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Stabilization of Expansive Soil Using Costus adolphi-friderici Loes Fiber with 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 adolphi-friderici Loes*. Expansive soil samples collected along a newly constructed road in Rivers State, Nigeria were prepared and analyzed to investigate the improvement in the soil properties such as maximum dry density (MDD), optimum moisture content (OMC), consistency limits, California bearing ratio (CBR) and unconfined compressive strength (UCS) after being stabilized with bagasse ash, cement and their composite. The results revealed that the initial values of MDD, OMC, liquid limit (LL), plastic limit (PL), plasticity index (PI), California bearing ratio (CBR) and unconfined compressive strength (UCS) of the expansive soil were greatly altered after stabilization with cement, bagasse ash and their composite mixture. There was increase in CBR (unsoaked and soaked soil samples) and UCS with increasing proportion of the bagasse ash, in which the optimum UCS and CBR was recorded at 8% proportion of bagasse ash. This improvement indicates that the bagasse ash alone or with cement, can be used as stabilizing material. Therefore, bagasse ash processed from *Costus adolphi-friderici Loes* is recommended to be used in stabilization of soil for road pavement and load bearing soils.
Keywords: Stabilization, *Costus adolphi-friderici Loes, MDD, OMC, CBR and Consistency Limits*

1. INTRODUCTION
Bagasse is a fibrous residue that remains after crushing the stalks of Bush Sugarcane, and contains short fibers. It consists of water, fibers, and small amounts of soluble solids. Percentage contribution of each of these components varies according to the variety, maturity, method of harvesting, and the efficiency of the crushing plant. When juice is extracted from the cane sugar, the solid waste material is known as bagasse. When this waste is burned it gives ash called as bagasse ash. Manikandan and Moganraj (2014) had found that the combined effect of bagasse

ash and lime were more effective than the effect of bagasse ash alone in controlling the consolidation characteristics of expansive clay along with the improvement in other properties.

Seco *et al.* (2011) studied the stabilization of an expansive clay, consisting of the reduction of its swelling capacity and the improvement of its mechanical capacities by the addition of by-products and waste materials of industrial origin. Of the waste materials, the most notable is the behavior of Rice Husk Fly Ash, highly effective in stabilizing clay from the two aspects considered in this experiment. In another study, Ramakrishna and Pradeep (2006) studied combined effects of RHA and cement on engineering properties of black cotton clay. From strength characteristics point of view they had recommended 8 % cement and 10 % RHA as optimum dose for stabilization.

Sharma *et al*., (2008) investigated the behavior of expansive clay stabilized with lime, calcium chloride and RHA. The optimum percentage of lime and calcium chloride was found to be 4 % and 1% respectively in stabilization of expansive clay without addition of RHA. From UCS and CBR point of view when the clay was mixed with lime or calcium chloride, RHA content of 12 % was found to be the optimum. In expansive clay–RHA mixes, 4% lime and 1% calcium chloride were also found to be optimum.
Goyal *et al*., (2007) reported that SCBA with high specific surface area, high contents of amorphous silica and calcium oxide fulfilled the principal requirements of a pozzolanic material. Ganesan *et al*., (2007) studied on the use of bagasse ash (BA) as partial cement replacement material in respect of cement mortars. Up to 20 % of ordinary Portland cement can be optimally replaced with well-burnt bagasse ash without any adverse effect on the desirable properties of concrete. Several studies have been carried out on the effectiveness of clay stabilization by RHA admixing.

Basha, *et al*., (2005) studied the stabilization of residual clay by chemically using cement and RHA. In general, 6 %, 8 % of cement and 10 %, 15 % RHA show the optimum amount to reduce the plasticity of clay. CBR value determined maximum at 4% cement and 5 % RHA mixtures with clay. According to compressive strength and PI, 6 %, 8% of cement and 15 %, 20 % RHA showed the optimum amount to improve the properties of clay. Studies have shown the effect of reinforcement on swelling behavior of clays (Puppala and Musenda, 2000); reduction of soil swell potential with fibre reinforcement (Loher *et al*. 2000), and effect of fibres on swelling characteristics of bentonite (Banu *et al*., 2009).

