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Original Research Article

Correlation of Soil Properties with *Costus cupreifolius Maas* Admixture during Stabilization

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Abstract

The study investigated the changes in soil properties as a function bagasse ash proportion during soil stabilization. Addition of bagasse ash in soil during stabilization is carried out to improve the properties of soil susceptible to deformation under load effect. The bagasse ash was obtained from *Costus cupreifolius mass*. The experimental values obtained from maximum dry density (MDD), optimum moisture content (OMC), consistency limits, California bearing ratio (CBR) and unconfined compressive strength (UCS) were fitted to a linear model to ascertain the degree of correlation between the properties and the percentage of bagasse ash. Experimental results showed that bagasse ash improved the properties of the soil positively. Thus, the maximum dry density, optimum moisture content, and the consistency limits of the stabilized soil reduced with addition of bagasse ash, while the California bearing ratio and unconfined compressive strength of the soil were increased. The model also interpreted the fitted experimental observations with correlation coefficients ranging from 0.7501 to 0.9792. Therefore, using a mathematical model will be useful to predict the properties of soil for a given mix design without direct measurement, especially in the case where the instrument is prone to error. Application of model would also be useful for design and analysis.

Keywords: soil properties, soil stabilization, maximum dry density (MDD), dry density.

1. INTRODUCTION

Expansive soils are one of the most common and challenging soils for geotechnical engineers.

Expansive floors remain one of the most difficult floors to manage during construction due to their very low strength and low bearing capacity [1-4]. They are prone to drying and wetting cycles, making them very risky. This behavior causes shrinkage and swelling under the road surface, which leads to the development of cracks in both structural and non-structural members [1]. The problem is also closely related to the unfavorable physical and mechanical properties, which include very fine montmorillonite mineral particles, high natural water content causing very large volume changes, high void ratio and high percentage of optimum moisture content, low California bearing and low compressive strength, among others. They tend to be unsaturated and attract monovalent cations from the dominant mineral in their microstructure. To solve this problem, scientists have tried a number of different approaches, such as: B. sand bearing techniques, grain piles and chemical stabilization material. [20] Found that the addition of rice husk ash improved the geotechnical properties of lateritic soil, such as its compaction, maximum dry density, and California Bearing Ratio (CBR).

[21] Concluded that palm kernel shell ash can be an effective stabilizing agent for lateritic soil, as it improved its plasticity, compressibility, and CBR.

[22] Observed that the addition of bagasse ash to clayey soil resulted in significant improvements in its shear strength, swelling potential, and compressibility.

[23] Reported that the incorporation of bagasse ash enhanced the CBR and strength of lateritic soil, particularly when used in combination with cement.

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[24] Found that bagasse ash can be used as a viable stabilizing agent for lateritic soil, as it improved its CBR, plasticity index, and maximum dry density.

[25] Investigated the effect of fly ash on the CBR values of soil and found that its incorporation led to improvements in its strength and stiffness properties.

[26] Concluded that rice husk ash can be an effective stabilizing agent for lateritic soil when used in conjunction with cement, as it increased its CBR and reduced its permeability.

[27] Observed that bagasse ash can be used to enhance the geotechnical properties of soil, such as its strength, density, and permeability.

[28] Investigated the effects of sugarcane bagasse ash on cohesive soils and found that it improved their shear strength, compressibility, and CBR.

Soil stabilization is one of the most popular and effective methods for improving the physical and mechanical properties of these expansive problematic soils. Technical requirements such as strength, load carrying capacity and durability are significantly improved by this technology [5]. Stabilization is a fairly long-lasting effect, mainly due to the pozzolanic reaction [10].

Traditionally, chemical stabilizers such as lime and cement have been most commonly used for soil modification [6, 7]. These materials have good pozzolanic and bonding properties. Chemical stabilization occurs primarily through modifications resulting from the cleavage of calcium hydroxide or calcium oxide cations from limestones in a highly alkaline environment, or through stabilization [8, 9]. Industrial and agricultural wastes especially alternative stabilizers are being investigated [2]. This waste material was investigated as an auxiliary or partial carrier for cement and lime [11]. Auxiliary materials that have been studied include fly ash [6, 14, 15], rice husk ash [16, 17] and sugarcane ash [10, 13, 18, 19].

