SHRINKAGE CHARACTERISTICS OF COMPACTED LATERITE SOIL–FLY ASH MIXTURES

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ABSTRACT:

Low design tolerance for shrinkage is a critical requirement for soils used in most engineering projects such as barriers and covers in waste disposal facilities. To meet this requirement, emphasis has to be put on the dimensional changes that occur in the material with variations in composition and compaction conditions. In this study, volumetric shrinkage strain of compacted laterite soil admixed with locally generated fly ash subjected to desiccation under laboratory conditions are presented. The tests were conducted on mixtures of laterite soil and varying percentages of fly ash (0 – 20%) by weight of dry soil prepared at moulding water contents of between 10 – 20% using three energy levels that represent compaction energies expected in the field at no compaction delay. Experimental data was used to explore relationships between shrinkage strain and the identified variables, that is, plasticity index, moulding water content and compaction energy. Results obtained indicate that volumetric shrinkage strain decreased with increase in fly ash content to values as low as 0.08% for 20% fly ash content. Specimens with fly ash content ≥15% on the dry side of compaction experienced increase in volume (i.e. swelling) resulting from greater moisture deficiency and random particle orientation. Relatively high shrinkage strain values (up to 8%) were observed at greater moulding water contents. A systematic trend between compaction energy and shrinkage strain could not be established from the data, and for all specimens, no visible cracks were observed regardless of the moulding water contents.

INTRODUCTION

The effect of shrinkage on soils rich in clay minerals often considered suitable for constructing barriers and covers in waste containment facilities can be of great concern from an engineering point of view. Construction specifications for such facilities typically require that the moulding water content fall within a specified range often 0 – 2 % wet of optimum (Benson *et al.*, 1999; Daniel and Benson, 1990; Daniel and Wu, 1993). This minimizes the hydraulic conductivity, a key parameter for soil barriers and covers. The major implication is that soils compacted wet of optimum contain more water and therefore undergo large volume changes during drying in areas where long term desiccation is experienced (Abrecht and Benson, 2001). The resulting shrinkage and shrinkage cracks may lead to ineffective barrier and cover systems. This is a great challenge to the geotechnical engineer who has to strike a balance between these two requirements and develop appropriate guidance for construction that will meet the objectives of low hydraulic conductivity and simultaneously have adequate resistance to shrinkage upon desiccation.

One of the measures outlined by Daniel and Wu (1993) to address the problem of desiccation of low hydraulic conductivity compacted soil barriers is the use of soils rich in sand that combine the attributes of low hydraulic conductivity and low shrinkage upon drying. Similarly, the addition of fly ash, which is a non-plastic material, can prove worthwhile in suppressing the shrinkage potentials of compacted lateritic soils and by extension the susceptibility of the soil to desiccation cracking. The purpose of this study therefore is to investigate the effectiveness of fly ash treatment in reducing volumetric shrinkage strain in compacted lateritic soils subjected to desiccation.

BACKGROUND

Field studies on shrinkage behaviour of clay barriers have shown that desiccation can induce severe cracking of unprotected soil barriers (Montgomery and Parsons, 1990; Boynton and Daniel, 1985; Khire *et al.*, 1997). Khire *et al.* (1997) have also shown that compacted clay barriers in earthen covers undergo seasonal changes in water content even at significant depth due to seasonal variations in precipitation and evapotranspiration.

Shrinkage tests by Dejong and Warkentin (1965) on mixtures of Leda clay and varying percentages of small glass beads revealed minimal to practically no shrinkage in bars containing less than 33% clay. Klepp and Olson (1985) investigated desiccation of two highly plastic clays and observed that the volumetric shrinkage strains induced by desiccation was linearly proportional to compaction water content but was sensitive to dry density and compaction energy. They also reported that shrinkage strains were far less in clayey sand than in soils with little sand. Similarly, research work on shrinkage behaviour of compacted soils by Boynton and Daniel (1985) revealed that cracks that fully penetrated 64mm thick compacted soil slabs developed in less than 24 hours. Daniel and Wu (1993) reported results specimens of clayey soils that were compacted with three compactive efforts over a range of water content between 10 to 20%. The results indicated that shrinkage increased with higher compaction water content but there was no clear trend between compaction effort and shrinkage strains. Phifer *et al.*, (1995) reported significant shrinkage strain values (~20%) on desiccated test specimens of processed kaolinite and natural kaolinite soil prepared to evaluate the effect of desiccation on hydraulic conductivity. However, no cracks were observed on the specimens.

