

STABILIZATION OF EXPANSIVE SOIL USING BAUHINIA THONNINGII (KALGO) FRUIT ASH

U.H. Rawayau¹, A.Y. Abdulfatah^{1*} and R.B. Shuaibu²

¹Department of Civil Engineering, Bayero University, Kano, Nigeria

²Department of Civil Engineering, Kano State Polytechnic, Kano State, Nigeria

*Corresponding author: email: ayabulfatah.civ@buk.edu.ng; +2348066031086

ABSTRACT

Due to excessive shrinkage and swelling characteristics, black cotton soils (BCS) pose a serious challenge to engineering structures founded on/in them. Soil stabilisation using cementitious or pozzolanic materials is usually a common practice of improving the engineering properties of the soil. In this study, the potential of Bauhinia thonningii fruit ash (BTFA) for stabilization of BCS was investigated. The BTFA used was obtained by controlled burning of Bauhinia thonningii fruit in an incinerator at a temperature of 600⁰C for 45min. After cooling and sieving through 75 μ m standard sieve; chemical composition analysis of the ash was conducted using (XRF) procedures. Laboratory tests were conducted in accordance with BS 1924 (1990) on black cotton soil treated with 0%, 2%, 4%, 6%, 8%, 10% and 12% BTFA. The soil was classified as A-7-5(17) and CH according to the American Association of State Highway and Transport Officials and the Unified Soil Classification System. British Standard Light (BSL) and British Standard Heavy (BSH) compactive efforts were used. Samples were cured for 7, 14, and 28 days to determine the unconfined compressive strength (UCS), California bearing ratio (CBR), and compaction characteristics. Improvement on the engineering properties of BCS with varying degree was observed. Plasticity index, liquid limit, and optimum moisture content decreased with an increase in BTFA content while plastic limit and maximum dry density (MDD) increased with increasing BTFA content. The maximum UCS values attained at 28 days curing period were 242kN/m² with BSL at 6% and 698kN/m² with BSH at 10% BTFA contents respectively. Thus, the results satisfied the sub-base requirements by the Nigerian Federal Ministry of Works. The Nigerian General Specification of 30% CBR criterion for sub-base was not achieved with BTFA content of 10%. Based on these observations, BCS treated with BTFA could be recommended as a sub-grade material in road construction with 10% content being the optimum. For general stabilisation for sub-base and base courses, a mixture of BTFA and cement or lime might be required.

Keywords: Expansive soil, Bauhinia Thonningii fruit ash, Compaction, Unconfined compressive strength and California bearing ratio

1 INTRODUCTION

Expansive soils are widely known to pose several challenges for engineering construction. They are considered a potential natural hazard that can cause extensive damage to structures if not treated adequately. This type of soil swells when given an access to water and shrinks when it dries out [1, 2]. In general, expansive soils have high plasticity, and are relatively stiff or dense. The expansive nature of the soil is most prevalent near the ground surface where the profile is subjected to seasonal and environmental changes. These soils often have a significant amount of montmorillonite clay mineral present. The higher the number of monovalent cations absorbed to the clay mineral (e.g. sodium), the more severe the expansive soil problem [3]. In road construction, replacing this type of

soil with a better one from a far distance will make the construction too expensive and thus soil stabilization is the best option. A common expansive soil found in Nigeria is the black cotton soil which is prevalent in the North-Eastern region. This soil is generally confined to the semi-regions of tropical and temperate and is abundant where the annual evaporation exceeds the precipitation [4]. Its mineralogy is dominated by the presence of montmorillonite which is characterized by large volume change from wet to dry seasons and vice versa. Deposits of black cotton soil in the field show a general pattern of cracks during the dry season of the year [5].

The objective behind soil stabilization is to improve the engineering properties of the soil such as density, strength and cohesion between its particles, and to reduce the soil's plasticity. Some of the materials that are traditionally used for soil stabilization include cement, lime and fly ash. These binders, with other similar materials, are used in certain proportions to improve the soils through chemical change. There have recently been attempts by researchers to use other local materials with pozzolanic properties such as rice husk ash and bagasse ash to replace traditional binders in soil stabilization [6]. This is considered necessary as a result of the exorbitant cost of cement. *Bauhinia thonningii*, called *Kalgo* in Hausa Language, is a local tree plant whose fruit may have the potentials of being used for soil stabilization. It is found in abundance in Northern part of Nigeria [7] and it has been used locally in earthen buildings. This fruit is botanically known as *Piliostigma thonningii*, belonging to the family of caesalpiniaceae that comprises of trees, shrubs or very rarely scramblers. These types of fruits are distributed in Africa and Asia in open woodland and savannah regions that are moist as well as wooded grasslands in low to medium altitudes [8]. The fruit is hairy, hard and flattish pod, which turns rusty brown, woody, twisted and splits at ripening and usually persistent on the tree between June and September [8]. The aim of this research is therefore to use the burned fruit ash of this plant for soil stabilization.

