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Original Research Article

Highway Pavement Stabilization of Soil with *Costus bracteatus Rowlee* and Cement

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Abstract: The study investigated the performance of cement and bagasse ash composite as soil stabilizer. The bagasse ash was obtained from *Costus bracteatus Rowlee*. Lateritic soil samples collected along a newly constructed road in Rivers State, Nigeria were prepared and analyzed for effect of the composite stabilizer on maximum dry density (MDD), optimum moisture content (OMC), consistency limits, California bearing ratio (CBR) and unconfined compressive strength (UCS). The results revealed that swelling potential, volume change MDD, OMC, liquid limit (LL), plastic limit (PL) and plasticity index (PI) of the stabilized lateritic soil decreased with increasing proportion of cement-bagasse ash composite, while CBR (unsoaked and soaked soil samples) and UCS were with increasing proportion of cement-bagasse ash composite. This study established that the optimum proportion of bagasse ash is 8% and that inclusion of an appropriate proportion of bagasse ash in cement in soil stabilization would enhance the properties of soil suitable for road pavement. Therefore, *Costus bracteatus Rowlee* is recommended to be used in soil stabilization, particularly as composite material.

Keywords: Lateritic soil, soil stabilizer, *Costus bracteatus Rowlee*, optimum moisture content (OMC), California bearing ratio (CBR).

1. INTRODUCTION

Soil stabilization offers a technically and economically feasible solution to many engineering problems, especially in road construction. Extensive testing to evaluate the enhancement of desired mechanical properties such as strength, durability and volumetric stability, etc. It is very important to offer a viable solution. Stabilizers such as lime and cement are commonly used to increase soil strength. Industrial and agricultural waste products such as fly ash, rice husk ash and bagasse ash have pozzolanic properties so they can be used as soil stabilizers. The unstable nature of expansive soils makes it notoriously unsafe, and highly problematic (Fondjo, Theron, & Ray, 2021). It is clayey in nature, characterized by large volume changes and high shear failure on contact with water (Bhuj and Gaikwad, 2022). Expansive soils have a potential swelling and shrinkage phenomenon which is strongly influenced by factors of clay mineralogy composition, environment, stress conditions and soil properties that describe the functional relationship of the development and shrinkage potential of the research area (Merouane and Mamoune, 2018). The potential instability of expansive soil resources must be determined to prevent the continuous collapse of the building structure (Kshatriya, Sathe, and Kankarej, 2022; Darikandeh and Phanikumar, 2021; Akinwande and Aderinola, 2020; Khan, Wang, and Patterson, 2017) and the service life of the facility and infrastructure (Diome and Biaye L, 2022). Soil stabilization offers a technically and economically feasible solution to many engineering problems, especially in road construction. Extensive testing to evaluate the enhancement of desired technical properties such as strength, durability and volumetric stability, etc. It is very important to offer a viable solution. Stabilizers such as lime and cement are commonly used to increase soil strength. Industrial and agricultural waste products such as fly ash, rice husk ash and bagasse ash have pozzolanic properties so they can be used as soil stabilizers.

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Bagasse ash is an industrial waste material from the sugar industry (Singh and Siddique, 2022; Siddique and Cachim, 2018; and Patel 2022). Sugarcane (Saccharum Officinarum) is the largest crop in the world by volume, producing a large number of wet pockets and the management of this residue is very important from an environmental point of view. The views of Ouedraogo, Sawadogo, Sanou, Bagasse ashrro, Nassio, Seynou and Zerbo (2022) show that bagasse ash is produced by calcining Bagasse ash at temperatures ranging from 550 °C to 750 °C with a heating step of 2 to 3 hours, resulting in the production of pozzolanic ash and cement material to make cement.

Improving the properties of BCS requires soil stabilization techniques (Rehman, 2020). Several types of stabilizing agents have been used for BCS stabilization. BCS can be stabilized with fly ash (FA) (Nanda, 2021; Chethan and Ravi Shankar, 2021). Prudhvi and Chellaiah (2022) stabilize the soil with salt. (Majeed and Tangri, 2021, soil stabilized with industrial waste. Garg, Biswas, Kumar, Siddharth and Singh, 2021), stabilized with coal slag (Navagire, Sharma and Rambabu. 2021). Mai-Bade, Chinade, Batari, and Saeed, (2021) and Premkumar, Subha, Sandhiya, and Narayanan, (2021) used lime, cement, e-scrap, peanut shell ash, bagasse ash, and plantain peel dust, removed asphalt, z-waste, and mill ore to stabilize BCS.