Natural fibres have been used to reduce shrinkage cracks in clayey soils without the least environmental nuisances and at almost low performance costs (Sivakumar and Babu, 2008). They are obtained from the waste of palm fruits and have acceptable mechanical properties and durability in natural conditions (Marandi *et al.*, 2006; Zare, 2008).

Gandhi (2012) successfully worked on improving the existing poor and expansive sub grade clay using bagasse ash. Bagasse ash effectively dries wet clay and provides an initial rapid strength gain, which is useful during construction in wet, unstable ground conditions. The swell potential of expansive clay decreases by replacing some of the volume previously held by order to evaluate the possibility of their use in the industry. He conducted tests like Liquid Limit, Plastic Limit, Plasticity Index, Shrinkage Limit, Free Swell Index and Swelling Pressure with the increasing percentage of Bagasse ash at 0 %, 3 %, 5 %, 7 % and 10 % respectively .He found out that as the percentage of bagasse ash increases in the clay sample, all the properties decrease. This study investigated the performance of composite mixture of cement and bagasse ash obtained from *Costus adolphi-friderici Loes* as stabilization agent for soil improvement.

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 Etche road in Etche 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 adolphi-friderici Loes was collected from the bush and transported to the laboratory for further processing. The collected *Costus adolphi-friderici Loes* 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 4, 6, 8, 10 and 12% by weight of the soil. Each of the weight percent was mixed with 500g of clay soil. Similarly, the cement was divided into portions at 4, 6, 8, 10 and 12% by weight of the soil and mixed separately with 500g of the clay soil. Another set of mixed containing 40% bagasse ash and 60% cement were prepared and mixed with the clay soil. The weight percent of the combined composite of cement and bagasse ash were prepared at 4, 6, 8, 10 and 12% of soil weight. The mix design is shown in Table 1.

Table 1: Mix design of soil stabilization

Total mix (%)	**Group I Mix: Bagasse only**
0	500g natural soil + 0g bagasse ash
4	500g natural soil + 20g bagasse ash
6	500g natural soil + 30g bagasse ash
8	500g natural soil + 40g bagasse ash
10	500g natural soil + 50g bagasse ash
12	500g natural soil + 60g bagasse ash
	Group II Mix: Cement only
0	500g natural soil + 0g cement
4	500g natural soil + 20g cement
6	500g natural soil + 30g cement
8	500g natural soil + 40g cement
10	500g natural soil + 50g cement
12	500g natural soil + 60g cement
	Group III Mix: 60% Cement and 40% Bagasse ash
0	500g natural soil + 0g cement + 0g bagasse ash
4	500g natural soil + 12g cement + 8g bagasse ash
6	500g natural soil + 18g cement + 12g bagasse ash

8	500g natural soil + 24g cement + 16g bagasse ash
10	500g natural soil + 30g cement+ 20g bagasse ash
12	500g natural soil + 36g 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.

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

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:

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

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 for various mix design are discussed as outlined.

3.1 Maximum dry density and optimum moisture content

Table 2: Maximum dry density and optimum moisture content of soil-stabilization material options

	MDD (kg/m^3)			**OMC (%)**		
Percentage (%)	Cement	Bagasse	Composite	Cement	Bagasse	Composite
0	2211.88	2211.88	2211.88	14.46	14.46	14.46
4	2037.64	1880.34	1974.72	13	11.1	12.24
6	1975.93	1773.86	1895.10	12.02	10.3	11.33
8	1926.32	1738.77	1851.30	11.35	9.47	10.60
10	1896.07	1712.15	1822.50	10.64	9.01	9.99

