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Research Article

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Compaction Characteristics of Black Cotton Soil-Sand Mixture for Road Work

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Abstract Black cotton soil (BCS) has been described as problematic soil because of significant amounts of clay minerals present in it. Its swell-shrink movement has been reported to pose serious problems to engineering structures. This paper looked into the influence of adding sand to BCS (0-100 %, by dry weight of soil sample at 10 % interval) on compaction characteristics and properties of the soil. The study utilized three different compaction standards: British Standard Light (BSL), British Standard Heavy (BSH) and West African Standard (WAS). Index properties of the natural soil sample showed that the soil is clay of high plasticity or CH, which is of poor engineering benefits. There was a gradual decrease in liquid limit (from 50 % to 29.4 %) and plasticity index (from 30 %to19.9 %) of BCS as sand content of the mixture was increased from 0 to 100 %respectively. The Optimum Moisture Content (OMC) of BCS-sand mixture decreased by 48.8 %, 57.1 % and 41.1 % while the Maximum Dry Density (MDD) increased by about 20.4 %, 14.3 % and 15.4 % for BSL, BSH and WAS respectively. The study recommended the addition of 10-100 % [at least 10%] sand to the natural BCS for use as sub-grade layer, but not for sub-base or lateritic base layers in highway construction.

Keywords Liquid limit, Plasticity index, Dry-density, Moisture-content, Sub-grade layer

Introduction

Soil improvement is of major concern in the construction activities due to rapid growth of urbanization and industrialization. The term soil improvement is used for the techniques which improve the index properties and other engineering characteristic of weak soils such as black cotton soils (BCS). BCS are dark coloured expansive clays found in North-East Nigeria and other parts of the world such as India and USA. As the name indicates, BCS derived its name from the fact that the cotton plants thrives well in it [1]. Generally, lands with BCS are fertile and very good for agriculture, horticulture, sericulture and aquaculture. They are capable of absorbing large volumes of water due to the presence of montmorillonite in their mineralogy [2-4]. However, they present various challenges to engineers all over the world due to their characteristics of severe loss of strength, excessive swelling and shrinking properties which result in cracking and long term settlement, with respect to changes in moisture regime [5-7]. They are thus considered problematic soils. As a result, structures, roads and highways constructed on these soils are subjected to severe deformations, resulting in poor performance and frequent repairs leading to high cost of maintenance. Thus, in a natural state, these soils are not suitable for subgrade construction without improvement of their engineering properties.

Many researchers have studied soil properties as they relate to stabilization using various treatment agents with a view to achieving design objectives. Stabilization makes it possible for soils to support themselves and other imposed loads. Stabilization of BCS must improve the swell potential for strength gain to be attained. However, the swell potential is associated with increased plasticity indices and higher cat-ion exchange capacity. The cat-ion exchange capacity(CEC) of soils containing montmorillonite mineral (BCS) is mainly due to the presence of Sodium ions (NA^{++}), Potassium ions (K^{++}), Magnesium ions (Mg^{++}) and Calcium ions (Ca^{++}). This creates additional water affinity for clay soils, leading to high swell potential. Hence, the lower the CEC, the more the strength gains [8].

One way of improving the strength property of soil is by stabilization which brings about changes in soil properties modified to a more stable soil and also retain maximum strength properties due to water proofing measures. In altering the properties of a soil to obtain the different characteristics, the choice of a particular method of stabilization depends on the nature of the soil and the cost of the stabilizing agent. The stabilization processes may include mechanical, chemical, electrical or thermal processes [9].

Various efforts have been made to stabilize BCS. Literature references on these studies indicate potential use of waste products, cement, lime, admixtures and other materials on the improvement of geotechnical characteristics of expansive soils. [10-14]. However, little work has been done on the effect of sand on the strength properties of treated BCS as a road pavement material.

Problem Statement

BCS is an expansive type of clay that exhibits swell-shrink characteristics, with cracks at the surface during the dry period due to high volume of montmorillonite in its mineralogical content. It increases in volume on absorbing water during rainy season and decreases in volume when the water evaporates from them [15]. The volume increase (swell) if resisted by any structure resting on it; then vertical swelling pressure is exerted by the soil on the structure. This pressure if not controlled, may cause uplifting and distress in the structure [16]. The devastating behaviour of the troublesome material such as collapsing behaviour, dispersive characteristics, remarkable swell potential, low bearing values and unnecessary cracks makes it unsuitable for construction of engineering structures such as embankment, roads and buildings [17].

