

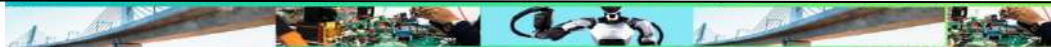
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Evaluation of Index Properties of Black Cotton Soil Stabilized with Soya Bean Husk Ash

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Abstract

The objective of this study was to assess the index characteristics of Black Cotton Soil Stabilized with Soy Bean Husk Ash (SBHA). The Gamadadi region of Borno state, Nigeria, provided the black cotton soil used in the study. To find the liquid limit, plastic limit, plasticity index, and linear shrinkage, the Atterberg limit test was used. Additionally, a sieve analysis test was carried out. The soil was classed as CH (Clay of high plasticity) under the Unified Soil Classification System (USCS, ASTM 1992) and as belonging to the A-7-6(0) group under the AASHTO (1996) classification system. When conditions change from wet to dry, the soil's color changes, appearing grayish-black. The soil's index properties showed that the liquid limit was 52%, which decreased to 46% at 16% SBWA. Similarly, the plastic limit decreased from 19.52% to 16.37% at 16% SBHA. This was because higher-valence cations replaced weakly bonded ions in the clay, causing particle flocculation and the release of absorbed water. As a result of pozzolanic reactions and clay dilution, the plasticity index decreased from 32.48% to 29.63%, indicating reduced clay activity and enhanced soil stability. At 16% SBHA, the specific gravity drops from 2.63 to 2.38 and the shrinkage limit drops from 22.86% to 14.29%. While the Optimum Moisture Content increased from 18.41% to 24.54%, the Maximum Moisture Content (OMC) dropped from 1.68g/cm³ at 0% SBHA to 1.58g/cm³ at 12% SBHA and then increased to 1.59g/cm³ at 16% SBHA. To improve the index qualities of black cotton soil, an ideal SBHA level of 12% is recommended.

Keywords: SBHA, Specific gravity, Atterberg limit, sieve analysis.

1. INTRODUCTION

Black cotton soil (BCS), which is predominantly found in tropical and subtropical regions, is well known for its high swelling and shrinkage characteristics resulting from the presence of expansive clay minerals such as montmorillonite. These soils exhibit significant volume change when subjected to variations in moisture content, leading to serious engineering problems such as cracking, differential settlement, and structural damage to pavements, buildings, and other civil engineering infrastructures constructed on them. Because of these unfavorable characteristics, black cotton soil is generally considered problematic for construction unless its engineering properties are improved through stabilization techniques (Philip-Abasiri et al., 2025; Gidebo & Mareeswaran, 2023).

Soil stabilization is widely used in geotechnical engineering to improve the strength, durability, and load-bearing capacity of problematic soils. Conventional stabilizing materials such as lime, cement, and bitumen have been successfully used to enhance the engineering properties of expansive soils. However, the high cost of these materials and their associated environmental impacts, particularly carbon dioxide emissions during cement production, have encouraged researchers to explore more sustainable and environmentally friendly alternatives (Shaba et al., 2025; Balcha, 2025).



In recent years, agricultural waste materials have gained considerable attention as potential stabilizing agents due to their availability, low cost, and pozzolanic properties. Several studies have demonstrated that agricultural ashes such as rice husk ash, coconut shell ash, and bagasse ash can significantly improve the geotechnical properties of expansive soils by reducing plasticity and enhancing soil strength. These materials contain reactive silica and alumina which can react with calcium in the presence of moisture to form cementitious compounds that improve soil structure and bonding (Rahman et al., 2021; Nangulama et al., 2024).

The utilization of agricultural waste materials for soil stabilization also contributes to sustainable construction practices by promoting waste recycling and reducing environmental pollution. Agricultural ashes can modify the soil fabric through particle flocculation and agglomeration, which improves soil gradation and reduces the dominance of fine particles within expansive soils (Almuaythir et al., 2025). Consequently, the use of agro-waste ash as a stabilizing material has become an important research focus in modern geotechnical engineering.

