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The Influence of Compactive Effort on the Desiccation-Induced Volumetric Shrinkage of Compacted Bagasse Ash Treated Foundry Sand As Hydraulic Barrier Material

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ABSTRACT

Laboratory tests were conducted to assess the effect of compactive effort on the desiccation-induced volumetric shrinkage strain of compacted waste foundry sand treated with up to 8% bagasse ash (a pozzolana) by dry weight of foundry sand for use as a hydraulic barrier material in waste containment applications. The compative energy levels of reduced British standard light (RBSL), British standard light (BSL), West African standard or 'intermediate' (WAS) and British standard heavy (BSH) efforts were utilized at molding water contents of 2% dry of optimum, 0% optimum moisture content and 2% and 4% wet of optimum. A compaction plane of acceptable values for volumetric shrinkage strain (VSS) based on the regulatory value ≤ 4% was used to assess the effect of compactive effort on desiccation-induced shrinkage of bagasse ash treated foundry sand. Higher compactive effort generally recorded less volumetric shrinkage strain values. Generally, VSS values increased with higher molding water content and increased with higher initial degree of saturation for all compactive efforts. However, at 6% and 8% bagasse ash treatment levels, higher compactive effort, did not result in lower VSS values, especially at WAS and BSH compactive efforts. This can be attributed to the lack of sufficient water at higher compactive efforts to meet the hydration demands at higher treatment levels.

KEYWORDS: Bagasse ash, Compaction, Volumetric shrinkage strain.

INTRODUCTION

Desiccation-induced volumetric shrinkage of liner materials causes cracking in the soil body or a consequence of pressure exerted on the soil body. Cracks create paths for the transfer of fluids; broken soils can increase the infiltration of surface water into the containment system or fluids into the surrounding soil and groundwater (Benson, et al., 1994). Gray (1989) categorized cracks into two major types, in line with the system of their formation. The magnitude of the changes that result from the shrinkage and swelling of fine soil particles is often large enough to cause damage to small buildings, highways and sidewalks. The yearly cost of damages to buildings, roads, airports, pipelines, hydraulic barrier systems and other structures amounts to approximately 9 billion dollars (Benson and Trast, 1995).

Enormous amounts of solid wastes are increasingly generated within the urban centers of developing countries located in the tropical and sub-tropical

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regions. Safe disposal in properly constructed, compacted-clay-lined landfills is necessary in order to avoid health challenges due to the contamination of ground water (Osinubi and Ijimdya, 2011). The major challenge presented by waste disposal facilities is the leachate that drains from the facility into groundwater. Other materials used as liners or covers in waste containment systems, in addition to natural clayey soils, include processed clay/sand-processed clay mixtures, geosynthetic materials and industrial waste products (Albrecht and Benson, 2001; Osinubi and Eberemu, 2010b; Moses and Afolayan, 2013).

In Nigeria, there are 50 commercial foundries with a total consumption capacity of about 4000 tons of silica sand, bentonite and charcoal (Okeke and Sadjere, 1991). Large quantities of waste materials from mineral, agricultural, domestic and industrial sources are generated daily and the safe disposal of these wastes is increasingly becoming a major concern around the world (ETL, 1999). These wastes, if properly treated, could be modified for use as structural components of highway pavements or as waste containment materials. Sugar cane is a major raw material for sugar production. It is grown on 25000-30000 hectares in Nigeria with a production rate of about 80 tons/hectare (Misari et al., 1998). Bagasse is the fibrous residue obtained from sugar cane after the extraction of sugar juice at sugar cane mills (Medjo and Riskowski, 2004), while bagasse ash is the residue obtained from the incineration of bagasse in sugar producing factories and is known to possess pozzolanic properties (Osinubi and Ijimdya, 2008). Research work has been carried out on the improvement of geotechnical characteristics of soils using bagasse ash (Osinubi and Ijimdya, 2008). However, no work has been done on the influence of compactive effort on the volumetric shrinkage strain of compacted bagasse ash treated foundry sand as a hydraulic barrier material. The study was aimed at evaluating the influence of compactive efforts on compacted foundry sand treated with bagasse ash for use in waste containment applications.

