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CONTROL OF SHRINKAGE IN COMPACTED LATERITIC SOIL TREATED WITH BENTONITE

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ABSTRACT

Although the potential for desiccation induced shrinkage exists when fine grained lateritic soil – bentonite mixture is used as liner and cover material in waste landfills, appropriate design measures and construction techniques can control this phenomenon and thus minimize the problems associated with it. This paper presents a method of controlling shrinkage that delineates compaction conditions within which the compacted soil will exhibit volumetric shrinkage allowed for such projects. In the study, volumetric shrinkage strain measurements were made on desiccating soil samples containing 0 – 10% bentonite by dry weight prepared at moisture contents ranging from 10 – 20% and compacted with four energy levels namely Reduced British Standard Light (RBSL), British Standard Light (BSL), West African Standard (WAS) and British Standard Heavy (BSH). Results of the study indicate that all samples exhibited volumetric shrinkage with the amount of shrinkage increasing with higher bentonite content and increasing moisture content. The measured shrinkage strains were related to water content and dry unit weight in an acceptable zone on the water content – dry unit weight curve. Data points within the acceptable zone represent test results with shrinkage strain of ≤ 4%. This approach will ensure good control over the quality of compacted soils as well as compliance with requirement of ≤ 4% normally specified by most regulatory agencies for shrinkage strain.

Keywords: *Acceptable zone, Bentonite, Compaction conditions, Lateritic soil, Volumetric shrinkage.*

INTRODUCTION

The tendency of compacted soil liners and covers used in waste landfills to shrink, form desiccation cracks when exposed to variations in climatic and environmental conditions is directly related to the shrinkage strains and associated stresses developed within the soil mass during drying (Holtz and Kovacs, 1981; Corser and Cranston, 1991; Benson, 1997; Khire et al., 1997).

Desiccation induced shrinkage occur when compacted soils are exposed to the atmosphere and pore water evaporates, causing the development of negative pore water pressure in the soil. Negative pore pressures results in increased effective stress and consequent reduction in volume.

Because the pore pressure acts in all directions the soil tends to shrink in all directions and cracking results (Haines, 1923; Holtz and Kovacs, 1981; Benson and Khire, 1995; Albrecht and Benson, 2001; Osinubi and Amadi, 2007).

While these cracks may be very small in size, they pose serious problems because they will become preferential flow channels. Such flow channels within the liner matrix must be avoided since they significantly increase the hydraulic conductivity, k and can lead to an eventual piping failure and loss of hydraulic integrity (Bowders and Daniel, 1987; Anandarajah, 2003). Day and Daniel, (1985) predicted that the effect of desiccation and cracking may increase the hydraulic conductivity by as much as 1000 times the value measured in the laboratory.

This is an important issue for mineral barriers used in lining and capping of landfills as it can render such liners useless.

It is therefore necessary to take precautions against this problem.

Achieving a material with the desired property requires close attention to three major factors namely (i) material selection (ii) Water content at compaction and density (iii) post construction measures (Daniel, 1993; Benson et al., 1994; Oweis and Khera, 1998; Osinubi et al., 2006b). While the first two can be controlled by appropriate design, the third objective can be effectively controlled by quickly covering the liner with a suitable protective layer after construction.

Moisture content and dry unit weight values can greatly affect a soil's ability to restrict the transmission of flow. Little variations in water content and dry unit weight may lead to great changes in the performance criteria for barriers in waste landfills namely hydraulic conductivity, shear strength and volumetric shrinkage strain (Mitchell, 1965).

If the soil is too dry at the time of compaction, low hydraulic conductivity may be difficult to attain. On the other hand, if the soil is too wet, a number of problems such as weak soils, slope instability caused by low strength and workability problems in additionto desiccation-induced shrinkage/cracks may arise. Thus, ranges of water contents within which the compacted soil will exhibit specification requirements of $k \leq 1x\ 10^{-7}$ cm/s, volumetric shrinkage $\leq$ 4% and unconfined compressive strength $\geq$ 200kN/m^2 must be delineated (Daniel and Benson, 1990; Daniel, 1993; Daniel and Wu, 1993; Oweis and Khera, 1998; Osinubi et al., 2006a,b).