Soya bean husk ash (SBHA) is an agricultural by-product obtained from the controlled combustion of soybean husks. The ash contains significant amounts of silica and other oxides that can contribute to pozzolanic reactions when mixed with clay soils. These reactions can improve soil structure, reduce plasticity, and enhance the engineering behavior of expansive soils. Despite its potential benefits, the application of SBHA in soil stabilization remains relatively limited compared with other agricultural waste ashes.

Therefore, evaluating the effect of Soya Bean Husk Ash on the index properties of black cotton soil is important for assessing its suitability as a sustainable soil stabilizing material. Index properties such as liquid limit, plastic limit, plasticity index, and particle size distribution provide essential information about soil behavior and classification for engineering applications. This study therefore evaluates the influence of SBHA on the index properties of black cotton soil with the aim of determining its effectiveness as an environmentally friendly and cost-effective stabilizing agent for geotechnical engineering applications.

2. MATERIALS AND METHODS

2.1 Materials

2.1.1 Black Cotton (Expansive) Soil

Disturbed soil samples for this study were collected from Gamadadi, Borno State, Nigeria, at coordinates 10.320163° N and 11.5484146° E. Samples were obtained from a depth range of 1.5 m to 2.0 m, after removing the topsoil to about 1.5 m.



Plate 1: Location of the Site

2.1.2 Water

Tap water used in the study was collected from the Soil Laboratory of the Department of Civil Engineering, Nigerian Defence Academy, Kaduna, Nigeria.

2.1.3 Soya Beans Husk Ash (SBHA)

Soya bean husk used in this research were obtained from the Crossing area in Kachia LGA, Kaduna State 9° 52' 24" N, 7° 57' 18" E. The shells were completely burned under atmospheric conditions, sealed in plastic bags and transported to the Civil Engineering Laboratory at the Nigerian Defence Academy campus for crushing. The resulting



ash was sieved through a BS No. 200 sieve and stored in sealed containers for later mixing with lateritic soil at the required proportions

2.1.4 Sample Preparation

- i. The black cotton soil was air dried and pulverized.
- ii. The soya beans husk ash was added to the laterite in varying percentage of 0 to 8%.
- iii. In the preparation of samples, if soya beans shell ash was not included then, the air-dried soil was mixed with a certain quantity of water.
- iv. If soya beans shell ash is used, the adopted content of material is mixed first into the air-dried soil with small increments using the hand, making sure that all the material are mixed thoroughly, so that a fairly homogenous mixture can be obtained, and then the certain required water is added.

2.2 Methods

2.2.1 Natural moisture content

BS 1377 (1990) Part 2 was used to determine the natural moisture content of the soil obtained from the site. Three weighing containers were thoroughly cleaned and weighed to the nearest 0.01g (M1). The sample was crumbled and loosely placed in the containers, and the containers with the samples were weighed together to the nearest 0.01g as M2. The containers were then dried in an oven at 105-110°C for 24 hours. After that, the containers and samples were removed and weighed dry to the nearest 0.01g as M3. The natural moisture content (as collected on site) is calculated as the average of the three oven dried samples given by eqn. (1):

$$w = \frac{M_2 - M_1}{M_3 - M_1} \times 100 \quad (1)$$

2.2.2 Particle size distribution

Particle size analysis was performed in accordance with BS 1377; 1990 Part 2. To obtain the particle size distribution, dry sieving was performed on 200g of soil sample. The same procedure was carried out on all SBHA - treated soils

2.2.3 Specific gravity

The specific gravity was determined using the BS 1377 (1990) test (B) for fine-grained soils. The density bottle and stopper were weighed precisely to the nearest 0.001g (m1). The air dried soil was placed in the density bottle, and the bottle, contents, and cover were all weighed as m2. After adding just enough water to cover the soil, the solution was gently stirred to remove any air bubbles. After that, the bottle was completely filled and covered. The covered bottle was then wiped dry, and the entire assembly was weighed to the nearest 0.001g (as m3). The bottle was then emptied and completely filled with water, wiped dry, and weighed to the nearest 0.001g (m4). The bottle was then emptied and completely filled with water, wiped dry, and weighed to the nearest 0.001g (m4). Eqn. (2) is used to calculate specific gravity:

$$G_s = \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_1)} \quad (2)$$

The same procedure was carried out on all of the SBHA treated soils.

