

## Original Research Article

# Stabilization of Ula-Ubie-Ubeta Town Road Laterite Soil with *Costus Lateriflorus* Bagasse Fibre

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**Abstract:** The study evaluated the influence of *Costus lateriflorus* bagasse fibre on the properties of expansive soils. Laterite and clay soil samples along Ubeta-Ula-Ubie road in Ahoada West LGA of Rivers state, Nigeria were prepared and subjected to laboratory analysis for swelling potential, volume change, maximum dry density (MDD), optimum moisture content (OMC), consistency limits, California bearing ratio (CBR) and unconfined compressive strength (UCS). Preliminary analysis classified the soils as A-7- 6 on the AASHTO classification system. Swelling potential, volume change, maximum dry density (MDD), liquid limit (LL) and plasticity index (PI) of the stabilized Laterite and clay soils along Ubeta-Ula-Ubie road decreased with increasing percentage of *Costus lateriflorus* bagasse fibre, while optimum moisture content (OMC), plastic limit (PL) and unconfined compressive strength (UCS) increased with the addition of *Costus lateriflorus* bagasse fibre. Results established that increase bagasse fibre content improved the properties of the soil suitable for road construction. However, the bagasse fibre performed better in Laterite soil than clay soil, and 7.5% bagasse fibre would be appropriate for use as stabilization material in soil with similar characteristics like the Laterite and clay soil along Ubeta-Ula-Ubie road.

**Keywords:** Soil, *Costus lateriflorus* Bagasse Fibre, CBR, UCS, Consistency Limits.

## 1. INTRODUCTION

Soil is a porous medium that exhibits low stress behavior, with geotechnical properties varying with environmental factors. Due to population growth and ever-increasing urbanization, there is a huge demand for unstable and eroded soils with poor geotechnical properties. Therefore, developing an effective stabilization technique for environmentally sensitive soils will assist to improve soil properties (Sato *et al.*, 2016; Bordoloi *et al.*, 2017).

In the past, countless soil improvement techniques have been proposed and applied to stabilize weaker soils prior to construction. The proposed improvement method can be classified into two types: (i) mechanical stabilization method and (ii) chemical stabilization method. Mechanical methods include displacement and replacement, stilt construction, preloading, rock column methods, soil nailing, and the application of synthetic reinforcement. The chemical stabilization method consists of deep in-situ mixing and surface stabilization with cement, fly ash, bottom ash, bentonite, gypsum, silica and blast furnace slag (Celik and Nalbantoglu, 2013; Yadu and Tripathi, 2013; Ozdemir, 2016; Sharman and Sivapullaiah, 2016). Chemical stabilization techniques have also been widely incorporated into the ash of some organic materials obtained from the incineration process (Iorliam *et al.*, 2102). However, some materials used in mechanical and chemical stabilization are associated with some environmental problems such as global warming from high carbon emissions, high energy prices, pollution (air, soil and water), depletion of non-renewable resources and

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influx of natural resources and hazardous substances on the geoenvironment (Sakaray *et al.*, 2012; Al-Swaidani *et al.*, 2016; Dilrukshi *et al.*, 2016).

Therefore, the using environmentally friendly materials to modify weaker soils would be most suitable for soil improvement and to ensure sustainable land use (Achal *et al.*, 2016; Dilrukshi *et al.*, 2016; Fagone *et al.*, 2017). The concept and principle of strengthening soil with the help of fibers was pioneered by Vidal in 1969, who found that the addition of reinforcement elements to the soil mass increased the shear strength of the surrounding area (Vidal, 1969). Previous studies reflect a variety of reinforcing materials ranging from low modulus polymeric materials to high strength sheet metal used as geosynthetics to enable fiber reinforcement (Bordoloi *et al.*, 2017). These conventional synthetic fibers are mainly a by-products, which is a finite non-renewable resource on earth. Geosynthetic products have gained popularity due to their flexibility in processing, high specific hardness and low cost (Pujari *et al.*, 2017). Moreover, advantages such as environmental friendliness, resource richness, minimal energy consumption, high profitability and potential, has made soil stabilization with natural fiber in recent times to emerge as one of the developing techniques for sustainable soil stabilization in geotechnical engineering as compared to other engineering techniques (Ibrahim *et al.*, 2010; Sharma *et al.*, 2015; Fagone *et al.*, 2017; Ghosha *et al.*, 2017). Alternative use of natural fibers for traditional geosynthetic reinforcement to increase load carrying capacity has shown great potential and is receiving increasing attention in geotechnical engineering, which is still relatively new technique that deserves further investigation (Hejazi *et al.*, 2012; Fagone *et al.*, 2017; Ghosha *et al.*, 2017).