The geotechnical properties of lateritic soil is usually improved for hydraulic applications such as liners and cover in waste landfills by incorporating some percentage of bentonite. The addition of bentonite modifies its plasticity, hydraulic conductivity and cation exchange capacity (CEC) favourably but the shrinkage properties are adversely affected (Osinubi and Amadi, 2007, 2008). To overcome this limitation and ensure long term performance, shrinkage control is initiated at the design stage, during and after construction.

The objective of this study is to delineate compaction conditions that meet specification requirement with respect to shrinkage. This will guide the engineer in ensuring compliance with specifications as well as quality control during construction.

MATERIALS AND EXPERIMENTAL METHODS

Materials

Study Soil: The soil used in this study is a natural reddish brown lateritic soil with inclusions of white mottles obtained by disturbed sampling method from a borrow pit at Km 15 along the Zaria – Sokoto road in Zaria, (Latitude 11°15' N and Longitude 7°45' E) Nigeria. A study of the geological and soil maps of Nigeria after Akintola (1982) and Areola (1982) respectively show that soil samples from that borrow source belong to the group of ferruginous tropical soils derived from igneous and metamorphic rocks. The index and compaction properties of the soil mixtures measured in accordance with standard procedures outlined in BS 1377 (1990) and Head (1992) are summarized in Table 1, while the oxide composition is presented in Table 2. Previous study on soil sample from the study location by Osinubi (1998) indicate that the soil contains kaolinite as the dominant clay mineral.

Table 1: Properties of soil - bentonite mixtures

Property	Bentonite Content, %				
	0	2.5	5	7.5	10
Natural moisture content (%)	19.60	-	-	-	-
Liquid Limit (%)	42.20	48.0	49.5	53.5	57.0
Plasticity Index (%)	22.22	26.64	28.56	30.72	33.42
Linear shrinkage (%)	5.56	5.98	6.91	8.02	8.73
USCS Classification	CL	CL	CL	CH	CH
Specific gravity	2.60	2.58	2.54	2.51	2.48
pH	6.67	7.2	7.4	7.6	7.9
Color	Reddish-brown				
Dominant Clay Mineral	Kaolinite				

Table 2: Oxide composition of lateritic soil and Bentonite

Oxide	Concentration (%)	
	Lateritic soil*	Bentonite
CaO	0.28	0.86
SiO_2	35.60	58.14
Al_2O_3	27.40	21.73
Fe_2O_3	2.40	2.46
MgO	0.22	2.42
SO_3	0.85	ND
Mn_2O_3	2.00	ND
K_2O	ND	0.52
TiO_2	ND	1.86
Na_2O	ND	2.08
Loss on ignition	146.00	13.28

(*Adapted from Osinubi, 1998); ND – Not determined

Bentonite: Bentonite exists in both granular and powdered form. The powdered bentonite used in this study was obtained from a major supplier in Lagos, Nigeria. A sieve analysis of the air dry material showed that the percentage passing No. 200 sieve is 92%. The oxide composition as well as some properties of the bentonite are reported in Tables 3 and 4, respectively. The plasticity index (PI) of the bentonite indicates that it is a highly plastic material and has a high swelling potential.

Table 3: Properties of bentonite used in the study

Property	Quantity
Liquid Limit (%)	250
Plasticity Index (%)	205
Percent Passing # 200 Sieve	92
Specific Gravity	2.38
Swelling Potential	High

Methods

Shrinkage/Desiccation Test

Air dried lateritic soil samples were mixed with the relevant quantities of bentonite (0, 2.5, 5, 7.5 and 10% by dry weight of soil) consistent with the bentonite content reported by Lundgren (1981), Garlanger et al. (1987), O'Sadnick (1995) as well as Kenny et al. (1995) and the required percentage of tap water (0 - 20) was added and thoroughly mixed until a uniform consistency was achieved.