2 MATERIALS AND METHOD

Expansive Black Cotton Soil: The expansive black cotton soil used in this study was collected from Baure village (latitude $10^{\circ} 16'N$ and longitude $11^{\circ} 21'E$) in Yamaltu-Deba Local Government Area of Gombe State, Nigeria. The black cotton soil was collected by the method of disturbed sampling after removing the top soil at 0.5m depth and transported in sacks to the Civil Engineering Laboratory, Faculty of Engineering, Bayero University Kano. Little amount of the sample was sealed in polythene bag for the determination of natural moisture content. The soil was air dried, pulverized and sieved through 75 μ m sieve (BS No. 200 sieve) as required for laboratory testing. Preliminary analysis of the sample was conducted for the purpose of classification as well as to have background information that will serve as a benchmark for understanding possible changes in the soil's properties after treatment with BTFA.

Bauhinia thonningii Fruit: The *Bauhinia thonningii* Fruit was obtained from Kano, a North-Western City of Nigeria. The Fruit was dried and grounded using local grinding machine then burnt under controlled temperature of 600°C for 45mins in a furnace at the Art and Industrial Design Department, School of Technology, Kano State Polytechnics. The procedure required that in order to get the amorphous form of the ash. The Ash obtained was sieved through BS Sieve no. 200 (75 μ m) as specified in [9]. The ash was then subjected to XRF test and its oxide composition was determined at the Nigerian Geological Survey Agency, National Geosciences Research Laboratory (NGRL) Kaduna, Nigeria. The XRF was performed on both the powdered fruit and the ash as presented in Table 1.

Water: The water used in the mixing of samples was potable water free from suspended solids and organic materials.

Table 1. Oxide Composition of BCS, BTF and BTFA

Compounds	<u>Mineral Compositions</u>		
	BCS (%)	BTF (%)	BTFA (%)
SiO ₂	49.2	4.28	42.60
Al ₂ O ₃	15	0.32	5.24
K ₂ O	1.52	31.80	28.90
CaO	9.61	11.60	16.20
SO ₃	0.21	0.07	2.45
Fe ₂ O ₃	16.7	1.70	1.52
TiO ₂	2.17	0.96	0.16
P ₂ O ₅	-	0.30	-
MgO	-	1.10	-
Na ₂ O	-	0.88	-
MnO	0.17	-	0.16
CuO	-	-	0.13
Others	5.42	47.10	-
Loss of Ignition (%)	-	-	2.64

2.1 Experimental work

Tests were conducted on both natural and treated samples in accordance with the procedures outlined in [9]. The first phase of the investigation was the preliminary analysis which involved tests on natural soil to investigate the index and engineering properties. These tests included: Moisture Content, Atterberg limit tests, Sieve Analysis test, Specific Gravity, Free swell, Compaction test (BSL and BSH), unconfined compressive strength (UCS) and California Bearing Ratio (CBR). The second phase involved the addition of varying proportions of *Bauhinia thonningii* Fruit Ash (i.e., 0, 2, 4, 6, 8, 10 and 12%) by dry weight of the soil to investigate its effect on the soil properties. The tests conducted in this phase included; Atterberg limits, compaction (BSL and BSH), CBR and UCS.

3 RESULTS AND DISCUSSION

3.1 Natural Soil

The natural soil was characterised for the purpose of classification as well as to have background information that will serve as a benchmark for understanding possible changes in the soil's properties after treatment with BTFA. Table 2 presents the index properties of the natural black cotton soil.