The main objective of this study is to explore the ability of natural fibers obtained from *Costus lateriflorus* bagasse plant as soil stabilizing material. Properties such as swelling potential, volume change, maximum dry density, optimum moisture content, consistency limits, California bearing ratio and unconfined compressive strength were investigated for samples stabilized with or without *Costus lateriflorus* bagasse fibre.

## **2. MATERIALS AND METHODS**

### **2.1 Materials**

The materials used are stated and briefly explained under the following subheadings.

#### **2.1.1 Soil**

The soils used for the study were collected from Ula-Ubie-Ubieta road in Ubie Districts of Ekpeye, Ahoada-West Local Government of Rivers State, beside the failed sections of the road at 1.5 m depth. The location lies on the recent coastal plain of the North-Western of Rivers state of Niger Delta.

#### **2.1.2 *Costus lateriflorus* Bagasse**

The *Costus lateriflorus* bagasse is a wide plant, medicinally used in the local areas, and it mostly found in the bushes. The plant was collected from Oyigba Town bush, in Ubie Clan of Ahoada-West, Rivers State, Nigeria.

#### **2.1.3 Cement**

The cement used was Portland cement, purchased in the open market at Mile 3 market road, Port Harcourt, Rivers State.

### **2.2 Method**

Tests conducted were maximum dry density, moisture content determination, consistency limits, California bearing ratio (CBR) and unconfined compressive strength (UCS).

#### **2.2.1 Moisture – Density (Compaction) Test**

This laboratory test is performed to determine the relationship between the moisture content and the dry density of a soil for a specified compactive effort.

#### **2.2.2 Moisture Content Determination**

The natural moisture content of the soil as obtained from the site was determined in accordance with BS 1377 (1990) Part 2. The sample as freshly collected was crumbled and placed loosely in the containers and the containers with the samples were weighed together to the nearest 0.01g.

#### **2.2.3 Consistency Limits**

The liquid limit (LL) is arbitrarily defined as the water content, in percent, at which a part of soil in a standard cup and cut by a groove of standard dimensions will flow together at the base of the groove for a distance of 13 mm (1/2in.) when subjected to 25 shocks from the cup being dropped 10 mm in a standard liquid limit apparatus operated at a rate of two shocks per second.

### 2.2.4 California Bearing Ratio (CBR) Test

The California Bearing Ratio (CBR) test was developed by the California Division of Highways as a method of relegating and evaluating soil- subgrade and base course materials for flexible pavements.

### 2.2.5 Unconfined Compression (UC) Test

The unconfined compressive strength is taken as the maximum load attained per unit area, or the load per unit area at 15% axial strain, whichever occurs first during the performance of a test. The primary purpose of this test is to determine the unconfined compressive strength, which is then used to calculate the unconsolidated undrained shear strength of the clay under unconfined conditions.

## 3. RESULTS AND DISCUSSION

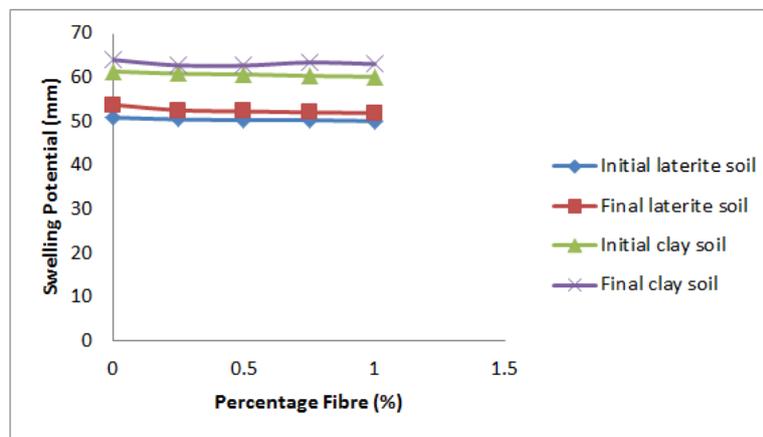
Laboratory analysis on the swelling potential, volume change, maximum dry density (MDD), optimum moisture content (OMC), consistency limits, California bearing ratio (CBR) and unconfined compressive strength (UCS) of stabilized Laterite and clay soils along Ubeta-Ula-Ubie road in Ahoada West LGA of Rivers state of Nigeria are presented and discussed in this section.