Specimens were prepared with four compactive efforts i.e., namely Reduced British Standard Light (RBSL), British Standard Light (BSL), West African Standard (WAS) and British Standard Heavy (BSH) to simulate the range of compaction energies expected in the field. The BSL and BSH compaction procedures are described in BS 1377 (1990) Procedure as well as Head, (1994). The West African Standard (WAS) compaction is an intermediate effort which is in accordance with Nigerian General Specification (1997) is the conventional energy level commonly used in the West African region (Osinubi, 1998).

Volumetric shrinkage was measured by extruding a compacted cylinder of specimen from the mould and allowed to air dry in the laboratory. Measurements of the height, diameter and weight of the specimen were taken after 28 days. The average values of height and diameter were used to compute the volumetric shrinkage strain.

RESULTS AND ANALYSIS

Basic Properties of Soil Mixtures

The particle size distribution curves of the soil mixtures are presented in Fig. 1. The natural soil contains appreciable amounts (57 – 61%) of fines. The classification of the soil mixtures based on *Unified Soil Classification System* (USCS) presented in Table 1 indicate that mixtures containing 0 – 5% bentonite may be classified as inorganic clay soils of low plasticity (CL) while sol mixtures with 7.5 – 10 bentonite are classified as CH soils.

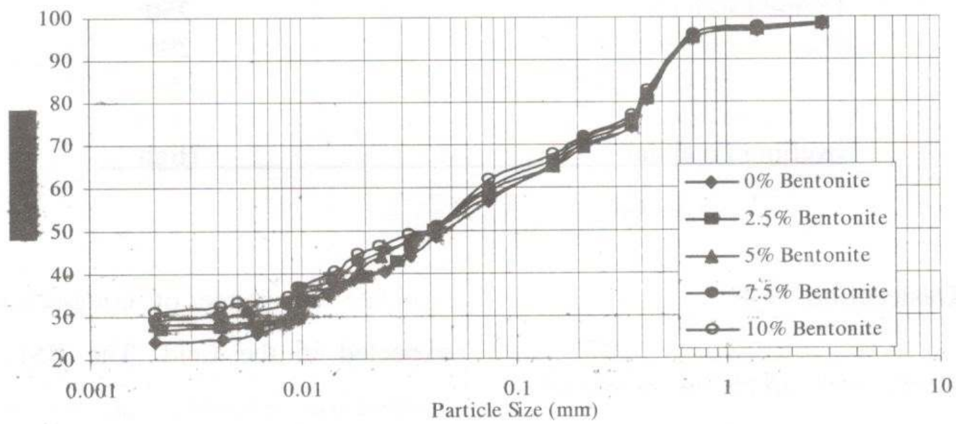

Fig. 1: Particle Size Distribution of Soil-Bentonite mixtures and Base soil.

Significant increases in plasticity index (PI) and linear shrinkage were recorded for the various soil mixtures with the addition of bentonite into the base soil. The plasticity index (PI) increased from 22.22 to 33.42% while the linear shrinkage increased from 5.56 to 8.73%. A plot of plasticity index/linear shrinkage versus bentonite content is shown in Fig. 2. The increasing trend in plasticity index is indicative of the increase in clay fraction (bentonite) in the soil samples. The activity, A, (A = PI/Clay fraction) increased from 0.9 for the natural soil to 1.075 for sample containing 10% bentonite.