The BCS of north-eastern Nigeria is specifically originated as a result of weathering of shaly, clayey sediments and basaltic rock [7, 18-22] reported that BCS of Nigeria contains more of the montmorillonite clay mineral with defined swell properties and expensive tendencies. These lacustrine sediments of north-eastern Nigeria cover an extensive area of103,555 km^2 (40, 000 square miles). They are poor materials to employ in highway or airfield construction because they contain high percentages of plastic clay. Consequently, lime and cement has been used to appreciably improve the properties of black cotton soils to make them meet the requirements for construction works. However, the cost of incorporating the additive is prohibitive and recent studies have focused on potentially cost effective materials that can improve the properties of deficient soils [23]. This study is aimed at the evaluation of the suitability of compacted BCS treated with sand. Suggesting its suitability as an additive and as an admixture when used with standard stabilizers for highway pavement works; not much is known in literature about its geotechnical behavior or characteristics, hence the need for this study.

Materials and Methods

Materials

The soil used in this study is BCS (dark grey in colour), obtained from Kwadon town (10^0 13’N, 11^0 23’E) in Yamaltu Deba Local Government Area of Gombe State in the North Eastern part of Nigeria. The community called the soil ‘Kasan Kalari’. After careful surveying, suitable pits were located and excavation was made to a depth of about 3 meters. Disturbed samples were then collected and transported in sacks to the Department of Civil Engineering soil laboratory, ATBU Bauchi. Little amount of the sample was sealed in polythene bag for determining its natural moisture content. The soil was air dried and pulverized as recommended by [24].

Sand used was collected from a nearby river (about 30m away from the position where the BCSwas collected).

Experimental Methods

Laboratory tests were conducted on BCS and sand samples in accordance with BS standard.

Preliminary Tests

Preliminary tests were conducted on BCS and sand samples in accordance with [25], with the aim of classifying the soils. These tests include determination of natural moisture content, sieve analysis, specific gravity and Atterberg limits.

Tests carried out on BCS-sand mixture

Various proportions of BCS and sand were thoroughly mixed and the following tests conducted on the mixture:

Atterberg Limits

The liquid limit (cone penetrometer method), plastic limit (PL) and plasticity index (PI) of the sand stabilized BCS have been determined in the laboratory in accordance with [23]. Varying percentages of sand were added to the BCS from 0 % - 100 % at an increment of 10 % by dry weight of the soil (method of addition and not by replacement)

Compaction Tests

These were conducted in accordance with earlier reported method [23] .The objective of the compaction tests is to obtain relationships between compacted dry density and soil moisture content. The compaction efforts adopted for this research was that of the Standard Proctor 'light' weight (BSL), Modified Proctor 'heavy' weight (BSH) and West African Standard (WAS). A graph of moisture content against dry density was plotted for the three standards, from which the corresponding OMCs and MDDs were obtained. The procedure was repeated by adding 10 %, 20 %, 30 %, 40 %, 50 %, 60 %, 70 %, 80 %, 90 % and 100 % sand to the natural BCS (method of addition and not by replacement).

The BSL/BSH procedure was also repeated for the West African standard, but in this case using a 4.5 kg rammer, falling through a height of 450 mm. The soil was placed in five layers with each layer given 10 blows.

Results and Discussion

Index Properties

Tables 1 and 2 present a summary of the preliminary tests conducted on BCS and sand respectively. The BCS was classified as clay soil of high plasticity [26-27]. This is because it has a liquid limit of 50 and Plasticity index of 30. In terms of MDD, BSH procedure gave the highest value of 1.74 Mg/m^3 while BSL procedure gave the highest value of OMC as 21.50 %.

On the other hand, sand used in this experiment was classified as uniformly well graded soil according to [26] in [27]. This is because it has a coefficient of curvature (C_c) of 0.9 which falls between the range of 0.5-2.0 for well graded soils and uniformity coefficient (C_u) of 2.5 which is below 3.0 as specified for uniform soils.