12	1840.41	1661.33	1768.78	10.06	8.6	9.48

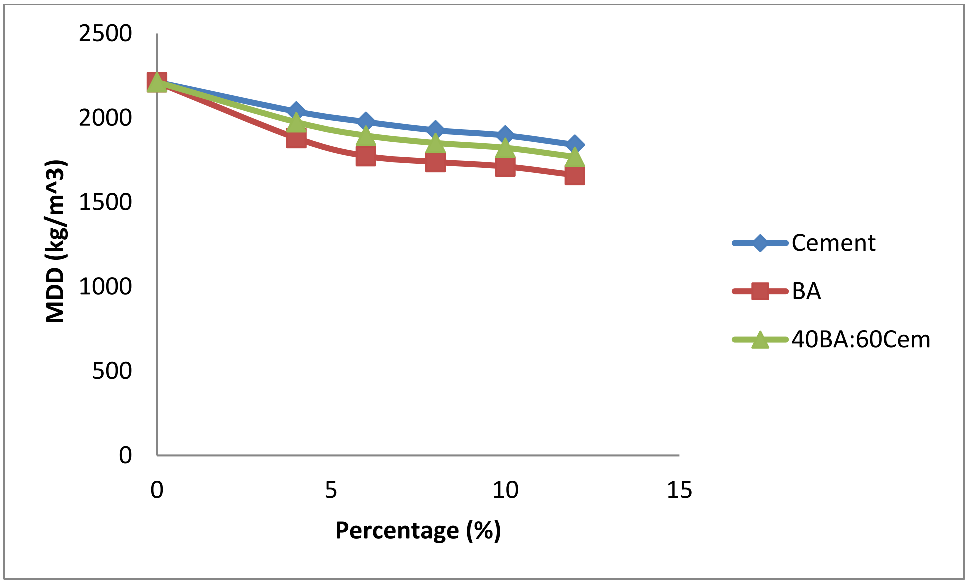

Figure 1: Variation of MDD under different stabilizing agents

Figure 1 shows the variation in maximum dry density (MDD) of stabilized subgrade soil at various percentages of bagasse ash, cement and their composite of cement. The profiles indicate that MDD decreased with increasing percent of bagasse ash, cement and the composite of stabilizing agents. As presented in Table 2, the MDD of the 0% stabilized soil is recorded as 2212kg/m^3, while it decreased to 1840kg/m^3 at 12% cement, 1661kg/m^3 at 12% bagasse ash and 1769kg/m^3 at 12% combination of cement and bagasse ash (composite). The results showed that the sample stabilized with bagasse ash only reduced the soil density more than the composite mixture and least in the sample stabilized with cement only.