### 3.1 Swelling potential

The results of swelling potential of Laterite and clay soils stabilized with *Costus lateriflorus* bagasse fibre at 0 – 1.0% weight percent are shown in Table 1, while the profiles with respect to the weight percent are shown in Figure 1.

**Table-1: Effect of fibre product on swelling potential of the soils**

Bagasse fibre (%)	Swelling Potential (mm)			
	Initial Laterite soil	Final Laterite soil	Initial clay soil	Final clay soil
0	50.85	53.78	61.35	63.99
0.25	50.68	53.34	60.85	62.73
0.5	50.45	53.06	60.68	62.69
0.75	50.27	52.78	60.34	63.39
1	50.18	52.62	60.17	63.04



**Fig-1: Swelling potential versus bagasse fibre content**

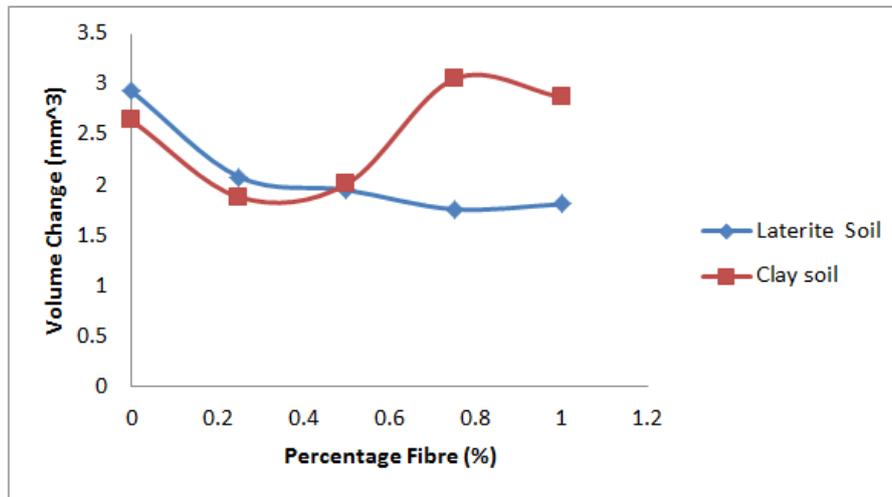
The profiles of swelling potential of stabilized Laterite soil and clay soil at *Costus lateriflorus* bagasse fibre content of 0 – 1.0% weight percent are shown in Figure 1. The profiles indicated that the swelling potential of stabilized clay soil at initial and final conditions were higher than that of stabilized Laterite soil. However, the swelling potential of the stabilized clay and Laterite soils slightly decreased with increasing percentage of the bagasse fibre. The results in Table 1 showed that the swelling in Laterite soil with no stabilizer increased from 50.85 to 53.78mm (5.76% swelling increase). Also, the swelling in clay soil with no stabilizer increased from 61.35 to 63.99mm (4.30% swelling increase). But with the addition of bagasse fibre as stabilizer reduced the swelling potential in Laterite and clay soils by 4.12% and 3.09% respectively, at 0.25% bagasse fibre, while at 1.0% at bagasse fibre, the swelling potential in Laterite and clay soils reduced by 3.61% and 4.77% respectively. These results indicate that lateritic soil of Ubeta-Ula-Ubie Road has higher swelling potential than the clay soil. Though, from the swelling percentages, it clearly shows that both type of soils possessed low swelling potential, which affirmed the reports of some studies that observed that clayed or lateritic soil in Nigeria are of low swelling potential (Okonkwo *et al.*, 2016; Tse and Ogunyemi).

