

## Performance of Costus Lateriflorus Bagasse Ash and Cement as Stabilization Materials for Soil in Road Construction

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### Abstract

The study investigated the performance of Costus lateriflorus bagasse ash and cement composite for stabilization of Laterite and clay soils from Ubeta-Ula-Ubie road in Ahoadha West LGA of Rivers state, Nigeria. The soil samples were prepared and tested for variations in maximum dry density (MDD), optimum moisture content (OMC), consistency limits, California bearing ratio (CBR) and unconfined compressive strength (UCS), maximum dry density (MDD), liquid limit (LL) and plasticity index (PI) of the stabilized laterite and clay soils decreased with increasing percentage of the bagasse ash composite, while optimum moisture content (OMC), plastic limit (PL) and unconfined compressive strength (UCS) were increased with the proportion of bagasse ash. This study establishes that an appropriate proportion of bagasse ash content in soil stabilization would enhance the properties of soil suitable for pavement and road construction. Comparatively, bagasse ash performed better in Laterite soil than clay soil at optimum proportion of 0.75% and 7.5% cement composition.

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

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### 1. INTRODUCTION

Expansive soils are known to exhibit dual properties of excessive swelling and shrinking under various moisture conditions. This expansive soil swelling-shrinkage property, which is dependent on the loading and suction history of the soil, causes strains that are significantly larger than elastic strains and cannot be predicted by classical elastic or plastic theories. The movement is usually uneven and so large that it causes significant damage to the structure and the overlying pavement (Nelson and Miller, 1992).

Some of the characteristic behaviour of expansive soil, most often, is cracks that are evident on road surfaces and building structures. The cost of such defects and damages is very high. Many land improvement techniques have been used to limit or reduce the severity of damage caused by Expansive soil of civil engineering structures; these include lime and cement stabilization (Nebro, 2002; Osinubi *et al.*, 2009; Tesfaye, 2011).

Cement are generally used to treat cohesive soils with expansive properties because of their effectiveness in reducing expansive properties, increasing strength, lowering plasticity index, expansion and shrinkage potential, and controlling volume changes (Osinubi and Thomas, 2007). However, lime is considered more suitable for stabilizing clay soils with a fine grain content of more than 25%, as it makes the soil more friable, less plastic and therefore easier to work with. The reaction of cement with soil causes an increase in strength. The increase in strength is mainly due to the chemical reaction between lime, clay minerals and amorphous materials in the soil. When they are absent or present in small quantities, lime is used in conjunction with the pozzolan. Pozzolanic materials such as clay ash, fly ash, shell ash, coconut ash, etc. are often used in lime and cement mixtures to stabilize soils (Brooks, 2009; Amu, 2011; Chittaranjan *et al.*, 2011; Laxmikant *et al.*, 2011; Mu'azu, 2007; Osinubi and Thomas, 2007; Sabat, 2012).

Bagasse ash is reported to have pozzolanic properties. Bagasse ash has been reported to contain large amounts of silica and other suitable oxides which enhance good pozzolanic activity (Chusilp *et al.*, 2009; Hailu, 2011). Ash is used alone or as a lime and cement additive to stabilize lateritic soils and black cotton (Osinubi and Thomas, 2007; Osinubi *et al.*, 2009; Amu, 2011; Sabat, 2012). With cement price rising daily in developing countries like Nigeria, the efficient use of bagasse ash for technical purposes would be of great economic importance. The successful use of bagasse ash as an additive alongside with cement to stabilize expansive soil will reduce the amount of cement, thereby reducing project cost. This is in addition to freeing the environment from the harmful effects of this waste on the environment. The main objective of this study is to evaluate the combine effect of bagasse ash and cement on the performance of expansive soil properties.