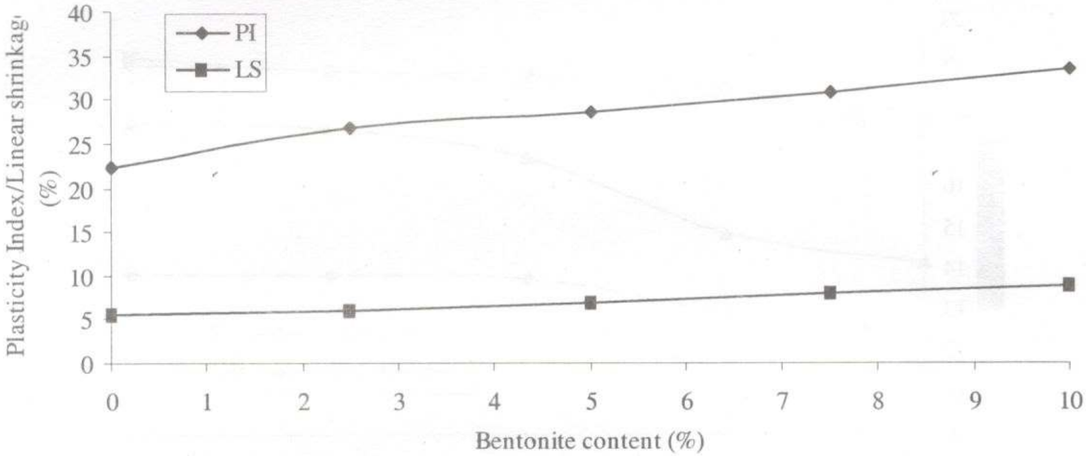

Fig. 2: Variation of Plasticity index/Linear shrinkage with Bentonite Content

Compaction Characteristics

The maximum dry unit weight decreased slightly while the optimum moisture content increased. The variations of maximum dry unit weight and optimum moisture content with bentonite content for the various mixtures are shown in Figs. 3 and 4.