MATERIALS AND METHODS

Materials

Foundry Sand: The foundry sand used in this study was obtained from Defense Industries Corporation of Nigeria (DICON), Kaduna (latitude 10°30'N and longitude 7°27'E), Nigeria.

Bagasse Ash: The bagasse ash utilized in this work was reported by Osinubi and Ijimdya (2008) to be pozzolanic based on its oxide composition. The ash which passed through BS no. 200 sieve (75 μm apertures) was mixed at four different molding foundry sand – bagasse ash mixtures in stepped increment of 2% up to 8% by dry weight of foundry sand.

Methods

Index Properties: Laboratory tests were conducted to determine the index properties of the foundry sand and foundry sand - bagasse ash mixtures in accordance with BS (BS 1377, 1990 and BS 1924, 1990).

Compaction: The compactive energy levels used are: the Reduced British Standard Light (RBSL), British Standard Light (BSL), West African Standard (WAS) and British Standard Heavy (BSH). The tests involving moisture-density relationships and volumetric shrinkage were carried out. Air dried soil samples passing through BS sieve with 4.76 mm apertures mixed with 0, 2, 4, 6 and 8% bagasse ash by weight of dry soil were used. Reduced British standard light is the effort derived from 2.5 kg rammer falling through 30 cm onto three layers, each receiving 15 uniformly distributed blows (BS 1377, 1990). British standard light is the effort derived from 2.5 kg rammer falling through 30 cm onto three layers, each receiving 27 uniformly distributed blows (BS 1377, 1990). West African standard compactive effort (WAS) was carried out using energies derived from a rammer of 4.5 kg mass falling through a height of 45 cm in a 1000 cm^3 mould. The soil was compacted in five layers, each layer receiving 10 blows. Finally, British standard heavy (BSH) compaction moisture density relationships were determined using energy derived from a rammer of 4.5 kg mass falling through a height of 45 cm in a 1000 cm^3 mould. The soil was compacted in 5 layers, each receiving 27 blows.

Volumetric Shrinkage: The volumetric shrinkage upon drying was measured by extruding cylindrical specimens, compacted using the RBSL, BSL, WAS and BSH compactive efforts. Air dried foundry sand - bagasse ash mixtures were compacted at four different molding water contents *viz*; 2% dry of optimum moisture content, 0% optimum moisture content, 2% and 4% wet of optimum moisture. The extruded cylindrical specimens were placed on a laboratory bench for 40 days to dry naturally at a uniform temperature of 29 ± 2ºC. This method is considered to be better than the method used by Daniel and Wu (1993) in which compacted cylindrical specimens were dried in an air-conditioned building. This is because natural drying in the laboratory is considered to duplicate field conditions (Taha and Kabir, 2005; Osinubi and Eberemu, 2010b; Moses and Afolayan, 2013). Measurements of diameters and heights for each specimen were taken with the aid of a vernier caliper accurate to 0.05 mm. The average diameter and height were used to compute the volumetric shrinkage strain using eq. (1).

$$Vs = (Vo - V_f)100\% / V_0 \qquad (1)$$

where

V_S = Volumetric strain;

V_0 = Original volume of compacted wet cylindrical specimen.

V_{f} = Final volume of dry cylindrical specimen.

DISCUSSION OF RESULTS

Chemical Composition

The oxide composition of bagasse ash used is summarized in Table 1.

Table 1. Oxide composition of bagasse ash

Oxide	Bagasse ash (%)
CaO	3.23
SiO_2	57.12
Al_2O_3	29.73
Fe2O_3	2.75
Mn_2O_3	0.11
$Na_2O + K_2O$	-
SO_3	0.02
TiO_2	1.10
Loss on Ignition	5.89

(Osinubi and Ijimdya, 2008).