**Table 1: Oxide composition of bagasse ash (Hailu, 2011)**

| Constituents                   | % composition |
|--------------------------------|---------------|
| SiO <sub>2</sub>               | 65.58         |
| Al <sub>2</sub> O <sub>3</sub> | 5.87          |
| Fe <sub>2</sub> O <sub>3</sub> | 4.32          |
| CaO                            | 1.78          |
| MgO                            | 1.23          |
| K <sub>2</sub> O               | 6.41          |
| Na <sub>2</sub> O              | 1.02          |
| P <sub>2</sub> O <sub>5</sub>  | 1.35          |
| SO <sub>3</sub>                | 0.18          |
| Cl <sub>2</sub>                | < 0.1         |
| MnO                            | 0.05          |
| TiO <sub>2</sub>               | 0.25          |
| L.O.I                          | 10.48         |

## 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, Ahoaada-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 Ahoaada-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 regrading 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 Ubetta-Ula-Ubie road in Ahoaada West LGA of Rivers state of Nigeria are presented and discussed in this section.

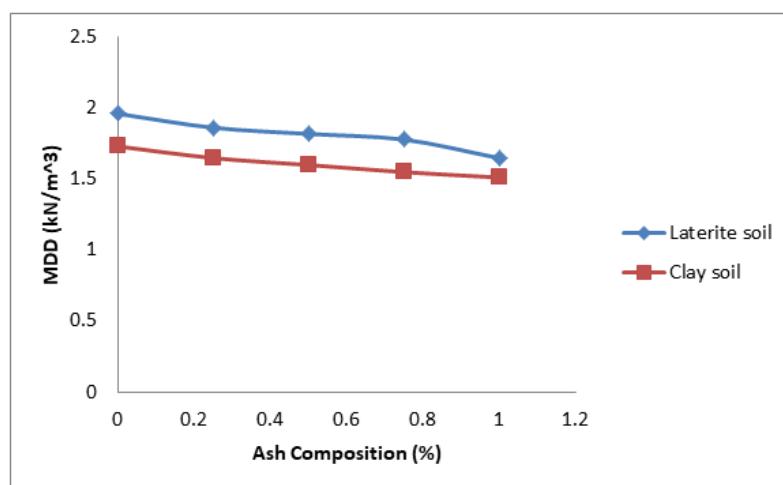
### 3.1 Maximum dry density

The results of maximum dry density (MDD) of lateritic and clay soils stabilized with fixed composition of cement at 7.5% and Costus lateriflorus bagasse ash at

composition ranging from 0.25% – 1.0% are shown in Table 1, while Figure 1 shows the profile of MDD for stabilized clay and Laterite soils.

**Table 1: Effect of bagasse ash and cement composite on soil MDD**

| Ash content (%) | MDD (kN/m <sup>3</sup> ) |           |
|-----------------|--------------------------|-----------|
|                 | Laterite soil            | Clay soil |
| 0               | 1.96                     | 1.73      |
| 0.25            | 1.862                    | 1.648     |
| 0.5             | 1.818                    | 1.599     |
| 0.75            | 1.778                    | 1.549     |
| 1.0             | 1.648                    | 1.511     |



**Figure 1: MDD of soil stabilized with bagasse ash and cement composite**

Figure 1 showed the profiles of maximum dry density (MDD) of laboratory compaction tests of Laterite and clay soils from Ubeta-Ula-Ubie road stabilized with 7.5% cement and varying proportions of bagasse ash from 0 – 1.0%. Results showed that MDD decreased with increase in bagasse fibre proportion in both soil types. Comparatively, MDD in Laterite soil was higher than in clay soil sample. The MDD of 0% 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 decreased to 1.650 and 1.534 kN/m<sup>3</sup> for lateritic soil clay soils, respectively as bagasse ash proportion increased to 1.0% at fixed cement proportion of 7.5%. The MDD values recorded in this study were below the value (1.84 kN/m<sup>3</sup>) reported in deltaic soil located Ahoada and other parts of Rivers State by Omotosho and Eze-

Uzomaka (2008). Though, the soil was stabilized with only cement between 2% and 15% proportion. However, the trends in maximum dry density was in conformity with soils stabilized with various proportions of different species of bagasse (Akobo *et al.*, 2018; Charles *et al.*, 2018; Ngekpe *et al.*, 2018; Nwikina *et al.*, 2018).

