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Volumetric Shrinkage of Compacted Soil Liner for Sustainable Waste Landfill

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One of the main principal sources that contributes to the release of leachates in the environment is the municipal solid waste in landfill facilities. To mitigate the negative effects of leachate, landfill liner is constructed to provide a protective barrier that will not allow the leachate to pass through the compacted soil, which may cause groundwater contamination. Due to seasonal variation in tropical regions, compacted or natural soil liners tend to lose moisture when dry. This result to volumetric shrinkage, which causes cracks that affect the engineering properties and performance of the soils. Groundwater can easily be affected by leachate permeating through these cracks in soils because of desiccation induced by volume change. This paper aims to evaluate the effect of fines content at various gradation and moulding water content on volumetric shrinkage property of compacted laterite soil; and to compare the results with the regulatory standard for compliance to mitigate the negative effects of leachate on the environment. The technique used in this study was to vary the gradation of laterite soil at different moisture contents to achieve a sustainable result. It is observed that the volumetric shrinkage increase as the percentage of fines content increase with corresponding water content. The changes in volumetric shrinkage with time shows a sharp increase within the first five to ten d of drying and then become constant. The soil needs to be compacted on the dry side of optimum moisture content or at the optimum moisture content in order to meet the regulatory criteria of ≤ 4 %.

1. Introduction

Environmentally, sustainability is anything that is not harmful to the environment and supports long-term ecological balance. It entails maintenance and enhancement of the environmental, social, and economic resourceful domains (Kayan et al., 2017). Engineering design can sustainably be incorporated in waste management framework to reduce the impacts on environmental and economic aspects. Careful design and management of landfills within the context of the available resources and local infrastructure can provide a cost-effective and safe disposal of waste, as the landfill is the most common solid waste treatment options in most parts of the worlds (Othman et al., 2017).

This research looks on how to sustainably design a compacted soil liner using tropical laterite soil. Laterite soil is found in the tropical regions of the world in abundance. It is used in many aspect of engineering, such as roads construction, building of houses, embankments, and recently soil liners. For a laterite soil to be effective as a barrier material (liner) in waste disposal facilities, it is expected to contain appreciable quantities of fines that enables the soil in its compacted state to yield low hydraulic conductivity values of $\leq 1 \times 10^{-9}$ m/s (Osinubi et al., 2012). Soil having high fines contents normally yield low hydraulic conductivity values, but lateritic soils with high fines content might not be used as liners and covers because of their tendency to undergo high volumetric shrinkage (Osinubi and Nwaiwu, 2006). Volumetric shrinkage occurs in compacted soils during desiccation as a direct function of volume of water to volume of soil when saturated. Soils with high fines content and a corresponding high plasticity index are more inclined to large volumetric shrinkage during drying (Osinubi et al., 2012). The long-term performance of hydraulic barriers can be an issue particularly in tropical areas

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because of variations in climatic conditions connected with wetting and drying. These variations frequently result in soil volume change that cause cracks and provide an avenue of ways for leachate to pass through (Amadi, 2012). Landfill leachate comprises of various distinctive inorganic and organic compounds in dissolved or suspended form, containing heavy metals such as cadmium, chromium, lead, zinc, nickel and xenobiotic substances (Mendoza et al., 2017). This leachate jeopardize the wellbeing of not only humans and animals, but also the environment if permitted to permeate into under groundwater without protective measures to alleviate its movement (Bello, 2011).

The aim of the research is to evaluate the effect of fines content at various gradation and moulding water content on volumetric shrinkage property of compacted laterite soil; and to compare the results with regulatory standard for compliance to mitigate the negative effects of leachate on the environment.

2. Methodology

Laterite soil collected from site was air dried and sieved through 4.75, 2 and 0.63 mm British Standard sieve. The gradations of laterite soil specimen investigated at different moulding water contents of - 4 %, - 2 %, 0 % (Optimum Moisture Content, OMC), + 2 % and + 4 % are:

a) 30, 30 and 40 percent of fines, gravel and sand, denoted as L1.
b) 20, 40 and 40 percent of gravel, sand and fines, denoted as L2.
c) 10, 40 and 50 percent of gravel, sand and fines, denoted as L3.

