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Original Research Article

Effectiveness of *Costus asplundii maas* as Admixture of Lime in Soil Stabilization of Highway Pavement

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Abstract: The study investigated the performance of lime and bagasse ash composite as soil stabilizer. The bagasse ash was obtained from *Costus asplundii maas.* Soil samples collected along a newly constructed road in Rivers State, Nigeria were prepared and analyzed for effect of the composite stabilizer on swelling potential, volume change, 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 lime-bagasse ash composite, while CBR (unsoaked and soaked soil samples) and UCS were with increasing proportion of lime-bagasse ash composite. This study established that the optimum proportion of bagasse ash is 10% and that inclusion of an appropriate proportion of bagasse ash in lime in soil stabilization would enhance the properties of soil suitable for road pavement. Hence, *Costus asplundii maas* is recommended to be used in soil stabilization, particularly as composite material with lime.

Keywords: The bagasse ash, *Costus asplundii maa*, Soil samples, constructed road.

1. INTRODUCTION

Lime is a traditional stabilizer that generally relies on pozzolanic reactions and cation exchange for modification and/or stabilization. Of all the traditional stabilizers, limestone is probably the most frequently used material and is produced by the decomposition of limestone at high temperatures [1]. Lime stabilization is a form of soil stabilization or soil improvement technique used in construction projects. Expansive tillage with lime for better use in construction is an advanced technology that has been tried and tested around the world for decades [2].

[10] found that the addition of sugarcane bagasse ash and lime effectively stabilized soft clay, leading to improved compressive strength and reduced compressibility.

[11] demonstrated that the pozzolanic reaction between fly ash and soil improved the compressibility and strength of the soil, leading to improved geotechnical properties.

[12] found that the addition of lime and fly ash improved the engineering properties of a highly expansive soil, resulting in improved stability and reduced expansion.

[13] showed that the geotechnical properties of soil can be improved through the use of bagasse ash, leading to increased strength and reduced compressibility.

[14] demonstrated that lime and bagasse ash can effectively improve the geotechnical properties of clay soil, leading to improved strength and reduced compressibility.

[15] found that the addition of bagasse ash improved the geotechnical properties of subgrade soil, leading to increased strength and reduced compressibility.

[16] demonstrated that the addition of bagasse ash to lateritic soil stabilized with lime led to improved geotechnical properties, resulting in increased strength and reduced compressibility.

Clay soils can be treated by adding a small percentage by weight of lime, improving many of the technical properties of the soil and producing better building materials [2]. When the soil is stabilized with lime, the lime reacts with the clay minerals to induce a

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series of physicochemical processes that improve the technical properties of the clay [3]. In most clays, chemical reactions between the limestone and clay minerals last for months and years, resulting in a continuous and gradual increase in strength. Processes that are responsible for rapid property changes are different from processes that result in long-term strength gains; however, both processes have the potential to significantly affect the durability of tillage [4].

Compared to other methods, lime stabilization is the most frequently used method for repairing foundations and substructures in road construction [2]. This technique has also been shown to be an effective approach for reducing pavement loads [5].

There are different types of limes; however, hydrated lime and quicklime are the most common types used to stabilize fine-grained soils. The amount of lime used to stabilize most soils is usually in the 5-10% range [6].

Limestone reactions that lead to improvement of clay properties involve two main steps: primary reaction (short-term treatment) and secondary reaction (long-term treatment) [6].
[17] showed that the addition of lime and bagasse ash improved the strength properties of black cotton soil, leading to increased stability and reduced compressibility.
[18] found that bagasse ash can effectively stabilize soil, resulting in increased strength and reduced compressibility.
[19] demonstrated that the addition of bagasse ash and rice husk ash effectively stabilized lateritic soil, leading to improved geotechnical properties and increased strength.
[20] showed that lime effectively improved the strength and stiffness behavior of soil, resulting in increased stability and reduced compressibility.
[21] found that the addition of sugarcane bagasse ash improved the stabilization of black cotton soil, resulting in increased strength and reduced compressibility.
[22] demonstrated that lime and sugarcane bagasse ash effectively stabilized black cotton soil, leading to improved geotechnical properties and increased strength.
[23] showed that the addition of bagasse ash and lime effectively stabilized soil, resulting in increased strength and reduced compressibility.

