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Original Research Article

Modification of Expansive Soil with Costus Lateriflorus Bagasse Ash for Road Pavement Materials

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Abstract: This study evaluates the effect of costus lateriflorus bagasse ash on expansive soil properties. Laterite and clay samples from the Ubeta-Ula-Ubie road at Ahoada West LGA in Rivers, Nigeria were prepared and laboratory analysis performed for development potential, volume change, maximum dry density (MDD), optimum moisture content (OMC), consistency limits, California bearing ratio (CBR) and unconfined compressive strength (UCS). Initial analysis classified the soil as A-7-6 under the AASHTO classification system. The development potential, volume change, maximum dry density (MDD), liquid limit (LL), and plasticity index (PI) of laterite and stable clay on the Ubeta-Ula-Ubie road decreased with increasing proportion of bagasse Costus ash lateriflorus, while optimum moisture content (OMC), plastic limit (PL) and unconfined compressive strength (UCS) were increased by the addition of Costus lateriflorus bagasse ash. The results showed that increasing the ash content of bagasse increased the soil properties suitable for road construction. However, bagasse ash performs better on lateritic soils than on clay soils, and 7.5% bagasse ash would be suitable for use as a stabilizer in soils with similar properties to laterite and clay soils in the Ubeta-Ula-Ubie road.

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

1. INTRODUCTION

Stabilization is the process of soil compaction. It is mostly combined with a binder like cement, lime or bio-wastes to improve the soil's technical properties like ductility, swelling potential, dry density, shear strength and load bearing capacity. Stabilization with bio-waste or natural materials like sand is called mechanical stabilization, while the incorporation of commercially available additives like cement is called chemical stabilization. All is geared towards to improving the gradation, texture or plasticity of the soil. Soil foundation can be stabilized to increase strength and durability while reducing erosion and dust formation. The ultimate goal is to develop a soiling material or system that will withstand the service conditions and life expectancy of the engineering project (Arpan and Rishabh, 2012).

Rimal *et al.* (2019) demonstrated that stabilizer increased the bearing capacity of soil layer to support pavement and subsoil by increasing the shear strength of the soil and/or controlling the potential for shrinkage and expansion in soil. From expansive clays to granular materials, stabilization can be used to treat a wide range of subclass materials. Higher resistance values, lower ductility, lower permeability and reduced pavement thickness are some of the benefits of adding these components to stabilization process. Research in geotechnical and building materials focuses on locally available agricultural and industrial wastes with disposal problems. The use of various industrial and agricultural wastes as soil stabilizers has been reported by researchers (Okagbue, 2007; Yadu *et al.*, 2011; Bethlehem, 2015; Patrick, 2016; Ewa et al., 2016; Fazal *et al.*, 2020).

Studies on cement kiln dust (CKD) as a chemical stabilizer have been reported. CKD improves the technical properties of tillage and improves its performance as a base and construction material (Hesham, 2013; Vivek and Rajesh, 2015; Miller and Azad, 2000; Mohamed, 2002). According to Nishantha *et al.* (2020), CKD or a combination of fly ash (FA) and lime kiln dust (LKD) can be used for long-term stabilization of the soil base of the three soil types tested, while FA and LKD can be used for short-term

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stabilization. Limestone dust, a by-product of limestone resulting from the crushing process limestone, has also been used as soil stabilizer. Thus, the effects of gravel dust and lime dust on the geotechnical properties of clay were reported by Hassan et al. (2021). According to this study, Atterberg clay boundaries decrease with increasing dust content. The compacting properties of clay deteriorate with increasing gravel dust content. MDD increases while OMC decreases with increasing lime dust. Gravel dust, on the other hand, lacks calcium oxide. The soil layer of the Niger Delta in Nigeria is usually soft clay with high plasticity and tends to change in volume with swelling due to wetting and drying, which causes damage to the soil layer beneath the pavement structure, Ewa *et al*., (2016).

Rice husk ash (RHA) is an agricultural waste that has been extensively studied for its pozzolanic properties as a soil stabilizer. (Rahman, 1986) reported an increase in unconfined compressive strength and the fraction of California camp in RHA-treated laterite soils of up to 20%. (Alhassan, 2008) reported an increase in CBR values for submerged and non-submerged clay soils treated with rice husk ash. However, Basha *et al*., (2005), was of a contrary opinion as they showed that RHA cannot be used alone as stabilizer in soil stabilization due to the lack of cementitious properties. When combined with lime or cement, stabilization of RHA in clay, loam-clay, sand-clay, sand-clay soils resulted to a tremendous increase in compressive strength (Basha *et al*., 2005; Muntohar and Hantoro, 2000).

