Effect of Cashew Nut Shell Ash on Volumetric Shrinkage of Compacted Clay Soil

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ORIGINAL RESEARCH

Abstract- Hydraulic conductivity value of a compacted clay soil can rise above the minimum regulatory value during desiccation thereby induces large cracks in an engineered landfill. In the quest to reduce the degree of cracking that will be generated dues to the volumetric shrinkage of the compacted clay soil, which in turn will reduce the amount of leachate that will be percolating into the underground water system, an investigation was performed by treating a clay soil with up to 16% Cashew Nut Shell Ash (CNSA) content using three compactive efforts (Standard proctor (SP), West African standard (WAS) and Modified Proctor (MP)) at -2, 0, 2 and 4% of optimum moisture content (OMC). Samples were extruded from the compaction moulds and placed on the laboratory table to air dry for 30 days at a uniform regulated temperature of 27 ± 2^{O}c in order to evaluate the suitability of the material for the construction of cover and liner in an engineered landfill. Results indicated that the OMC and maximum dry density (MDD) increased with higher CNSA treatment. Volumetric shrinkage strain (VSS) increased with; higher CNSA, higher moulding moisture content and moisture content relative to the optimum. Effect of CNSA on the soil showed that all specimens prepared at 2% dry of optimum to 4% wet of optimum for 4% and 8% soil-CNSA mixtures for the three compactive efforts, met the maximum allowable regulatory VSS criterion of4%, thus making the material suitable for the construction of cover and liner in waste dumping ground.

Keywords- Cashew nut shells ash, Clayey soil, Engineered landfill, Melding moisture content, Volumetric shrinkage strain.

1 Introduction

With increased industrialization and large quantities of waste being generated and deposited on a daily basis in waste containment sites, leachates emanating from the dumping sites pose harmful effects on the earth's subsurface most especially the water bodies beneath the earth's surface. When percolated into the soil, the leachates can pollute the earth and the underground water system with toxic substances; these toxic substances are normally organic chemicals which are very hazardous to humans and the environment (Eberemu et al., 2011).

The percolation of contaminants into the water bodies beneath the earth's surface, through the cracks generated as the result of continues wetting and drying of the waste containment systems can be minimised by dumping the wastes in an engineered landfill with a cover and liner in any of the following forms; compacted in-situ clay, compacted borrowed clay from another source and a geomembrane or a synthetic material (Osinubi and Eberemu, 2010). The cover serves as a cap that reduces the amount of precipitation that enters into the wastes deposited in the engineered landfill thereby preventing the generation of leachates and the main purpose of the liner is to avert the flow of leachates generated in the engineered landfill from seeping into the soil and water bodies beneath the earth's surface.

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Volumetric shrinkage is the decrease in volume of a soil mass during desiccation. It is the function of quantity of water to quantity of soil when saturated (George et al., 2019). Soil samples with high percentage of fine content and high plasticity index may experience large volumetric shrinkage during desiccation (Eberemu et al., 2011). Large cracks, heave and subsidence can occur in waste dumping sites during desiccation. Cracks develop at the surface and spread deeper inside their matrix as the numerical values of hydraulic conductivity increase (Khire et al., 1997) thus allowing the flow and infiltration of leachates into the soil and water bodies beneath the earth's surface.

During materials consideration and selection, the paramount properties to be considered in selecting the most suitable materials for the construction of cover and liner in a waste containment facility is VSS. Daniel (1993) recommended that for any materials to be selected for the construction of cover and liner, the maximum VSS should be 4%. Hence, to recommend a suitable material for the construction of cover and liner which can withstand environmental stresses, stabilization of clayey impermeable soils becomes paramount (Olumide and Jonathan, 2019). Various stabilization materials such as, rice husk ash, lime, asphalt, fly ash, blast furnace slag, aqueous polymers and bagasse ash have been shown by researchers to improve the shrinkage properties and dust generation of compacted clay soils for up to 15% treatment (Osinubi and Eberemu 2010, George et al., 2019 and Eberemu et al., 2011). This study looks into the performance of CNSA for the treatment of clay soil because of the availability of the material.

The rate of production of cashew (Anacardium occidentale L.) has increased in Nigeria since the past ten years due to high demand of the nuts. Cashew is an important tropical crop with spreading branching which can attain the height of 9–14 meters. The tree was mainly used in afforestation schemes for the control of erosion specifically in the Eastern part of Nigeria (Olunloyo, 1996) but now the production has spread all over the country. Nigeria produces about 120,000 tons of dried cashew nuts annually and is the sixth largest producer in the universe (Offor et al., 2019). Cashew nut shell is the residue obtained after milling the cashew nut, usually disposed indiscriminately or burnt off. Large quantities are dumped after processing the nut which in turn, pollutes the environment. CNSA is obtained from the cashew nut shell combusted at a very high temperature.