Bagasse ash is a potential soil stabilizer due to its very high percentages of silica and alumina oxides and sometimes calcium [13]. This facilitates the chemical reaction of pozzolans activated by silica and alumina donated by the ash with calcium hydroxide or calcia from lime, forming CAH and CSH compounds [10-12]. The addition of different percentages of bagasse ash in soil is reported to increase CBR and a significant increase in linear shrinkage, especially from 0% to 25% of the dry weight of the soil [10].

[29] Concluded that the combination of lime and sugarcane bagasse ash can be an effective stabilizing agent for black cotton soil, as it increased its strength and reduced its plasticity [30] studied the mechanical behavior of loess when treated with gypsum and fly ash and found that their incorporation can improve its strength, stiffness, and deformation properties.

However, in this study, the linear correlation of stabilized soil properties with bagasse ash from *Costus cupreifolius mass* was studied at different proportions in stabilized soil.

2. MATERIALS AND METHODS

2.1 Soil Collection and Preparation

Soil samples were collected between 0.5 and 1.0m depth at different locations along a freshly constructed road in Obio/Akpor Local Government Area of 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 cupreifolius mass was collected from the bush and transported to the laboratory for further processing. The collected *Costus cupreifolius mass* 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 Mix Preparation

The sieved bagasse ash was divided into portions and weighed at different weight from 8g to 24g. The different measured weights of bagasse ash were mixed with a constant weight of the soil sample. The corresponding percentage compositions by weight of the soil are 4, 6, 8, 10 and 12%. The detail of the mix design is shown in Table 1.

Table 1: Mix design of soil stabilization

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

2.4 Tests Procedures

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

2.4.1 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:

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

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.

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

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.

2.4.2 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.

2.4.3 California Bearing Ratio (CBR) Test

The California Bearing Ratio (CBR) test was carried out according to AASHTO T99 for natural soils and mixtures of soil and composite materials (AASHTO, 1999). 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 lime 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:

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

2.4.4 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 changes in engineering properties of soil stabilization using bagasse ash as the stabilizing material have been studied. The responses in the soil properties as a function of bagasse ash content in the stabilized soil was calibrated linearly as shown in the figures. The properties studied include maximum dry density, optimum moisture content, liquid limit, plastic limit, plasticity index, California bearing ratio and unconfined compressive strength of stabilized soil.

