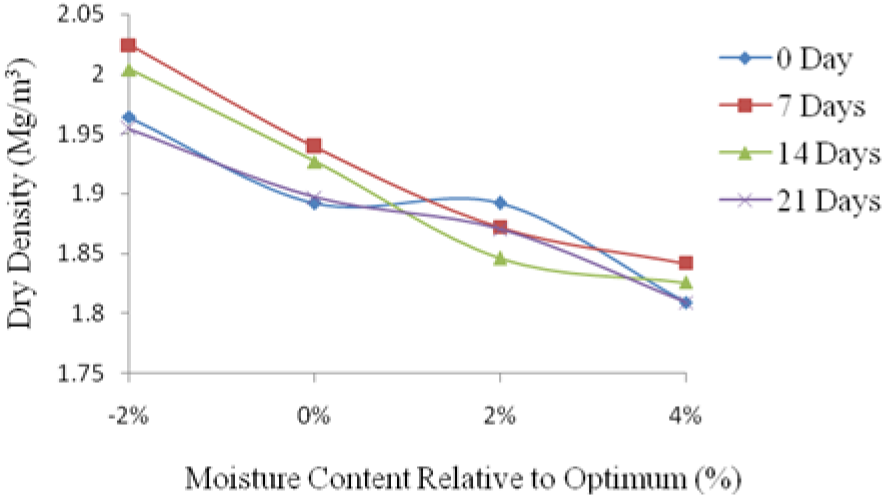

Figure 7: Variation of dry density with Moisture Content relative to optimum for Sample A using the SP compactive effort

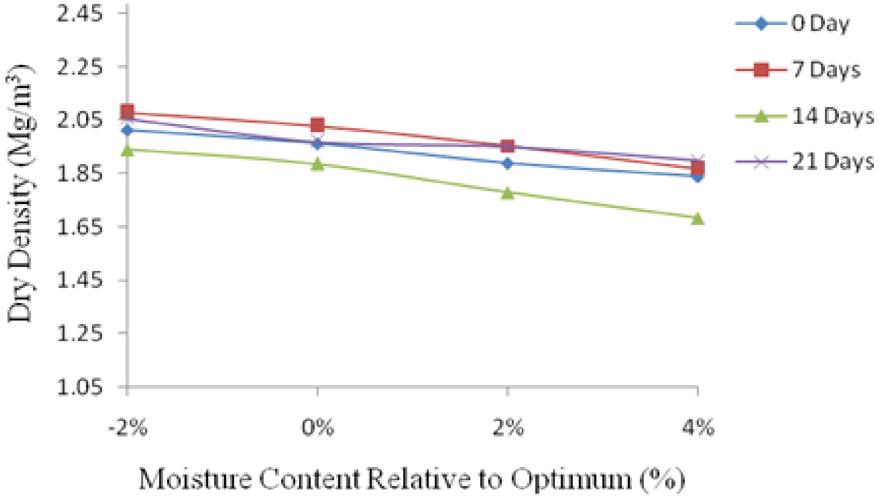

Figure 8: Variation of dry density with Moisture Content relative to optimum for Sample B using the SP compactive effort

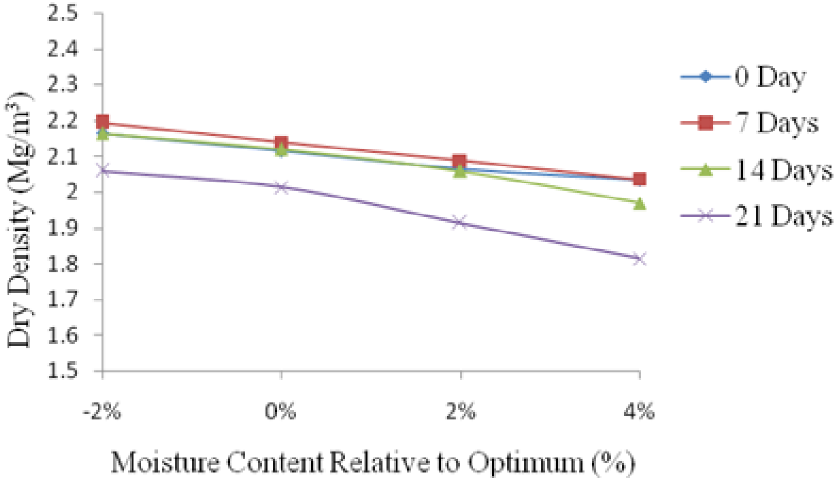

Figure 9: Variation of dry density with Moisture Content relative to optimum for Sample A using the MP compactive effort