Of recent, investigations have been carried out on the shrinkage characteristics of laterite soil. Nwaiwu (2003) conducted shrinkage tests when developing an acceptable zone for lateritic soil barriers in waste containment systems following methods described by Daniel and Benson (1990). Test specimens were subjected to four compaction efforts at moulding water contents between 10 to 25%. Volumetric shrinkage strain values up to 12.32% were reported while Eberemu (2003) reported improvement in volumetric shrinkage strains from 15% to 2% when the soil was stabilized with foundry slag.

All these studies demonstrate that in regions of long dry season, shrinkage and desiccation cracks can occur in compacted soil barriers and covers of waste containment facilities. Fly ash, a fine grained, non – plastic residue generated in power stations has been used extensively in the treatment of clayey soils. Ash content required are however dependent on the specific ash and soil type and must be evaluated for each situation (Ferguson, 1993).

Materials and Methods

Soil: The soil used in this study is a natural reddish brown lateritic soil collected from a borrow pit in Shika – Zaria, Nigeria (Latitude $11^{0}15'$ N and Longitude $7^{0}45'$ E). In a study of soil samples from this borrow pit; Osinubi (1998a) reported that kaolinite is the predominant clay mineral in the soil. The properties of the soil sample obtained in accordance with standard procedures outlined in BS 1377 (1990) and its oxide composition taken from Osinubi (1998a) are presented in Tables 1 and 2, respectively.

Fly Ash: The fly ash used is a waste product from Oji River thermal station in Enugu state. It is of the class F type having low calcium oxide content. The specific gravity of this ash is 2.06 and is non-plastic as are most fly ashes. Only fraction passing through BS sieve No. 200 was used throughout the test without additional treatment. The chemical composition of this ash is presented in Table 3.

TEST PROCEDURES:

Specimens containing fly ash (0, 5, 10, 15, 20%) were mixed with the relevant quantities of dry soil and fly ash and the required percentage of tap water (10, 12.5, 15, 17.5, 20%) based on the dry weight of specimen was added and thoroughly mixed until a uniform consistency was achieved. Plasticity tests were conducted following procedures outlined in BS 1377 (1990).

Specimens for compaction were prepared with three compaction efforts: the British standard Light (BSL), British Standard Heavy (BSH) compaction and West African Standard (WAS) compaction to simulate the range of compaction energies expected in the field. The BSL and BSH compaction procedures are described in BS 1377 (1990). The WAS compaction in accordance with Nigerian General specification (1970) is the conventional energy level commonly used in the region (Ola, 1980; Osinubi, 1998b).

Volumetric shrinkage strain was measured by extruding a compacted cylinder of specimen from the mould and allowed to dry slowly on a laboratory table. Measurements of the height and diameter of the specimen were made when there was no further decrease in weight. The average values of height and diameter were used to compute the volumetric shrinkage strain.

RESULTS AND DISCUSSIONS

Variations of volumetric shrinkage strain with some identified variables namely plasticity index, moulding water content, and compaction energy were developed using data obtained from the experiment and were examined to determine variables that are significantly correlated to shrinkage.

Plasticity Index (PI): The Plasticity Index (PI) of the soil was reduced from 22.22% for the natural soil to 3.54% for soil treated with 20% fly ash as shown in Figure1. The fly ash acted as non-plastic filler imparting some degree of particle aggregation to cause a gradual reduction in the plasticity. Low shrinkage values were obtained at reduced plasticity due to increased fly ash content while higher plasticity values, which correspond to low fly ash contents, gave rise to increased shrinkage strain. The reason for this being that the amount of water removed in soils during desiccation increases with increasing soil Plasticity Index. As plasticity increases, porosity increases; therefore more water is available for removal. On the other hand, low plasticity soils exhibit flat Soil Water Characteristic Curve (SWCC), leading to the smallest release of water for a given change in suction (Miller *et al.*, 2001). The F- statistic in Table 4 underscores the fact that the trend is significant at 0.05 level.