Adepegba *et al*. (2018) found that the incorporation of bagasse ash in lateritic soil stabilized with cement improved the strength and durability properties of the mixture. Gupta and Sharma (2019) investigated the effects of bagasse ash and lime on the engineering properties of expansive soil and reported significant improvements. Kumar *et al*. (2020) evaluated the use of bagasse ash and cement for the stabilization of soil and concluded that the mixture exhibited improved properties. Akinmusuru *et al*. (2018) studied the strength characteristics of lateritic soil stabilized with cement and bagasse ash and reported improved performance. Dukari *et al*. (2017) investigated the effects of sugarcane bagasse ash and cement on the plasticity and compaction characteristics of black cotton soil and reported significant improvements. Siddique and Mehtab (2016) studied the effects of rice husk ash on the plasticity and compaction characteristics of soil and reported that the mixture exhibited improved properties. Adegoke *et al*. (2018) evaluated the use of bagasse ash and lime for the stabilization of lateritic soil and reported that the mixture exhibited improved performance. Akinmusuru *et al*. (2017) investigated the use of bagasse ash for the improvement of geotechnical properties of lateritic soil and reported significant improvements. Mohammed *et al*. (2019) evaluated the use of bagasse ash and cement as stabilizing agents for black cotton soil and reported significant improvements in the properties of the mixture. Meena and Rajor (2017) investigated the effects of bagasse ash on the strength characteristics of soil-cement mixtures and reported improved performance. Ng'andu *et al*. (2016) studied the potential of sugarcane bagasse ash as a pozzolanic material in soil stabilization and reported that it exhibited significant improvements. Taha and Al-Sanousi (2014) evaluated the use of sugarcane bagasse ash and cement for the stabilization of expansive clayey soil and reported improved performance.

Thus, this study the main objective of this study is the evaluation of bagasse ash obtained from *Costus bracteatus Rowlee* as effective stabilization material in comparison with cement.

2. MATERIALS AND METHODS

2.1 Soil collection and preparation

Lateritic soil samples were collected between 0.5 and 1.0m depth at different locations along newly constructed road in Rivers State. Lumps formed in the soil were crushed to reduce the size. The soil was washed severally to remove contaminants, dirt and other organic matters. Thereafter, the soil was sieved using 2.36mm sieve size.

2.2 Bagasse ash preparation

Costus bracteatus Rowlee was collected from the bush and transported to the laboratory for further processing. The collected *Costus bracteatus Rowlee* was cut into pieces. The preparation was done according to the method described by Okonkwo *et al*. (2016). Thus, the bagasse was calcined in an oven at 800ºC for about 2 hours, and then allowed to cool. The cooled calcined bagasse was milled using milling machine to fine powdered ash and then sieved with 75 microns sieve size.

2.3 Cement

Cement was purchased in Mile 3 market, Port Harcourt, Rivers State.

2.4 Mix Preparation

The sieved bagasse ash was divided into portions at 2.5, 5%, 7.5% and 10% weight of subgrade soil. Each of the weight percent was mixed with a constant weight of 8% cement. 500g soil sample was stabilized or compacted with the different mix proportions of bagasse-cement composite. This is to investigate the effect of the composite mixture on the improvement of subgrade soil. The mix design is shown in Table 1.

Table 1: Mix design of soil stabilization

Bagasse ash (%)	Mix
0	500g natural soil + 0g cement + 0g bagasse ash
4	500g natural soil + 40g cement + 8g bagasse ash
6	500g natural soil + 40g cement + 12g bagasse ash
8	500g natural soil + 40g cement + 16g bagasse ash
10	500g natural soil + 40g cement + 20g bagasse ash
12	500g natural soil + 40g cement + 24g bagasse ash

2.5 Tests Procedures

The experimental procedure for each laboratory test is conducted according to Standards for soil stabilization and analysis.

2.5.1 Optimum moisture content and maximum dry density

The maximum dry density (MDD) and optimum moisture content (OMC) of the soil were determined from the natural moisture content and dry density analysis. Thus, the natural moisture content of the soil as obtained from the site was determined in accordance with AASHTO T99 (AASHTO, 1999). The sample as freshly collected was crumbled and placed loosely in the containers and were weighed together to the nearest 0.01g. A representative sample of natural soil as well as the composite soil samples was weighed and dried in the oven at temperature of 105±5°C for about 12 hours. The weight before and after drying was recorded. The moisture content is calculated as:

$$MC = \frac{w_o - w_d}{w_o} \times 100\% \quad (1)$$

where: $MC =$ Moisture content (%), $w_o =$ weight of soil or composite soil samples before drying (g) and $w_d =$ weight dried soil or composite soil samples (g).

The dry weight obtained from the determination of moisture content was used to determine the dry density of the natural and composite soils. Each weighed dried soil sample was put into a density bottle. The bottle with soil content was dropped gently in a graduated cylinder filled with water. The volume of water displaced was recorded. The dry density is then calculated as the ratio of dry weight to the volume of water displaced.

$$\text{Dry density (g/cm}^3\text{)} = \frac{\text{Dry weight of sample}}{\text{Volume of sample displaced}} \quad (2)$$

The values of dry density obtained were plotted against the natural moisture content. From this plot, the values of MDD and OMC of the soil were evaluated for each of the mix design.