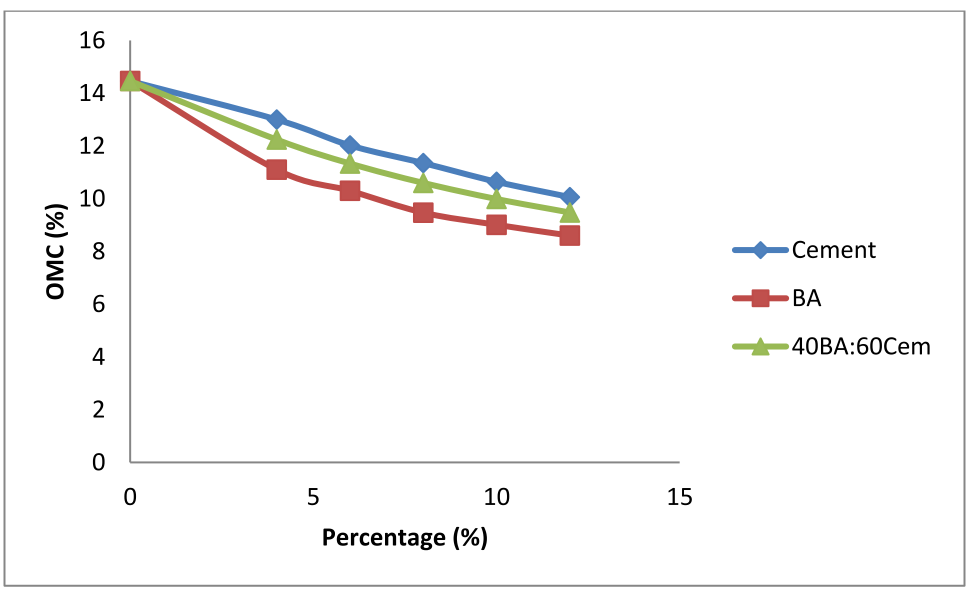

Figure 2: Variation of OMC under different stabilizing agents

Figure 2 shows the variation in optimum moisture content (OMC) of stabilized subgrade soil at various percentages of bagasse ash, cement and their composite of cement. Like MDD, the OMC of the stabilized soil decreased with increasing percent of bagasse ash, cement and the composite mixture. As presented in Table 2, the OMC of the 0% stabilized soil was recorded as 14.46%. However, at 4% proportion of the stabilizing agents, the OMC of the soil was 13.00% for cement, 11.10% for bagasse ash and 12.24 for the composite, which decreased to 10.06% at 12% cement, 8.60% at 12% bagasse ash and 9.48% at 12% combination of cement and bagasse ash. All the stabilizing agents lowered the soil moisture content effectively, but the OMC of the soil sample stabilized with bagasse ash only was the lowest followed by the composite mixture and highest in the sample stabilized with cement only.

3.3 Consistency limits

Table 3: Consistency limits of soil-stabilization material options

Percentage (%)	**Liquid Limit (%)**			**Plastic Limit (%)**			**Plasticity Index (%)**		
	Cement	Bagasse	Composite	Cement	Bagasse	Composite	Cement	Bagasse	Composite
0	49.62	49.62	49.62	19.23	19.23	19.23	30.39	30.39	30.39
4	47.29	44.5	46.17	18.55	17.12	17.98	28.74	27.38	28.2
6	45.33	40.55	43.42	17.97	15.8	17.10	27.36	24.75	26.316
8	43.38	37.72	41.12	17.27	15.05	16.38	26.11	22.67	24.734
10	41.85	35.32	39.24	16.11	14.7	15.55	25.74	20.62	23.692
12	41.06	35.25	38.74	14.92	14.3	14.67	26.14	20.95	24.064

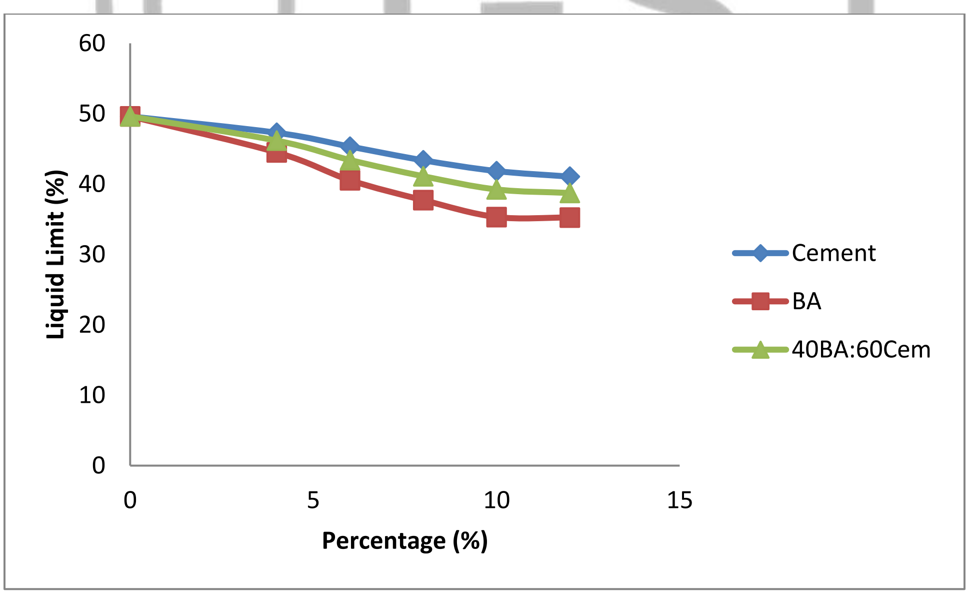

Figure 3: Variation of liquid limit under different stabilizing agents

Figure 3 shows the variation in liquid limit (LL) of stabilized subgrade soil at various percentages of bagasse ash, cement and their composite of cement. The LL of the stabilized soil decreased with increasing percent of bagasse ash, cement and the composite mixture. The LL of the 0% stabilized soil was recorded as 49.62% (Table 3). However, at 4% proportion of the stabilizing agents, the LL reduced to 47.29% for cement, 44.50% for bagasse ash and 46.17 for the composite, and then decreased further to 41.06% at 12% cement, 35.25% at 12% bagasse ash and 38.74% at 12%

combination of cement and bagasse ash. Comparatively, the LL was most reduced in soil sample stabilized with bagasse ash only followed by the composite mixture and least in the sample stabilized with cement only.