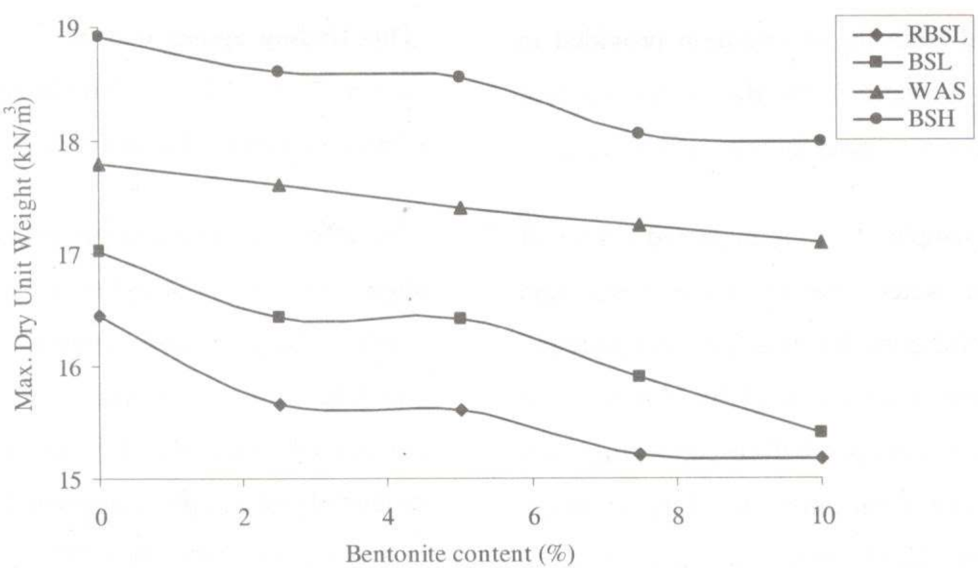

Fig. 3: Variation of maximum dry unit weight with bentonite content

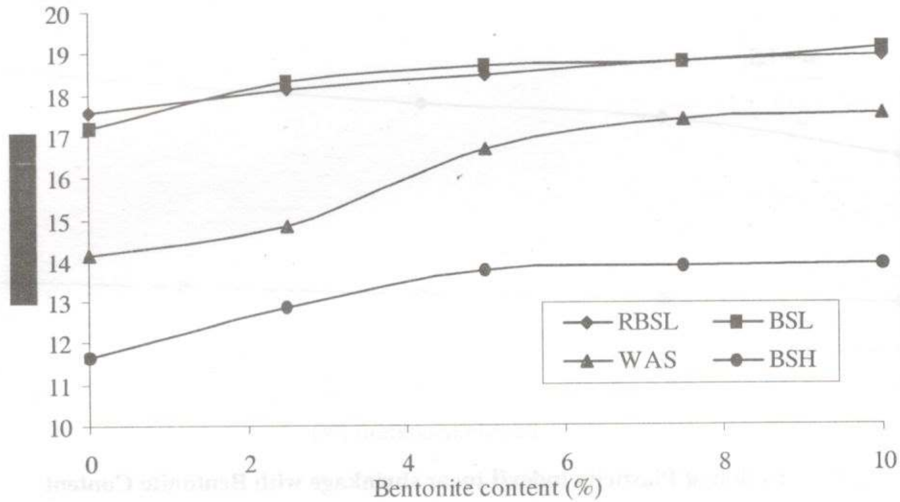

Fig. 4: Variation of optimum water content with bentonite content

Effects of Compaction Conditions

The effect of water content on volumetric shrinkage for each soil mixture can be evaluated from the information provided in Fig. 5. Variations in the water content resulted in non linear increase in shrinkage.

When samples are compacted wet of optimum water content, more water and fewer solid particles exist per unit volume, thus, more room is available for the soil particles to collapse before contacting each other during desiccation, resulting in larger volumetric shrinkage strain. Hence, the total amount of shrinkage is closely related to relative volumes of water and soils present in the soil sample (Haines, 1923; Albrecht and Benson, 2001).

The severity of the phenomenon increases with increasing water affinity of the soil.

This finding agrees with those reported by Khire et al. (1997) Albrecht and Benson (2001) as well as Osinubi et al. (2006a,b).

The effect of compaction energy is also shown in Fig. 5. Samples compacted with lower energies had higher volumetric shrinkage values. Consequently, samples compacted with RBSL and BSL efforts plotted above samples compacted with WAS and BSH energies. The BSH compactive effort simulates the highest achievable effort in the field and it recorded the lowest volumetric shrinkage values in all the samples.

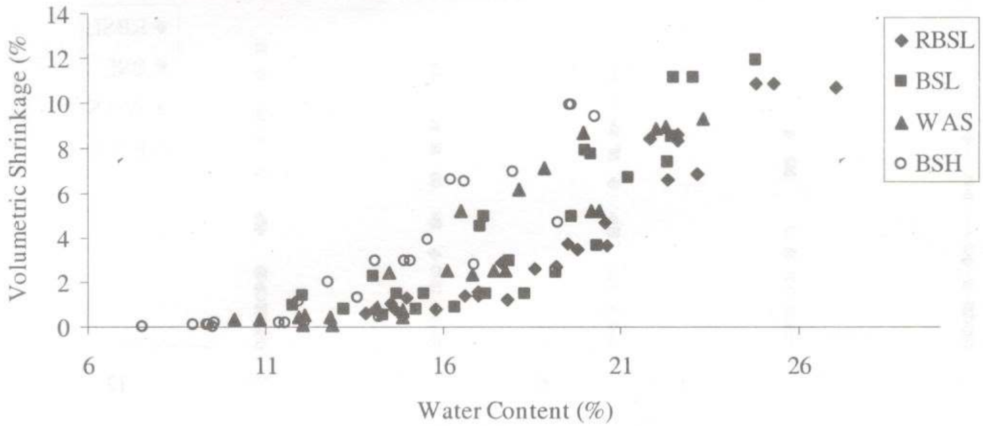

Fig. 5: Variation of Volumetric shrinkage with water content

Variation of Volumetric Shrinkage with Bentonite Content

Shrinkage of lateritic soil - bentonite samples increased with the proportion of bentonite.

These increases are associated with changes in kaolinite/montmorillonite ratio, which are the dominant clay minerals in lateritic soils and bentonite respectively (Osinubi and Amadi, 2007). Samples with higher bentonite content (i.e., montmorillonite fraction) had greater proportion of water that was removed during drying. This follows from the expanding lattice structure and the water adsorption properties that montmorillonite clay soils would shrink much more. Relatively high values of 9% were recorded for samples containing 10% bentonite. The increase was due to increase in plasticity index in the soil bentonite mixtures that had a greater affinity for water.