These gradations were selected to check the ones that comply with regulatory standards requirement of ≤ 4 %, which has been generally specified by most researchers and environmental agencies for volumetric shrinkage at various water contents (Yamusa et al., 2017). Any soil that exceed 4 % volumetric shrinkage strain when desiccated cannot be used as liner in waste containment applications.

Air-dried soil at various gradations were compacted in accordance to the procedures outlined in the BS 1377:1990 at - 4 %, - 2 %, 0 %, + 2 % and + 4 % with respect to the OMC. Then the samples were extruded out of the cylindrical moulds and placed on a bench in the laboratory at a constant temperature of 26 ± 2 ºC for 30 d to dry. A Vernier calliper accurate to 0.05 mm was used to take daily measurements of the diameters and heights for each sample. Volumetric shrinkage strain was computed by using the average diameters and heights (Eberemu, 2011).

3. Results and Discussion

Index properties results of laterite soil from the laboratory tests is shown in Table 1. The soil is classified as very high plasticity sandy silt with gravel (MV) according to the British Standard code of practice for site investigations.

Table 1: Index Properties of Laterite Soil

Parameters	Value
Natural Moisture Content	34 %
Specific Gravity	2.7
% Passing BS 63µm sieve	30 %
Optimum Moisture Content, OMC	30 %
Maximum dry density, MDD	1.35 mg/m^3
Liquid Limit, LL	76 %
Plastic Limit, PL	42 %
Plasticity Index, PI	34 %
BS Classification	MV

3.1 Effect of Time

The changes in Volumetric Shrinkage Strain (VSS) with time at different Moulding Water Contents (MWC) for L1, L2 and L3 are shown in Figures 1, 2, and 3. There is sharp increase in VSS within the first five to ten d of drying in all gradations. Thereafter, the gradations gradually become constant until fully dried. Volumetric shrinkage strain is proportional to moulding water content i.e. the higher the MWC, the higher the VSS. As the fines content increases the VSS also increases. L3, which has the highest fines content of 50 %, records the largest values of VSS.