2.5.2 Consistency limits

The consistency limits of the soil at the various stabilizing mix proportions were carried out. They include liquid limit (LL), plastic limit (PL) and plasticity index (PI). The liquid limit is arbitrarily defined as the percentage of water content in soil that makes a soil start to behave like a liquid. About 120 grams of the filtered and air-dried sample will be collected from the filtered portion of the soil obtained. Distilled water was mixed with soil to form a homogeneous paste. The homogeneous portion of the paste is poured into Casagrande utensil cup and distributed in portions with a few taps of spatula. It is cut to a depth of 1 cm, and excess soil was returned to the disk. The bottom of the cup was divided by the diameter of the passing cutter through the nearest center line to make a sharp groove. The cup was then released at a crank speed of two revolutions per second until the two halves of the grinding cake are connected to each other a length of approximately (12mm) solely by flow. The number of strokes required to approximately (12mm) close the groove is recorded. A representative portion of the soil was removed from the beaker to determine the moisture content. The test was repeated three times for cleaning between 27 and 52 at different humidity levels.

The plastic limit test determines the lowest moisture content at which the soil becomes plastic. The initial drying and sieving procedure for liquid limit was followed for PL test. The PL test was determined by remolding repeatedly a small ball of the soil and manually rolling it out into a 1/8 in thread. The moisture content at which the thread crumbled before being completely rolled out was recorded and taken as plastic limit.

The plasticity index was determined by subtracting the value of PL from LL. Thus, PI is the difference between the liquid limit and plasticity limit. Thus, PI = LL – PL.

2.5.3 California Bearing Ratio (CBR) Test

The California Bearing Ratio (CBR) test was carried out according to AASHTO T193-93 for natural soils and mixtures of soil and composite materials. The CBR test was carried out on samples compacted at the optimum moisture content using the standard compaction test. Soil samples that have been compacted by the CBR matrix are immersed in a water bath for 7 days to obtain the submerged CBR value. In a cubic centimetre matrix, 5.0kg of soil, bagsse ash and cement was mixed at optimal moisture content. The sample was compacted in three layers with 56 tampering blows of 2.5kg. The CBR is obtained as a ratio of the force required to effect a given depth of penetration from a standard penetrator piston into a soil sample compacted at a known moisture content and density, up to the standard load required to achieve the same penetration depth in standard gravel sample. Mathematically, CBR is computed as:

$$CBR = \frac{\text{Test object load}}{\text{Standard gravel load}} \times 100\% \qquad (3)$$

2.5.4 Unconfined compressive strength

The unconfined compressive strength (UCS) 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.

3. RESULTS AND DISCUSSION

The results of the engineering properties obtained during the laboratory analysis are discussed in this section.

3.1 Maximum dry density and optimum moisture content

The maximum dry density and optimum moisture content obtained from the stabilization of subgrade soil with admixture of cement and bagasse ash are plotted to understand the pattern of the trends with respect to the proportions of admixture in the soil.