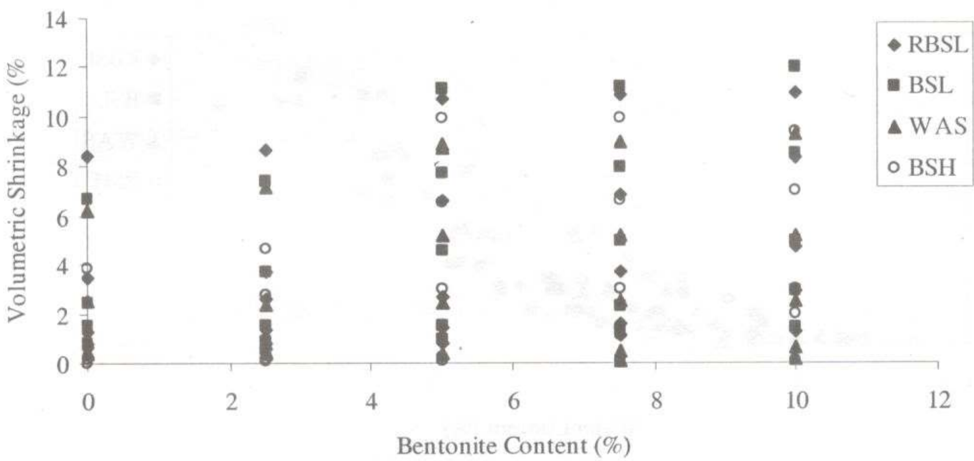

Fig. 6: Variation of volumetric shrinkage with bentonite content

Compaction Control

Delineation of water content and dry unit weight

Generally, the physical properties of most soils in engineering applications such as shrinkage, strength, hydraulic conductivity etc are tied directly or indirectly to compaction with water content as an index (Lamb, 1954; Benson and Daniel, 1990; Mitchell, 1976; Benson et al., 1994). The increase or decrease in compaction water content produces opposite trends with respect to these physical properties.

Design involves using measured shrinkage results to delineate suitable ranges of compaction water content and corresponding dry unit weights on the compaction curve referred to as acceptable zone. The acceptable zone encompasses data points representing test results meeting or exceeding acceptance criterion. In this study, a maximum allowable volumetric shrinkage of 4%, found in literatures and adopted by most regulatory agencies was used. This method is similar to the technique adopted by Daniel and Wu, 1993 which followed the procedure described by Daniel and Benson, (1990).

The acceptable zones for the various lateritic soil – bentonite mixtures are shown in Figs. 7 – 11. Thus all water content - dry unit weight points within the acceptable zones in Figs. 7 – 11 correspond to compacted soil mixtures with volumetric shrinkage strain ≤ 4%. The upper boundary of the acceptable zone in all cases is the zero – air void line.

This has the greatest potential for field application and helps to improve the long term performance of compacted soil liner.

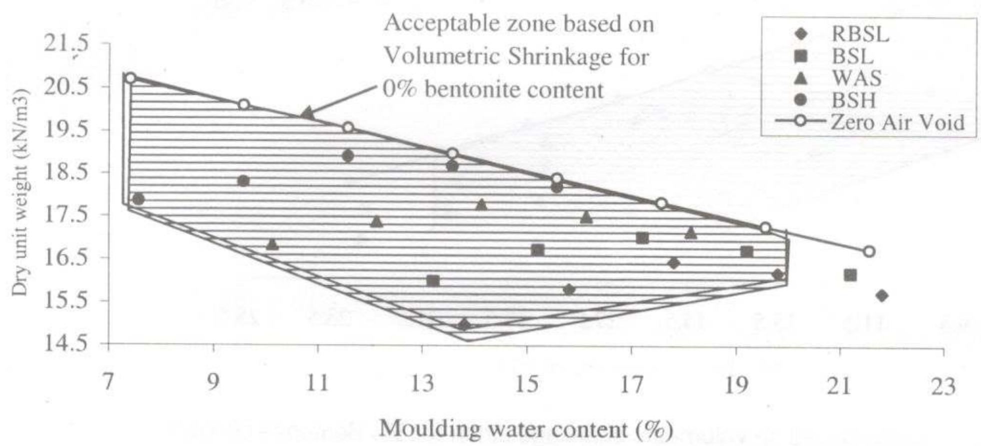

Fig. 7. Acceptable zone based on volumetric shrinkage strain for 0% Bentonite content