### 3.2 Optimum moisture content

The results of optimum moisture content (OMC) for the lateritic and clay soils stabilized with fixed composition of cement at 7.5% and Costus lateriflorus bagasse ash at composition ranging from 0.25% – 1.0% are shown in Table 2. Also, the profiles of OMC for the stabilized soils are shown in Figure 2.

**Table 2: Effect of bagasse ash and cement composite on OMC of the soils**

| Ash content (%) | OMC (%)       |           |
|-----------------|---------------|-----------|
|                 | Laterite soil | Clay soil |
| 0               | 11.59         | 15.44     |
| 0.25            | 12.36         | 15.49     |
| 0.5             | 12.44         | 15.67     |
| 0.75            | 12.76         | 15.88     |
| 1               | 13.3          | 16.12     |

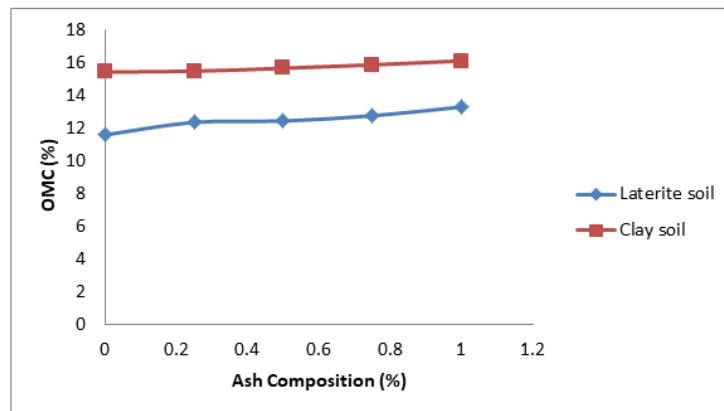
**Figure 2: OMC of soil stabilized with bagasse ash and cement composite**

Figure 2 showed the profiles of optimum moisture content (OMC) of compaction test on laterite and clay soils from Ubeta-Ula-Ubie road stabilized with cement at 7.5% and varying proportions of bagasse ash from 0 – 1.0%. The results showed that OMC increased with increase in percentage of bagasse ash in both soils. Clay soil recorded higher percentage of OMC compared to lateritic oil. The OMC of 0% stabilized lateritic and clay soils was obtained as 11.59% and 15.44%, respectively, but increased to 12.82% for lateritic soil and 16.16% for clay soil, as the bagasse ash proportion was increased to 1.0% at fixed cement proportion of 7.5%. The values of OMC recorded were within the ranges reported in some previous works using composite of cement and bagasse ash (Okonkwo *et al.*, 2016; Akobo *et al.*, 2018; Charles *et al.*, 2018; Ngekpe *et al.*, 2018; Nwinkina *et al.*, 2018). The OMC values obtained in this work were within the ranges recorded

for mechanical stabilization of clay soil using waste foundry sand and river sand which also increased with increasing percentage of stabilization material (Omotosho and Eze-Uzomaka, 2008; Essien and Charles, 2016; Bhardwaj and Sharma, 2020). The optimum moisture content reported by Sas and Głuchowski (2013) for 0% stabilized sandy-silty clay was 10.7%, but increased to 11.41% when 6% cement was added.

### 3.3 Consistency limits of the stabilized soils

The results of consistency limits (liquid limit (LL), plastic limit (PL) and plasticity index (PI)) of the stabilized with fixed composition of cement at 7.5% and Costus lateriflorus bagasse ash at composition ranging from 0.25% – 1.0% are shown in Table 3, while the profiles are shown in Figure 3.