### 3.2 Volume change

The results of volume change in laterite and clay soils stabilized with *Costus lateriflorus* bagasse fibre at 0 – 10% weight percent are shown in Table 2, while the profiles are shown in Figure 2.

**Table-2: Effect of fibre product on volume change of the soils**

Bagasse Fibre (%)	Volume change (mm <sup>3</sup> )	
	Laterite Soil	Clay soil
0	2.93	2.64
0.25	2.08	1.88
0.5	1.95	2.01
0.75	1.76	3.05
10	1.81	2.87



**Fig-2: Volume change versus bagasse fibre content**

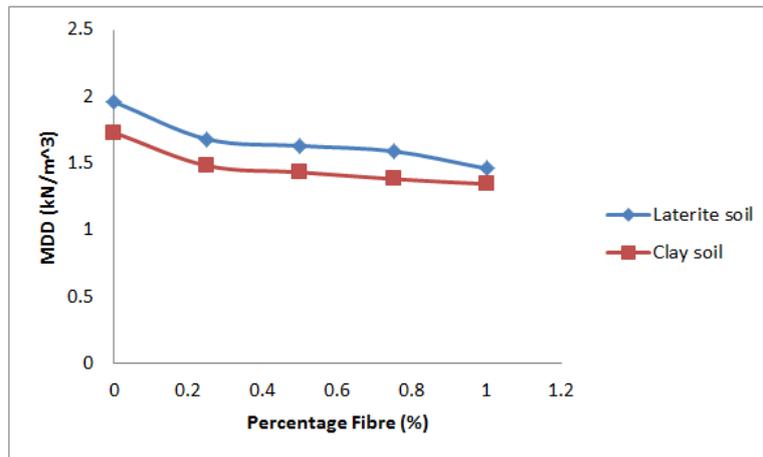
Figure 2 shows the profiles of volume change in stabilized lateritic soil and clay soil at 0 – 10% of *Costus lateriflorus* bagasse fibre content in the soils. From the profiles, the volume change in the stabilized clay and lateritic soils decreased with increasing percentage of the bagasse fibre content in the mix. The result showed that volume change in the stabilized clay soil was lower than that of stabilized lateritic soil. Thus, from results in Table 2, volume change in lateritic and clay soils with no stabilizer was 2.93mm<sup>3</sup> and 2.64mm<sup>3</sup>, but with inclusion of bagasse fibre as stabilizer, the volume change reduced between 2.66mm<sup>3</sup> and 2.44mm<sup>3</sup> in lateritic soil and between 2.03mm<sup>3</sup> and 1.40mm<sup>3</sup> when the bagasse fibre content in the soil was added between 2.5% and 10%. Like swelling potential, the lateritic soil along Ubeta-Ula-Ubie Road has higher volume change than clay soil. In soils where there is high proportion of fine grains of silt and clay, volume changes may be high, especially when in contact with water, which can weaken the soil structure and consequent reduction in overall strength (Jawad et al., 2014; Tse and Ogunyemi, 2016).

### 3.3 Maximum dry density

The results of maximum dry density (MDD) for the lateritic and clay soils stabilized with *Costus lateriflorus* bagasse fibre at 0 – 10% weight percent are shown in Table 3. Also, the profiles of MDD for the stabilized soils are shown in Figure 3.

**Table-3: Effect of bagasse fibre on MDD of the soils**

Bagasse fibre (%)	MDD (kN/m <sup>3</sup> )	
	Laterite soil	Clay soil
0	1.96	1.73
0.25	1.68	1.481
0.5	1.63	1.432
0.75	1.59	1.382
1	1.46	1.344