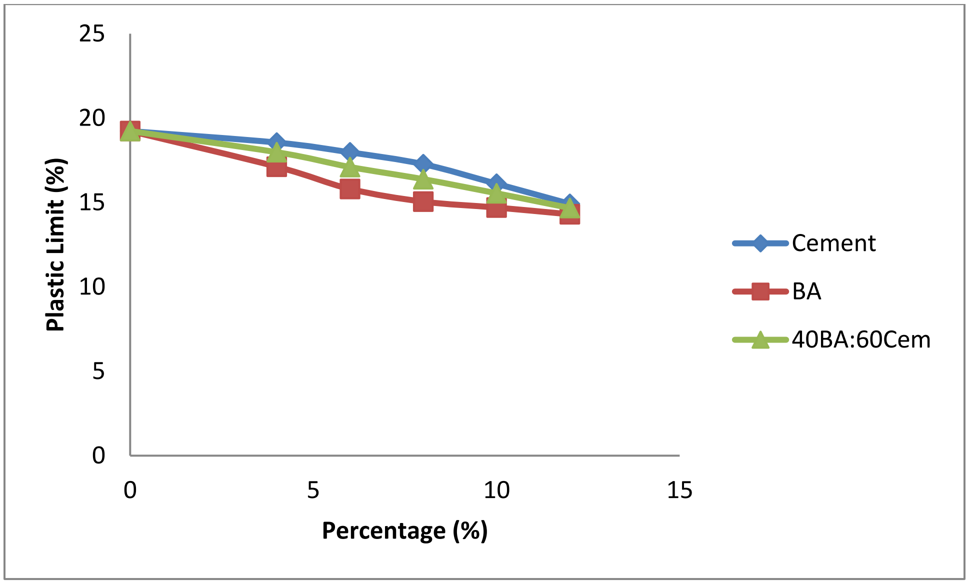

Figure 4: Variation of plastic limit under different stabilizing agents

Figure 4 shows the variation in plastic limit (PL) of stabilized subgrade soil at various percentages of bagasse ash, cement and their composite of cement. The PL of the stabilized soil decreased with increasing percent of bagasse ash, cement and the composite mixture. The PL of the 0% stabilized soil was recorded as 19.23%. At 4% proportion of the stabilizing agents, the PL reduced to 18.55% for cement, 17.12% for bagasse ash and 17.98 for the composite, and then decreased further to 14.92% at 12% cement, 14.30% at 12% bagasse ash and 14.67% at 12% combination of cement and bagasse ash. On comparison, the PL reduced most in soil sample stabilized with bagasse ash only followed by the composite mixture and least in the sample stabilized with cement only.