**Table 3: Effect of bagasse ash and cement composite 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        |              |
| 0.25            | 37.57                  | 18.07             | 19.5              | 55.41             | 25.08        | 30.33        |              |
| 0.5             | 36.72                  | 18.45             | 18.27             | 53.78             | 26.01        | 27.77        |              |
| 0.75            | 34.89                  | 19                | 15.89             | 52.99             | 27.65        | 25.34        |              |
| 1               | 31.42                  | 20.05             | 11.37             | 49.48             | 28.99        | 20.49        |              |

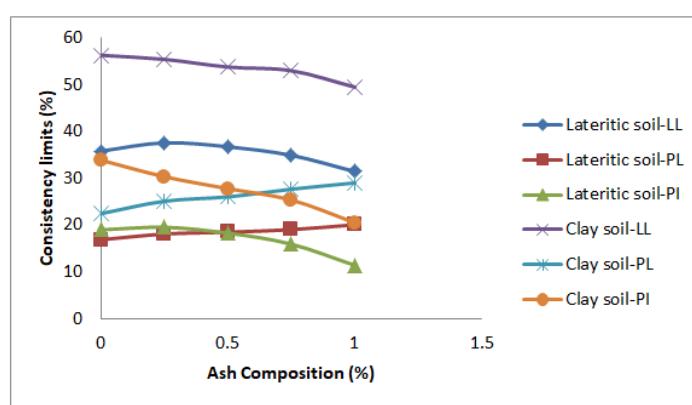
**Figure 3: Consistency limits of soil stabilized with bagasse ash and cement composite**

Figure 3 showed profiles of liquid limit (LL), plastic limit (PL) and plasticity index (PI) of lateritic and clay soils from Ubeta-Ula-Ubie road stabilized with 7.5% cement and 0 to 1.0% bagasse ash. The results showed that LL in laterite and clay soils gradually decreases as the percentage of bagasse ash was increased. Clay soil recorded higher percentage of LL compared to lateritic soil. The LL of 0% stabilized lateritic and clay soils were 35.81% and 56.29% respectively, but decreased to 30.36% for lateritic soil and 48.64% for clay soil as the bagasse ash proportion was increased to 1.0% at fixed cement proportion of 7.5%.

Unlike liquid limit, the plastic limit (PL) in lateritic and clay soils increased consistently as the bagasse fibre proportion was increased. Again, clay soil recorded higher percentage in PL compared to lateritic soil. The of 0% stabilized lateritic and clay soils were obtained as 16.84% and 22.43% respectively, but increased to 18.91% for lateritic soil and 27.76% for clay soil as the bagasse ash proportion was increased to 1.0% at fixed cement proportion of 7.5%.

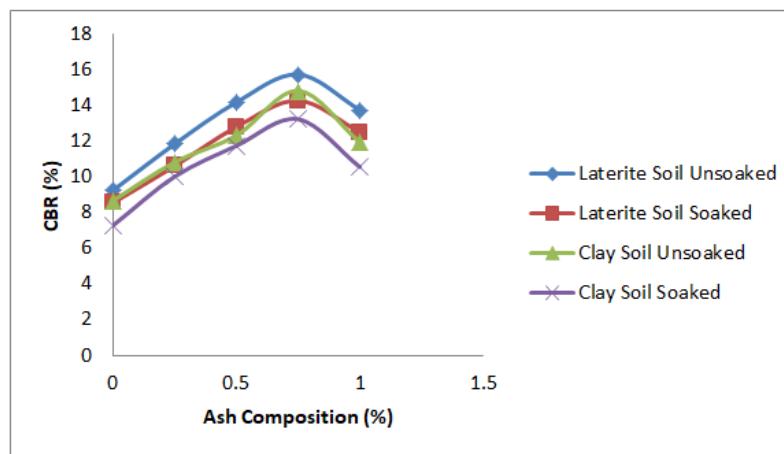
Also, the plasticity index (PI) of Laterite and clay soils decreased as bagasse ash was increased in the stabilized sample. Again, clay soil recorded a higher percentage in PI compared to lateritic soil. The PI percentage of 0% stabilized laterite and clay soil samples were obtained as 18.97% and 33.86% respectively, but decreased to 11.45% for lateritic soil and 20.88% for clay soil, as the bagasse ash proportion was increased to 1.0% at fixed cement proportion of 7.5%. The behavior of consistency limit of the soils was synonymous to reports from other studies on composite stabilization soil for pavement or road construction (Akobo et al., 2018; Charles et al., 2018; Ngekpe et al., 2018; Nwikina et al., 2018). The decrease in plasticity index was attributed to impact of stabilizer on soil (Jain et al., 2015; Kale et al., 2019; Bhardwaj and Sharma, 2020).