**Fig-3: MDD versus bagasse fibre content**

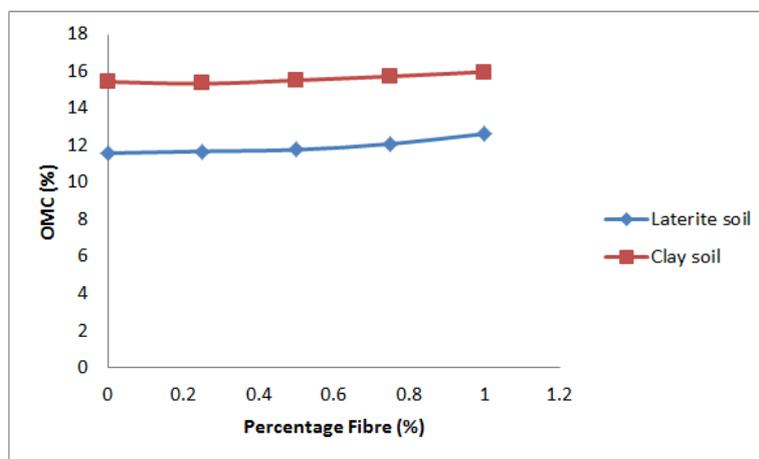
Figure 4.3 showed the profiles of maximum dry density (MDD) of laboratory compaction tests of lateritic and clay soils along Ubeta-Ula-Ubie Road stabilized with 0 to 10% bagasse fibre. The results showed that MDD decreased with increase in percentage of bagasse fibre content in both type of soils. Lateritic soil recorded higher percentage of maximum dry density compared to clay soil. The MDD in non-stabilized lateritic and clay soils was obtained as 1.96 kN/m<sup>3</sup> and 1.73 kN/m<sup>3</sup> respectively, but with bagasse fibre as stabilized material in the soils, the MDD value decreased to 1.642 at 2.5% and further to 1.428kN/m<sup>3</sup> at 10% in lateritic soil, while in clay soil, MDD decreased to 1.458 at 2.5% and further to 1.321kN/m<sup>3</sup> at 10%. The MDD recorded in this study were below the values reported in soils located within Olakwo in Etche L.G.A., Emohua and Igwuruta in Emohua and Ikwerre L.G.As of Rivers State (Tse and Ogunyemi, 2016). In another study, stabilization of clay soil with waste foundry sand between 10% and 40%, increased the MDD, which was attributed to higher specific gravity and surface area of the stabilized material compared to particles of clay soil (Bhardwaj and Sharma, 2020).

### 3.4 Optimum moisture content

The results of optimum moisture content (OMC) for the lateritic and clay soils stabilized with *Costus lateriflorus* bagasse fibre at 0 – 10% weight percent are shown in Table 4. Also, the profiles of OMC for the stabilized soils are shown in Figure 4.

**Table-4: Effect of bagasse fibre on OMC of the soils**

Bagasse Fibre (%)	OMC (%)	
	Laterite soil	Clay soil
0	11.59	15.44
0.25	11.69	15.34
0.5	11.77	15.52
0.75	12.09	15.73
1	12.63	15.97



**Fig-4: OMC versus bagasse fibre content**

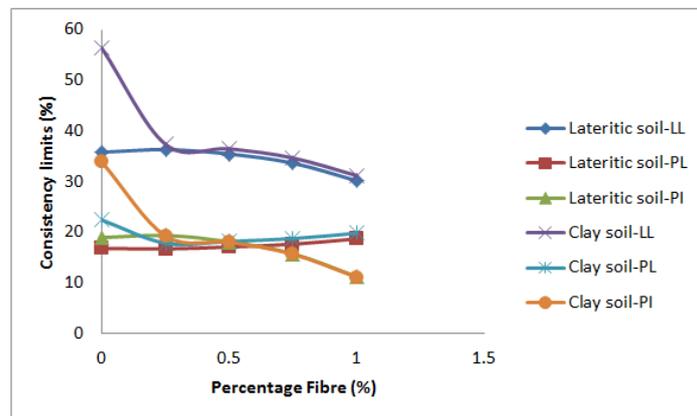
Figure 4.4 showed the profiles of optimum moisture content (OMC) of compaction test on lateritic and clay soils along Ubeta-Ula-Ubie road stabilized with 0 to 10% bagasse fibre. The results showed that OMC increased with increase in percentage of bagasse fibre content in both type of soils. Clay soil recorded higher percentage of OMC compared to lateritic soil. The OMC in the non-stabilized lateritic and clay soils was obtained as 11.59% and 15.4% in respectively, but with stabilization of 2.5 – 10% bagasse fibre with the soils, OMC increase ranged from 12.14 to 13.08% in the lateritic soil, and from 15.30 to 15.93% in clay soil. The percentages of OMC (8-10%) recorded by Tse and Ogunyemi (2016) in lateritic soils located within Olakwo, Emohua and Igwuruta towns of Rivers State were below the values in this study, and any soil with OMC above 10% are not suitable for use under bituminous surfacing (Tse and Ogunyemi, 2016). The another study, stabilization of clay soil with waste foundry sand between 10% and 40%, increase in OMC with increasing percentage of stabilizer was attributed to the properties of soil rich in some clay minerals such as montmorillonite with high water holding capacity (Mgangira and Jones, 2006; Kumar *et al.*, 2016; Bhardwaj and Sharma, 2020).