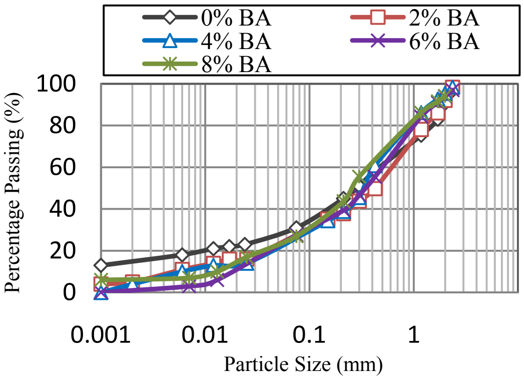

Figure (1): Particle size distribution curve for untreated and treated foundry sand

Index Properties

The index properties and compactions of the untreated and treated foundry sand are shown in Table 2. The particle size distribution curves are shown in Fig. 1. The non-plastic sand is classified as A-2-4(0) according to AASHTO classification system and SM according to the Unified Soil Classification System. The liquid limit slightly decreased initially in value from 19% to 18% and later increased to a peak value of 23.3% at 4% bagasse ash treatment. This increase can be attributed to the increase in water absorption or changes in the particle packing of the mixture. Beyond 4% bagasse ash content, the liquid limit reduced in value. Foundry sand has been reported by Johnson (1981) as not possessing plasticity, largely due to the presence of a high percentage of fine sand and due to the high temperature bentonite has been subjected to. Treatment of foundry sand with bagasse ash did not improve its plasticity, while the linear shrinkage was not significantly affected since the soil is predominantly sand.

Table 2. Index properties of treated and untreated foundry sand

Properties	Bagasse ash content (%)				
	0	2	4	6	8
LL, %	19.0	18.0	23.3	19.4	18.8
PL, %	N.P	N.P	N.P.	N.P	N.P
PI, %	N.P	N.P.	N.P.	N.P.	N.P.
SL, %	0.9	1.0	0.0	0.9	0.7
%PASSING No. 200 SIEVE	31	26.5	27	27.5	26.5
AASHTO	A-2-4(0)	A-2-4(0)	A-2-4(0)	A-2-4(0)	A-2-4(0)
USCS	SM	SM	SM	SM	SM
GS	2.64	2.65	2.66	2.60	2.56
MDD (Mg/m^3)					
RBSL	1.91	1.84	1.83	1.86	1.91
BSL	1.96	1.89	1.89	1.88	1.89
WAS	2.00	1.92	1.92	1.97	1.91
BSH	2.08	2.08	2.05	1.99	1.99
OMC (%)					
RBSL	12.0	12.5	13.0	13.0	13.0
BSL	11.5	11.6	11.7	12.0	12.2
WAS	9.5	8.6	9.5	10.0	11.3
BSH	8.3	8.6	7.7	8.6	8.3
pH	8.9	9.9	10.2	10.6	10.8
Colour	Brown				

NP= Non-Plastic.

COMPACTION CHARACTERISTICS

Maximum Dry Density

A general decrease in maximum dry density for all the four energy levels was recorded as shown in Figure 2. The MDD generally decreased with higher bagasse ash treatment up to 8%, especially for BSL and BSH compactive effort. This could probably be a result of the low specific gravity of bagasse ash of 2.20 replacing foundry sand (Osinubi and Ijimdya, 2008) compared to that of foundry sand which is 2.64. Finally, above 4% bagasse ash content, especially for RBSL and WAS, an increase in maximum dry density was observed which could possibly be a result of the formation of new compounds.

Optimum Moisture Content

Generally, there is an increase in the optimum moisture content (OMC). An observed increase with higher bagasse ash content was recorded, except for an initial decrease observed for BSH energy level as shown in Fig.3. This could be attributed to the increase in fines content due to the inclusion of bagasse ash which has a larger surface area that required more water to react or complete its hydration reaction. These results are in agreement with those reported by Moses and Afolayan (2013).

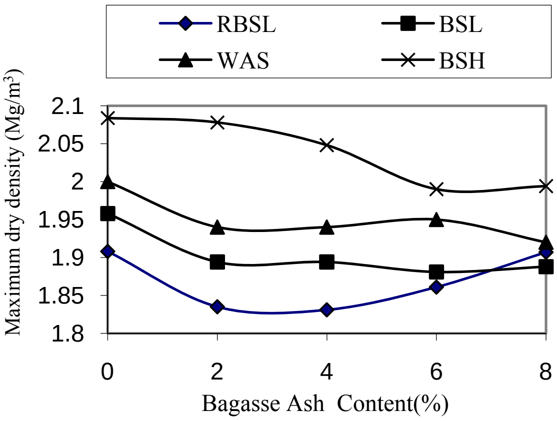

Figure (2): Variation of maximum dry density of foundry sand with bagasse ash content