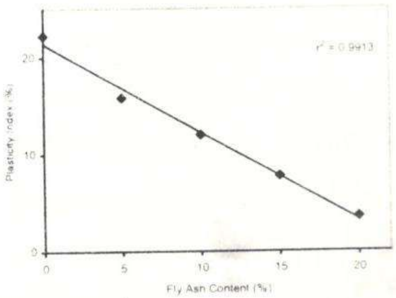

Figure 1: **Variation of plasticity Index with Fly ash content**

Fly Ash Content: The amount of shrinkage that occurs in soils as water leaves is closely related to the relative volumes of water and solids present as well as the particle size (Holtz and Kovas, 1981). High affinity for water by fine-grained clay soils with active clay minerals results in the absorption of large quantity of water into its matrix. During the process of desiccation, the saturation of soil is reduced and the remaining pore water is held at increasingly large suction, hence, the soil experiences large interparticle (capillary) stress as water retreat from the pore spaces. This brings the soil particles closer together up to a point when the soil particles contact each other, and begins to resist additional volume change. For a fly ash stabilized soil, however, flocculation mechanism brings about bigger soil grains and larger pore spaces. The capillary stresses are reduced (as the effective pore sizes increased) and it becomes difficult to bring these bigger particles together as in the natural soil. Consequently, air enters and occupies the space between these particles. This, in part explains the lower volumetric shrinkage in specimens containing varying quantities of fly ash.

Graphical representations of the effects of fly ash content on volumetric shrinkage at the various moulding water contents are shown in Figure 2 and the important features are:

(1) Volumetric shrinkage strain was substantially lowered with increase in fly ash content to values as low as 0.08% for specimens containing 20% fly ash compacted at 15% moulding water content. The F statistics in Table 4 confirms that the trend is significant at 0.05 level.

(2) Secondly, it was observed that from 15% fly ash content on the dry side of optimum (0–15% moulding water content), some form of increase in volume (ie swelling) of specimens occurred. Abduljauwad (1993) attributed the swelling to greater moisture deficiency and a lower degree of saturation as well as more random particle arrangement resulting from the addition of fly ash. This is in agreement with Holtz and Kovas (1981) who observed that soils with random fabrics

tend to swell more than soils with more oriented fabrics.

Compaction Condition (Moulding water content and compaction energy): The relationship between volumetric shrinkage and moulding water content for the various laterite soil – fly ash mixtures are shown in Figure 3. Volumetric shrinkage showed significant variation with moulding water content. Specimens compacted at greater moulding water contents shrunk more during drying which is consistent with Daniel and Wu (1993). This is so because when specimens are compacted at high water contents, more water exists within the pore spaces and thus are prone to large volumetric shrinkage strain during drying. The volumetric shrinkage strain is proportional to the volume of water leaving the pore spaces (Albrecht and Benson, 2001). Volumetric shrinkage strain value up to 8% was recorded at 20% water content for the natural laterite soil specimen.

The result of F- tests in Table 4 revealed that moulding water content was statistically significant.

A visual comparison of the graphs in Figures 2 and 3 tends to suggest that the moulding water and fly ash contents correlate equally with volumetric shrinkage strain but the F and p values in Table 4 indicate stronger correlation with fly ash content.

Compactive Effort: The influence of compaction energy on volumetric shrinkage strain for each level of fly ash concentration can be assessed from the information provided in Figure 3. Within the range of fly ash and moulding water content used in this investigation, there was no systematic relationship between shrinkage behaviour and compaction energy. Although, in most of the Figures specimens compacted with British Standard Heavy (BSH) representing the highest efforts generally plotted above specimens compacted with lower efforts suggesting higher shrinkage values for higher efforts. This can be explained by the fact that soils compacted with higher efforts have small pores that give rise to high capillary pressure, hence the resultant higher shrinkage strain. The F- statistic also did not rule out a trend at 0.05 level as presented in Table 4.The lack of clear relationship between volumetric shrinkage strain and compactive effort in the present study is similar to the results of Daniel and Wu (1993) as well as Nwaiwu (2003).

CRACKING OBSERVATIONS

Physical examination of all the specimens revealed that there were no visible cracks for natural laterite soil as well as those containing varying percentages of fly ash, regardless of the moulding water and compactive effort. Similar behaviour should be expected in the field, although it may be argued that the conditions in the laboratory may not fully simulate adverse climatic conditions in the field that influence crack susceptibility.

CONCLUSION AND RECOMMENDATION

In this study, laboratory tests were carried out to investigate the effectiveness of using fly ash to ameliorate the shrinkage problems of a naturally occurring lateritic soil. Specimens were prepared by adding varying concentrations of fly ash at different compaction energies over a range of moulding water content and allowed to desiccate slowly. From test results, it was found that increase in fly ash content reduced volumetric shrinkage strain substantially (from 8% for untreated laterite to 0.08% for 20% ash content). This is linked to alteration in the grain size of the laterite soil caused by the flocculation – agglomeration mechanism of fly ash stabilization.

On the other hand, specimens compacted at higher moulding water content shrunk more upon drying. The effect of compactive efforts on shrinkage behaviour of the mixtures was less clear and no visible cracks were observed in any of the specimen regardless of the moulding water content.