The aim of this study is to investigate the effect of CNSA on the volumetric shrinkage of compacted clay soil in order to assess the suitability of the material for the construction of cover and liner in an engineered landfill. The utilization of CNSA to enhance the soil characteristics will go a long way to safeguard the environment and actualize the desires of most developing nations for using locally available agricultural waste products for construction activities to minimize cost

2 Materials and Methods

2.1 Materials

Soil: The clay soil used in this study was collected at a depth of 1m along the roadside at Waterboard area (7.076367O, 6.252032O), Auchi, Edo State. Details of the soil parameters are presented in table 2.

CNSA: Cashew nut shells were sourced from Kogi State. The cashew nut shell was dried in the sun for fourteen days and then burnt for 5 hours at a temperature of 750^{o}c in a gas furnace to obtain the ash (CNSA). BS No. 200 sieve was used to sieve the ash. At an incremental step of 4% ranging from 0% to 16%, the CNSA was mixed with the clay soil to obtain four different specimens for the analysis. Oxide composition of the CNSA used which was determined via XRF analyser, Model PW-1800, is presented in Table 1.

Table 1. Oxide Composition of CNSA used

Oxide	Concentration (%)
SiO_2	62.38
Al_2O_3	14.78
CaO	0.91
Fe_2O_3	11.86
MgO	1.53
K_2O	0.52
SO_3	0.98

2.2 Methods

Index Characteristics: Index characteristics of all the five specimens used were determined according to the procedures outlined in British Standard BS1377 (1990). The relationship between moisture and density were examined using the dried samples which passed through BS No.200 sieve. Mixtures of dried soil and CNSA to obtain the various specimens were done by weight.

Compaction: SP and MP compaction tests carried out in this study were in accordance with the procedures outlined in BS1377 (1990) while WAS compaction test was in compliance with the procedures outlined in the Nigeria General Specification (1997). The major differences between the WAS and MP compaction procedures are that only 10 blows of the rammer per lift were applied in WAS while 27 blows applied in MP. These three types of compactive efforts were examined in order to simulate the likely compaction energies that may be carried out on the field.

Volumetric Shrinkage: Extruded specimens from the compaction apparatus were placed on the laboratory table as shown in figure 1, to air dried for a period of 30 days at a uniform regulated temperature of 27 ± 2^{o}c. Using a digital vernier calliper, three measurements of heights and diameters of each extruded samples were taken every five days and the average values were used to calculate the VSS using equation 1:

$$VSS = \frac{V_i - V_c}{V_i} \quad (1)$$

Where; Vi is the initial volume of wet compacted extruded sample and Vc is the current volume of the drying compacted extruded sample.

Fig. 1: Drying of specimens on the laboratory table

3 Results and Discussion

3.1 Index Characteristics

Summary of the index characteristics of the specimens is presented in Table 2. The soil contains Illite/Smectite as dominant minerals and the overall index characteristics shows that the soils are considered as low plasticity clay CL according to unified soil classification system (ASTM, 1992) and A-6(8) according to AASHTO soil classification system (AASHTO, 1986). The plasticity indices decreased with high CNSA content due to decrease in liquid limit and increased in plastic limits. Soils having higher plasticity indices and liquid limits would have high percentage of clay particles and would yield lower hydraulic conductivities (Benson et al., 1994). Hitherto, Rowe et al. (1995) and Daniel (1993) recommended that for any materials to be considered for the construction of cover and liner (hydraulic barrier) in an engineered landfill, the plasticity index should be greater than 7% thus the various specimens (soil-CNSA mixes) examined in this study can be selected for the construction of cover and liner in waste containment sites.