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

The California bearing ratio (CBR) for unsoaked and soaked stabilized laterite and clay soils stabilized with fixed composition of cement at 7.5% and Costus lateriflorus bagasse ash at composition ranging from 0.25% – 1.0% are shown in Table 4, while the profiles are shown in Figure 4.

**Table 4: Effect of bagasse ash and cement composite on CBR**

| Ash content (%) | CBR (%) | 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   | 10.61                  | 10.83              | 10.02                |                  |
| 0.5             | 14.19   | 12.81                  | 12.33              | 11.75                |                  |
| 0.75            | 15.75   | 14.28                  | 14.83              | 13.24                |                  |
| 1               | 13.75   | 12.51                  | 11.93              | 10.55                |                  |



**Figure 4: CBR of soil stabilized with bagasse ash and cement composite**

Figure 4 shows the profiles of CBR for unsoaked and soaked Laterite and clay soils stabilized with 7.5% cement and varying proportions of bagasse ash from 0 – 1.0%. 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 ash. From the recorded results, CBR for

unsoaked non-stabilized laterite and clay soil samples were obtained as 9.25% and 8.55%, while CBR for soaked 0% stabilized laterite and clay soil samples were recorded as 8.67% and 7.28%, respectively. The maximum CBR value was recorded at 0.75% bagasse ash with fixed cement proportion of 7.5%. At this maximum value, the CBR was recorded as 17.15% for

unsoaked Laterite soil, 15.13% for unsoaked clay soil, 15.33% for soaked Laterite soil and 14.98% for soaked clay soil. There was decrease in CBR beyond 0.75% proportion of bagasse ash in the stabilized soils.

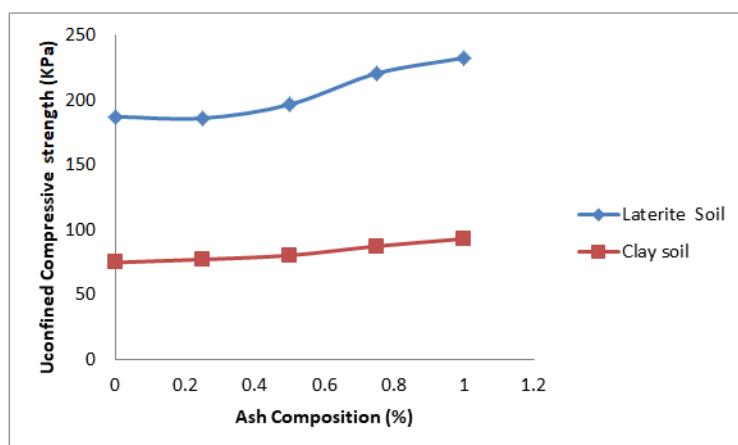
California Bearing Ratio (CBR) test is an important parameter for empirical estimation of soil bearing capacity under soaked and dry conditions (Tse and Ogunyemi, 2016). Thus, increase in CBR is an indication that the composite material is capable of improving the properties of soil for earthworks. Also, 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 (Okonkwo *et al.*, 2016; Akobo *et al.*, 2018; Charles *et al.*, 2018; Ngekpe *et al.*, 2018; Nwikina *et al.*, 2018). However, the stabilized Laterite soil performed better than clay soil in terms of CBR.