Volumetric Shrinkage Strain with Molding Water Content

The variations in VSS with molding water content at different energy levels are shown in Figs. 4-8. The designers have practically no control over the magnitude of the changes that will be imposed on the barrier (i.e., the degree of desiccation the barrier will undergo). A safe volumetric shrinkage strain (VSS) value of less than or equal to 4% VSS upon drying for compacted cylindrical soil liners has been used to predict field desiccation due to cracking as recommended by Daniel and Wu (1993). Generally, as the bagasse ash content increases and at higher energy levels, there is a decrease in the desiccation induced volumetric shrinkage strain. Specimen compacted at greater molding water content shrank more during drying which is consistent with recorded works (Daniel and Wu, 1993). The reason for this is not farfetched, because dry shrinkage in fine grained soils according to Haines (1923) depends on particle movement as a result of pore water tension developed by capillary menisci.

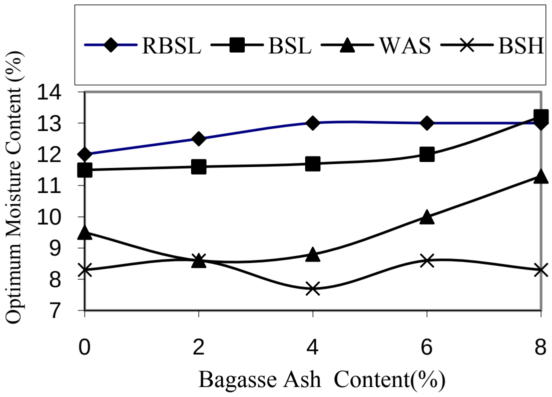

Figure (3): Variation of optimum moisture content of foundry sand with bagasse ash content

For the untreated specimen (see Fig. 4) compacted between 2% dry and 4% wet of OMC of compacted specimens, satisfactory results were recorded at the two energy levels of WAS and BSH only. Progressive treatment of specimen generally recorded a decline in the desiccation induced volumetric shrinkage strain; this behavior can be attributed to the pozzolanic input of the bagasse ash which reduces the fine grained soils and binds the dsarticles much closer together (Osinubi and Eberemu, 2010b; Moses and Oriola, 2010). Furthermore, samples compacted at higher molding water contents have more water in their void spaces that would result in higher shrinkage on drying, since volumetric shrinkage is proportional to the volume of water leaving the pores (Albercht, 1976; Moses and Afolayan, 2013). Molding water content between 2% dry and 4% wet of OMC of compacted specimens produced satisfactory results only at ranges of molding water content of 7.5-12.2% and 6.3-9.6% for WAS and BSH compactive efforts, respectively. The minimum volumetric strain ranges were attained at 7.5% and 6.3% molding water content for WAS and BSH compactive efforts, respectively.

At 2% bagasse ash treatment and molding water content between 2% dry and 4% wet of OMC of compacted specimens (see Fig. 5), there was a general decrease in the volumetric shrinkage strain, and this can be attributed to the pozzolanic input of the bagasse ash that reduced the fines content in the mixtures, as coarser fractions of soils were formed. Thus, 2% bagasse ash treatment of foundry sand recorded acceptable volumetric shrinkage strain values in the ranges of molding water content of 10-14.5%, 9.6-12.5%, 6.6-10.4% and 6.6-12.6% for RBSL, BSL, WAS and BSH compactive efforts, respectively. The results at 4% bagasse ash treatment (see Fig. 6) further show an improvement in that it produced better acceptable shrinkage strain values. This is attributed to the effect of increasing bagasse ash content (Osinubi and Eberemu, 2010b; Moses and Oriola, 2010).