The first occurs within hours or days after lime addition, and at this stage three major chemical reactions occur, namely cation exchange, flocculation and agglomeration, and carbonization, leading to rapid structural and plastic changes [1]. Subsequent reactions take place from month to year and the main reaction at this stage is the pozzolanic reaction. Improved soil properties such as workability, reduced plasticity index, reduced volume change, and reduced clay particle size were associated with a rapid effect. While increased soil strength and durability were associated with long-term treatment effects. Although the pozzolanic reaction process is slow, some increase in pozzolanic strength can be achieved during the primary reaction [1].

Clay minerals have negatively charged sites on their surface that absorb and retain cations through electrostatic forces. Cations are positively charged ions such as calcium (Ca2+), magnesium (Mg2+) and potassium (K+). The ability of the soil to hold cations is called the cation exchange capacity (CEC). In cation exchange and reactions, divalent calcium ions replace monovalent cations normally associated with clays [6].

Flocculation is a process in which clay particles change their structure from a flat and parallel structure to a more random orientation [6]. Agglomeration is believed to occur when the flocculated clay particles begin to form weak bonds at the interfaces of the clay particles, due to the deposition of cement material on the surface of the clay particles. Flocculation and agglomeration cause changes in the structure of clay from a fine-grained plastic material to a granular soil, clay particles tend to stick together to become larger particles, improving the Atterberg limit and soil properties for tillage. Carbonation is the partial or complete conversion of calcium hydroxide to the carbonate phase by reaction with carbon dioxide. The pozzolanic soil-lime reaction involves the reaction between lime and silica and soil alumina to form cementitious materials [6].

Lime is considered effective in stabilizing fine-grained soils above 25% because it makes the soil more variable with less plastic and therefore easier to work with [7]. Lime can be used alone or in combination with other materials to treat different types of soil. Limestone reactivity depends on the mineralogical properties of the soil and the increase in soil strength is mainly due to chemical reactions between limestone, clay minerals and amorphous components in the soil.

Limestone reacts with most clay minerals, which has a significant impact on soils containing montmorillonite and a lower impact on soils containing kaolinite, due to the high cation exchange capacity of montmorillonite compared to kaolinite [2]. The main aim of this study, is to is investigate the performance of bagasse ash obtained from *Costus asplundii maas.* as admixture to lime in soil stabilization.

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 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 asplundii maas was collected from the bush and transported to the laboratory for further processing. The collected *Costus asplundii maas* was cut into pieces. The preparation was done according to the method described by Okonkwo et al. [8]. 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 Lime

Lime 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% lime. 500g soil sample was stabilized or compacted with the different mix proportions of bagasse-lime 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

Total mix (%)	Mix
0	500g natural soil + 0g lime + 0g bagasse ash
4	500g natural soil + 40g lime + 8g bagasse ash
6	500g natural soil + 40g lime + 12g bagasse ash
8	500g natural soil + 40g lime + 16g bagasse ash
10	500g natural soil + 40g lime + 20g bagasse ash
12	500g natural soil + 40g lime + 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 [9]. 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.

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

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.

2.5.2 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 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:

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

2.5.4 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 lime and bagasse ash are plotted to understand the pattern of the trends with respect to the proportions of admixture in the soil.