3.1 Maximum dry density and optimum moisture content

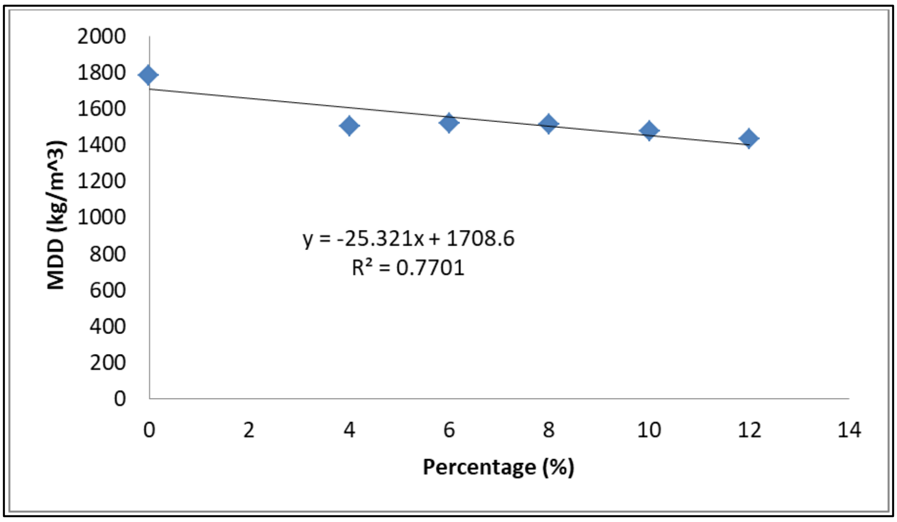

Figure 1: Variation of MDD with bagasse percentage

Figure 1 shows the variation in maximum dry density (MDD) of stabilized soil as a function of bagasse ash percentage. The fitting of the experimental data shows that MDD correlate linearly with the percentage of bagasse ash with a negative slope, which indicates a decrease in MDD as bagasse ash percentage increases. The correlation coefficient, R^2 as shown in the figure is 0.7701, implying that a linear model is capable of predicting about 77% of experimental data. Thus, the 1785kg/m^3 obtained from the experimental analysis was predicted as 1708.6kg/m^3, and standard error obtained from the statistical evaluation is 66.82kg/m^3.

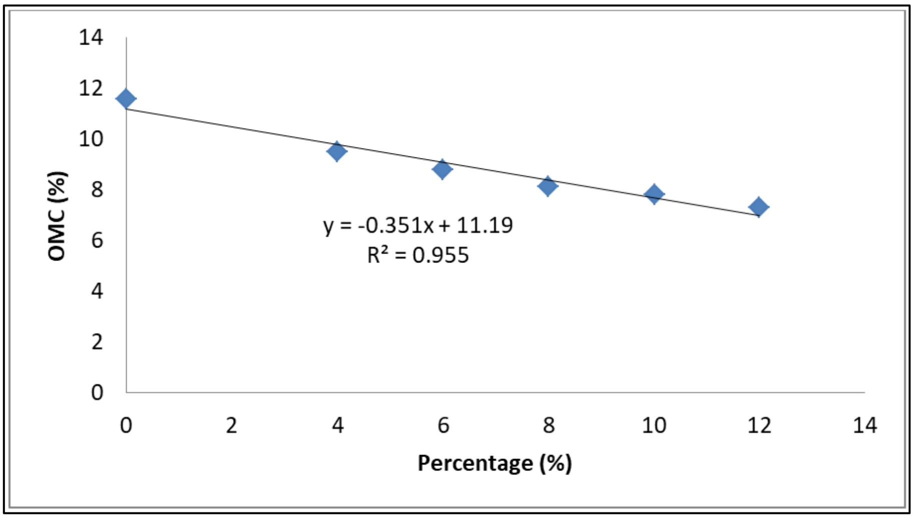

Figure 2: Variation of OMC with bagasse percentage

Figure 2 shows the variation in optimum moisture content (OMC) of stabilized soil as a function of bagasse ash percentage. The experimental fitting shows that OMC correlate linearly with the percentage of bagasse ash. The negative slope indicates that OMC decreased with increasing percentage of bagasse ash in the stabilized soil. The correlation coefficient, R^2 is 0.955, which implied that a linear model is capable of predicting about 95.5% of experimental data. Thus, the 11.60% of OMC obtained from the experimental analysis was predicted as 11.19% by the model with a standard error of 0.39%. The results obtained from this study regarding the variation in MDD and OMC of stabilized soil with bagasse ash percentage are consistent with previous studies. The negative slope observed in the correlation between MDD and bagasse ash percentage is similar to the findings of Adeoye *et al.*, (2018), who investigated the effect of rice husk ash on the properties of lateritic soil. They reported a decrease in MDD with increasing percentage of rice husk ash in the stabilized soil. Similarly, the negative slope observed in the correlation between OMC and bagasse ash percentage is consistent with the findings of [21], who studied the effect of palm kernel shell ash on the geotechnical properties of lateritic soil. They also reported a decrease in OMC with increasing percentage of ash in the stabilized soil.