2.2.4 Atterberg limits

The test consists of determining the liquid limits, plastic limits, and plasticity index for natural and stabilized soils. They were also carried out in accordance with BS 1377 (1990) Part 2 Test1 (A) for natural.

3. RESULTS AND DISCUSSION

3.1 Characteristics of natural Black Cotton Soil

The preliminary test conducted on the natural properties of the soil revealed that the soil has low moisture content of 18.58% because the soil sample were collected at the beginning of rainy season. The summary of the soil's index properties is presented in Table 1, The particle size distribution curve of the soil is illustrated in Figure 1. According to the Unified Soil Classification System (USCS (ASTM, 1992), the soil is classified as CH, which denotes a high plasticity clay, while under the AASHTO classification system (AASHTO, 1986), it falls within the A-7-6(0) category, typically associated with clayey soils of fair to poor engineering quality.



The soil appears grayish-black in colour, transitioning between shades as it moves from wet to dry conditions. Laboratory tests indicate that the soil has a liquid limit (LL) of 52.0%, a plastic limit (PL) of 19.52%, and a plasticity index (PI) of 32.4%. These results show that the soil possesses a moderate to high degree of plasticity, indicating that it can undergo significant volume changes (shrinkage and swelling) when subjected to moisture variations.

Such characteristics suggest that, in its natural state, the soil may present challenges for engineering applications, particularly as a subgrade or foundation material, unless properly stabilized or treated to improve its strength and reduce its plasticity.

Table 1: Characteristics of Natural Black Cotton Soil

Property	Quantity
Percentage passing No. 200 sieve (dry Sieve)	1.5
Natural Moisture Content (%)	18.7
Liquid limit (%)	52.0
Plastic limit (%)	19.52
Plasticity Index (%)	32.4
Linear Shrinkage	22.86
Specific gravity	2.46
AASHTO Classification	A-7-6 (0)
UCS Classification	CH
colour	Greyish black
Dominant clay miner	Montmorillonite

3.2 Sieve Analysis

Fines are defined as the fraction of the soil particles that pass through the openings of the No. 200 sieve (0.075mm). Soils with very low fines typically have too little silt- and clay sized material to produce suitably low hydraulic conductivity. The dry sieving of black cotton soil treated with 0%, 4%, 8%, 12% and 16% Soya bean husk ash (SBHA) for British standard light (BSL) is shown in Figure 2.

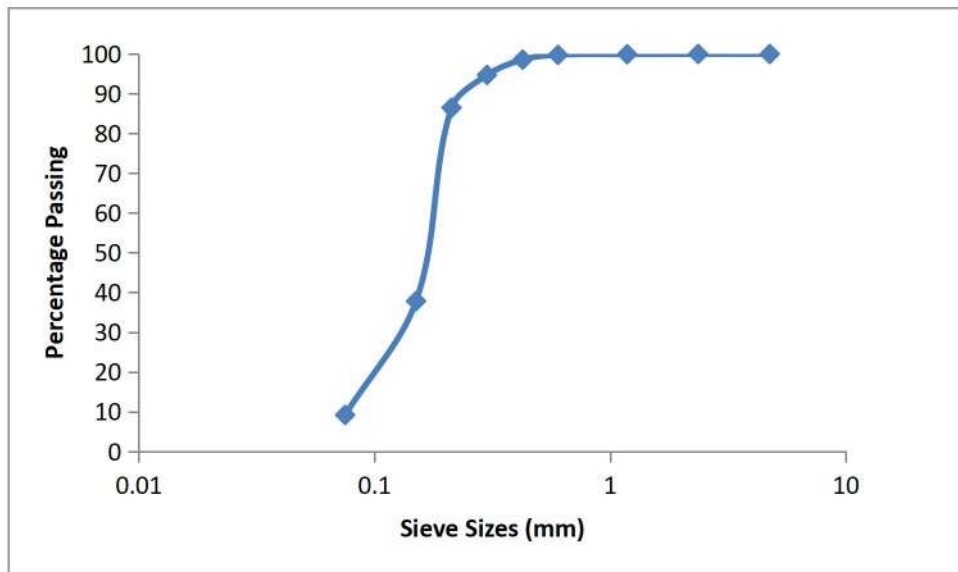


Figure 1: Particle size distribution curve of the natural soil.