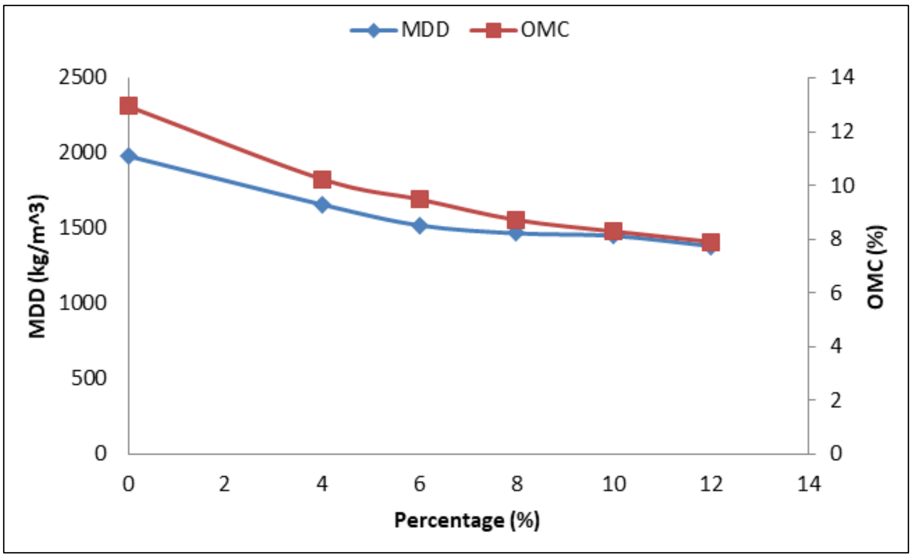

Figure 3: Effect of lime-bagasse composite mixture on MDD and OMC

The result of maximum dry density (MDD) and optimum moisture content (OMC) at various stabilising percentages of bagasse ash with Lime percent is shown in Figure 1. The profile indicates that MDD decreased with increasing percent of bagasse ash in the mixture with Lime. From analysis, the value of MDD for soil with no admixture is 1982kg/m^3, but decreased to 1384kg/m^3 as the content of bagasse ash in the Lime-bagasse composition increased to 12%. Thus, there is significant reduction of MDD between the soil stabilized with and without Lime and bagasse ash admixture.

Similarly, OMC decreased with increasing proportions of bagasse ash in the Lime-bagasse composite mixture. Thus, the value of OMC in the soil without the bagasse-Lime composite was 12.95%, but decreased to 7.91% as the content of bagasse ash in the Lime-bagasse composite increased to 12%. The result shows reduction in OMC between the soil stabilized with and without Lime and bagasse ash admixture.

The findings of this study align with previous studies that have also investigated the effects of lime and ash admixture on soil stabilization. For example, a study by [12] found that the addition of lime and fly ash to soil resulted in a decrease in MDD and OMC. Similarly, another study by [10] reported that the addition of lime and sugarcane bagasse ash to soil resulted in a decrease in MDD and an increase in stiffness.

Additionally, the reduction in MDD observed in this study may be attributed to the pozzolanic reactions that occur between the lime and bagasse ash admixture and the soil particles. This is supported by the findings of a study by [11] which found that the pozzolanic reactions between fly ash and soil particles result in a decrease in MDD.

Overall, the results of this study provide valuable insights into the effects of lime and bagasse ash admixture on the maximum dry density and optimum moisture content of subgrade soil. These findings can be useful in the development of sustainable and cost-effective methods for soil stabilization.

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 lime and bagasse ash are plotted to understand the pattern of the trends with respect to the proportions of admixture in the soil.