Therefore, to develop an appropriate and reliable design mix that will limit shrinkage values to acceptable range in a fly ash treated soil will require the determination of shrinkage-plasticity as well as shrinkage-moisture relationships.

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Table 1: Index properties of natural soil sample

Characteristics	Description
Natural moisture content (%)	5.8
Passing No. 200 BS sieve (%)	60.8
Liquid Limit (%)	42.2
Plastic Limit (%)	19.98
Linear shrinkage (%)	9.5
AASHTO classification	A-7-6
USCS Classification	CL
Specific gravity	2.76
Maximum Dry Unit Weight (British Standard Heavy) (kN/m^3)	18.88
Optimum Moisture Content (%)	12.5
pH	6.67
Colour	Reddish brown

Table 2: Oxide Composition of soil sample

Oxide composition	Percentage
CaO	0.28
SiO_2	35.60
Al_2O_3	27.40
Fe_2O_3	2.40
MgO	0.22
SO_3	0.85
Mn_2O_3	2.00
P_2O_5	-
Loss on ignition	146.00

(Adapted from Osinubi, 1998a)

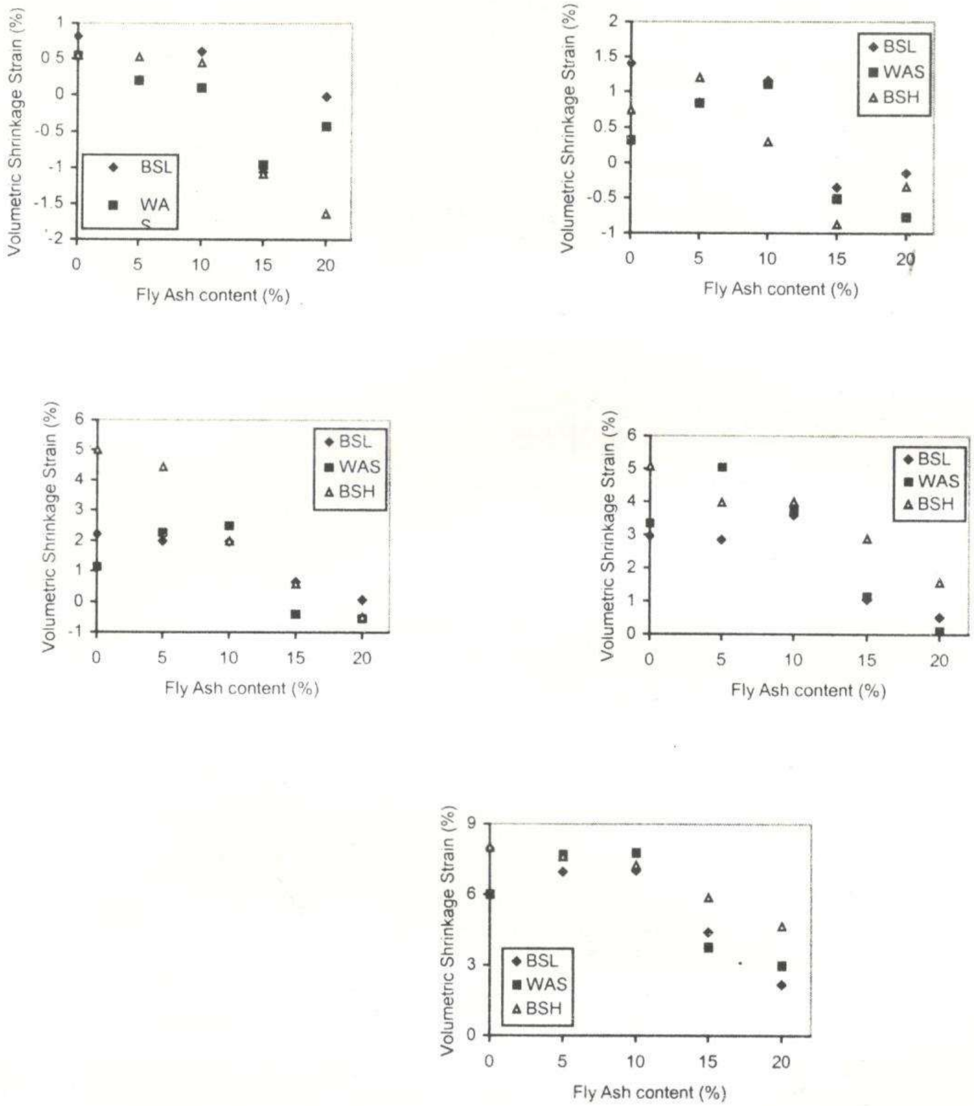
Table 3: Oxide composition of Fly ash (%).