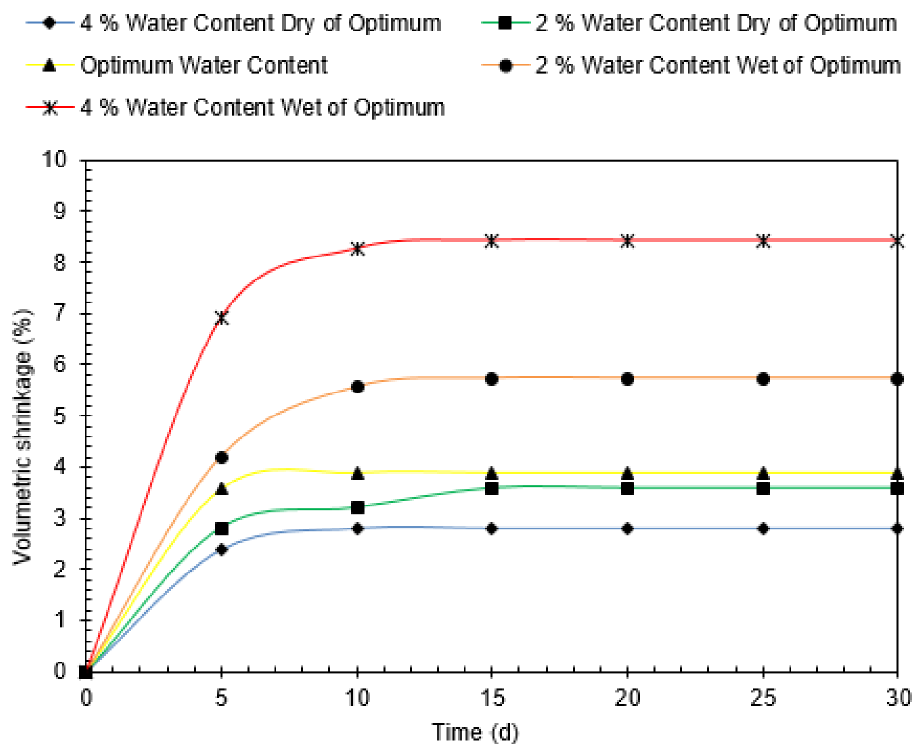

Figure 1: Volumetric shrinkage strain against time for L1

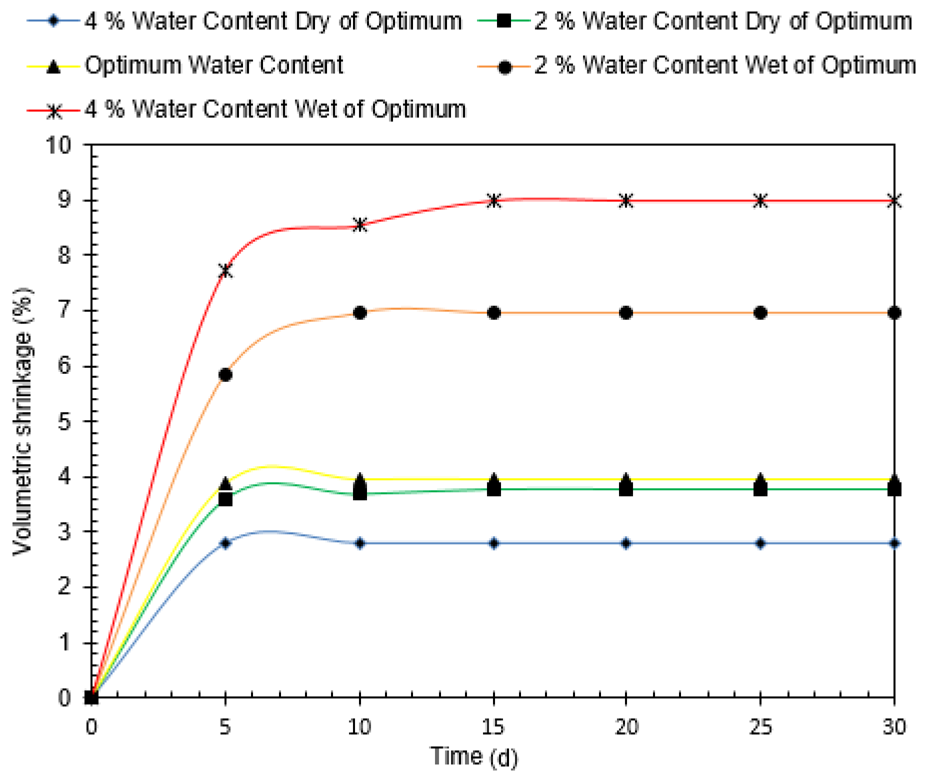

Figure 2: Volumetric shrinkage strain against time for L2

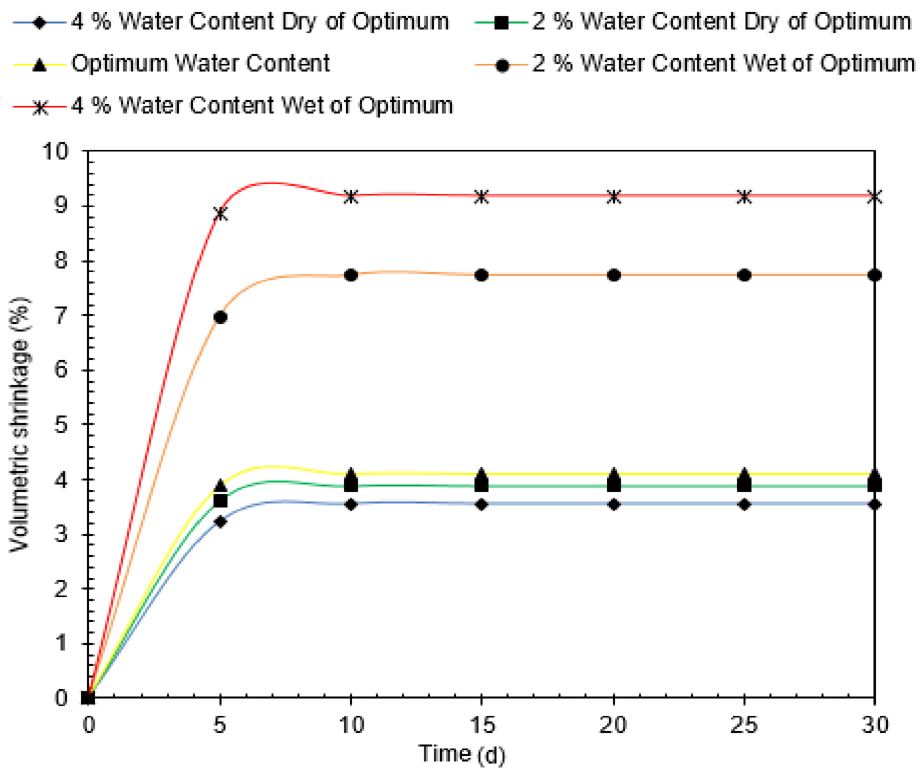

Figure 3: Volumetric shrinkage strain against time for L3

3.2 Effect of Moulding Water Content

Hydraulic integrity of fine-grained soils is often lost due to desiccation cracking during their designed expectancy span. To achieve a low hydraulic conductivity in soil liners, soils are compacted on the wet side of optimum water content (Amadi, 2012). Nonetheless, such condition results in high shrinkage values, which was also the case in this study. The variation in VSS at different moulding water contents is shown in Figure 4