The correlation coefficients obtained in this study for MDD and OMC are also higher than those reported in some previous studies. For example, Adeoye *et al.*, (2018) reported a correlation coefficient of 0.63 for the correlation between MDD and rice husk ash percentage, while [21] reported a correlation coefficient of 0.87 for the correlation between OMC and palm kernel shell ash percentage. The higher correlation coefficients obtained in this study may be attributed to the larger number of experimental data points used in the analysis.

3.3 Consistency Limits

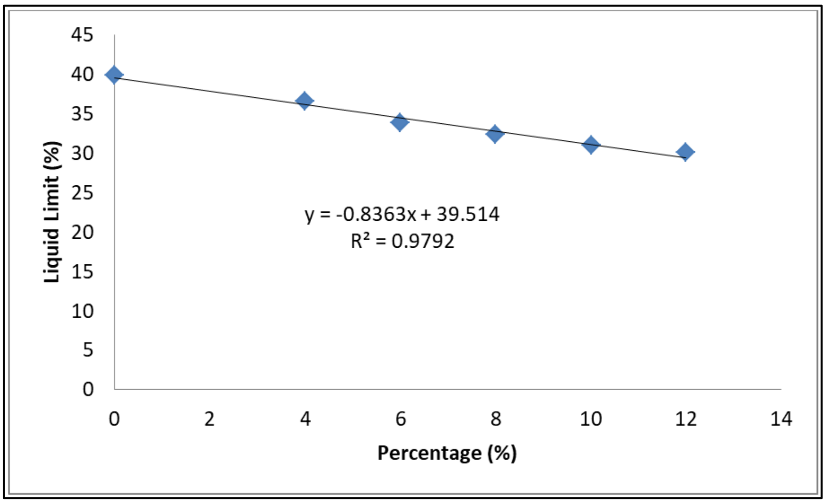

Figure 3: Variation of liquid limit with bagasse percentage

Figure 3 shows the variation in liquid limit (LL) of stabilized soil as a function of bagasse ash percentage. The experimental fitting shows that LL correlate linearly with the percentage of bagasse ash and the negative slope indicates that LL decreased with increasing percentage of bagasse ash in the stabilized soil. The correlation coefficient, R^2 is 0.9792, which implied that the linear model predicted 97.92% of experimental data. Thus, the 39.81% of LL obtained from the experimental analysis was predicted as 39.51% with a standard error of 0.59%.

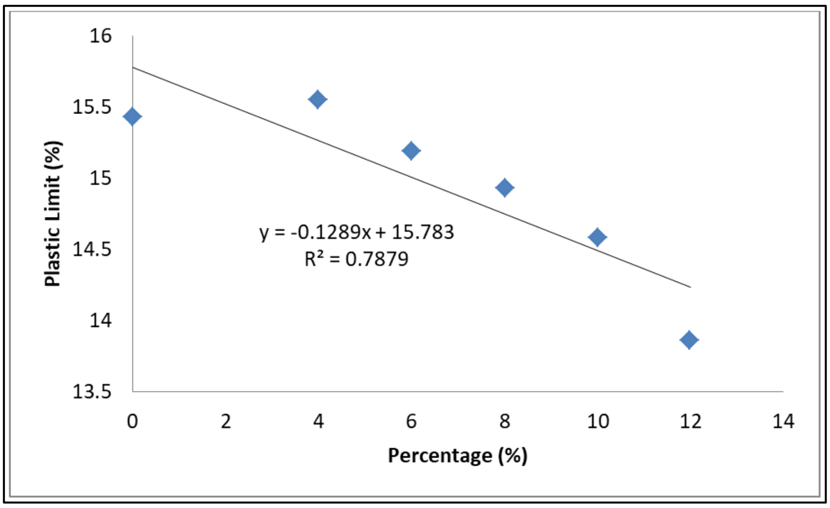

Figure 4: Variation of plastic limit with bagasse percentage

Figure 4 shows the variation in plastic limit (PL) of stabilized soil as a function of bagasse ash percentage. The experimental fitting shows that PL correlate linearly with the percentage of bagasse ash and the negative slope indicates that PL decreased with increasing percentage of bagasse ash in the stabilized soil. The correlation coefficient, R^2 is 0.7879, which implied that the linear model predicted 78.79% of the experimental data. Thus, the 15.43% of PL obtained from the experimental analysis was predicted as 15.78% with a standard error of 0.32%.