### 3.5 Consistency limits of the stabilized soils

The results of consistency limits (liquid limit (LL), plastic limit (PL) and plasticity index (PI)) of the stabilized soils at 0 – 10% bagasse is shown in Table 5, while the profiles are shown in Figure 5.

**Table-5: Effect of bagasse fibre on consistency limits of the soils**

Bagasse Fibre (%)	Consistency limits (%)					
	Lateritic soil-LL	Lateritic soil-PL	Lateritic soil-PI	Clay soil-LL	Clay soil-PL	Clay soil-PI
0	35.81	16.84	18.97	56.29	22.43	33.86
0.25	36.32	16.74	19.39	37.35	17.85	19.28
0.5	35.47	17.12	18.16	36.5	18.23	18.05
0.75	33.64	17.67	15.78	34.67	18.78	15.67
1	30.17	18.72	11.26	31.2	19.83	11.15



**Fig-5: Consistency limits versus bagasse fibre content**

Figure 5 showed profiles of liquid limit (LL), plastic limit (PL) and plasticity index (PI) of lateritic and clay soils along Ubeta-Ula-Ubie Road stabilized with 0 to 10% bagasse fibre. The results showed that LL in lateritic soil initially increased before declining as the fibre content was increased, but in clay soil, there was continuous gradual decrease in LL as the percentage of bagasse fibre content was increased. Clay soil recorded higher percentage of LL compared to lateritic soil. The LL in non-stabilized lateritic and clay soils were obtained as 35.81% and 56.29% respectively. However, in the lateritic soil sample stabilized with bagasse fibre, the LL value increased to 37.35% at 2.5% bagasse fibre and then decreased to 31.20% at 10% bagasse fibre. Also, in the clay soil sample, LL decreased to 55.22% at 2.5% bagasse fibre and further to 49.29% at 10% bagasse fibre.

Unlike liquid limit, the plastic limit (PL) in lateritic and clay soils increased consistently as the bagasse fibre content was increased. Again, clay soil recorded a higher percentage in PL compared to lateritic soil. The PL in non-stabilized lateritic and clay soils were obtained as 16.84% and 22.43% respectively. As indicated in Table 5, PL in the lateritic soil sample stabilized with bagasse fibre increased to 17.85% at 2.5% bagasse fibre and further to 19.83% at 10% bagasse fibre. Also, in the clay soil sample, PL increased to 24.89% at 2.5% bagasse fibre and further to 28.80% at 10% bagasse fibre.

Like liquid limit, the plasticity index (PI) in lateritic soil initially increased and then, decreased as the fibre content was increased, while in clay soil, there was gradual decrease in PI as bagasse fibre content was increased. Again, clay soil recorded a higher percentage in PI compared to lateritic soil. The PI percentage in non-stabilized lateritic and