Oxide	Quantity
SiO_2	46.02
Al_2O_3	24.16
Fe_2O_3	13.68
CaO	1.78
MgO	1.91
K_2O	5.58
Na_2O	5.31
MnO_2	0.56

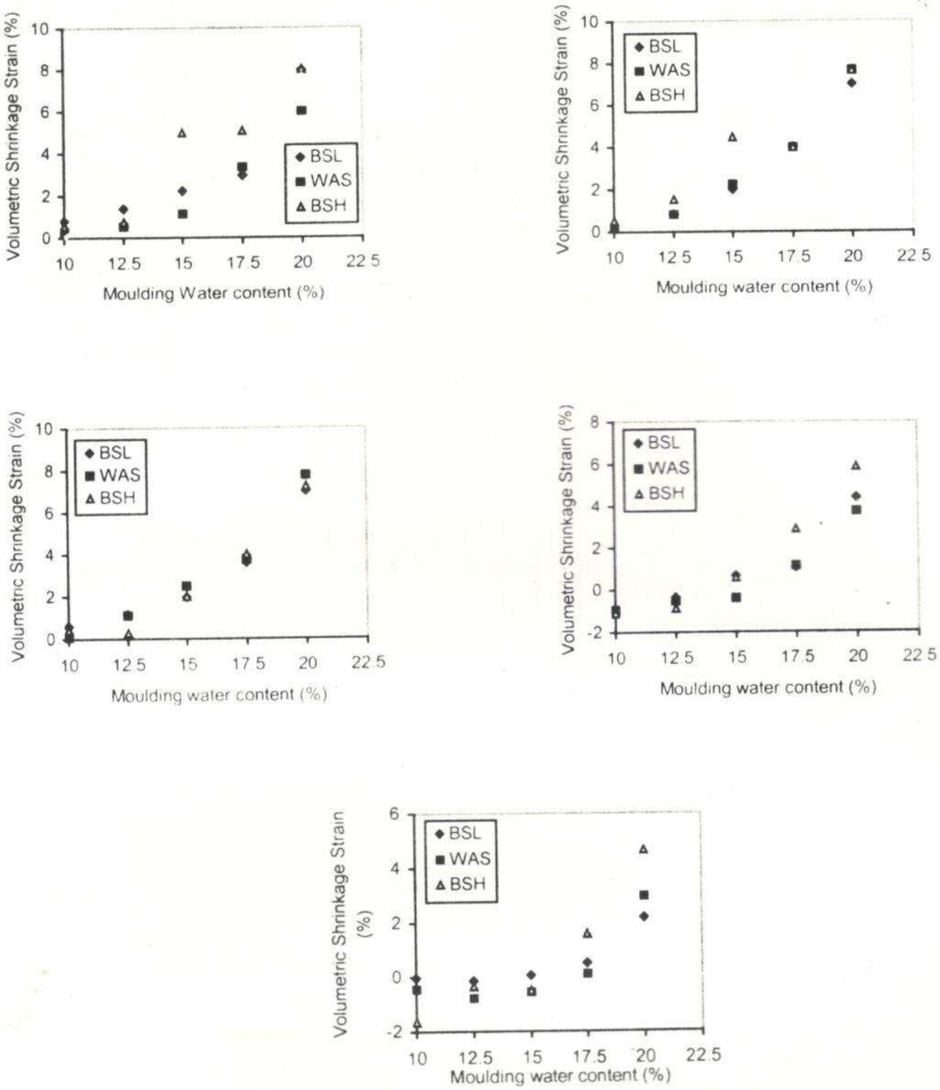
Table 4: Results of F-test showing the effect of fly ash, moulding water content and compaction effort on volumetric shrinkage

Variable	$F_{cal.}$	$F_{crit.}$	p-value	Statistical Inference
Plasticity Index	6.29018	1.349	6.1E-14	S
Fly Ash content	7.546	1.349	3.8E-16	S
Moulding water content	1.927	1.349	0.00348	S
Compaction Effort	9.938	1.349	1.1E-19	S

S = Significant; NS = Not Significant



Figures 2 a, b, c, d, & e: Variation of Volumetric shrinkage strain with fly Ash content at 10, 12.5, 15, 17.5, 20% moulding water content.



Figures 3 a, b, c, d & e: **Variation of Volumetric shrinkage strain with moulding water content at 0, 5, 10, 15, 20% Fly Ash content.**