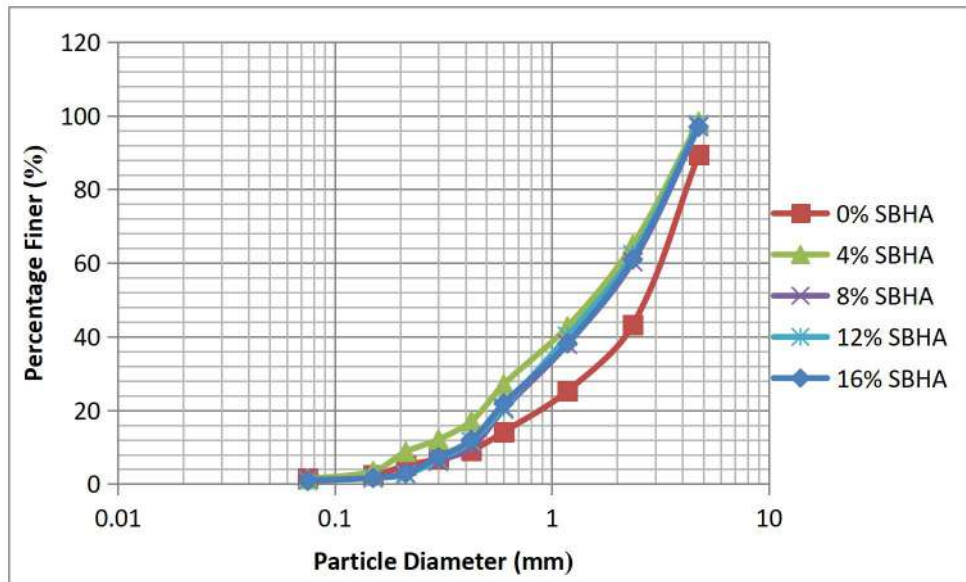


Figure 2: Particle size distribution curve for black cotton soil – SBHA (BSL compaction energy)

The percentage fine passing 0.075mm sieve decrease from 1.5% for the natural soil to 1.35%, 1.1%, 1.0% and 0.9% for 0%, 4%, 8%, 12% and 16% Soya bean husk ash (SBHA) respectively. The reduction indicates that the additional SBHA alters the soil gradation, making it coarser and less fine-grained. The trend can be attributed to the flocculation and agglomeration of clay particles resulting from cation exchange reactions between the calcium ions (Ca^{2+}) in the SBHA and monovalent cations (Na and K^+) in the black cotton soil. The result is consistent with findings of Osinubi and Nwaiwu (2005); Eberemu (2012); Amu and Adetuberu (2010).

3.3 Atterberg Limit

The addition of Soya Bean Husk Ash (SBHA) to Black Cotton Soil (BCS) resulted in a consistent reduction in the Atterberg limits (See Figure 3). The liquid limit decreased from 52% in the natural soil to 46% at 16% SBWA, due to flocculation and agglomeration of clay particles caused by cation exchange (Ca^{2+} from SBHA). Similarly, the plastic limit reduced from 19.52% to 16.37% at 16% SBHA, also attributed to the replacement of weakly bonded ions in the clay with higher-valence cations, which led to particle flocculation and release of absorbed water. Consequently, the plasticity index dropped from 32.48% to 29.63%, reflecting decreased clay activity and improved soil stability due to pozzolanic reactions and clay dilution. Overall, increasing SBHA content reduced soil plasticity, making the soil more stable and more suitable for engineering applications Edeh and Amadi, (2014; Amu and Adetuberu (2010); Osuolale, et al., (2025).