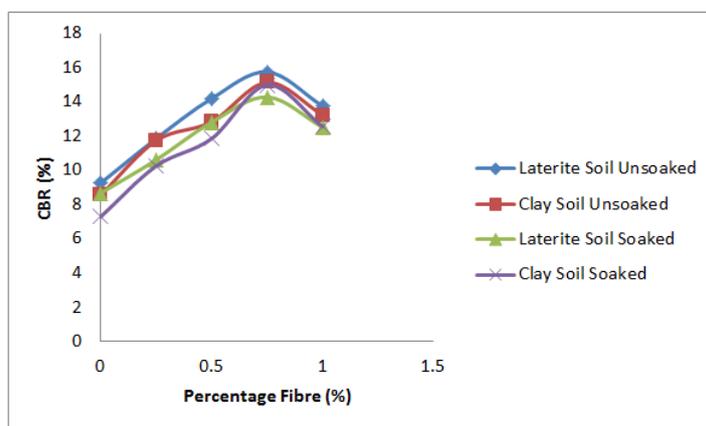
clay soils were obtained as 18.97% and 33.86% respectively. However, in the lateritic soil sample stabilized with bagasse fibre, PI increased to 19.328% at 2.5% bagasse fibre and then decreased to 11.15% at 10% bagasse fibre. Moreover, in the clay soil sample, PI decreased to 30.14% at 2.5% bagasse fibre and further to 20.30% at 10% bagasse fibre. A decrease in liquid limit and plasticity index at increasing content of stabilizer was reported by Bhardwaj and Sharma (2020), and they also observed that beyond 20% of the stabilized material, there was no change in plasticity index. Meanwhile, some studies attributed the reduction in consistency limits of stabilized soil to the impact stabilizers create on expansive soil (Dong *et al.*, 2013; Jain *et al.*, 2015; Kale *et al.*, 2019; Bhardwaj and Sharma, 2020).

### 3.6 California bearing ratio (CBR) of stabilized soil

The California bearing ratio (CBR) for unsoaked and soaked stabilized laterite and clay soils at 0 – 10% bagasse is shown in Table 6, while the profiles are shown in Figure 6.

**Table-6: Effect of bagasse fibre on CBR of the soils**

Bagasse Fibre (%)	Laterite Soil Unsoaked	Clay Soil Unsoaked	Laterite Soil Soaked	Clay Soil Soaked
0	9.25	8.55	8.67	7.28
0.25	11.85	11.73	10.61	10.25
0.5	14.19	12.83	12.81	11.85
0.75	15.75	15.13	14.28	14.98
1	13.75	13.23	12.51	12.55



**Fig-6: CBR versus bagasse fibre content**

Figure 6 shows the profiles of CBR for unsoaked and soaked Laterite and clay soils stabilized with 0 to 10% bagasse fibre. The CBR for unsoaked and soaked stabilized Laterite and clay soil increased with increase in bagasse fibre content to a maximum value at 7.5% bagasse fibre. From the recorded results, CBR for unsoaked non-stabilized lateritic and clay soil samples were obtained as 9.25% and 8.55% respectively, while for soaked non-stabilized lateritic and clay soil samples, the CBR were recorded as 8.67% and 7.28% respectively. In the lateritic soil sample stabilized with bagasse fibre, CBR increased to 11.85% for unsoaked Laterite soil, 10.61% for unsoaked clay soil, 10.83% for soaked Laterite soil and 10.02% for soaked clay soil, at 2.5% bagasse fibre. The CBR then increased further to 15.75% for unsoaked Laterite soil, 14.28% for unsoaked clay soil, 14.83% for soaked Laterite soil and 13.24% for soaked clay soil, at 7.5% bagasse fibre. Nevertheless, there was decrease of CBR in the Laterite and clay soil samples at 10% bagasse fibre (Table 6).