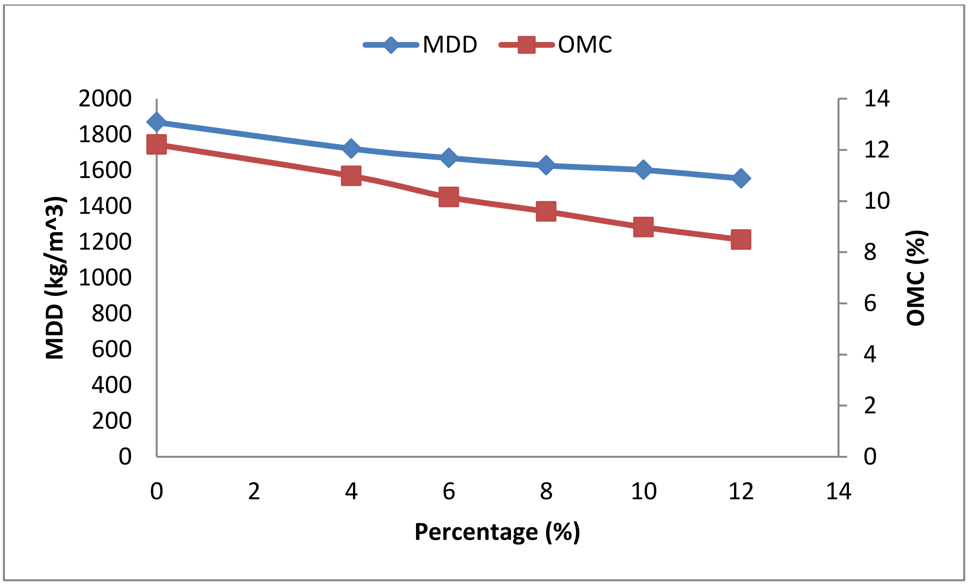

Figure 1: Effect of cement-bagasse composite mixture on MDD and OMC

The result of maximum dry density (MDD) and optimum moisture content (OMC) at various stabilising percentages of bagasse ash with cement percent is shown in Figure 1. The profile indicates that MDD decreased with increasing percent of bagasse ash in the mixture with cement. From analysis, the value of MDD for soil with no admixture is 1868kg/m^3, but decreased to 1554kg/m^3 as the content of bagasse ash in the cement-bagasse composition increased to 12%. Thus, there is significant reduction of MDD between the soil stabilized with and without cement and bagasse ash admixture.

Similarly, OMC decreased with increasing proportions of bagasse ash in the cement-bagasse composite mixture. Thus, the value of OMC in the soil without the bagasse-cement composite was 12.21%, but decreased to 8.49% as the content of bagasse ash in the cement-bagasse composite increased to 12%. The result shows reduction in OMC between the soil stabilized with and without cement and bagasse ash admixture.

The findings of this study are consistent with previous research on the use of bagasse ash as a soil stabilizer. For example, a study by Gupta and Sharma (2019) also found that the maximum dry density of soil decreased with increasing proportions of bagasse ash in the mixture with cement. Additionally, a study by Kumar *et al.* (2020) reported that the optimum moisture content of soil decreased with the addition of bagasse ash as a stabilizing agent.

Furthermore, a study by Adepegba *et al.* (2018) showed that the use of bagasse ash and cement as soil stabilizers can improve the strength and durability of the soil. These findings support the potential benefits of using bagasse ash as an eco-friendly and cost-effective alternative to traditional soil stabilizers.

3.2 Consistency limits

The consistency limits, which include liquid limit, plastic limit and plasticity index, obtained from the stabilization of subgrade soil with admixture of cement and bagasse ash are plotted to understand the pattern of the trends with respect to the proportions of admixture in the soil.

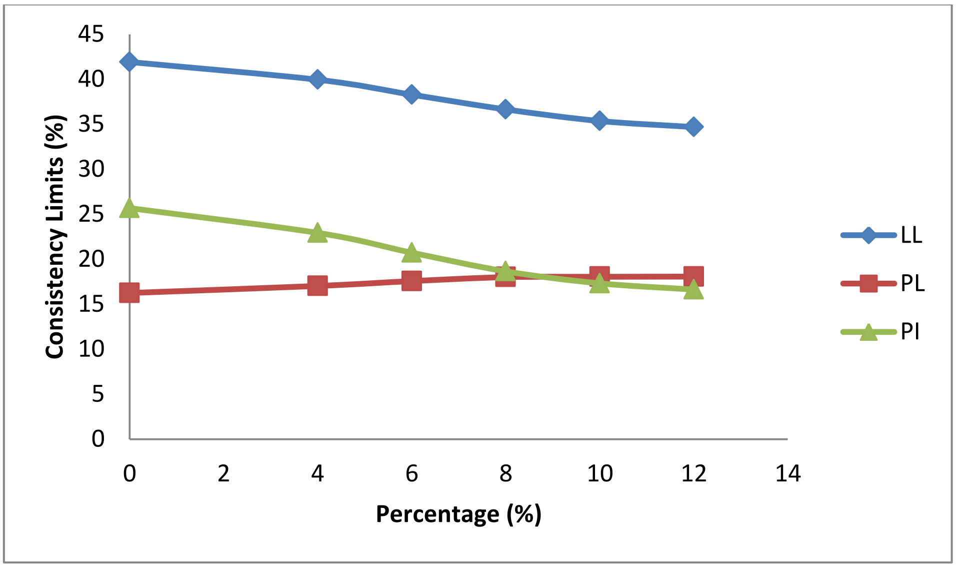

Figure 2: Effect of cement-bagasse composite mixture on consistency limits

Figure 2 of profiles of liquid limit (LL) plastic limit (PL) and plasticity index (PI) stabilized soil at various percentages of bagasse ash in the cement composite mixture. The profile indicates that LL decreased with increasing percent of bagasse ash in the mixture. From the analysis, the value of LL for soil with no admixture was 41.91%, but decreased to 34.68% as the content of bagasse ash in the cement-bagasse composite increased to 12%. There was reduction in LL between the soil stabilized with and without cement-bagasse ash admixture.

Similarly, profile indicates that PL decreased with increasing percent of bagasse ash in the mixture. From the analysis, the value of PL for soil with no admixture was 16.24%, and then decreased to 18.06% as the content of bagasse ash in the cement-bagasse composite increased to 12%. The increase in PL between the soil stabilized with and without cement-bagasse ash admixture indicates the distinct characteristics of the stabilizer, which has ability to alter the soil properties.