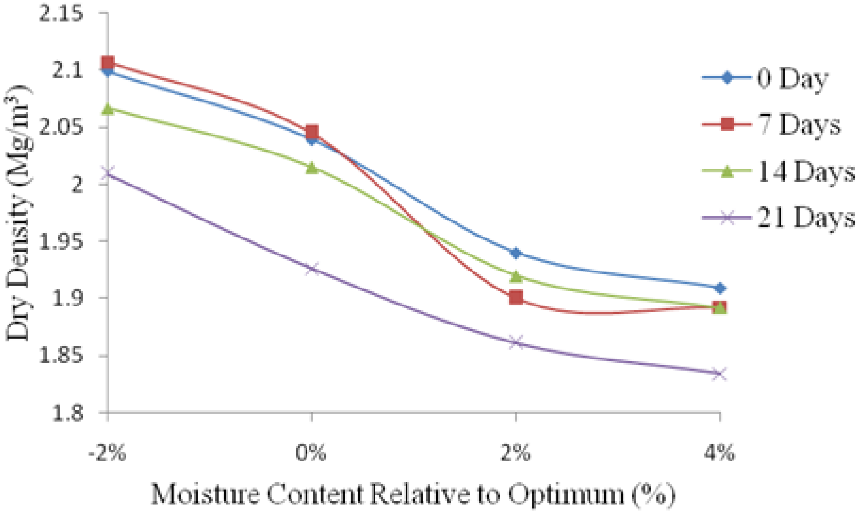

Figure 10: Variation of dry density with Moisture Content relative to optimum for Sample B using the MP compactive effort

Soil sample A with the RP compactive effort showed that for 7 and 14 days cured yielded similar features, while 0 and 21 days cured showed similar behaviour up to 2% on the dry side of the optimum. For the SP compactive effort, 7 and 14 days cured yielded the peak dry densities at 2% on the wet side of optimum and at optimum. An opposite trend was depicted at 2% on the dry side of optimum and at 14 days cured characterised with increase and subsequent decrease respectively. In general, the samples compacted at 2% on the wet side of optimum and 2% on the dry side of optimum showed similar behaviours for the hydration periods of 0 to 14 days in the case of MP compactive effort.

On the other hand, soil sample B showed that for 14 and 21 days cured highest dry densities with similar features for, 2% on the wet side of optimum up to optimum; but changes at 2% on the dry side of optimum in respect to the RP compactive effort. The SP compactive effort for 7 and 21 days cured periods gave similar characteristics, but least dry density at 14 days cured. It was observed that for the MP compactive effort, 0 and 14 days cured depicted similar trend all through, but 7 days cured showed a sharp decrease at 2% on the dry side of optimum.

3.4 Statistical Analysis of Results

Multiple Linear Regression Analysis (MLRA) using the Minitab version 16.1 was adopted considering the VSS, OMC and MDD test results for the three compactive efforts with a view to developing predictive models as presented in Table 3. The independent variable or response was the VSS, while the OMC and the MDD were the dependent variables or predictors.

Table 3: Models developed from MLRA

Sample	***Compactive effort***	***Regression equation***	R^2	***Validation*** R^2		***F value***
				Lab. VSS	Predicted VSS	
A	R P	$VSS = 16.9 + 0.369MC - 9.59DD$	97.5%	0.818	0.797	38.64
A	S P	$VSS = 11.3 + 0.485MC - 5.69DD$	95.3%	0.919	0.964	20.25
A	M P	$VSS = 22.2 + 0.461MC - 11.6DD$	98.9%	0.797	0.818	91.95
B	R P	$VSS = 25.8 + 0.196MC - 14.0DD$	96.3%	0.827	0.797	26.34
B	S P	$VSS = 6.75 + 0.176MC - 2.78DD$	93.7%	0.909	0.971	14.84
B	M P	$VSS = -1.62 + 0.462MC + 1.67DD$	96.8%	0.962	0.994	30.43

The entire VSS models yielded high values of coefficient of determinations ranging from 93.7 to 98.9% for S P and M P, P-values 0.011 to 0.063 for samples B and A.