Table 2. Index Properties of untreated Black Cotton soil

Property	Value/Description
Natural moisture content (%)	9.68
Liquid limit (%)	51.4
Plastic limit (%)	32.6
Plasticity index (%)	18.8
Linear shrinkage (%)	14.29
Free swell (%)	64.29
Specific gravity (%)	2.66
Percentage passing No. 200 sieve (%)	79.14
Percentage sand fraction (%)	20.86
Percentage silt fraction (%)	15.19
Percentage clay fraction (%)	63.95
AASHTO classification	A-7-5
Group Index	17
Colour	Dark grey
USCS classification	CH

The engineering properties of the natural black cotton soil are presented in Table 3. From Atterberg limits and sieve analysis tests the soil is classified as A-7-5(17) and CH in accordance with [10] and [11] respectively. The soil classifications showed that the soil is clayey with high plasticity (CH). The liquid limit and plasticity index values of 51.4% and 18.8% in Table 2 confirmed that the soil is highly plastic. Atterberg limits results have been observed to be very useful indicators of soil behaviour [12]. Using these parameters, the soil fell below the standard that is recommended for most engineering works. The findings of [13] corroborated this view. The free swell value of 64.29% indicated that the soil is of medium condition and physical inspection showed that the soil is dark grey in color. Particle size distribution curve indicated that the soil is well graded; containing 20.89% sand fraction, 15.19% silt fraction and 63.95% clay fraction.

The specific gravity of the soil was observed to be 2.66 which indicated the prevalence of montmorillonite, in conformity with [14] that reported a specific gravity range of 2.65 – 2.80. Table 3 signified that MDD values of 1.72Mg/m³ and 1.88Mg/m³, and OMC values of 15% and 13% were obtained for the British Standard Light (BSL) and British Standard Heavy (BSH) compactive energies respectively. The UCS values of 80kN/m² and 184kN/m² recorded for the natural soil at OMC for the two energy levels were relatively low. Similarly, low Un-soaked CBR values of 9.5% and 11.2% obtained at the energy levels of BSL and BSH further revealed that the material is not suitable for use as a construction material without modification. This is in agreement with [15] and [16].

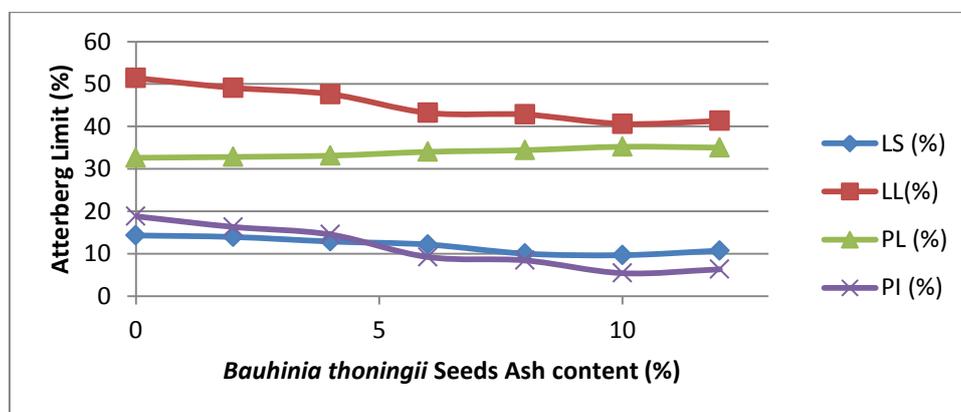
Table 3. Engineering Properties of Untreated Black Cotton soil

Property	Value/Description
Maximum Dry Density (MDD) BSL (Mg/m^3)	1.72
Maximum Dry Density (MDD) BSH (Mg/m^3)	1.88
Optimum moisture content (OMC) BSL (%)	15
Optimum moisture content (OMC) BSH (%)	13
Unconfined compressive strength using BSL (kN/m^2)	80
Unconfined compressive strength using BSH (kN/m^2)	184
Soaked California bearing ratio BSL (%)	8.7
Soaked California bearing ratio BSH (%)	10.4
Un-soaked California bearing ratio BSL (%)	9.5
Un-soaked California bearing ratio BSH (%)	11.2

3.2 Stabilized Soil

3.2.1 Evaluation of the effect of *Bauhinia thonningii* Fruit Ash on Atterberg Limits

Figure 1 shows the effect of BTFA on Atterberg limits. The liquid limit decreased with increase in BTFA content; and this could be attributed to BTFA being a pozzolana that aided flocculation and aggregation of the clay particles. The plastic limit also increased with increasing BTFA content. The peak value of 35.2% was observed at 10% BTFA content. This shows an increase of 2.6% when compared with the value obtained for the natural untreated soil. It was observed that, the plasticity index decreased with increase in BTFA content from 18.8% at 0% to 5.4% at 10% BTFA content, and then it increased slightly to 6.3% at 12% BTFA content. Generally, the plasticity index decreased sharply between 4 to 6% BTFA contents for the stabilized samples. The reason for the reduction in the plastic limit with increasing BTFA content could be attributed to the reduction in linear shrinkage with the addition of BTFA.