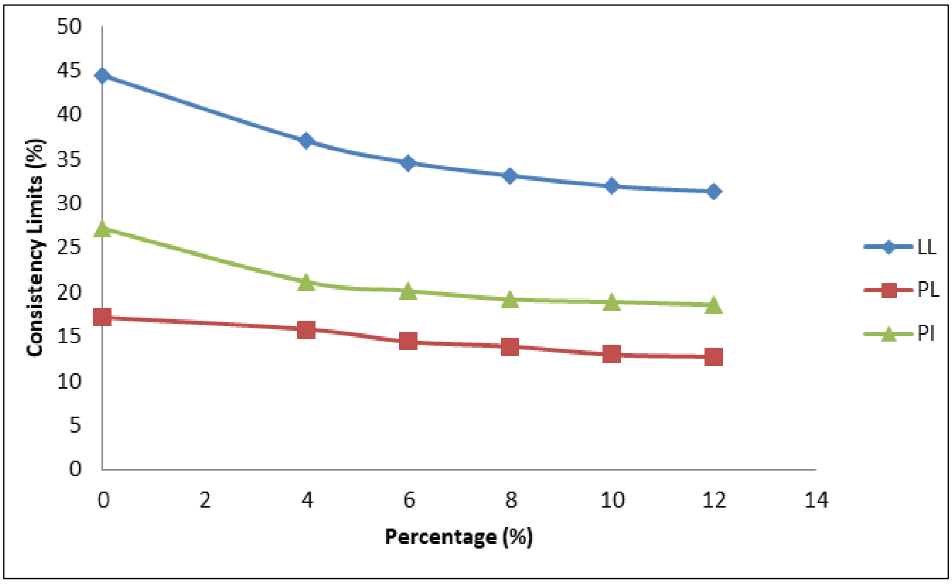

Figure 2: Effect of lime-bagasse composite mixture on consistency limits

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 Lime 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 44.47%, but decreased to 31.40% as the content of bagasse ash in the Lime-bagasse composite increased to 12%. There was reduction in LL between the soil stabilized with and without Lime-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 17.23%, and then decreased to 12.78% as the content of bagasse ash in the Lime-bagasse composite increased to 12%. The increase in PL between the soil stabilized with and without Lime-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 27.24%, which decreased to 18.62% as the content of bagasse ash in the Lime-bagasse composite increased to 12% respectively. Likewise, there was reduction in PI between the soil stabilized with and without Lime-bagasse ash admixture.

The findings on the consistency limits of soil stabilized with lime and bagasse ash in this study are consistent with previous studies that have investigated the effect of bagasse ash on soil properties. For example, a study by [14] reported a decrease in liquid limit, plastic limit and plasticity index of soil stabilized with bagasse ash. Another study by [16] also found that the addition of bagasse ash to soil led to a reduction in liquid limit and plasticity index.

The decrease in consistency limits observed in this study can be attributed to the pozzolanic properties of bagasse ash, which react with lime to produce cementitious compounds that stabilize the soil. This is supported by the findings of a study by [15], which showed that bagasse ash reacts with lime to form compounds such as calcium silicate hydrate, which improves the strength and stability of soil.

Overall, the results of this study suggest that the addition of bagasse ash to lime can effectively improve the consistency limits of subgrade soil. This finding has important implications for sustainable road construction, as bagasse ash is a waste product of the sugar industry and its use as a stabilizer can help reduce the environmental impact of this industry.

3.3 California Bearing Ratio

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

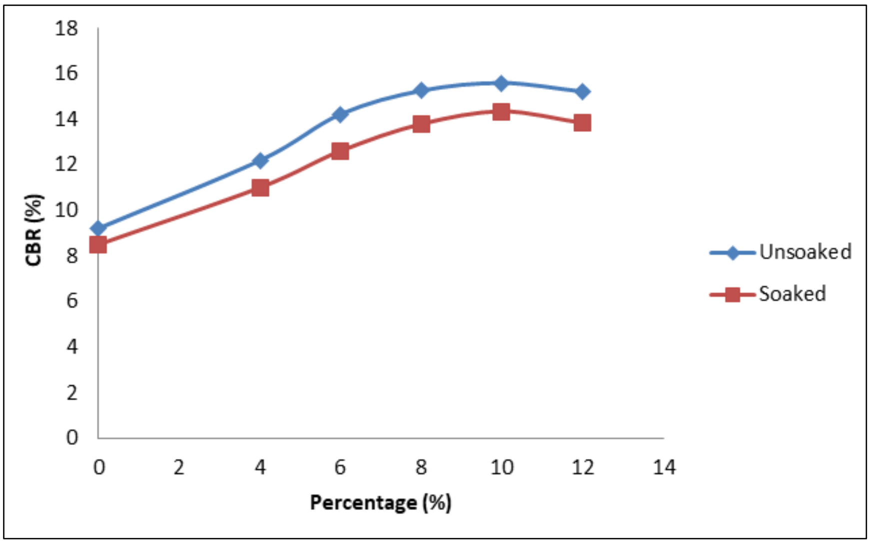

Figure 3: Effect of lime-bagasse composite mixture on CBR

Figure 3 shows the results of California bearing ratio (CBR) of the unsoaked and soaked stabilized soil at various percentages of Lime-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 9.23%, and then increased to a maximum value of 15.61% at 10% bagasse ash. However, the CBR value at 12% bagasse ash is 15.23%.

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 8.52%, and then increased to a maximum value of 14.36% at 10% bagasse ash. It decreased to 13.85% thereafter when 12% bagasse ash was added.