Sugar cane ash (SCBA), an agricultural waste, has been expansively studied as a soil stabilizer. Using SCBA for soil stabilization will address the environmental challenges of baggage disposal. When kaolinite-containing soils were stabilized with bagasse ash, the strength and index values increased to some extent, according to Athira and Sini (2019). Other studies have also shown stabilization with soil alone was ineffective and as such, should be with other materials (Osinubi *et al.*, 2009; Kharade *et al*. 2014). In a study, it was found that the unconfined compressive strength (UCS) value of tropical black clay increased with increasing proportion of limestone (Osinubi, 2006). Kiran and Kiran (2013) also found that a mixture of 15 percent bagasse ash and 4 percent lime significantly increased the compaction and strength of black cotton soil. Since studies have proven that sugarcane ash is capable of being used as soil stabilizer, this study has investigated the use of Costus lateriflorus bagasse as a soil stabilizer to improve the engineering properties of clay and Laterite soils for construction purposes.

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 Cemenet, 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

3.1 Swelling Potential

The results of swelling potential of Laterite and clay soils stabilized with Costus lateriflorus bagasse ash at 0 – 10% 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 ash product on swelling potential of the soils

Ash content (%)	Swelling Potential (mm)			
	Initial Laterite soil	Final Laterite soil	Initial clay soil	Final clay soil
0	50.85	53.78	61.35	63.99
2.5	50.68	53.34	62.45	64.48
5	50.45	53.06	62.03	63.92
7.5	50.27	52.78	61.95	63.59
10	50.18	52.62	61.78	63.18

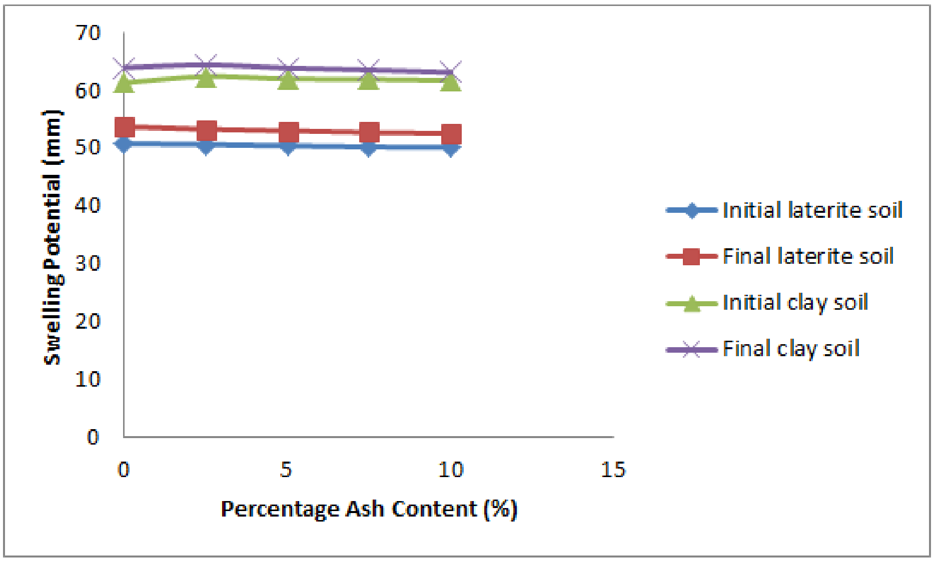

Fig-1: Swelling potential versus bagasse ash content

The profiles of swelling potential of stabilized Laterite soil and clay soil at Costus lateriflorus bagasse ash content of 0 – 10% 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 ash content in the mix. The results in Table 1 showed that the swelling in Laterite soil with no stabilizer increased from 50.85 to 53.78mm, implying 5.76% swelling in Laterite soil from initial to final condition. Also, the swelling in clay soil with no stabilizer increased from 61.35 to 63.99mm, representing 4.30% swelling potential. Meanwhile, the addition of bagasse ash as stabilizer reduced the swelling percentage in Laterite soil between 5.25 and 4.86% and between 3.25 – 2.27% in clay soil, at bagasse ash content of 2.5 – 10%. 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 ash at 0 – 10% weight percent are shown in Table 2, while the profiles are shown in Figure 2.