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Table 2. Index and compaction properties of the samples used

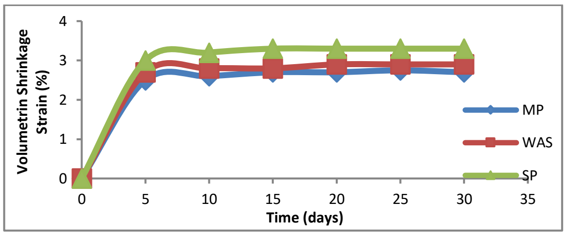
Property	Cashew Nut Shell Ash Content (%)				
	0	4	8	12	16
Liquid limit (%)	32.8	31.4	31.3	29.6	27.9
Plastic limit (%)	14.4	15.8	17.6	18.4	18.7
Plasticity index (%)	18.4	16.6	13.7	11.2	9.2
Linear shrinkage (%)	12.4	10.2	9.7	8.6	6.4
% passing BS. No. 200 sieve	58.63	54.18	56.47	54.84	56.62
AASHTO Classification	A-6(8)	A-6(7)	A-6(7)	A-6(4)	A-7-6(1)
USCS Classification	CL	CL	CL	CL	CL
Specific gravity	2.52	2.56	2.60	2.64	2.70
Maximum dry density [Mg/m3]					
Standard Proctor	1.32	1.41	1.52	1.58	1.60
West Africa Standard	1.44	1.49	1.57	1.69	1.84
Modified Proctor	1.57	1.62	1.79	1.85	1.94
Optimum moisture content [%]					
Standard Proctor	12.6	14.2	16.4	21.6	22.8
West Africa Standard	12.0	13.4	14.2	19.4	21.3
Modified Proctor	11.2	12.2	13.1	16.8	18.2

3.2 Compaction Characteristics

As summarised in table 2, the OMC and MDD increased respectively with higher CNSA treatment. The increase in OMC with higher CNSA treatment could be as a result of additional fines aggrandised to the soil sample, which increased the surface areas and required more moisture for hydration. Similarly, the increase in MDD with higher CNSA treatment could be as a result of the high specific gravity of the CNSA which is 2.67 compared to the specific gravity of the natural soil which is 2.52. It was also observed that, MDD increased while OMC decreased with higher compactive efforts for all the extruded specimens.

3.3 Volumetric Shrinkage Strain (VSS)

VSS is proportional to moulding moisture content. Variation in VSS over time prepared at OMC for all samples for the three compactive energies are shown in figure 2a-e. The VSS were affected by the compactive efforts. The computed values were observed to be higher at lower compactive energies due to the high amount of moulding moisture content.



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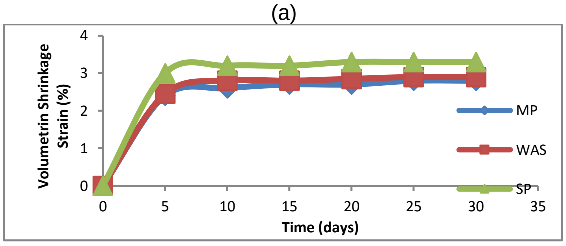

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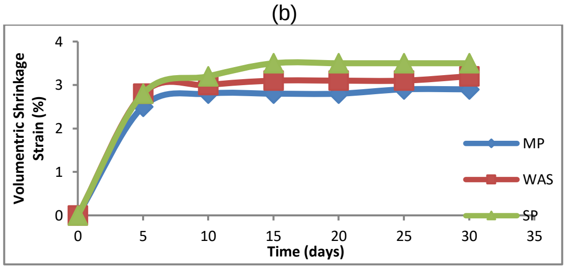

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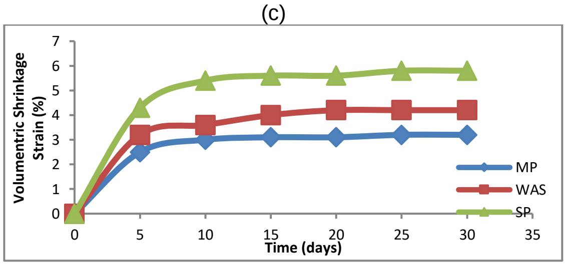

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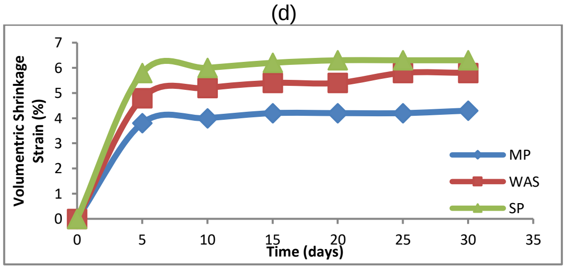

(e)

Fig. 2: Variation of VSS with time at the OMC for (a) 0% CNSA (b) 4% CNSA (c) 8% CNSA (d) 12% CNSA (e) 16% CNSA

3.4 Effect of Moulding Moisture Content

An increased in VSS was observed with higher moulding moisture content as shown in figure 3a-c. Specimens prepared at higher moulding moisture content stored more water in their void spaces thus shrank more during desiccation. VSS is also proportional to the amount of fineness of the soil sample. If two specimens collected from the same source but different fabrics are at the same initial moisture content, the sample that is more dispersed and deflocculated will shrink most during desiccation due to smaller pore size.