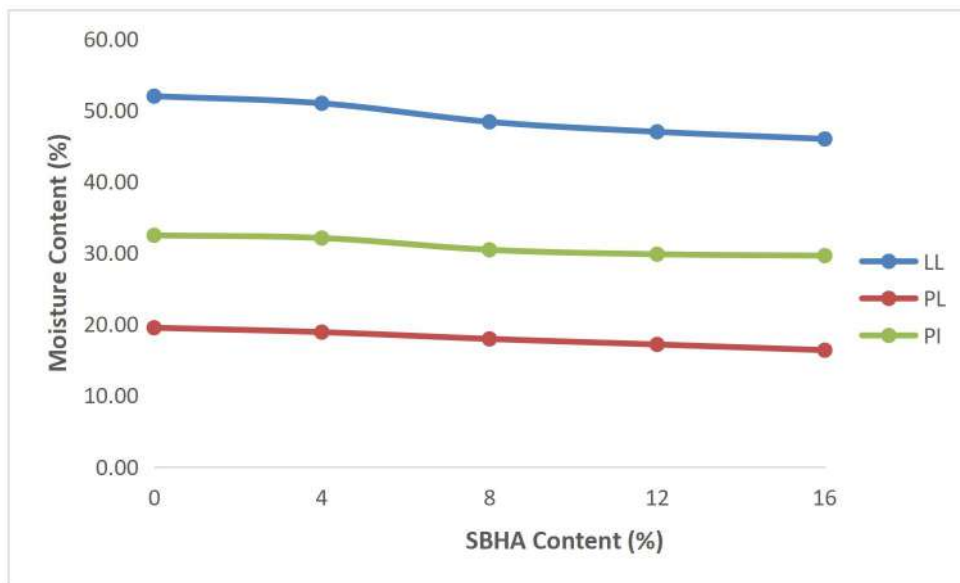


Figure 3: Variation of Atterberg limit with SBHA content



3.4 Linear Shrinkage

The shrinkage limit of the soil decrease with the increased in SBHA, the obtained were 22.86%, 18.57%, 17.86%, 16.43% and 14.29% for the natural soil (0%), 4%, 8%, 12% and 16% SBHA respectively. As shown in Fig. 4, this trend is in conformity with the findings report of Edeh and Amadi, (2014), Etim et al., (2022).

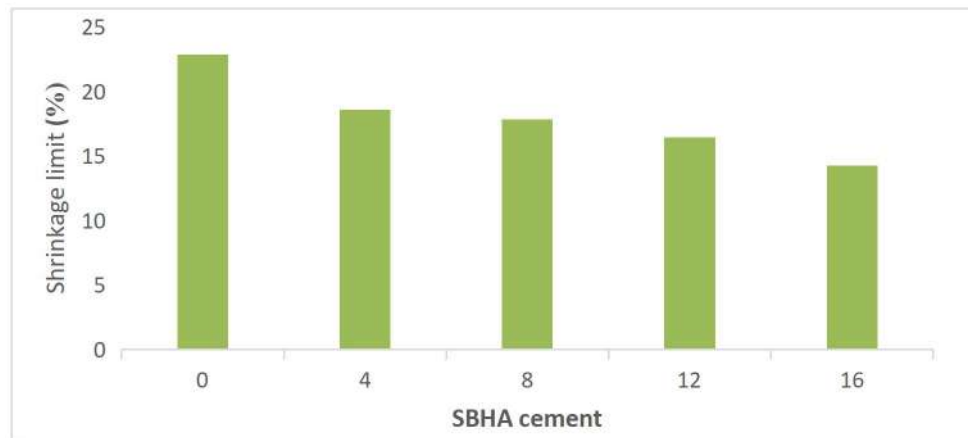


Figure 4: Shrinkage limit graph of black cotton soil with SBHA

3.5 Specific Gravity

The values of specific gravity recorded were 2.46, 2.48, 2.45, 2.43 and 2.38 for natural and stabilized soils at 4%, 8%, 12% and 16% SBHA, which shows that there were decreases from 4% SBHA to 16% SBHA (See Fig. 5). The specific gravity decreased with the increase in Soya bean waste ash (SBHA) as shown in Figure 4. below. The reduction is due to the lighter, porous, and less dense nature of SBHA compare to natural soil minerals, causing the blended soil-ash mix to have lower unit weigh as SBHA content increases.