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

Ash content (%)	Volume change (mm^3)	
	Laterite Soil	Clay soil
0	2.93	2.64
2.5	2.66	2.03
5	2.61	1.89
7.5	2.51	1.64
10	2.44	1.4

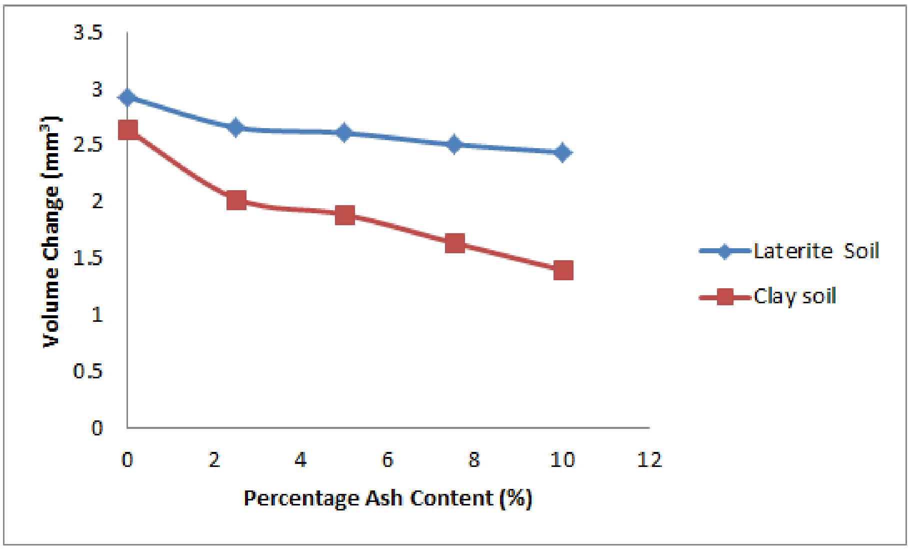

Fig-2: Volume change versus bagasse ash content

Figure 2 shows the profiles of volume change in stabilized lateritic soil and clay soil at 0 – 10% of Costus lateriflorus bagasse ash content in the soils. From the profiles, the volume change in the stabilized clay and lateritic soils decreased with increasing percentage of the bagasse ash 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 $2.93mm^3$ and $2.64mm^3$, but with inclusion of bagasse ash as stabilizer, the volume change reduced between $2.66mm^3$ and $2.44mm^3$ in lateritic soil and between $2.03mm^3$ and $1.40mm^3$ when the bagasse ash 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 ash 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 ash on MDD of the soils

Ash content (%)	MDD (kN/m^3)	
	Laterite soil	Clay soil
0	1.96	1.73
2.5	1.642	1.458
5	1.598	1.409
7.5	1.558	1.359
10	1.428	1.321

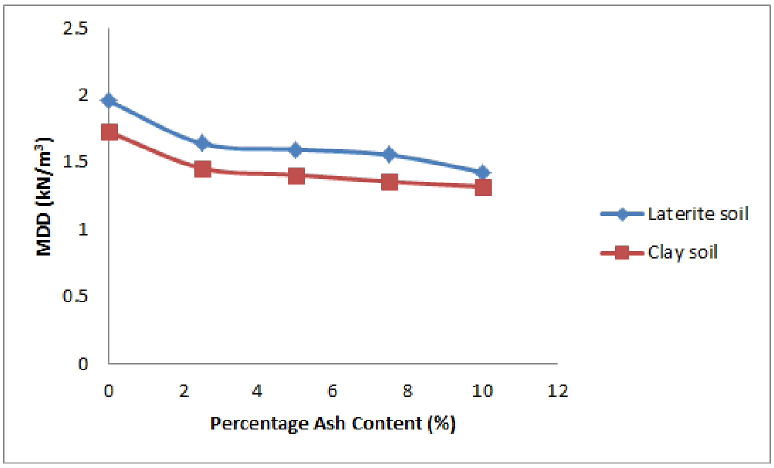

Fig-3: MDD versus bagasse ash content

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 ash. The results showed that MDD decreased with increase in percentage of bagasse ash 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^3 and 1.73 kN/m^3 respectively, but with bagasse ash as stabilized material in the soils, the MDD value decreased to 1.642 at 2.5% and further to 1.428kN/m^3 at 10% in lateritic soil, while in clay soil, MDD decreased to 1.458 at 2.5% and further to 1.321kN/m^3 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 ash 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 ash on OMC of the soils