Table 1: Index properties of soil sample (Black cotton)

S/N	Properties	Results
1.	Natural Moisture Content (%)	30.95
2.	Liquid Limits (%)	50
3.	Plastic Limit (%)	20
4.	Plasticity Index (%)	30
5	Linear Shrinkage (%)	13.57
6.	Specific Gravity	2.63
7.	Optimum Moisture Content (%)	16.80 (BSH), 18.50 (WAS), 21.50 (BSL)
8.	Maximum Dry Density(Mg/m^3)	1.74 (BSH), 1.70 (WAS), 1.56 (BSL)
9.	Soil Classification (BS 5930:1999 section 6)	CH, Clay of high plasticity

Table 2: Index properties of soil sample (Sand)

S/N	Properties	Results
1.	Particle size corresponding to 10 % finer, D_{10} (mm)	0.30
2.	Particle size corresponding to 10 % finer, D_{30}(mm)	0.46
3.	Particle size corresponding to 10 % finer, D_{60}(mm)	0.75
4.	Coefficient of Curvature, C_c	0.9
5.	Coefficient of Uniformity, C_u	2.5
6.	Specific Gravity	2.60
7.	Soil Classification (BS 5930:1999 section 6)	Uniform Soil (Well-graded sand)

Atterberg Limits

The liquid limit of the BCS generally decreases with increasing sand content as shown in fig. 1 from a peak value of 50 at 0% sand to 29.4 at 100% sand. This decrease also applies to plasticity index (fig. 1) which generally decreased from 30 % at 0 % sand to 19.9 % at 100 % sand. This is in accordance with that found by [13].

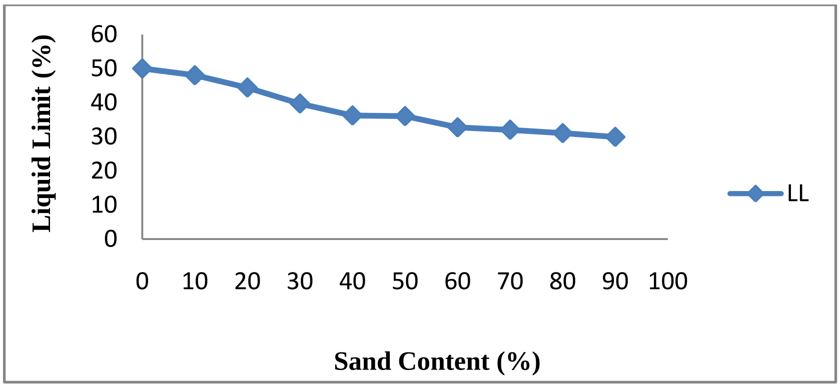

Figure 1: Variation of Liquid Limit with increase in sand content

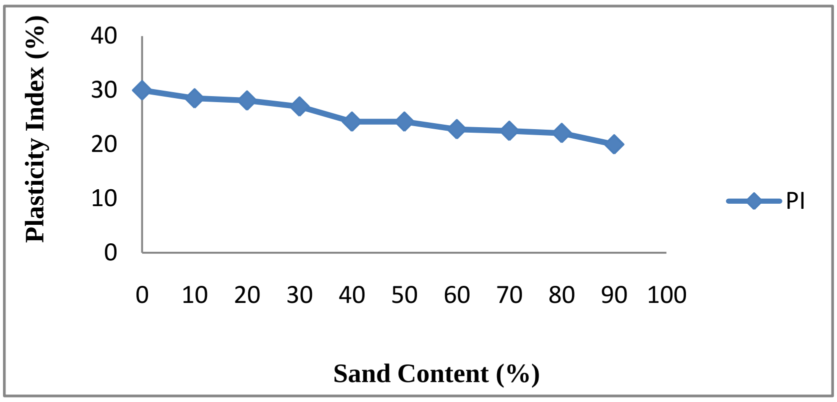

Figure 2: Variation of Plasticity Index with increase in sand content

Compaction

Generally, it was observed that MDD of the BCS-sand composite increases with an increase in sand content for all three procedures/standards as shown in fig. 3. The increase of MDD with increase in sand content is in accordance with [13] and [14] who both found that the MDD of BCS increases with increase in sand content. This occurs due to the reason that the void spaces between the sand particles are occupied by the BCS particles.

The variation of OMC with addition of sand to BCSis shown in Fig. 4. However, the OMC decreased as the percentage of sand increases.

Comparing MDD for the three standards of compaction, BSH compaction method gave the highest value of MDD across all percentages of sand used (fig. 3). This can be attributed to the fact that it has a rammer weighing 4.5 kg and compacted in five layers with each layer receiving 27 blows.