The improved resulting specific gravity for the remediated soils could indicate higher strength and material quality when compared to the contaminated soil, as reported by Oyediran and Enya (2021).

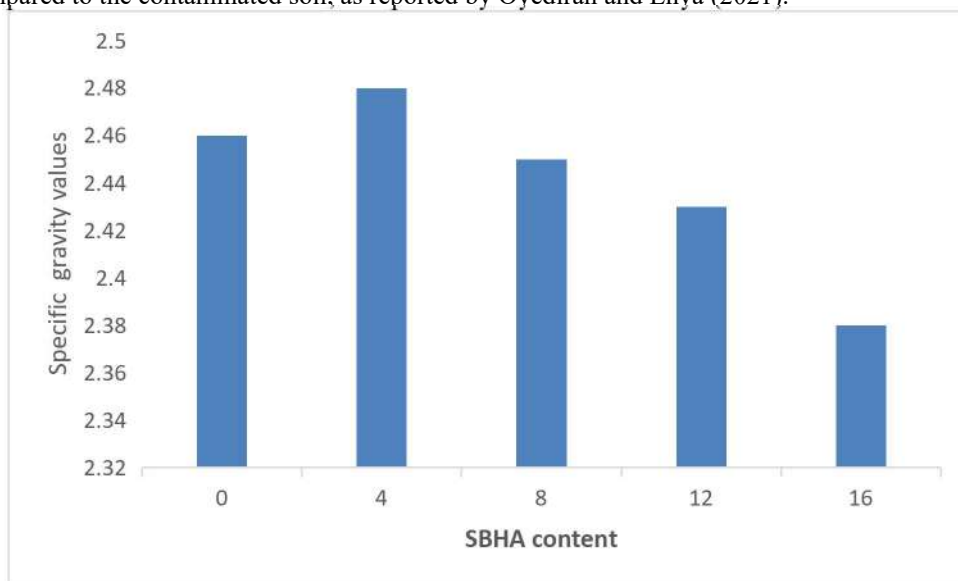


Figure 5: Specific Gravity graph of black cotton with SBHA

3.6 Compaction Characteristics

3.6.1 Maximum dry density

The variation of maximum dry densities (MDD) of stabilized black cotton soil with SBHA contents is shown in Fig. 6. Using British Standard Light, MDD values decreased with the increase in admixture SBHA contents. The MDD decreased from 1.68g/cm³ at 0% SBHA to 1.58g/cm³ at 12% SBHA content, and later increase to 1.59g/cm³ at 16% SBHA content the decrease may be due to the minimal effect of SBHA (with little calcium) on the workability of the stabilized soil. The flocculation and agglomeration of the clay particles due to ion exchange which is agreed with report of Etim et al., 2022.