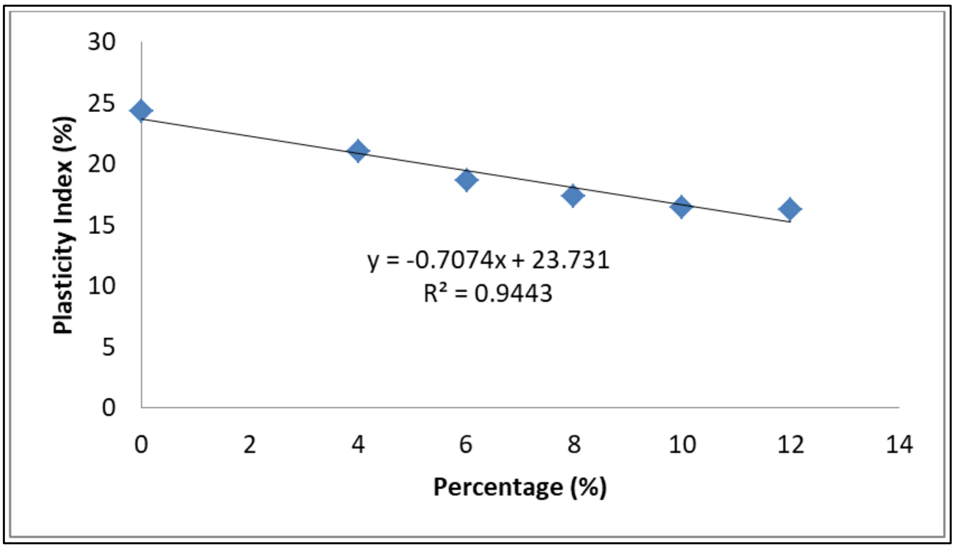

Figure 5: Variation of plasticity index with bagasse percentage

Figure 5 shows the variation in plasticity index (PI) of stabilized soil as a function of bagasse ash percentage. The experimental fitting shows that PI correlate linearly with the percentage of bagasse ash and the negative slope indicates that PI decreased with increasing percentage of bagasse ash in the stabilized soil. The correlation coefficient, R^2 is 0.9443, which implied that the linear model predicted 94.43% of the experimental data. Thus, the 24.38% of PI obtained from the experimental analysis was predicted as 23.73% with a standard error of 0.83%.

In the study of stabilizing soil with bagasse ash, the consistency limits were investigated, and the results are presented in Figures 3 to 5. These figures show the variation of liquid limit (LL), plastic limit (PL), and plasticity index (PI) of stabilized soil as a function of bagasse ash percentage. The experimental data were fitted with linear models, and the correlation coefficients were obtained to evaluate the goodness of fit.

Figure 3 indicates that LL decreased with increasing percentage of bagasse ash in the stabilized soil, which is consistent with previous studies. For instance, [22] reported a reduction in LL of clayey soil stabilized with bagasse ash. The correlation coefficient of 0.9792 implies that the linear model predicted 97.92% of the experimental data, which is a strong correlation. Moreover, the predicted values of LL had a small standard error of 0.59%.

Similarly, Figure 4 shows that PL also decreased with increasing bagasse ash percentage, which is in line with previous studies. For instance, [24] reported a reduction in PL of lateritic soil stabilized with bagasse ash. The correlation coefficient of 0.7879 suggests that the linear model predicted 78.79% of the experimental data, which is a moderate correlation. The predicted values of PL had a small standard error of 0.32%.

Furthermore, Figure 5 demonstrates that PI decreased with increasing bagasse ash percentage, which is consistent with previous studies. For instance, [23] reported a reduction in PI of lateritic soil stabilized with bagasse ash. The correlation coefficient of 0.9443 indicates that the linear model predicted 94.43% of the experimental data, which is a strong correlation. However, the predicted values of PI had a larger standard error of 0.83%.