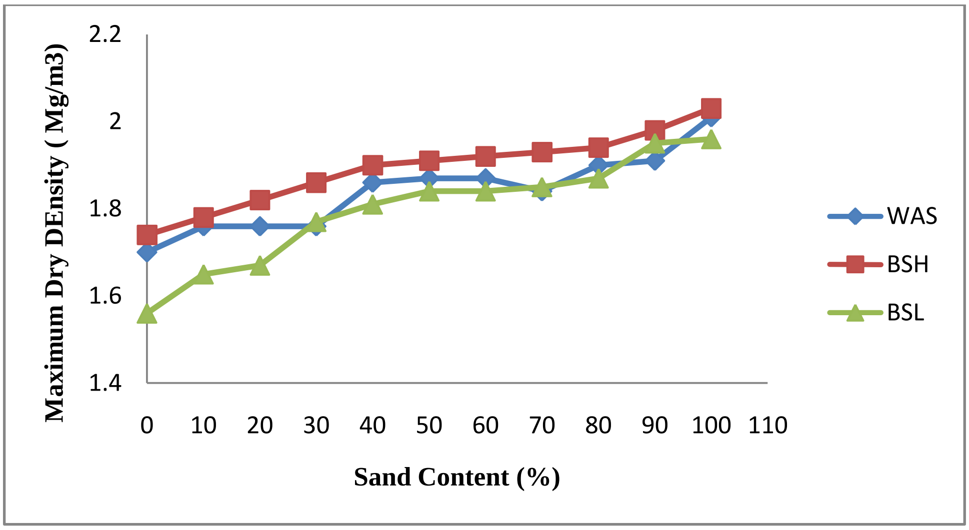

Figure 3: Variation of Maximum Dry Densities with sand content for WAS, BSH and BSL

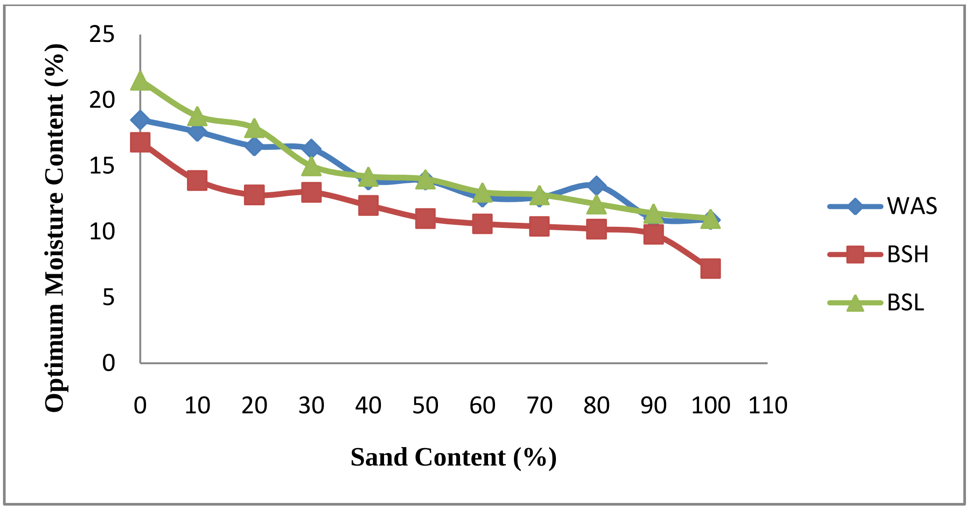

Figure 4: Variation of Optimum Moisture Contents with sand content for WAS, BSH and BSL

Conclusions

Based on the results obtained and subsequent analysis, the following conclusions were drawn:

I. The LL and PI values of 50 % and 30 % respectively for the natural BCS suggests that the soil is clay of high plasticity or CH [26]. Soils under these groups are of poor engineering benefit [28].

II. Generally, the LL and PI of BCS-sand mixture decreased with increasing sand content from 0-100 % (method of addition and not replacement). That is from a LL of 50 % at 0 % sand to 29.4 % at 100 % sand while PI decreased from 30 % at 0 % sand to 19.9 % at 100 % sand.

III. With increasing sand content from 0-100 % (method of addition and not replacement), the MDD increased by about 14.8 % (1740 to 2030 kg/m^3), 15.4 % (1700 to 2010 kg/m^3) and 20.4 % (1560 to 1960 kg/m^3) for BSH, WAS and BSLrespectively. While the OMC decreased by 57.1 %, 41.1 % and 48.8 % for BSH, WAS and BSL respectively.

Recommendations

The BCS with sand content of 10 % - 100 % can be used as subgrade material for highway construction based on [29]. This is because it has a LL and PI of less than 50 % and 30 % respectively. However, most of its properties (LL and PI for sand content 0-100 %) fall short of the requirements for lateritic base or sub-base material as stipulated in [30].

Furthermore, the requirements for use of material in highway construction go beyond its LL, PI and moisture-density relationship. Therefore, other tests such as California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) are recommended on this material before its actual suitability for the purpose of highway construction can be ascertained.

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