The results of the present study are in line with previous research findings that lime and bagasse ash can be used to improve the California bearing ratio of subgrade soil. For instance, a study by [17] showed that the CBR of lateritic soil stabilized with lime and bagasse ash increased from 3% to 20% with increasing percentages of bagasse ash. In another study, [18] reported that the CBR of black cotton soil stabilized with lime and bagasse ash increased from 2.5% to 12.5% with increasing percentages of bagasse ash. These findings suggest that the use of lime and bagasse ash as stabilizing agents can significantly improve the strength properties of subgrade soils.

3.7 Unconfined Compressive Strength

The unconfined compressive strength obtained from the stabilization of unsoaked and soaked subgrade soil with admixture of lime 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.

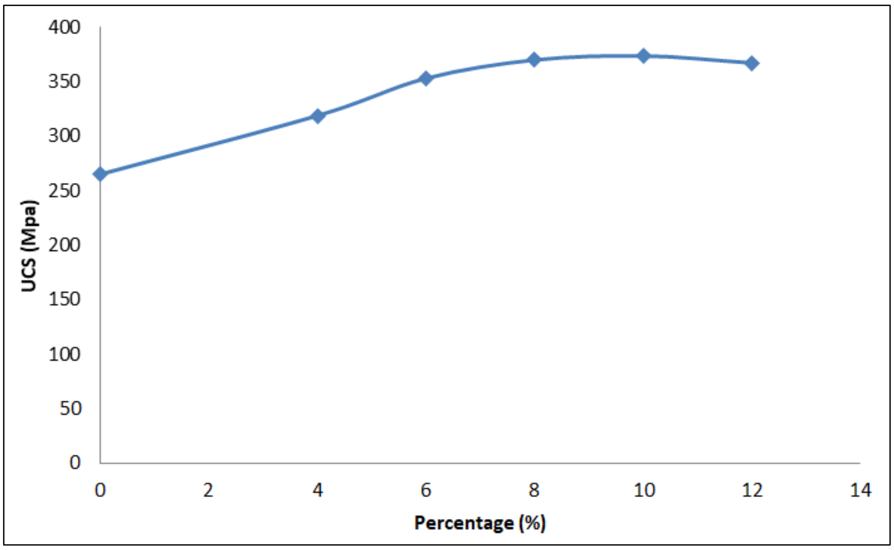

Figure 4: Effect of lime-bagasse composite mixture on UCS

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 Lime-bagasse composite was 265.24MPa, but the addition of bagasse ash and Lime increased to UCS value to a maximum value of 373.79MPa at 10% bagasse ash. The unconfined compressive strength at 10% was obtained 367.35MPa. The increase in unconfined compressive strength of the stabilized subgrade soil with Lime and bagasse ash composite indicated that bagasse ash is a useful admixture to lime in soil stabilization.

The results showed that the unconfined compressive strength of the stabilized soil increased with increasing percentage of bagasse ash in the composite mixture. This finding is in line with previous studies that have shown the beneficial effects of using bagasse ash as a soil stabilizer[19, 20].

The study also found that the maximum value of unconfined compressive strength (373.79 MPa) was obtained at 10% bagasse ash, compared to 265.24 MPa for the stabilized soil without Lime-bagasse composite. The increase in strength observed in the study can be attributed to the pozzolanic nature of bagasse ash, which reacts with the lime to form a cementitious material [23]. This finding is consistent with the results of previous studies that have reported an increase in strength when bagasse ash is used as a stabilizer [20, 21].

However, it is worth noting that the unconfined compressive strength analysis was only studied for 7 days curing. Longer curing periods may result in further improvement of the strength of the stabilized soil [20]. Therefore, future studies could investigate the strength development of the stabilized soil over longer periods to better understand the long-term effectiveness of using bagasse ash as a soil stabilizer.

4. CONCLUSION

The performance of bagasse ash as admixture to lime in soil stabilization improved the properties of the subgrade soil. This study shows that the composite of lime and bagasse ash from *Costus asplundii maas.* 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 lime and bagasse ash composite indicates that bagasse ash is a useful admixture to lime 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% lime recommended as the appropriate mixture proportion in soil stabilization. This study also recommends the use of *Costus asplundii maas.* bagasse ash with lime as stabilizer for soil susceptible to swelling and shrinkage.

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