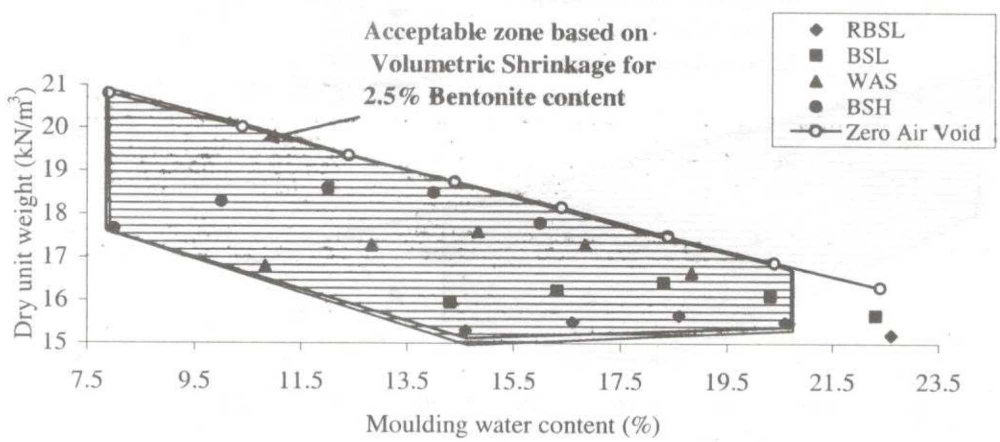

Fig. 8. Acceptable zone based on volumetric shrinkage strain for 2.5% Bentonite content

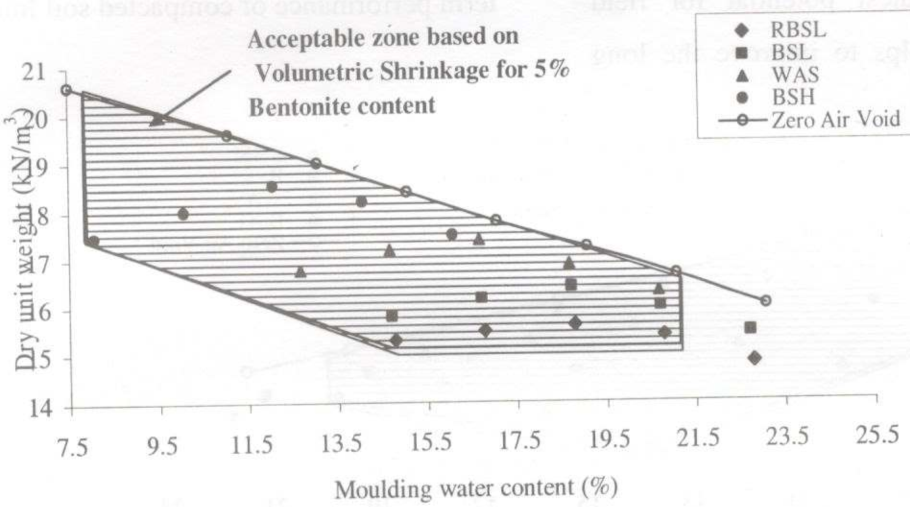

Fig. 9. Acceptable zone based on volumetric shrinkage strain for 5% Bentonite content