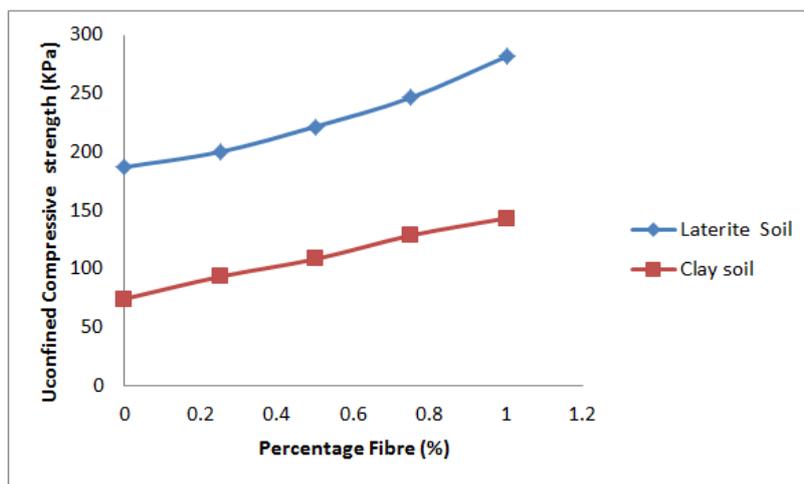
California Bearing Ratio (CBR) test is used for empirical estimation of the bearing capacity of sub-grade and sub-base materials under soaked and dry conditions (Tse and Ogunyemi, 2016). Thus, the increase in CBR of the stabilized soils is an indication that the bagasse fibre improved the properties of the soils. Also, the results showed that the CBR of the soaked soils was lower compared to the unsoaked soil samples, implying that soaking reduces the strength of the soils. This observation agreed with other studies on CBR of stabilized soil (Tse and Ogunyemi, 2016; Eltwati *et al.*, 2020). However, the stabilized Laterite soil performed better than clay soil in terms of CBR.

### 3.7 Unconfined compressive strength of stabilized soil

Compressive strength is another important property used in the analysis road construction work for on-site control of earthworks. Hence, the unconfined compressive strength (UCS) of the pavement obtained from the stabilized soil, and cured for 28 days was determined and compared. Table 7 showed the test results for the stabilized Laterite and clay.

**Table-7: Effect of bagasse fibre on unconfined compressive strength (UCS) of the soils**

Bagasse Fibre (%)	UCS (kPa)	
	Laterite Soil	Clay soil
0	187.17	74.57
0.25	200.13	93.6
0.5	221.76	108.6
0.75	246.53	128.8
1	281.6	143.4



**Fig-7: Unconfined compressive strength versus bagasse fibre content**

The test results for unconfined compressive strength (UCS) of stabilized Laterite and clay soil samples at 0 – 10% bagasse fibre is shown in Figure 7. From the profiles, UCS increased with increase in percentage of stabilized material. Thus, from the test results presented in Table 7, the unconfined compressive strength of the non-stabilized Laterite and clay soil samples was obtained as 187.18kPa and 74.57kPa, respectively. However, the UCS of bagasse stabilized Laterite soil sample increased from 185.95 to 232.57kPa at 2.5 - 10% bagasse fibre content. Also, the UCS of bagasse stabilized clay soil sample increased from 84.80 to 116.80kPa at 2.5 - 10% bagasse fibre content. The unconfined compressive strength in Laterite soil was far higher than those recorded in and clay soil at the corresponding percentage of bagasse fibre content in the stabilized soil. The increase in UCS recorded in this study after addition of bagasse fibre was also reported by Bhardwaj and Sharma (2020) for clay soil stabilized by waste foundry sand. The increase in UCS value on addition of stabilizing materials was due to the transition of smaller size particles into large size particles, leading to more compact structure and densification (Kumar *et al.*, 2016; Bhardwaj and Sharma, 2020).

#### 4. CONCLUSION

The soils are classified as A-2-6/SC and A-2-4/SM on the AASHTO classification schemes/Unified Soil Classification System. Swelling potential, volume change, maximum dry density (MDD), liquid limit (LL) and plasticity index (PI) of the stabilized Laterite and clay soils along Ubeta-Ula-Ubie road decreased with increasing percentage of *Costus lateriflorus* bagasse fibre, while optimum moisture content (OMC), plastic limit (PL) and unconfined compressive strength (UCS) increased with the addition of *Costus lateriflorus* bagasse fibre.

The swelling potential, volume change, percentage of OMC and consistency limits of the clay soil were higher than the stabilized Laterite soil at the corresponding amount of the bagasse fibre, while the recorded values of MDD, CBR and USC in the Lateritic soil were higher compared to the clay soil. Based on the results of the California Bearing Ratio (CBR) for unsoaked and soaked stabilized Laterite and clay soil, it is recommended that addition of 7.5% bagasse fibre would be appropriate for obtaining of good results in stabilization of Ubeta-Ula-Ubie road Laterite and clay soils.

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