Figure 1. Effect of *Bauhinia Thonningii* Fruit Ash on Atterberg Limits

3.2.2 Compaction Characteristics

Maximum dry density

Figure 2 shows the variations in MDD of the soil with the addition of BTFA. The maximum dry density for the British Standard Light (BSL) compactive effort for 0% BTFA is 1.72Mg/m^3 . The addition of BTFA into the soil from 2% to 6% caused a decrease in the MDD to 1.70Mg/m^3 . The MDD further increased to 1.75Mg/m^3 at 4%, 1.73Mg/m^3 at 8% and 1.77Mg/m^3 at 10% addition of BTFA. It subsequently decreased to 1.72Mg/m^3 at 12% of the BTFA content. The variation in MDD with increase in BTFA content with the British Standard Heavy (BSH) compactive effort can also be seen in Figure 2. At 0% BTFA content an MDD of 1.88Mg/m^3 was obtained while as the BTFA was added from 2% to 10%, there was a continuous increase in the MDD with a peak value of 1.9794Mg/m^3 at 10% BTFA content. Thus, the MDD value decreased at 12% BTFA content. The variation in MDD was as a result of differences in specific gravity values between the soil and BTFA. This difference makes the specific gravity of the Soil-BTFA composite to vary depending on the amount of BTFA added. The variation is therefore attributed to dispersed structures aggregation formed by the addition of the BTFA [17]. The behaviour of expansive soils is known to be controlled by diffused double layer. The addition of BTFA decreases the repulsive resistance to compactive effort and the BTFA composite gets compacted to higher densities [18]. The significant of these variations is that the BTFA has an effect on the geotechnical properties of the soil.

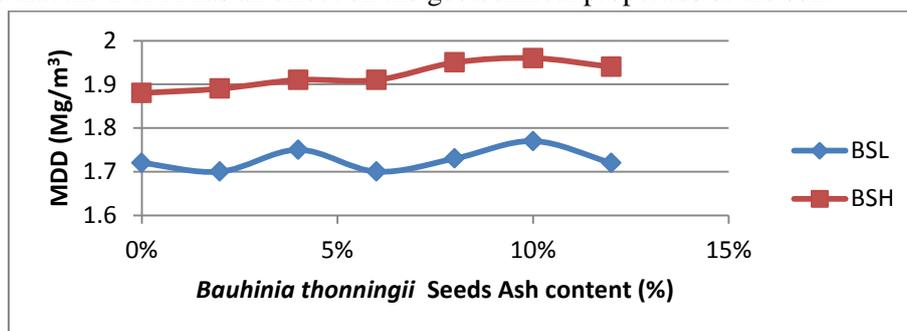


Figure 2. Variation of MDD of Black Cotton Soil with BTFA content

Optimum moisture content

Figure 3 shows the variation in optimum moisture content (OMC) of the black cotton soil as a result of the addition of BTFA. Though, there was no any significant change in the values of OMC, there was an increase in range between 10% and 14% for the two compactive energy levels. The increase in OMC could be due to increasing demand for water by various cations and clay mineral particles to undergo hydration reaction. The pattern of changes in OMC for the BSH compactive effort, is somewhat different probably because of the high compactive energy involved, hence the need for more moisture for the reaction to place. The variation in OMC was due to the fact that the BTFA has lesser specific surface area than the soil particles. This makes it to require lesser water for the lubrication of the composite in achieving the MDD [17].