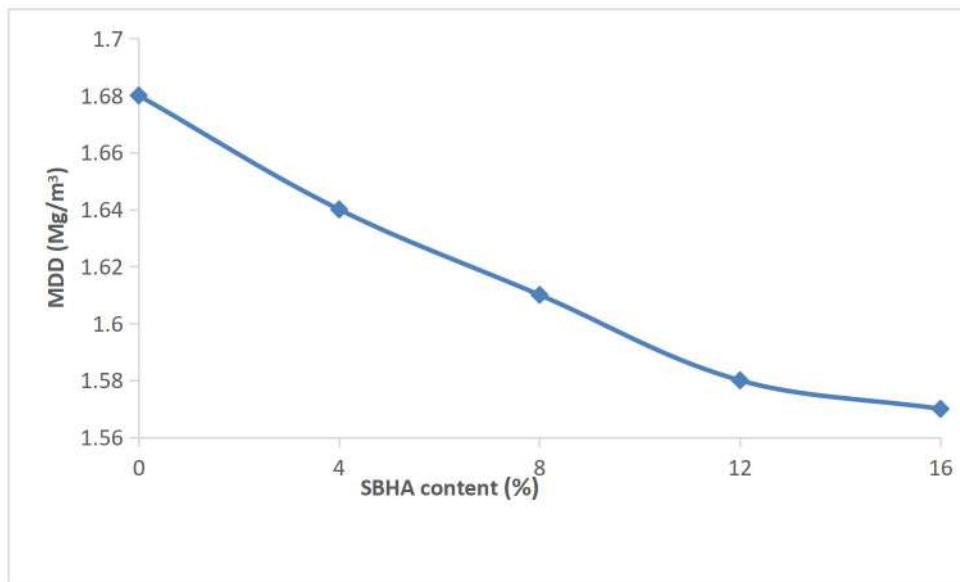


Figure 6: Variation of maximum dry density of stabilized soil with SBHA content

3.6.2 Optimum moisture content

The optimum moisture content (OMC) of black cotton soil increased with SBHA content up to 12% as shown in Fig. 7. Indicating higher water demand due to SBHA addition. Beyond 12% SBHA, a slight reduction in OMC was observed at 16%. The increase in OMC is attributed to the porous nature of SBHA and clay particle flocculation, resulted in lower OMC values. Overall, SBHA addition raises the moisture requirement of the soil, with the effect diminishing at higher SBHA contents which is agreed with report of Etim et al., 2022.

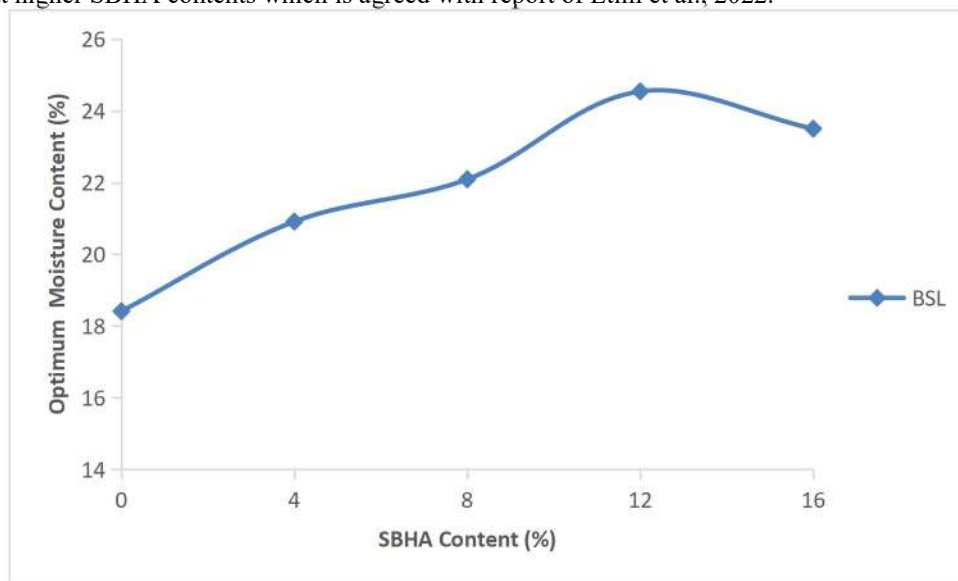


Figure 7: Variation of optimum moisture content of stabilized soil with SBHA content

4. CONCLUSION AND RECOMMENDATION

The preliminary characterization of the natural black cotton soil obtained from Gamadadi, Borno State, Nigeria, revealed that the soil belongs to the A-7-6 group according to the AASHTO (1996) classification system, and is classified as CH (Clay of high plasticity) under the Unified Soil Classification System (USCS, ASTM 1992). The soil exhibited a liquid limit of 52.0%, plastic limit of 19.52%, and a plasticity index of 32.48%, indicating a high degree of plasticity and expansiveness. Additionally, the soil recorded a linear shrinkage of 22.86%, free swell of 80%, and a specific gravity of 2.46, falls within the typical range for clay minerals, supporting the inference that the soil contains a significant proportion of fine-grained clay particles, likely dominated by montmorillonite or similar minerals. Collectively, these properties imply that the natural black cotton soil from Gamadadi is weak and problematic for engineering purposes in its natural state, necessitating stabilization to improve its properties. To improve the index



qualities of black cotton soil, an ideal SBHA level of 12% is recommended..

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