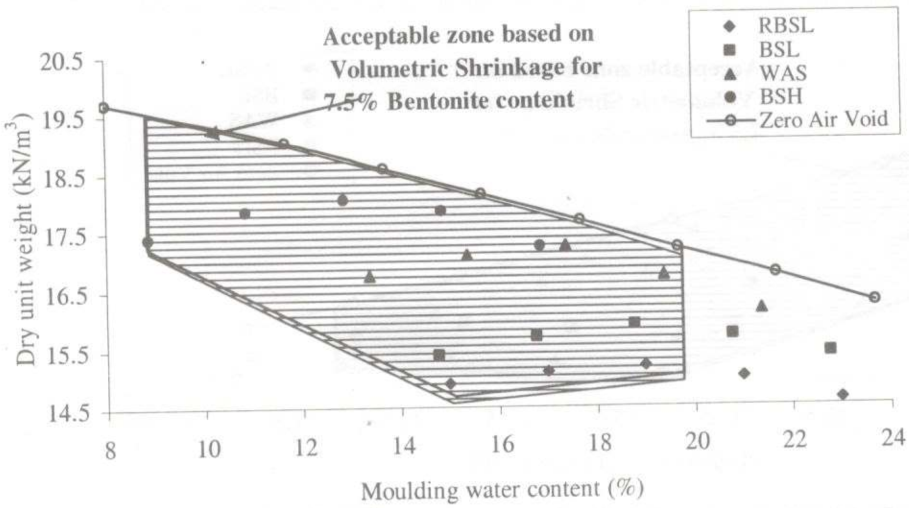

Fig. 10. Acceptable zone based on volumetric shrinkage strain for 7.5% Bentonite content

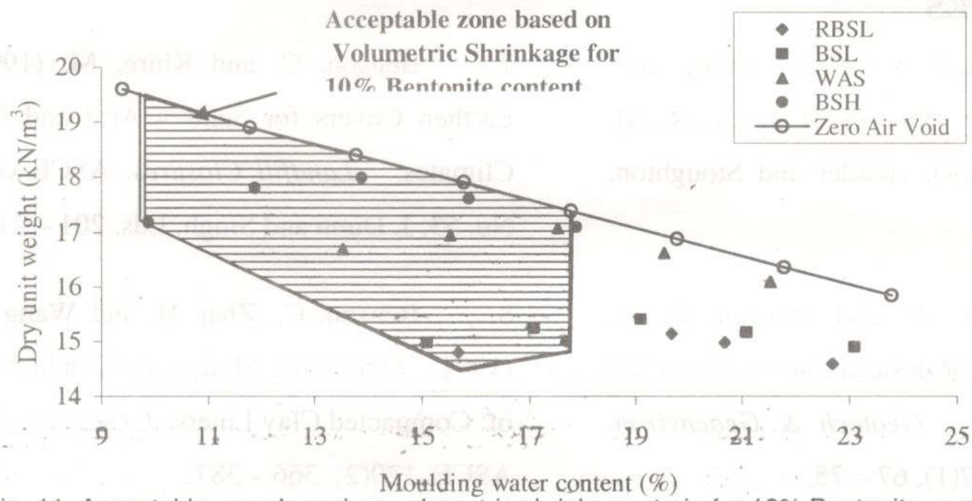

Fig. 11. Acceptable zone based on volumetric shrinkage strain for 10% Bentonite content

SUMMARY AND CONCLUSIONS

Laboratory tests were conducted on lateritic soil treated with up to 10% bentonite content. Soil mixtures were prepared at water contents ranging from 10 – 20% and compacted with four energy levels namely Reduced British Standard Light (RBSL), British Standard Light (BSL), West African Standard (WAS) and British Standard Heavy (BSH). Volumetric shrinkage strain measurements were made on desiccating soil samples. The addition of bentonite resulted in slight decrease in maximum dry unit weight while the optimum water content recorded an increase.

Generally, volumetric shrinkage strain increased with increase in bentonite content.

Test results were used to delineate ranges of water content and dry unit weight (acceptable zone) on the compaction curve for the various soil mixtures within which test specimens met threshold requirements of the performance criteria namely $V_{sh} \leq 4\%$ commonly specified by regulatory agencies.

These acceptable zones will serve as guide during field compaction as well as a quality control measure to ensure compliance with shrinkage limit.

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