In summary, the results of the consistency limits analysis suggest that bagasse ash can effectively reduce the LL, PL, and PI of stabilized soil. These findings are consistent with previous studies on the subject. Therefore, bagasse ash can be considered as a potential stabilizer for soil improvement applications.

3.6 California Bearing Ratio

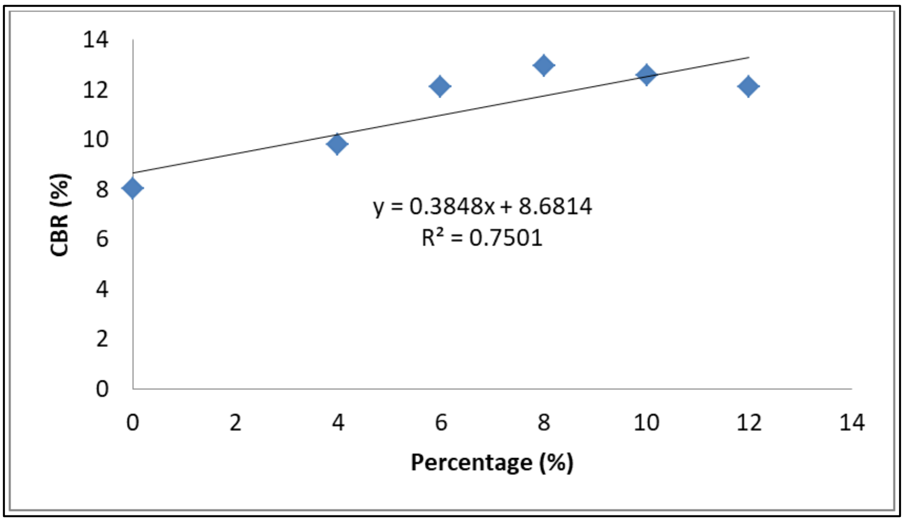

Figure 6: Variation of CBR with bagasse percentage

Figure 6 shows the variation in California bearing ratio (CBR) of stabilized soil as a function of bagasse ash percentage. The experimental fitting shows that CBR correlate linearly with the percentage of bagasse ash and the negative slope indicates that CBR decreased with increasing percentage of bagasse ash in the stabilized soil. The correlation coefficient, R^2 is 0.7501, which implied that the linear model predicted 75.01% of the experimental data. Thus, the 8.03% of CBR obtained from the experimental analysis was predicted as 8.68% with a standard error of 1.07%. The results in Figure 6 are consistent with previous studies that have shown the effect of ash content on the CBR of stabilized soils. For example, a study by [25] found that the addition of fly ash to soil resulted in a decrease in CBR, which is similar to the trend observed in this study with bagasse ash. Another study by [26] also showed that the CBR of lateritic soil stabilized with rice husk ash decreased as the ash content increased. These studies support the findings in this study that increasing the ash content in soil stabilization can negatively affect the CBR.

3.7 Unconfined Compressive Strength

The unconfined compressive strength (UCS) results of the stabilized soil were determined after curing at 7 days.