The result showed that PI also decreased with increasing percent of bagasse ash in the mixture. Thus, the value of PI for soil with no admixture was recorded as 25.67%, which decreased to 16.62% as the content of bagasse ash in the cement-bagasse composite increased to 12% respectively. Likewise, there was reduction in PI between the soil stabilized with and without cement-bagasse ash admixture.

The findings of this study are consistent with previous research which has reported a decrease in liquid limit, plastic limit, and plasticity index of soil when stabilized with cement and other pozzolanic materials. For instance, Akinmusuru *et al.* (2018) reported a reduction in liquid limit and plastic limit of lateritic soil stabilized with cement and bagasse ash. Additionally, Dukari *et al.* (2017) reported a decrease in plasticity index of black cotton soil stabilized with cement and sugarcane bagasse ash.

Furthermore, the observed reduction in liquid limit and plastic limit in this study can be attributed to the pozzolanic activity of bagasse ash, which reacts with the free lime in cement to form additional calcium silicate hydrate (C-S-H) gel. This results in the formation of a more stable structure with a reduced water-holding capacity. This finding is in agreement with the work of Siddique and Mehtab (2016) who reported a decrease in liquid limit and plastic limit of soil stabilized with cement and rice husk ash.

In conclusion, the results of this study demonstrate that the addition of bagasse ash to cement can improve the engineering properties of subgrade soil by reducing its liquid limit, plastic limit, and plasticity index. These findings are consistent with previous research and provide valuable insights for the development of sustainable and cost-effective soil stabilization techniques.

3.3 California Bearing Ratio

The California bearing ratio obtained from the stabilization of unsoaked and soaked subgrade soil with admixture of cement and bagasse ash are plotted to understand the pattern of the trends with respect to the proportions of admixture in the soil.

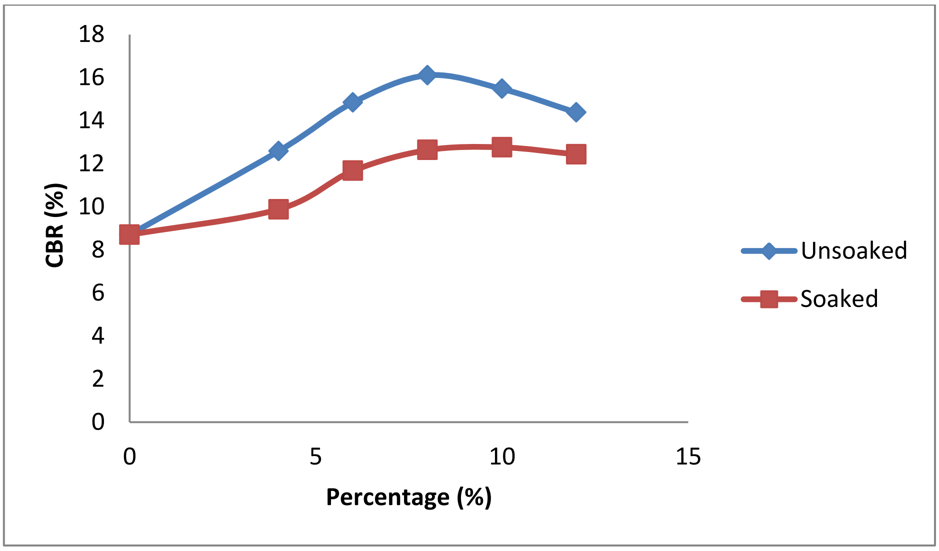

Figure 3: Effect of cement-bagasse composite mixture on CBR

Figure 3 shows the results of California bearing ratio (CBR) of the unsoaked and soaked stabilized soil at various percentages of cement-bagasse ash admixture. The profile of CBR for the unsoaked stabilized subgrade soil indicates that the stabilized soil increased with increasing percent of bagasse ash in the stabilization mixture. The CBR of the unsoaked stabilized soil with no admixture was 8.70%, and then increased to amaximum value of 16.10% at 8% bagasse ash. However, the CBRvalues at 10% and 12% bagasse ash are 15.47% and 14.37%, respectively.

Similarly, the profile of CBR for the soaked stabilized subgrade soil indicates that the stabilized soil increased with increasing percent of bagasse ash in the stabilization mixture. The CBR of the unsoaked stabilized soil with no admixture was 8.63%, and then increased to amaximum value of 12.76% at 8% bagasse ash. However, the CBRvalues at 10% and 12% bagasse ash are 12.61% and 12.43%, respectively.