At 6% bagasse ash treatment and molding water content between 2% dry and 4% wet of OMC of compacted specimens (see Fig. 7), slight improvement was observed in the volumetric strain values, indicating that optimum bagasse ash content has been attained and bagasse ash did not any longer fill the pores in the soil matrix, but rather began to displace the soil, and less water was available for a complete hydration reaction of the specimens. This was more pronounced at higher compactive effort. The ranges of water content that produced values of volumetric strain that are acceptable were at the moulding water content ranges of 11-15%, 10-12.8%, 8-12% and 6.4-12.2% at

RBSL, BSL, WAS and BSH compactive effort, respectively. Finally at 8% bagasse ash treatment and molding water content between 2% dry and 4% wet of OMC of compacted specimens (see Fig. 8), the same trend for 6% bagasse ash treatment was observed. This confirmed that further addition of bagasse after optimum produced little or no difference in the volumetric strain values at higher compactive effort. At lower compactive energy level, sufficient water is available to meet the hydration demand due to the pozzolanic action of bagasse ash. The moulding water content ranges that produced satisfactory results were at 11-13.9%, 10.2-14%, 9.3-13.8% and 6.3-12.3% at RBSL, BSL, WAS and BSH compactive efforts, respectively.

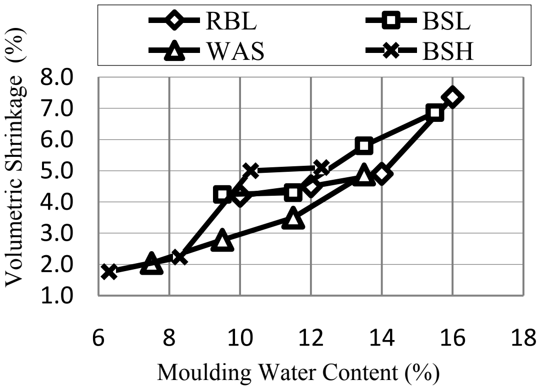

Figure (4): Variation of volumetric shrinkage strain with moulding water content for the natural soil

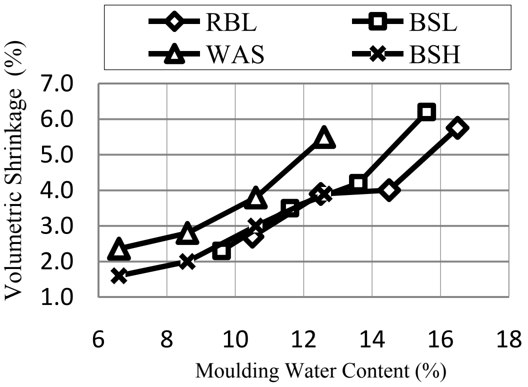

Figure (5): Variation of volumetric shrinkage strain with moulding water content at 2% bagasse ash treatment

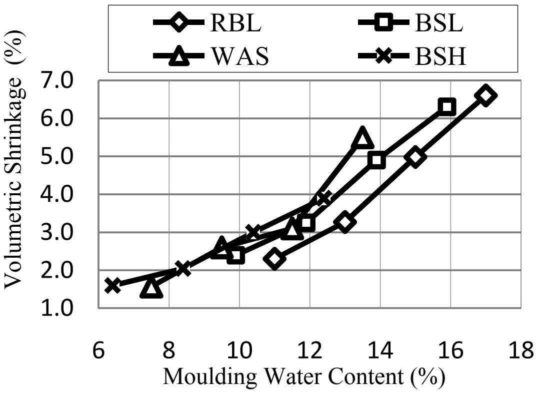

Figure (6): Variation of volumetric shrinkage strain with moulding water content at 4% bagasse ash treatment

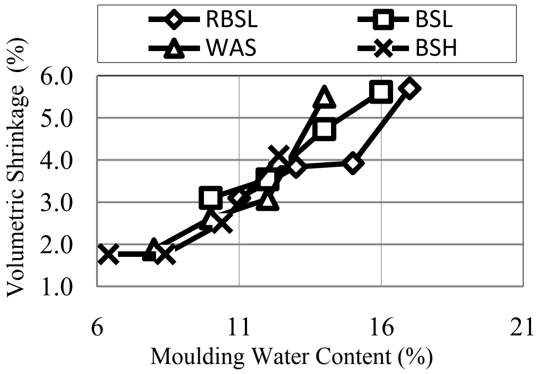

Figure (7): Variation of volumetric shrinkage strain with moulding water content at 6% bagasse ash treatment