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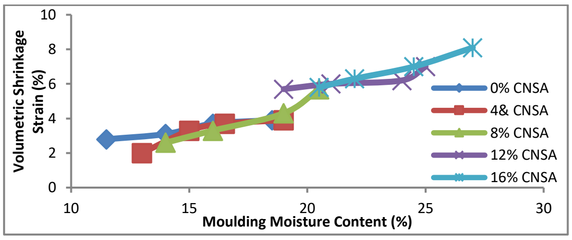
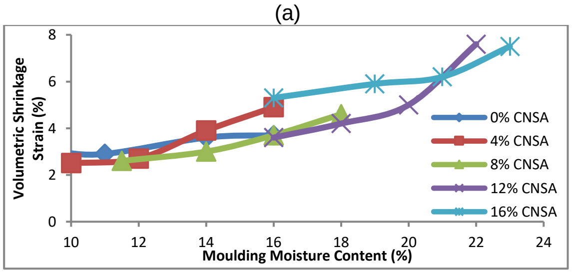


(a)



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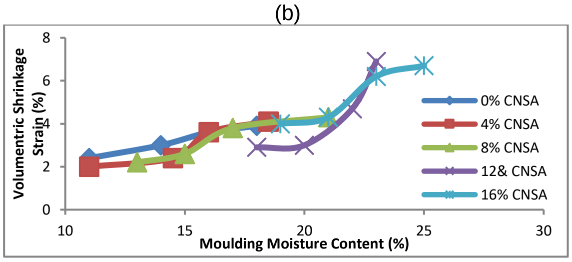


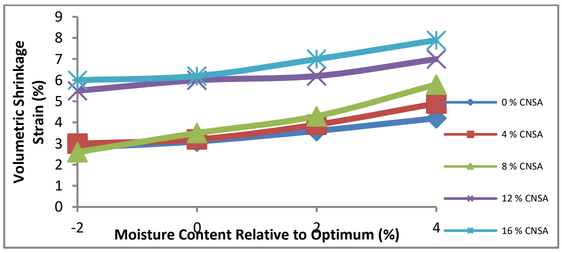
(c)

Fig. 3: Variation of VSS with moulding moisture content (a) SP (b) WAS and (c) MP

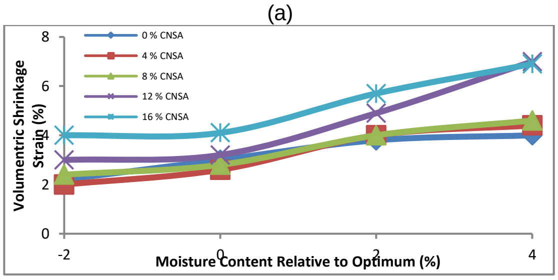
Results of specimens compacted between -2% to 4% of the OMC for all the three compactive energies for the natural soil falls between the allowable maximum VSS value of 4%. On treatment with 4% CNSA, the maximum VSS value of 4% was recorded for all specimens except for specimens compacted at 4% OMC for WAS and MP. For 8% CNSA, specimens compacted at 4% OMC for all compactive efforts and at 2% OMC for SP falls outside the maximum VSS value of 4%. On treatment with 12% CNSA, only the soil compacted at -2% dry of OMC for WAS and MP and soil compacted at OMC for MP falls between the maximum VSS value. While on treatment with 16% CNSA, the results fell totally above the allowable value for all compactive efforts. The result shows that the moulding moisture content, at which the recommended 4% VSS criterion was achieved, increased with higher CNSA treatment.

3.5 Effect of Moisture Content Relative to Optimum

Computed VSS result was observed to be heightened with higher moulding moisture content relative to optimum as presented in figure 4a-c. All extruded specimen prepared between 4% wet of optimum and 2% dry of optimum for all compactive efforts prepared with 0% CNSA, 4% CNSA (excepts for specimen compacted at 4% OMC for WAS and MP), 8% CNSA (excepts for specimen compacted at 4% OMC for all compactive efforts and 2% OMC for SP) and for 12% CNSA sample compacted at -2% OMC and 0% OMC for MP and sample compacted at -2% OMC for WAS met the maximum permissible VSS values of 4%.