The findings of this study are consistent with previous research that investigated the use of bagasse ash as a soil stabilizer. For example, the work of Akinmusuru *et al*. (2017) showed that the CBR of lateritic soil improved with the addition of bagasse ash, and the highest CBR value was obtained with a 10% bagasse ash content. Another study by Mohammed *et al*. (2019) investigated the use of bagasse ash and cement as stabilizing agents for black cotton soil, and the results showed that the CBR value increased with an increase in the percentage of bagasse ash and cement.

Furthermore, a study by Adegoke *et al*. (2018) investigated the use of bagasse ash and lime as stabilizing agents for lateritic soil, and the results showed that the CBR value increased with an increase in the percentage of bagasse ash and lime. These findings support the conclusion of this study that the addition of bagasse ash can improve the CBR of subgrade soil.

3.4 Unconfined Compressive Strength

The unconfined compressive strength obtained from the stabilization of soil with admixture of cement and bagasse ash was plotted to understand the pattern of the trends with respect to the proportions of admixture in the soil**.** The unconfined compressive strength (UCS) analysis of the stabilized soil was only studied for 7 days curing.

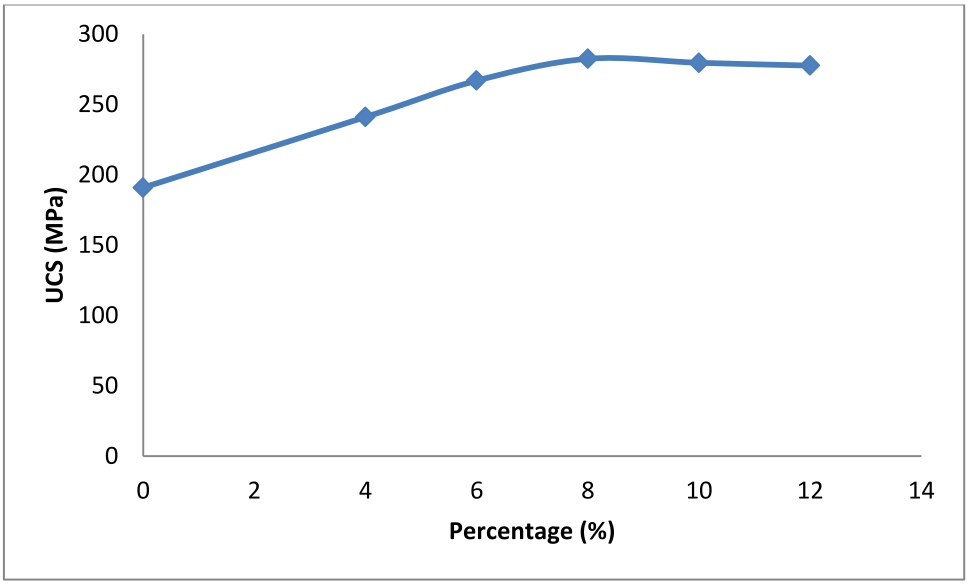

Figure 4: Effect of cement-bagasse composite mixture on UCS

The unconfined compressive strength (UCS) results of the stabilized soil was determined at 7 days curing is shown in Figure 4. The test showed that UCS increased with increasing percentage of bagasse ash in the composite mixture. From result, the unconfined compressive strength of the stabilized soil without cement-bagasse composite was 190.90MPa, but the addition of bagasse ash and cement increased to UCS value to a maximum value of 282.48MPa at 8% bagasse ash. The unconfined compressive strength at 10% and 12% are obtained as 279.63MPa and and 277.63MPa. The increase in unconfined compressive strength of the stabilized subgrade soil with cement and bagasse ash composite indicated that bagasse ash is a useful admixture to cement in soil stabilization.

The results of the study on the unconfined compressive strength (UCS) of stabilized soil using cement and bagasse ash as admixtures are consistent with previous studies. According to the study by Meena and Rajor (2017), the addition of bagasse ash as an admixture to soil-cement mixtures can improve the strength characteristics of the stabilized soil. Another study by Ng'andu *et al*. (2016) also found that bagasse ash can be effectively used as a pozzolanic material in soil stabilization, resulting in significant improvements in the compressive strength of the stabilized soil.

Furthermore, the results of the present study indicate that the proportion of bagasse ash in the composite mixture plays a crucial role in determining the strength characteristics of the stabilized soil. This finding is consistent with the results of the study by Taha and Al-Sanousi (2014), who reported that the strength of the stabilized soil increased with increasing proportions of bagasse ash in the composite mixture.

In conclusion, the present study confirms that bagasse ash can be effectively used as an admixture to cement in soil stabilization, resulting in significant improvements in the unconfined compressive strength of the stabilized soil. The findings of this study are consistent with previous studies on the use of bagasse ash as a pozzolanic material in soil stabilization.