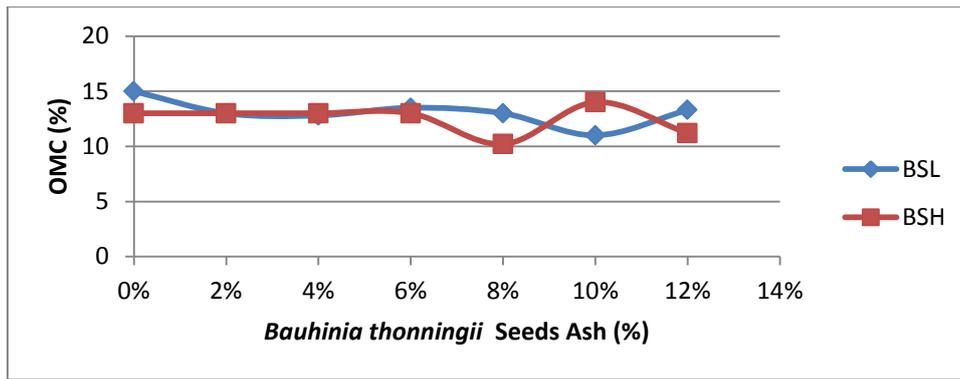


Figure 3. Variations of OMC of Black Cotton Soil with BTFA content

Unconfined Compressive Strength

Figures 4 and 5 show the variations in unconfined compressive strength (UCS) with BTFA contents for 7, 14, and 28 days curing. The samples were compacted to their maximum dry densities at the corresponding moisture contents, extruded from mould and waxed cured for the 7, 14, and 28 days respectively before subjecting them to testing. The results indicated a proportional increase in strength with BTFA contents respectively. The addition of BTFA has shown a progressive strength development with the corresponding longer curing periods. The 28 days peak UCS strength values for both compactive energies were recorded as 240kN/m² at 6% BTFA with BSL and 698kN/m² at 10% BTFA with BSH.

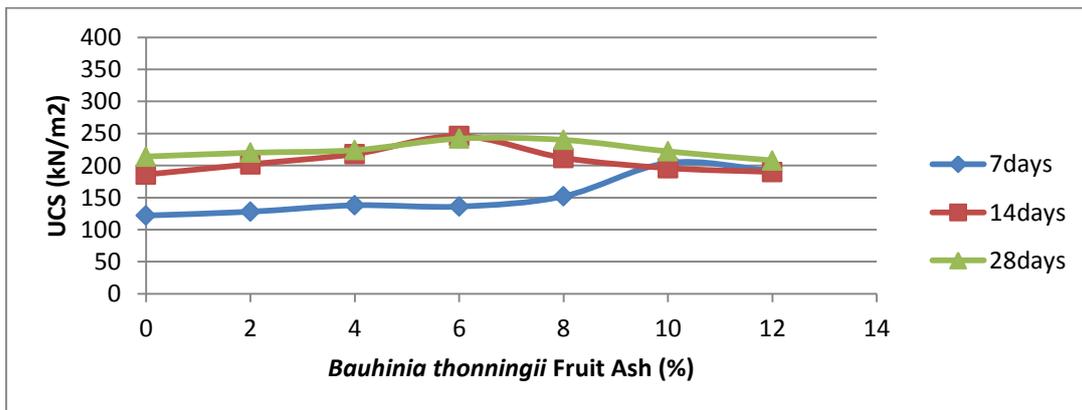


Figure 4. Variation of UCS with Black Cotton Soil with BTFA (BSL)

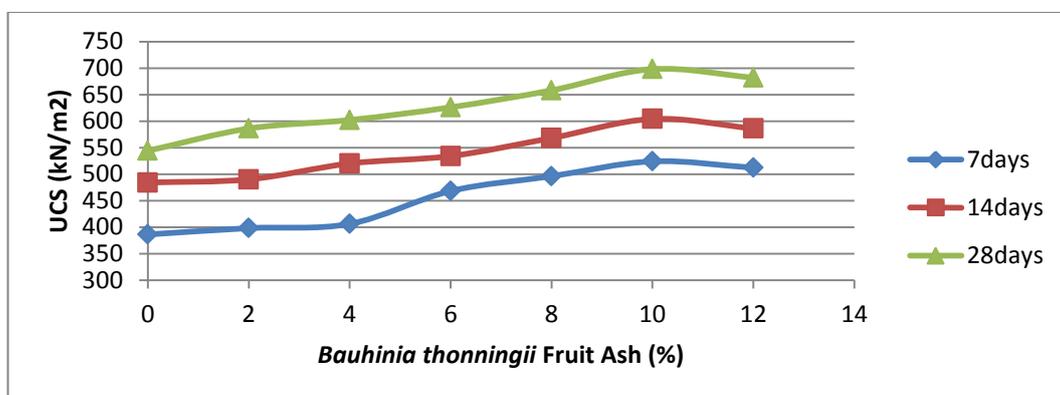


Figure 5. Variation of UCS with Black Cotton Soil with BTFA (BSH)

California Bearing Ratio (CBR)

A similar pattern to the UCS results was observed with the CBR results shown in Figures 6 and 7, which exhibited peak CBR values of 20% and 22% at 10% BTFA content for BSL and BSH for soaked specimens and values of 25% and 30% at 10% BTFA content for BSL and BSH for un-soaked specimens respectively. The recorded peak CBR values, apart from the value for the un-soaked specimen at 10% BTFA with BSH, are lower than the specifications in [16] where 30% CBR criterion is specified for sub-base. Based on these observations, BCS treated with BTFA could be recommended as a sub-grade material in road construction with 10% BTFA addition as the optimum value. The 10% BTFA un-soaked specimen with BSH could be used as a sub-base material.