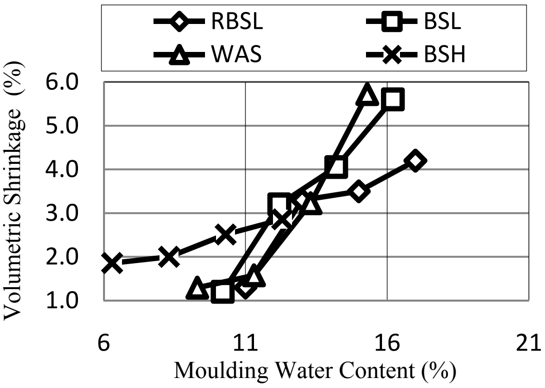

Figure (8): Variation of volumetric shrinkage strain with moulding water content at 8% bagasse ash treatment

Volumetric Shrinkage Strain with Degree of Saturation

The recorded results of the degree of saturation at different energy levels are shown in Figures 9, 10, 11, 12 and 13. The influence of the volumetric shrinkage strain with respect to the initial degree of saturation was investigated for various bagasse ash treatment levels and at different compactive efforts. Generally, the volumetric shrinkage strain increased for all compactive efforts as the initial degree of saturation increased. This trend was observed for all compactive energy levels irrespective of the bagasse ash content. The deflocculated particles reflected the capillary tension developed, this resulted in the relatively ease of particle movement, and this is brought about as a result of more water being present in the soil as the degree of saturation increased (Osinubi and Eberemu, 2010b; Moses and Afolayan, 2013). The untreated foundry sand (see Fig. 9) was compacted at an initial degree of saturation in the ranges of 62.3-84.0%, 62.5-87.7%, 43.3-69.3% and 57.7-87.7% at the energy levels of RBSL, BSL, WAS and BSH, respectively. For the untreated foundry sand, only two energy levels produced satisfactory volumetric strain values at 43.3-69.3% and 57.7-87.7% at energy levels of WAS and BSH, respectively.

At 2% bagasse ash treatment (see Fig. 10), the specimen was compacted at an initial degree of saturation in the ranges of 61.8-87.5%, 58.6-80.7%, 49.4-78.4% and 47.7-85.7% at RBSL, BSL, WAS and BSH compactive effort, respectively. All four energy levels produced satisfactory volumetric strain values at 61.8-84.0%, 58.6-80.7%, 49.4-78.4% and 47.7-85.7% at RBSL, BSL, WAS and BSH compactive effort, respectively. This indicates a marked deviation from the recorded trend for the untreated foundry sand specimen. This can be attributed to the pozzolanic input of the bagasse ash which reduces the fine grained soils (Osinubi and Eberemu, 2010b; Moses and Afolayan, 2013). At 4% bagasse ash treatment with specimen compacted at an initial degree of saturation in the ranges of 60.9-80.0%, 62.2-83.5%, 48.6-82.9% and 71.8-82.7% at RBSL, BSL, WAS and BSH compactive effort, respectively (see Fig11), generally a decrease in the volumetric strain for all four energy levels was recorded with satisfactory volumetric strain values at 60.9-79.0%, 62.2-80.1%, 48.6-75.0% and 71.8-82.7% at RBSL, BSL, WAS and BSH compactive effort, respectively.

Similarly, the observed trend at 6% bagasse ash treatment shows an improvement, because it produced (see Fig. 12) better acceptable shrinkage strain values. Specimens were compacted at an initial degree of saturation in the ranges of 64.4-89.1%, 57.5-85.7%, 59.1-94.3% and 53.9-90.3% at RBSL, BSL, WAS and BSH compactive effort, respectively. Generally, a decrease in the volumetric strain for all four energy levels was recorded with satisfactory volumetric strain values at 64.4-86.3%, 57.5-85.1%, 59.1-92.2% and 53.9-89.9% at RBSL, BSL, WAS and BSH compactive effort, respectively. Finally, 8% bagasse ash treatment (see Fig. 13) recorded further improvement in the volumetric strain values with specimens compacted at an initial degree of saturation in the ranges of 66.6-99.1%, 66.6-96.2%, 62.8-93.3% and 49.4-87.1% at RBSL, BSL, WAS and BSH compactive effort, respectively. Generally, a decrease in the volumetric strain for all four energy levels was recorded with satisfactory volumetric strain values at 66.6-99.1%, 66.6-95.0%, 62.8-92.0% and 49.4-87.1% at RBSL, BSL, WAS and BSH compactive effort, respectively. Generally, the inclusion of bagasse ash resulted in satisfactory volumetric strain results at all four energy levels: this can be attributed to the pozzolanic input (Osinubi and Eberemu, 2010b; Moses and Afolayan, 2013) of the bagasse ash which reduces the fine grained soils. It was shown that higher compactive effort generally recorded less volumetric shrinkage strain values, and this is consistent with previous works (Haines, 1923; Albercht, 1976; Albrecht and Benson, 2001; Moses and Oriola, 2010; Osinubi and Eberemu, 2010b; Moses and Afolayan, 2013).