4. CONCLUSION

The performance of bagasse ash as admixture to cement in soil stabilization improved the properties of the subgrade soil. This study shows that the composite of cement and bagasse ash from *Costus bracteatus Rowlee.* reduced the maximum dry density (MDD) and optimum moisture content of the soil, while the California bearing ratio and unconfined compressive strength were increased. The increase in unconfined compressive strength of the stabilized subgrade soil with cement and bagasse ash composite indicates that bagasse ash is a useful admixture to cement in soil stabilization. This also implies that the effectiveness of bagasse ash will not only solve environmental problems due to indiscriminate discharge of agricultural wastes, it will also serve as additive for soil stabilization, thereby reducing cost of procuring conventional materials for stabilization such as lime and cement, which are often used for road pavement. Though there was improvement of soil properties with addition of bagasse ash, but the optimum performance of the soil CBR and UCS was recorded at 8% bagasse ash in the mixture. Therefore, a mixture of 8% proportion of bagasse ash with 8% cement recommended as the appropriate mixture proportion in soil stabilization. This study also recommends the use of *Costus bracteatus Rowlee* bagasse ash with cement as stabilizer for soil susceptible to swelling and shrinkage.

REFERENCES

1. AASHTO (1999). Standard specification for transportation materials and methods of sampling and testing, American Association of state highway and transportation officials, National Press Building, Washington D.C.
2. Adegoke, A. K., Akinmusuru, J. O., & Olusunle, S. O. (2018). Stabilization of lateritic soil using bagasse ash and lime. International Journal of Engineering Research in Africa, 34, 60-71.
3. Adepegba, D. A., Oni, O. A., & Afolayan, O. J. (2018). Effect of Bagasse Ash on the Strength and Durability Properties of Lateritic Soil Stabilized with Cement. Journal of Materials in Civil Engineering, 30(3), 04018011.
4. Akinmusuru, J. O., Sani, I. S., & Adeyemi, A. A. (2017). Improvement of the geotechnical properties of lateritic soil using bagasse ash. Journal of Materials Science and Engineering A, 7(5), 205-214.
5. Akinmusuru, J.O., Olusunle, S.O., Ogunkunle, T.F., and Ogundiran, M.B. (2018). Strength characteristics of lateritic soil stabilized with cement and bagasse ash. Journal of Materials in Civil Engineering, 30(7), 04018131.
6. Akinwande, J., and Aderinola O.R. (2020). Sub-Soil Investigation of A Proposed Construction Site At Ado -Ekti, South Western, Nigeria. 7: 11471- 11476.
7. Bhujbal, P and Gaikwad, A.,(2022). Quantitative study of Shrinkage and Crack Development in Black Cotton Soil (February 25, 2022). Proceedings of the 3rd International Conference on Contents, Computing and Communication (ICCCC-2022), Available at SSRN: https://ssrn.com/abstract=4043364 or http://dx.doi.org/10.2139/ssrn.4043364
8. Chethan B. A. and Shankar R.A. U.(2021). Effect of Flash Flood and Weather Changes on Unconfined Compressive Strength of Cement- and Fly Ash-Stabilized Black Cotton Soil Used as Road Materials, International Journal of Pavement Research and Technology- Springer Science and Business Media, https://doi.org/10.1007%2Fs42947-021-00125-y
9. Darikandeh F., and Phanikumar B. R (2021) Swell-shrink behaviour of an expansive soil stabilised by CCR-fly ash (FA) columns and CCR-FA blends, Geomechanics and Geoengineering, DOI: 10.1080/17486025.2021.1928766
10. Diome F., and Biaye L.(2022). Study of Shrinkage and Swelling Phenomena in Clay Soils of Fanaye Middle Senegal River Valley): Simulation of Water Transfers in a Soil Column, Open Journal of Soil Science, 12, 151-169.
11. Dukari, J., Ochieng, G.M., and Oyawa, W.O. (2017). Effect of sugarcane bagasse ash and cement on the plasticity and compaction characteristics of black cotton soil. International Journal of Scientific Research in Science and Technology, 3(5), 147-154.
12. Fondjo A. A., Theron E., and Ray R.P. (2021). Semi-Empirical Model for Predicting the Swelling Stress of Compacted, Unsaturated Expansive Soils. Civil Engineering and Architecture, 9(1), 225 - 239. DOI:10.13189/cea.2021.090119
13. Garg R., Biswas T., Kumar A., Siddharth A., and Singh D.R.(2021). Stabilization of expansive soil by using industrial waste, Journal of Physics: Conference Series- IOP publishing, (1) 2070: 012238, https://doi.org/10.1088%2F1742-6596%2F2070%2F1%2F012238
14. Gupta, R. C., & Sharma, R. K. (2019). Effect of bagasse ash and lime on engineering properties of expansive soil. Geomechanics and Engineering, 18(4), 305-315.
15. Khan M.,Wang J., and Patterson W., (2017). A study of the swell-shrink behavior of expansive Moreland clay. International Journal of Geotechnical Engineering. 13. 1-13.
16. Kshatriya R., Sathe P. and Kankarej P., (2022) Analysis and Behavior of Retaining Wall on Black Cotton Soil by Using Software ‘PLAXIS 2D’ (February 25, 2022). Proceedings of the 3rd International Conference on Contents, Computing & Communication (ICCCC-2022), Available at SSRN: https://ssrn.com/abstract=4043255 or http://dx.doi.org/10.2139/ssrn.4043255
17. Kumar, S., Kumar, R., & Singh, B. (2020). Stabilization of Soil with Bagasse Ash and Cement. International Journal of Civil Engineering and Technology, 11(2), 265-275.
18. Mai-Bade U.Y., Chinade A.U., Batari A., and Saeed S.M., (2021).Stabilization of Black Cotton Soil Using Various Admixtures: A Review, Composite Materials. (5)2 :37-45. doi: 10.11648/j.cm.20210502.12
19. Majeed M. and Tangri A.P.(2021). Stabilization of soil using industrial wastes, Conference Series: Earth and Environmental Science-IOP publishing, https://doi.org/10.1088%2F1755-1315%2F889%2F1%2F012018, (1)889.
20. Meena, B. L., & Rajor, A. (2017). Effect of bagasse ash on strength characteristics of soil-cement mixtures. Journal of Materials in Civil Engineering, 29(3), 04016235.
21. Merouane F. Z and Mamoune S.(2018). M. A. Prediction of Swelling Parameters of Two Clayey Soils From Algeria Using Artificial Neural Networks, Mathematical Modelling in Civil Engineering, (14) 3: 11-26, Doi: 10.2478/mmce2018-0008
22. Mohammed, M. I., Ahmed, Y. M., & Ahmed, A. E. (2019). Evaluation of bagasse ash and cement as stabilizing agents for black cotton soil. International Journal of Geotechnical Engineering, 13(4), 374-380.
23. Nanda P. (2021). Black Cotton Soil Stabilization by Using Fly Ash - Kota Stone Slurry Mix, International Journal for Research in Applied Science and Engineering Technology , (11) 9: 1699-1703.Dio.10.22214/ijraset.2021.39086
24. Navagire O.P, Sharma S.K., and Rambabu D.(2021). Stabilization of black cotton soil with coal bottom ash, Materials Today: Proceedings- Elsevier 52: 979--985, https://doi.org/10.1016%2Fj.matpr.2021.10.447,
25. Ng'andu, B. M., Katema, M. J., & Tembo, B. D. (2016). Potential of sugarcane bagasse ash as a pozzolanic material in soil stabilization. Journal of Materials in Civil Engineering, 28(4), 04015195.