Ash content (%)	OMC (%)	
	Laterite soil	Clay soil
0	11.59	15.44
2.5	12.14	15.3
5	12.22	15.48
7.5	12.54	15.69
10	13.08	15.93

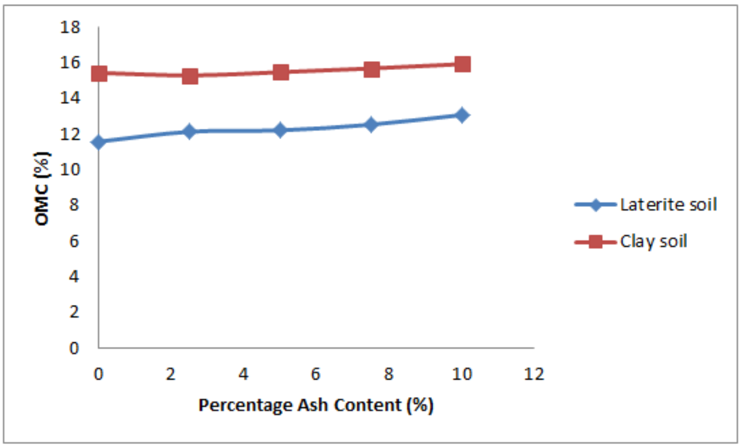

Fig-4: OMC versus bagasse ash content

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 ash. The results showed that OMC increased with increase in percentage of bagasse ash content in both type of soils. Clay soil recorded higher percentage of OMC compared to lateritic oil. 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 ash 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 ash on consistency limits of the soils

Ash content (%)	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
2.5	37.35	17.85	19.28	55.22	24.89	30.14
5	36.5	18.23	18.05	53.59	25.82	27.58
7.5	34.67	18.78	15.67	52.8	27.46	25.15
10	31.2	19.83	11.15	49.29	28.8	20.3

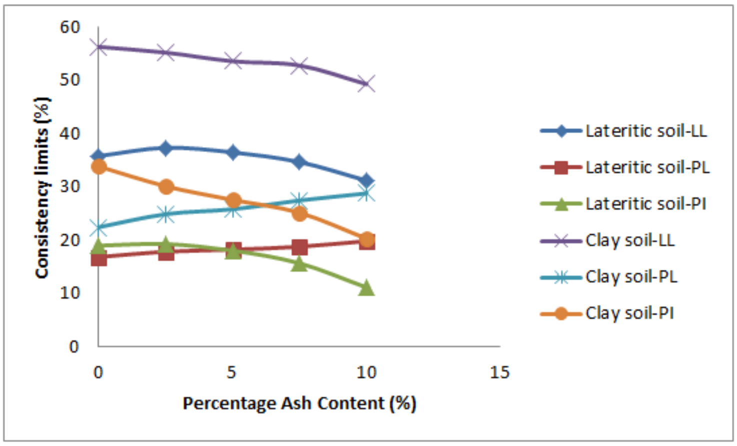

Fig-5: Consistency limits versus bagasse ash content

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 ash. The results showed that LL in lateritic soil initially increased before declining as the ash content was increased, but in clay soil, there was continuous gradual decrease in LL as the percentage of bagasse ash 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 ash, the LL value increased to 37.35% at 2.5% bagasse ash and then decreased to 31.20% at 10% bagasse ash. Also, in the clay soil sample, LL decreased to 55.22% at 2.5% bagasse ash and further to 49.29% at 10% bagasse ash.

Unlike liquid limit, the plastic limit (PL) in lateritic and clay soils increased consistently as the bagasse ash 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 ash increased to 17.85% at 2.5% bagasse ash and further to 19.83% at 10% bagasse ash. Also, in the clay soil sample, PL increased to 24.89% at 2.5% bagasse ash and further to 28.80% at 10% bagasse ash.

Like liquid limit, the plasticity index (PI) in lateritic soil initially increased and then, decreased as the ash content was increased, while in clay soil, there was gradual decrease in PI as bagasse ash 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 ash, PI increased to 19.328% at 2.5% bagasse ash and then decreased to 11.15% at 10% bagasse ash. Moreover, in the clay soil sample, PI decreased to 30.14% at 2.5% bagasse ash and further to 20.30% at 10% bagasse ash. 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 ash on CBR of the soils

Ash content (%)	CBR (%)			
	Laterite Soil Unsoaked	Clay Soil Unsoaked	Laterite Soil Soaked	Clay Soil Soaked
0	9.25	8.55	8.67	7.28
2.5	11.85	10.61	10.83	10.02
5	14.19	12.81	12.33	11.75
7.5	15.75	14.28	14.83	13.24
10	13.75	12.51	11.93	10.55