Table 4: Analysis of Variance (ANOVA) for Testing Significance of Regression

Sample	***Source of variation***	***Degree of freedom (df)***	***Sum of Squares (SS)***	***Mean Square (MS)***	$F = MS_R/MS_E$
A	Regression	2	8.6249	4.3124/2= 2.1562	2.1562/0.0558 = 38.64
	Residual Error	2	0.2231	0.1116/2= 0.0558	
	Total	4	8.8480		
A	Regression	2	12.0909	6.0454/2= 3.0227	3.0227/0.1493 = 20.25
	Residual Error	2	0.5971	0.2986/2= 0.1493	
	Total	4	12.6880		
A	Regression	2	8.7530	4.3765/2= 2.1883	2.1883/0.0238 = 91.95
	Residual Error	2	0.0950	0.0475/2= 0.0238	
	Total	4	8.8480		
B	Regression	2	8.5243	4.2622/2= 2.1311	2.1311/0.0809 = 26.34
	Residual Error	2	0.3237	0.1618/2= 0.0809	
	Total	4	8.8480		
B	Regression	2	1.9938	0.9969/2= 0.4985	0.4985/0.0336 = 14.84
	Residual Error	2	0.1342	0.0671/2= 0.0336	
	Total	4	2.1280		
B	Regression	2	7.7909	3.8954/2= 1.9477	1.9477/0.0643 = 30.43
	Residual Error	2	0.2571	0.1286/2= 0.0643	
	Total	4	8. 0480		

In order to measure the adequacy of the predicted models for estimation of VSS value, standard F-test procedure was carried out as outlined by (Montgomery and Runger, 2003); which used the analysis of variance (ANOVA). The result of the analysis of variance (ANOVA) is shown in Table 4. The F-distributions with degrees of freedom df_1 and $df_2 = 2$ such that the critical region will consist of a value exceeding 19.00. In this test, 95% level of confidence was chosen. Since the calculated F values ranging between 20.25 to 91.95 for sample A and 14.84 to 30.43 for sample B are greater than the tabulated F value ($F_{0.05,2,\,2} = 19.00$), the null hypothesis is rejected. It could be deduced that the Models are valid.

4.0 Conclusion

The basis of the study was to evaluate the effect of compactive efforts on desiccation induced volumetric shrinkage strain of some compacted tropical soils with a view to ascertain their suitability in landfill application. Based on the results presented in this paper, the following conclusions were drawn:

1. The chemical components of the soil samples predominantly constituted of 75.33 to 76.48% SiO_2, while the liquid limit and plasticity indices of the soil samples ranged from 44 to 50% and 19 to 22% respectively. This implied that the soils have conformed to some of the requirements for liner material (i. e. the liquid limit and plasticity index being at least 20% and ≥ 7% respectively for achieving low hydraulic conductivity).

2. The MP compactive effort gave the highest values of MDD ranging between 1.72 to 1.95 (Mg/m^3) which corresponds to OMC values not exceeding 7%, this connotes that there was an increase in MDD and decrease in OMC with higher compactive effort for both samples.

3. Variations of the VSS with moulding water content (relative to the optimum) for the RP, SP and MP compactive efforts for the soil samples were found to be within the range of 2.6 to 6.8%. This could infer that the soils compacted using the higher compactive effort showed lower values of VSS due to the closer packing of soil fabric as a result of higher compaction energy.

4. The measure of adequacy based on the predicted models for the estimation of VSS values using the analysis of variance (ANOVA) indicated that the calculated F is greater than the tabulated F values, hence the Models are valid.

The study showed yet another geotechnical application of some tropical soils for hydraulic barrier (liner) purposes. It is however, recommended that the construction of a liner system using tropical soils like other clayey soils should consider the other geotechnical parameters like Unconfined Compressive Strength (UCS) and hydraulic conductivity to produce a single acceptable zone that satisfies the three major conditions, as well as the compatibility of the liner soil with the liquid contaminant.

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