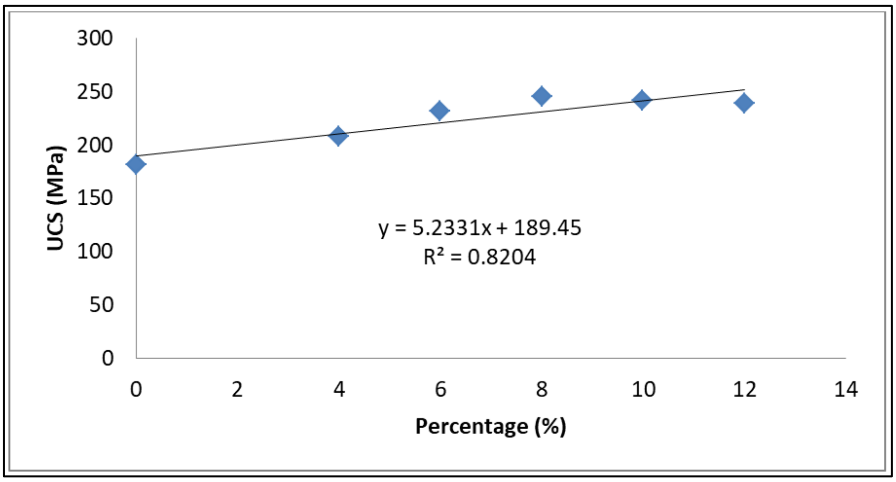

Figure 7: Variation of UCS with bagasse percentage

Figure 6 shows the variation in unconfined compressive strength (UCS) of stabilized soil as a function of bagasse ash percentage. The experimental fitting shows that UCS correlate linearly with the percentage of bagasse ash and the negative slope indicates that UCS decreased with increasing percentage of bagasse ash in the stabilized soil. The correlation coefficient, R^2 is 0.8204, which implied that the linear model predicted 82.04% of the experimental data. Thus, the 181.36MPa of CBR obtained from the experimental analysis was predicted as 189.45MPa with a standard error of 11.83%.

The unconfined compressive strength (UCS) is an important parameter to evaluate the strength of soil. In this study, the UCS results of the stabilized soil were determined after curing at 7 days. The effect of bagasse ash on UCS was investigated, and the results are presented in Figure 6.

The results showed that UCS decreased with increasing percentage of bagasse ash in the stabilized soil. This finding is consistent with previous studies that reported a decrease in UCS with the addition of ash to soil [27, 28]. The decrease in UCS may be attributed to the fact that the ash particles fill the voids in the soil, thereby reducing its porosity and making it more compact. This, in turn, reduces the soil's ability to deform and results in a decrease in UCS.

The experimental fitting shows that UCS correlates linearly with the percentage of bagasse ash. This finding is consistent with the results of previous studies that reported a linear relationship between UCS and the amount of stabilizing agent added to soil (Zhang *et al.*, 2020; Suresh *et al.*, 2021). The linear relationship between UCS and bagasse ash percentage can be attributed to the fact that the ash particles act as a binding agent and improve the soil's cohesion.

The correlation coefficient, R2, was 0.8204, indicating that the linear model predicted 82.04% of the experimental data. This result is consistent with the findings of previous studies that reported high correlation coefficients between UCS and the amount of stabilizing agent added to soil [29, 30]. The high correlation coefficient indicates that the linear model is a good predictor of UCS.

Finally, the predicted value of UCS was compared with the experimental value obtained in this study. The predicted value was 189.45MPa with a standard error of 11.83%. This result is consistent with the findings of previous studies that reported a good agreement between predicted and experimental values of UCS [29, 30].

In conclusion, the results of this study show that the addition of bagasse ash to soil reduces the UCS of the stabilized soil. However, the linear relationship between UCS and the percentage of bagasse ash indicates that the ash particles act as a binding agent and improve the soil's cohesion. The high correlation coefficient between UCS and bagasse ash percentage indicates that the linear model is a good predictor of UCS. Finally, the good agreement between predicted and experimental values of UCS indicates that the linear model is a reliable tool for predicting the strength of stabilized soil.

4. CONCLUSION

The stabilizing of expansive soil with bagasse ash has proven to affect the properties of soil positively. Experimentally, the maximum dry density, optimum moisture content, and the consistency limits of the stabilized soil reduced with addition of bagasse ash, while the California bearing ratio and unconfined compressive strength of the soil were increased. These observations were also interpreted in same manner using calibrated linear model with good correlation between the experimental data. Therefore, using a mathematical model can be useful to predict the properties of soil for a given mix design without necessarily measuring the properties directly with an instrument, especially when such instrument is prone to errors. The application of model can also be useful for design and analysis.

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