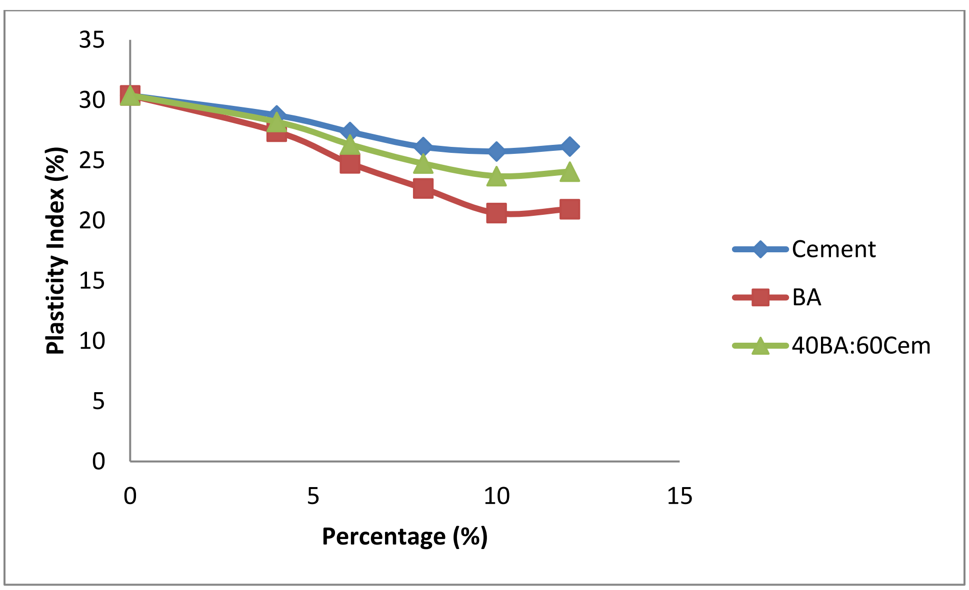

Figure 5: Variation of plasticity index under different stabilizing agents

Figure 5 shows the variation in plasticity index (PI) of stabilized subgrade soil at various percentages of bagasse ash, cement and their composite of cement. The PL of the stabilized soil decreased with increasing percent of bagasse ash, cement and the composite mixture. The PI of the 0% stabilized soil was recorded as 30.39%, while at 4% proportion of the stabilizing agents, the PI reduced to 28.74% for cement, 27.38% for bagasse ash and 28.20 for the composite mixture, and then continued to decrease further to the least values at 10% proportion of the various stabilizing agents. Between 10% and 12% mix proportions, the PI increased slightly from 25.74% to 26.14% for cement, 20.62% to 20.95% for bagasse ash and 23.69% to 24.06% for the composite mixture (see Table 3). Again, the PI reduced most in soil sample stabilized with bagasse ash only followed by the composite mixture and least in the sample stabilized with cement only.

3.6 California Bearing Ratio

Table 4: CBR of soil-stabilization material options

Percentage (%)	**Unsoaked CBR (%)**			**Soaked CBR (%)**		
	Cement	Bagasse	Composite	Cement	Bagasse	Composite
0	10.3	10.3	10.30	9.51	9.51	9.51
4	14.9	11.7	13.62	14.11	10.55	12.69
6	17.57	13.82	16.07	17.15	13.1	15.53
8	19.06	14.96	17.42	17.97	14.27	16.49
10	18.32	15.11	17.04	17.11	13.99	15.86
12	17.01	14.71	16.09	16.6	13.52	15.37