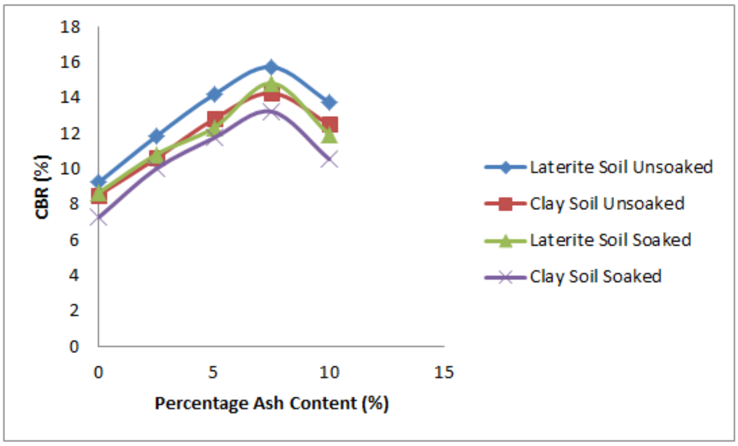

Fig-6: CBR versus bagasse ash content

Figure 6 shows the profiles of CBR for unsoaked and soaked Laterite and clay soils stabilized with 0 to 10% bagasse ash. The CBR for unsoaked and soaked stabilized Laterite and clay soil increased with increase in bagasse ash content to a maximum value at 7.5% bagasse ash. 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 ash, CBR increased to 11.85% for unsoaked Laterite soil, 10.61% for unsoaked clay soil, 10.83% for soaked Laterite soil and10.02% for soaked clay soil, at 2.5% bagasse ash. 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 ash. Nevertheless, there was decrease of CBR in the Laterite and clay soil samples at 10% bagasse ash (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 baggase ash 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 ash on unconfined compressive strength (UCS) of the soils

Ash content (%)	UCS (kPa)	
Percentage (%)	Laterite Soil	Clay soil
0	187.17	74.57
2.5	185.95	84.8
5	196.57	97.7
7.5	220.63	109.3
10	232.57	116.8

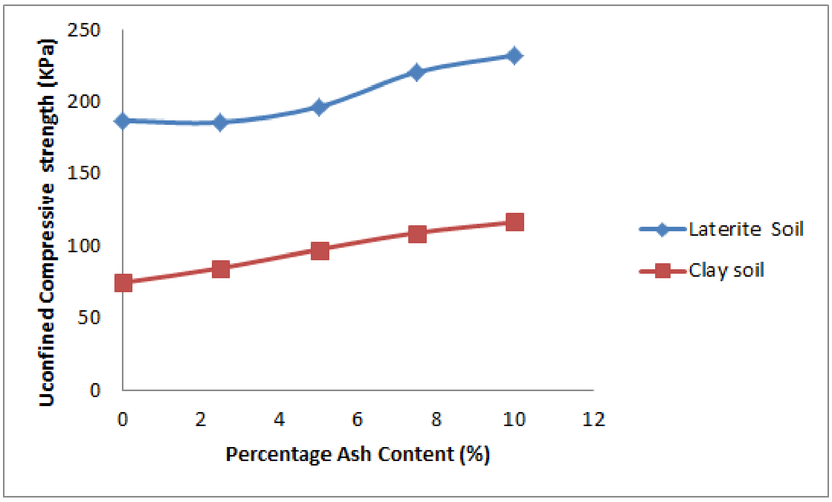

Fig-7: Unconfined compressive strength versus bagasse ash content

The test results for unconfined compressive strength (UCS) of stabilized Laterite and clay soil samples at 0 – 10% bagasse ash 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 ash content. Also, the UCS of bagasse stabilized clay soil sample increased from 84.80 to 116.80kPa at 2.5 - 10% bagasse ash content. The unconfined compressive strength in Laterite soil was far higher than those recorded in and clay soil at the corresponding percentage of bagasse ash content in the stabilized soil. The increase in UCS recorded in this study after addition of bagasse ash 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 ash, while optimum moisture content (OMC), plastic limit (PL) and unconfined compressive strength (UCS) increased with the addition of Costus lateriflorus bagasse ash.

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 ash, 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 ash would be appropriate for obtaining of good results in stabilization of Ubeta-Ula-Ubie road Laterite and clay soils.

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