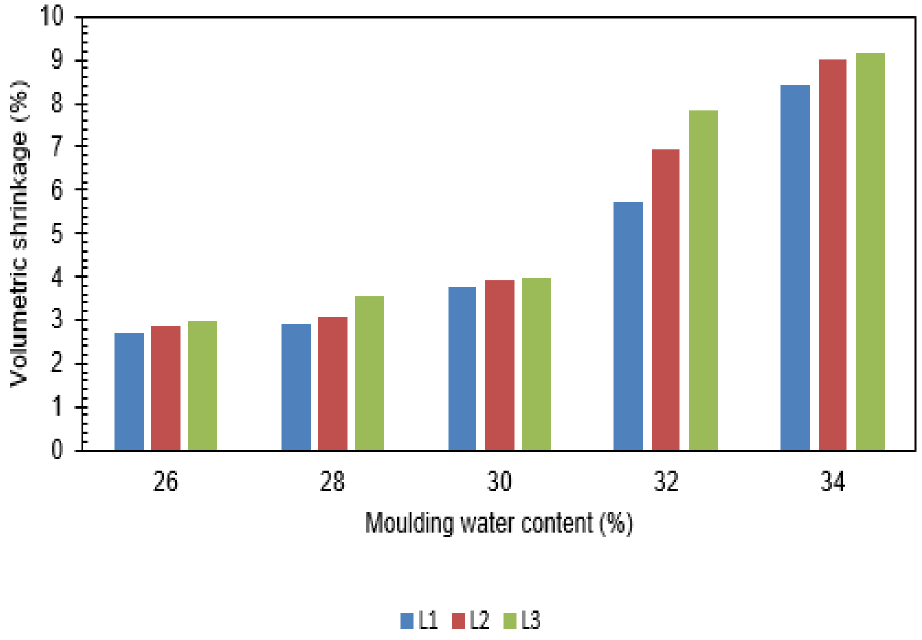

Figure 4: Volumetric shrinkage against moulding water content

Laterite soil specimens prepared at moulding water contents on the wet side of the OMC did not record satisfactory VSS results irrespective of the fines content. All the soil specimens prepared on the dry side of the OMCs and OMCs recorded lower VSS values than those on the wet of the OMCs. Generally, VSS increased with higher moulding water content (Osinubi and Eberemu, 2008) volumetric shrinkage is proportional to volume of water leaving the pore spaces of compacted soil samples (Osinubi and Eberemu, 2008). As moulding water contents is higher, it covers and fills more void spaces in the soil sample, which lead to higher shrinkage on drying.