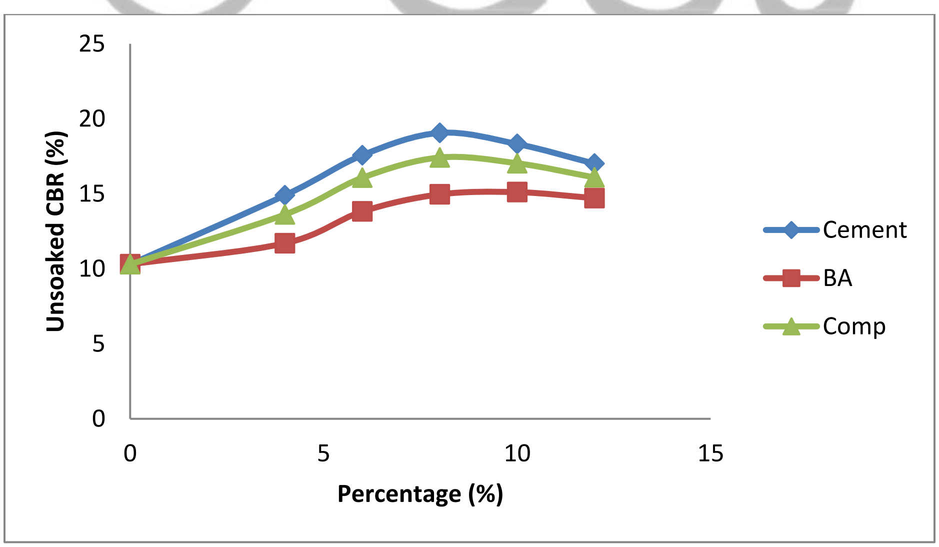

Figure 6: Variation of unsoaked soil CBR under different stabilizing agents

Figure 6 shows the variation in California bearing ratio (CBR) of the unsoaked stabilized soil at various percentages of bagasse ash, cement and their composite of cement. The CBR of the unsoaked stabilized soil increased with increasing percent of bagasse ash, cement and the composite mixture to a maximum value at 8% for cement and the composite mixture, while for bagasse ash, the maximum value CBR was observed at 10%. Thereafter, the CBR of the unsoaked soil decreased with increasing percentages of the stabilizing agents. Thus, the CBR of the unsoaked stabilized natural soil evaluated as 10.30%, increased to a maximum values of 19.06% for cement stabilized soil, 15.11% for bagasse ash stabilized soil and 17.42% for the cement-bagasse composite stabilized soil (see Table 4). The CBR of the unsoaked stabilized soil increased most in soil sample stabilized with cement only followed by the composite mixture and least in the sample stabilized with bagasse ash only. Since increase in CBR signifies an improvement in soil properties, it followed that the soil stabilized with cement has better performance than both the composite and bagasse ash alone.

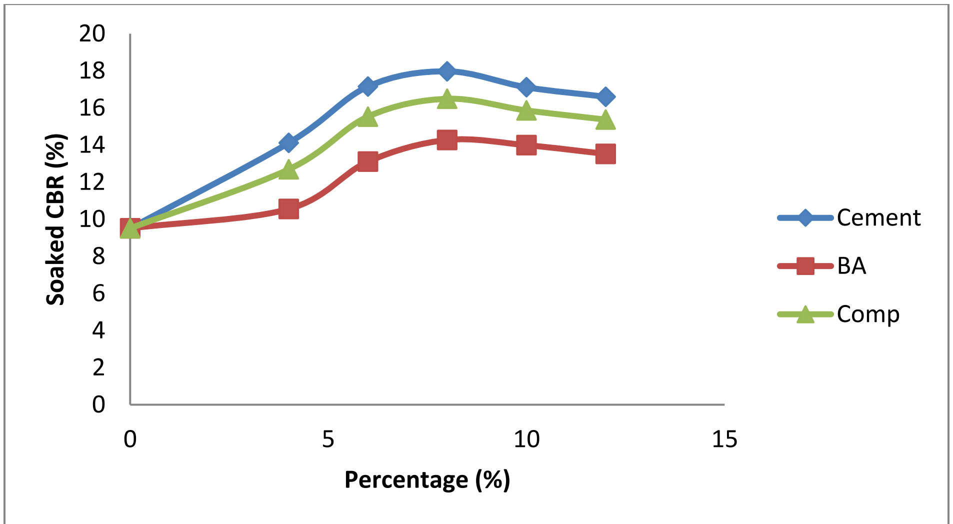

Figure 7: Variation of soaked soil CBR under different stabilizing agents

Figure 7 shows the variation in California bearing ratio (CBR) of the soaked stabilized soil at various percentages of bagasse ash, cement and their composite of cement. The CBR of the soaked stabilized soil increased with increasing percent of bagasse ash, cement and the composite mixture to a maximum value at 8% for cement, bagasse ash and the composite mixture. The CBR of the soaked soil decreases at 10% and 12% of the stabilizing agents. The CBR of the soaked stabilized soil was evaluated as 9.51%, which increased to a maximum values of 17.97% for cement stabilized soil, 14.27% for bagasse ash stabilized soil and 16.49% for the cement-bagasse composite stabilized soil (see Table 4). The highest increase of CBR for the soaked soil samples was in the soil sample stabilized with cement only, followed by the composite mixture and least in the sample stabilized with bagasse ash only. Generally, the results of the CBR confirmed that soil stabilized with cement performed slightly better than both the soil samples stabilized with the composite mixture and bagasse ash alone. Moreover, the CBR soaked soil samples is less than that of the unsoaked. Hence, the presence of water in road pavement will be more affected than in dry condition.