### 3.5 Unconfined compressive strength of stabilized soil

The unconfined compressive strength (UCS) of Laterite and clay soils stabilized fixed composition of cement at 7.5% and Costus lateriflorus bagasse ash at composition ranging from 0.25% – 1.0%, and cured for 28 days are shown in Table 5.

**Table 5: Effect of bagasse ash and cement composite on unconfined compressive strength**

| Ash content (%) | UCS (kPa)     |           |
|-----------------|---------------|-----------|
|                 | Laterite Soil | Clay soil |
| 0               | 187.17        | 74.57     |
| 0.25            | 185.95        | 76.93     |
| 0.5             | 196.57        | 80.12     |
| 0.75            | 220.63        | 87.2      |
| 1               | 232.57        | 92.92     |



**Figure 5: UCS of soil stabilized with bagasse ash and cement composite**

The profiles of unconfined compressive strength (UCS) of Laterite and clay soil samples stabilized with 7.5% cement and varying proportions of bagasse ash from 0 – 1.0% are shown in Figure 5. From the profiles, UCS increased with increasing percentage of stabilized material. The test results presented in Table 5 showed that unconfined compressive strength of 0% stabilized Laterite and clay soil samples was 187.18kPa and 74.57kPa, but increased to 281.60kPa and 94.54kPa for lateritic soil and clay soil, respectively when bagasse ash proportion increased to 1.0% at fixed cement proportion of 7.5%. 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 of soils due to addition of bagasse ash and cement composite have also been reported in previous studies (Okonkwo *et al.*, 2016; Akobo *et al.*, 2018; Charles *et al.*, 2018; Ngekpe *et al.*, 2018; Nwikina *et al.*, 2018). 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

Addition of cement and pulverized bagasse ash composite in soil as stabilization material shows some appreciable changes in properties of soil after stabilization. Thus, maximum dry density (MDD), liquid limit (LL) and plasticity index (PI) of the stabilized Laterite and clay soils from Ubeta-Ula-Ubie road decreased with increasing percentage of Costus lateriflorus bagasse ash at constant cement proportion, while optimum moisture content (OMC), plastic limit (PL) and unconfined compressive strength (UCS) increased.

The percentage of OMC and consistency limits of the clay soil were higher than the stabilized Laterite soil, while MDD, CBR and USC of Lateritic soil were higher compared to the clay soil sample. Based on results of the California Bearing Ratio (CBR) for unsoaked and soaked stabilized Laterite and clay soil, it

is recommended that 0.75% bagasse ash would be appropriate to obtaining good compaction of soil for road construction purpose.