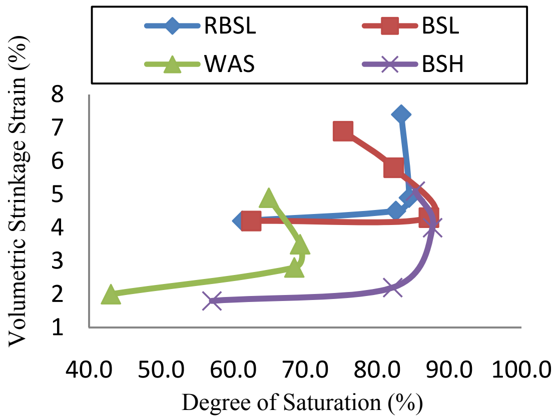

Figure (9): Variation of volumetric shrinkage strain with degree of saturation for 0% bagasse ash treatment

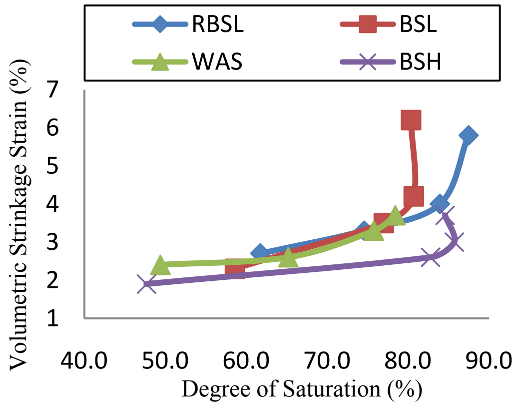

Figure (10): Variation of volumetric shrinkage strain with degree of saturation for 2% bagasse ash treatment

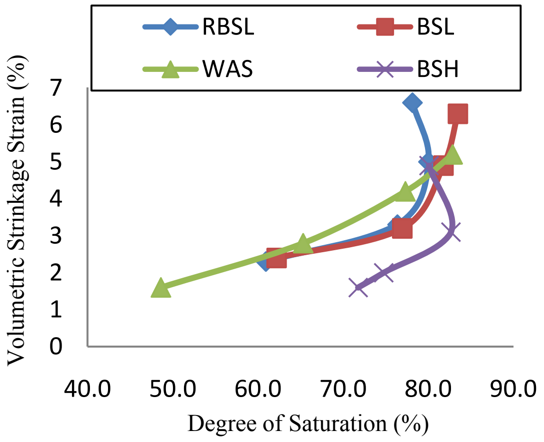

Figure (11): Variation of volumetric shrinkage strain with degree of saturation for 4% bagasse ash treatment

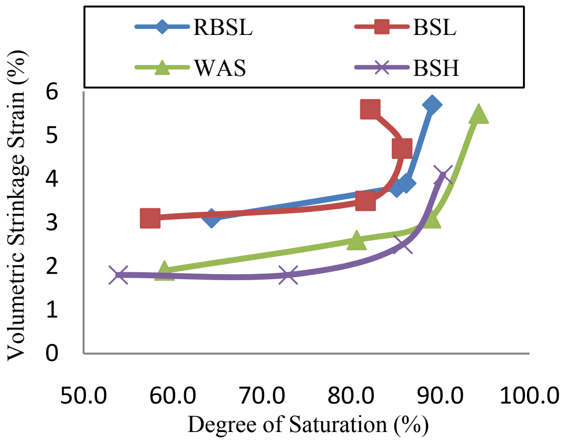

Figure (12): Variation of volumetric shrinkage strain with degree of saturation for 6% bagasse ash treatment