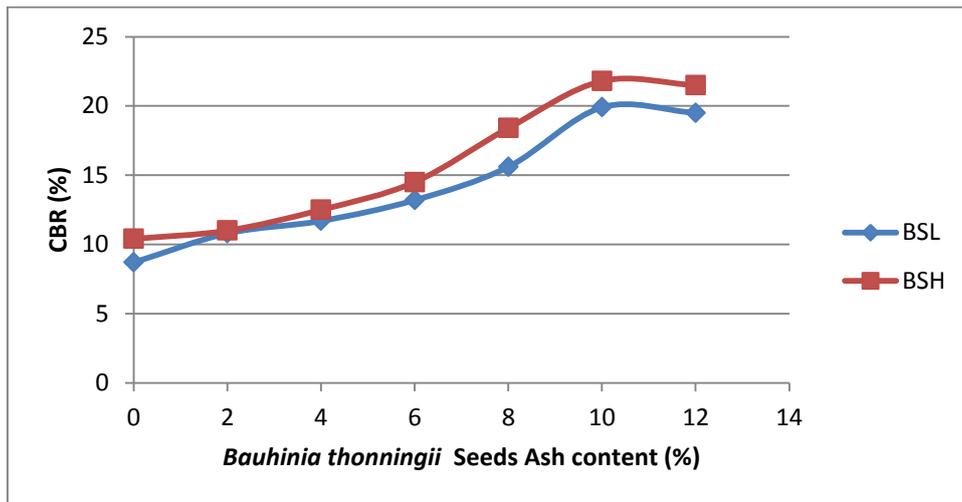


Figure 6. Variation of Soaked CBR with BTFA content (BSL and BSH compaction)

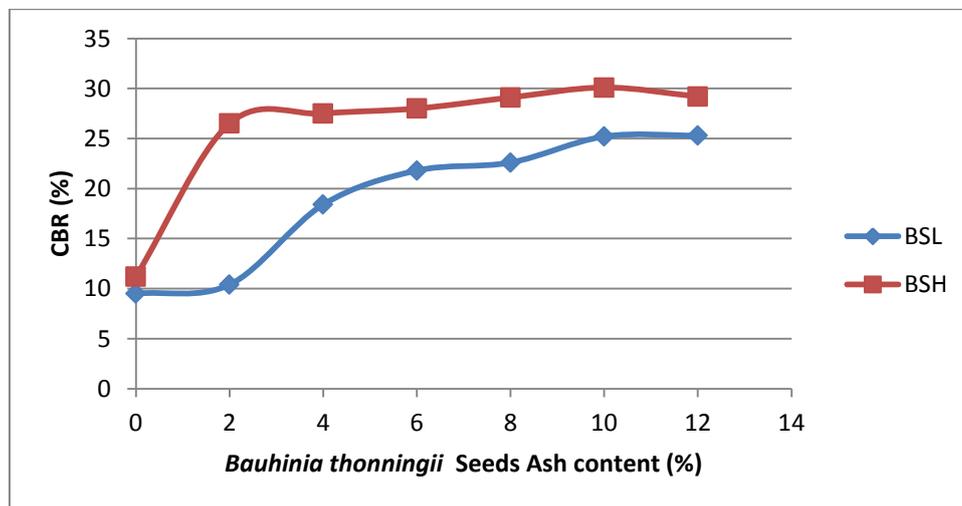


Figure 7. Variation of Un-soaked CBR with BTFA content (BSL and BSH compaction)

4 CONCLUSION

The black cotton soil used in this study is classified as A-7-5(17) soil based on AASHTO classification system and it is clay with low plasticity (CL) based on the Unified Soil Classification System. The results of the study have confirmed the effect of BTFA on the geotechnical properties of the soil; liquid limit, plastic limit plasticity index, compaction characteristics, unconfined compressive

strength and the California bearing ratio. An optimum of 10% BTFA content gave the peak improvement in the geotechnical properties of the black cotton soil and is therefore recommended. BCS treated with BTFA could be recommended as a sub-grade material in road construction with 10% BTFA addition as the optimum value and 10% BTFA un-soaked specimen with BSH could be used as a sub-base material.

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