## REFERENCES

- Akobo, I. Z. S., Iroaganachi, P. N., & Charles, K. (2018). Comparative strength evaluation of cementitious stabilizing agents blended with pulverized bagasse fibre for stabilization of expansive lateritic soils, *Global Scientific Journal*, 6(12), 239-255.
- Bhardwaj, A., & Sharma, R. K. (2020). Effect of industrial wastes and lime on strength characteristics of clayey soil, *Journal of Engineering, Design and Technology*, <https://www.dx.doi10.1108/jedt-12-2019-0350> [15th December, 2021].
- Charles, K., Nwikina, B. B., & Wokoma, T. T. T. (2018). Potential of cement, lime -costaceae lacerus bagasse fibre in lateritic soils swell–shrink control and strength variance determinations, *Global Scientific Journal*, 6(12), 273-290.
- Essien, U., & Charles, K. (2016). Comparative stabilization and model prediction of geotechnical parameters of ebekpo residual soils, Akwa Ibom State, Nigeria, *Journal of Scientific and Engineering Research*, 3(1), 129-137
- Jain, T., Yadav, G., Chandra, B., & Solanki, C.H. (2015). Comparative study of effect of waste material on black cotton soils in Surat region – a review, *Indian Geotechnical Conference-2015*, Pune, 12.
- Kale, R. Y., Wawage, R. & Kale, G. (2019). Effect of foundry waste on expansive soil (black cotton soil), *International Journal for Scientific Research and Development*, 7(2), 1800-1804.
- Kumar, A., Kumari, S., & Sharma, R. K. (2016). Influence of use of additives on engineering properties of clayey soil, *Proceedings of National conference: Civil Engineering Conference-Innovation for Sustainability (CEC-2016)*.
- Ngekpe, B. E., Charles, K., & Ode, T. (2018). Evaluation of cement, lime and bagasse fibre ash waste admixture on swell –shrink control of road embankment materials, *Global Scientific Journal*, 6(12), 220-238.
- Nwikina B. B., Charles, K., & Amakiri–Whyte, B., (2018). Modification of expansive lateritic soils of highway subgrade with blended composite materials and performance characteristics, *Global Scientific Journal*, 6(12), 256-272.
- Okonkwo, U. N., Agunwamba, J. C., & Iro, U. I. (2016). Geometric models for lateritic soil stabilized with cement and bagasse ash, *Nigerian Journal of Technology*, 35(4), 769-777.
- Omotosho, O., & Eze-Uzomaka, O. J. (2008). Optimal stabilization of deltaic Laterite, *Journal of the South African Institution of Civil Engineering*, 50(2), 10–17.
- Tse, A. C., & Ogunyemi, A. O. (2016). Geotechnical and chemical evaluation of tropical red soils in a deltaic environment: implications for road construction, *Journal of Geography and Geology*, 8(3), 42-51.
- Amu, O. O. (2011). Geotechnical properties of lateritic soil stabilized with sugarcane straw ash, *American Journal of Scientific and Industrial Research*, 12(11), 35-47.
- Brooks, R. M. (2009). Soil Stabilization with Fly ash and Rice Husk Ash, *International Journal of Research and Reviews in Applied Sciences*, 1(3), 29-38.
- Chittaranjan, M., Vijay, M., & Keerthi, D. (2011). Agricultural wastes as soil stabilizers. *International Journal of Earth Sciences and Engineering*, 4(06), 50-51.
- Chusilp, N., Likhitsripaiboon, N., & Jaturapitakkul, C. (2009). Development of bagasse ash as a pozzolanic material in concrete. *Asian Journal on Energy and Environment*, 10(3), 149-159.
- Hailu, B. (2011). Bagasse ash as cement replacing material, MSc Thesis, Addis Ababa University, Addis Ababa.
- Yadu, L., Tripathi, R. K., & Singh, D. (2011). Comparison of fly ash and rice husk ash stabilized black cotton soil. *International Journal of Earth Sciences and Engineering*, 4(06), 42-45.
- Mu’azu, M. A. (2007). Evaluation of Plasticity and Particle Size Distribution Characteristics of Bagasse Ash on Cement Treated Lateritic Soil, *Leonardo Journal of Sciences*, 17, 137-152.
- Nebro, D. (2002). Stabilization of Potentially Expansive Subgrade Soil Using Lime and Con-Aid, MSc Thesis, Addis Ababa University, Addis Ababa.
- Nelson, D., & Miller, J. (1992). Expansive Soils: Problems and Practices in Subgrade and Pavement Engineering, New York.
- Osinubi, K. J., & Thomas, S. A. (2007). Influence of Compactive Effort on Bagasse Ash Treated Soils, *Nigerian Journal of Soil and Environmental Research*, 7, 92-101.
- Osinubi, K. J., Bafyau, V., & Eberemu, A. O. (2009). Bagasse ash stabilization of lateritic soil. In *Appropriate technologies for environmental protection in the developing world* (pp. 271-280). Springer, Dordrecht.
- Sabat, A. K. (2012). Utilization of Bagasse Ash and Lime Sludge for Construction of flexible Pavements in Expansive Soil Areas, *Electronic Journal of Geotechnical Engineering*, 17, 12-23.
- Tesfaye, A. (2001). Chemical Treatment of Black Cotton Soil to make it Usable as a Subgrade Material, MSc. Thesis, Addis Ababa University, Addis Ababa.