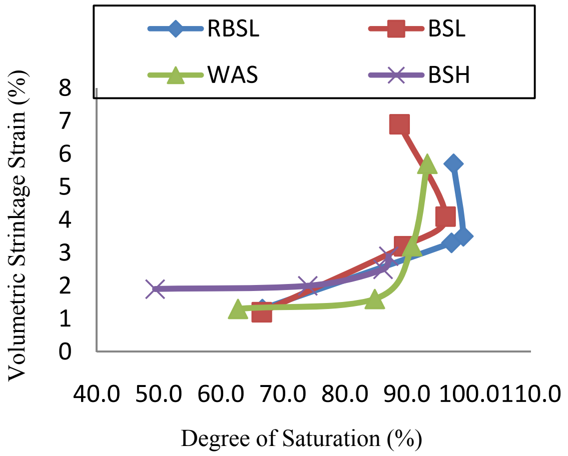

Figure (13): Variation of volumetric shrinkage strain with degree of saturation for 8% bagasse ash treatment

The Influence of Compactive Effort on Volumetric Shrinkage Strain at Different Treatment Levels

The influence of compactive effort on volumetric shrinkage strain at different treatment levels is shown in Figure 14. Generally, the volumetric strain reduced with increasing bagasse ash content at OMC at all the energy levels. This is largely attributed to the pozzolanic input of bagasse ash (Osinubi and Eberemu, 2009b, 2010b; Moses and Afolayan, 2013). However, at higher compactive effort, an optimum value of ash content is attained, where no further significant change is observed in the volumetric strain values (Moses and Afolayan, 2013).

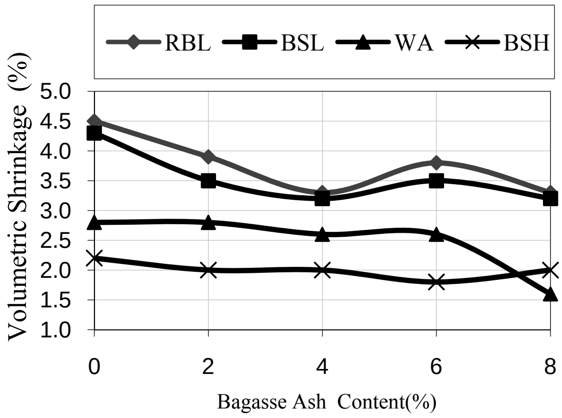

Figure (14): Variation of volumetric shrinkage strain with bagasse ash content

CONCLUSIONS

Laboratory tests were carried out on foundry sand (an industrial waste) treated with up to 8% bagasse ash (a pozzolana as well as an agricultural waste) to assess the influence of desiccation-induced volumetric shrinkage strain on the material for use as liners and covers in waste containment systems.The non-plastic foundry sand was classified as A-2-4(0) and SM according to AASHTO and USCS classification systems. Bagasse ash treated foundry sand did not yield any significant improvement in the index properties of the mixtures. Specimens prepared at molding water contents of 2% dry of optimum, 0% optimum moisture content, 2% and 4 % wet of optimum moisture, were compacted at four energy levels: Reduced British standard light (RBSL), British standard light (BSL), West African Standard or 'intermediate' (WAS) and British standard heavy (BSH) efforts.

Based on the regulatory value ≤ 4% for an acceptable volumetric shrinkage strain (VSS), VSS recorded a decrease in value with higher bagasse ash treatment at higher and lower molding water content, up to 4% bagasse ash treatment level. VSS generally increased with higher initial degree of saturation for all compactive efforts, irrespective of the level of bagasse ash treatment. Finally, at 6% and 8% bagasse ash treatment, no further change in volumetric strain values was observed. This confirmed that further addition of bagasse ash after optimum treatment level of 4% bagasse ash content produced little or no difference in the volumetric strain values. Thus, higher compactive efforts have less moisture to complete or meet the hydration demands of treated specimens at higher bagasse ash treatment levels.

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