3.3 Effect of Fines Content

The volumetric shrinkage strain shows great variation with fines content at different moulding water content as shown in Figure 5. In this study, specimen compacted at higher percentage of fines content shrinks more during drying than at lower fines content. This is because soils with higher fines content have a greater affinity for water (Bello, 2011). Volumetric shrinkage strain increased with increasing plasticity index and clay content (Albrecht and Benson, 2001). The acceptable VSS values of ≤ 4 % were recorded at the OMC and on the dry side of the OMC. In this experiment, L1, L2 and especially L3 on the wet side of OMC had undergone high volumetric shrinkage that can provide access to leachate to contaminate groundwater.

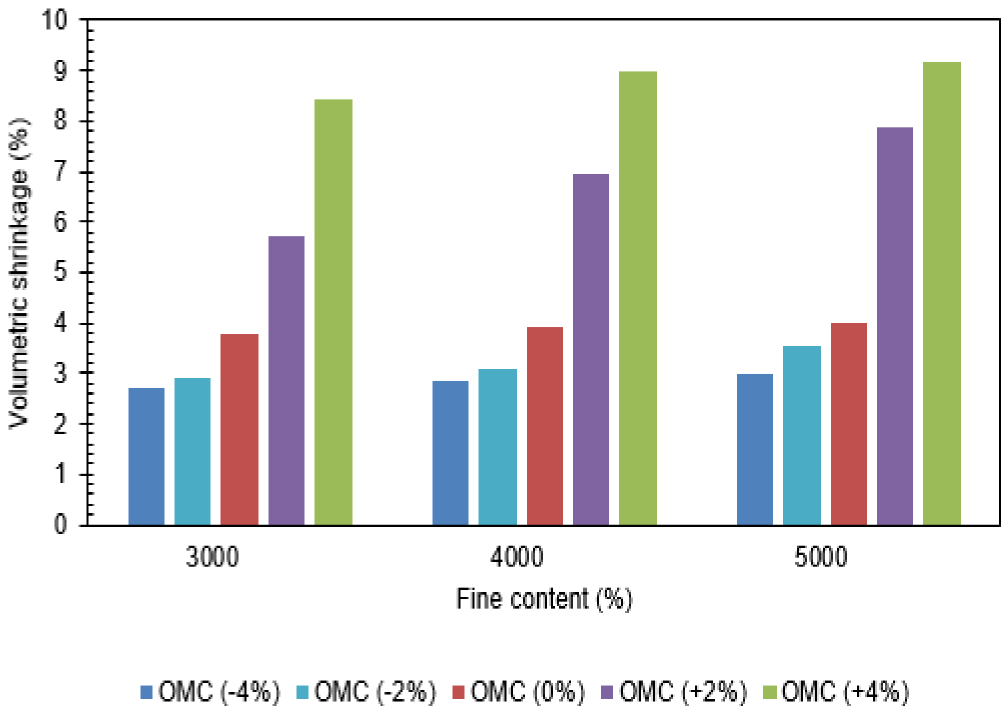

Figure 5: Volumetric shrinkage against fines content

4. Conclusion

Tropical laterite soil samples were prepared at different fines and moulding water contents and left to dry in the laboratory. Between the dry and wet sides of optimum moisture content, there was significant change in volumetric shrinkage strain. VSS increased substantially towards the wet side and decreased gently towards the dry side of optimum. Based on the overall outcome of this study, higher volumetric shrinkage occurred on various gradations on the wet side of optimum moisture contents that can lead to creating pathways for leachate to contaminate groundwater aquifers. Hence, the laterite soil should be compacted on OMC or the dry side of OMC for a sustainable solution based on environmental point of view.

The volumetric shrinkage properties of the soil should be appropriately evaluated to sustainably design and construct sanitary waste landfills. Proper design would prevent failures associated with hydraulic barriers in sanitary landfills that are caused due to wet and dry seasons in tropical regions of the world. It is suggested that more variation of gradations at different moulding water contents should be investigated to find their effect on volumetric shrinkage due to seasonal changes in tropical regions. The effects of fines content on shear strength and hydraulic conductivity of compacted laterite soils at various gradations and different moulding water contents are also encouraged to be investigated.

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