26. 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.
27. Ouedraogo M., Sawadogo M., Sanou I., Barro M., Nassio S., Seynou M., and Zerbo L. (2022). Characterization of sugar cane bagasse ash from Burkina Faso for cleaner cement production: Influence of calcination temperature and duration, Results in Materials, (4) https://doi.org/101016/j.rinma.2022.100275.
28. Patel D. (2022). Study of partial replacement of bagasse ash in concrete. 3: 983-992.
29. Premkumar R.,. Subha B, Sandhiya P.S., and Narayanan S, K., (2021). Stabilization of Black Cotton Soil with Groundnut Shell Ash, Materials Research Proceedings, 19: 44-50, https://doi: https://doi.org/10.21741/9781644901618-6
30. Prudhvi M., and Chellaiah G.,(2022). Comparative Analysis of Utilization of Salts for Stabilization of Black Cotton Soil, Lecture Notes in Civil Engineering - Earthquake Geotechnics,189-194, doi: 10.1007/978-981-16-5669-9_16
31. Rehman, and Mujeeb. (2020). Comparative Study on Stabilized Black Cotton Soil. 05: 46-52. https://www.researchgate.net/publication/344592180_Comparative_Study_on_Stabilized_Black_Cotton_Soil
32. Siddique R., and Cachim P. (2018). Waste and Supplementary Cementitious Materials in Concrete, Woodhead Publishing Series in Civil and Structural Engineering, 599-621, https://doi.org/10.1016/B978-0-08-102156-9.00034-1.
33. Siddique, R., and Mehtab, P. (2016). Effect of rice husk ash on the plasticity and compaction characteristics of soil. International Journal of Pavement Engineering, 17(8), 715-723.
34. Singh M., Singh J, and Siddique R.(2022). Sustainable Concrete Made with Ashes and Dust from Different Sources, Bagasse ash, Woodhead Publishing Series in Civil and Structural Engineering, 177-233, https://doi.org/10.1016/B978-0-12-824050-2.00001-2.
35. Taha, M. R., & Al-Sanousi, A. (2014). Stabilization of expansive clayey soil using sugarcane bagasse ash and cement. International Journal of Geotechnical Engineering, 8(3), 248-256.