(a)



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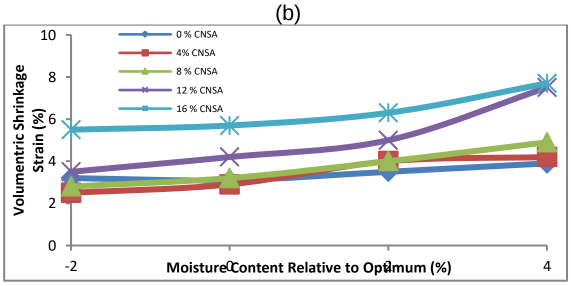

(c)

Fig. 4: Variation of VSS with moisture content relative to optimum (a) SP (b) WAS (c) MP

3.6 Effect of CNSA Content

VSS heightened with higher CNSA treatment as shown in figures 5a-c. For SP, specimens processed at -2% and 4% wet of optimum for 4% CNSA, 8% CNSA up to OMC for 12% CNSA treatments met the permissible maximum regulatory VSS result of 4%. Conversely, specimen with CNSA contents greater than 12% and compacted at 2% and 4% wet of optimum could not fulfil the VSS criterion. For WAS, specimens prepared at -2% and 2% wet of optimum and for 4%, 8% and 12% CNSA treatment, respectively, met the VSS criterion. Specimens processed with CNSA contents higher than 12% and at 4% wet of optimum for 12% CNSA treatment did not fulfil the VSS criterion. For MP, specimens processed at -2% and 2% wet of optimum up to 8% CNSA contents, and specimens processed at 2% wet of optimum for 12% CNSA contents also met the VSS criterion. While specimens processed with CNSA contents higher than 12% and for 2% dry of optimum up to 4% wet of optimum for 12% CNSA, gave VSS values greater than 4%. Monitoring the CNSA treatment and VSS behaviour shows that higher CNSA treatment results in addition of more fines with larger surface areas to the mixture thus require much moisture for hydration.

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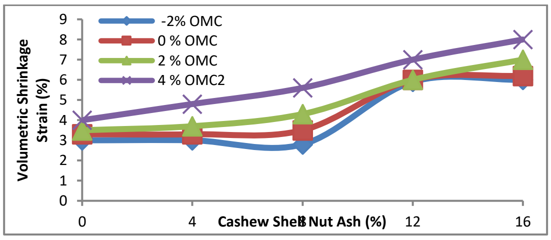
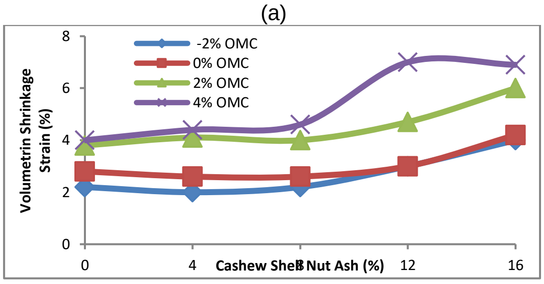


(a)



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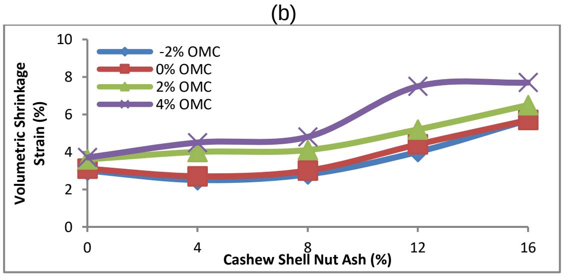

(c)

Fig. 5: Variation of VSS with CNSA (a) SP (b) WAS (c) MP

4 Conclusion

The following conclusions are drawn based on the findings from this research; MDD and OMC heightened with higher CNSA treatment. Mass of all the compacted extruded specimens and their VSS result computed were high within the first five days of the laboratory drying and it became constant at the fifteen days due to total loss of moisture as the cavity pressure decayed to zero. VSS values heightened as the moulding moisture content relative to optimum increases. All extruded specimens processed at 4% wet of optimum and 2% dry of optimum for 4% and 8% treatment with CNSA for all compactive efforts, met the regulatory maximum allowable VSS criterion of 4%. Based on the result of this finding, 4% to 8% CNSA (by weight) content should be added to a clayey soil to be used for a construction of covers and liners in an engineered landfills as this will improve the soil compressibility characteristics irrespective of the placement condition between wet and dry of optimum moisture content. Also, it will enhance the absorptive capacity for critical pollutants from leachate such as heavy metals, thereby reducing the degree of cracking and dust generation that may developed due to continue wetting and drying of the waste containment facility which in turn will prevent the entering of precipitation into the wastes and also avert the infiltration of leachates from the engineered landfill into the underground water system and the earth's subsurface.

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