3.7 Unconfined Compressive Strength

The unconfined compressive strength (UCS) results of the stabilized soil were determined via curing at 7 days. The result is shown in Table 5.

Table 5: UCS of soil-stabilization material options

Percentage (%)	Cement	Bagasse	Composite
0	226.02	226.02	226.02
4	285.45	238.91	266.83
6	316.02	270.53	297.82

8	334.44	285.52	314.87
10	331.07	279.69	310.52
12	328.7	274.46	307.00

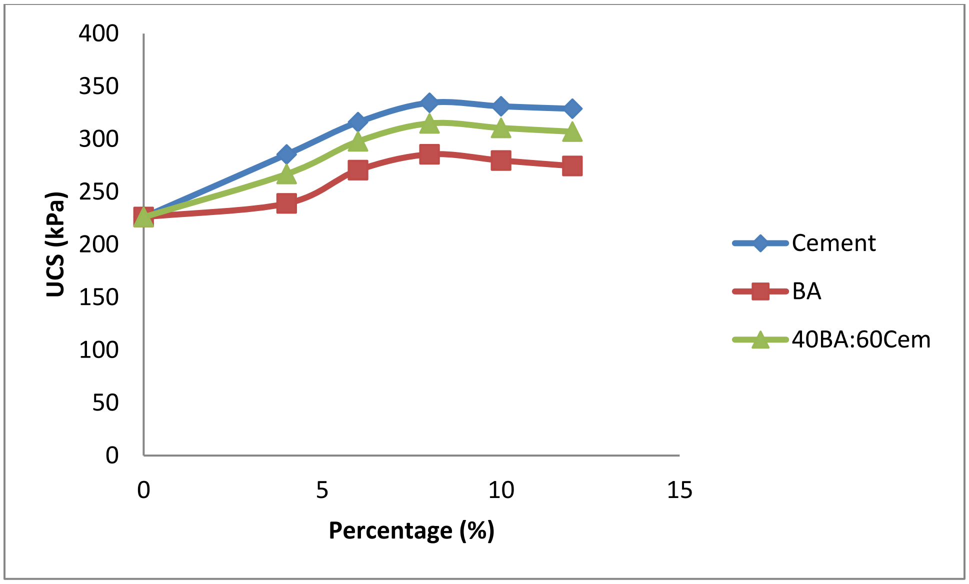

Figure 8: Variation of UCS under different stabilizing agents

Figure 8 shows the variation in unconfined compressive strength (UCS) of the stabilized soil at various percentages of bagasse ash, cement and their composite of cement. Like CBR, the maximum unconfined compressive strength of the stabilized soil increases with increasing percent of bagasse ash, cement and their composite mixture and was maximum at 8% proportions of cement, bagasse ash and the composite mixture. From 10% to 12% of the stabilizing agents, UCS value decreases. The UCS of the 0% stabilized soil was 226.02MPa, which increased to a maximum value of 334.44MPa for cement stabilized soil, 285.52MPa for bagasse ash stabilized soil and 314.87MPa for the cement-bagasse composite stabilized soil (see Table 5). The highest increase of UCS was in the soil sample stabilized with cement only, followed by the composite mixture and least in the sample stabilized with bagasse ash only. Generally, increase in soil compressive strength indicates the capability of soil to bear imposed load. Hence, UCS values confirmed again, that the soil stabilized with cement performed better than the soil samples stabilized with the composite mixture and bagasse ash alone. However, the improvement of of the stabilized subgrade soil with bagasse ash, cement or their composite, showed that bagasse ash alone, or its combination with cement, is an effective additive for soil stabilization, which will be suitable for road pavement and load bearing soil.

4. CONCLUSION

The addition of cement, bagasse ash as stabilizing agent in expansive soil shows great improvement in the soil properties. Maximum dry density (MDD) and optimum moisture content of the soil reduces after the adding cement, bagasse ash and their composite in the expansive soil. The constancy limits of the soil was also improved by these stabilizing agents. The California bearing ratio and unconfined compressive strength of the subgrade soil also increased, which is an indication of strength to withstand any imposed load. The study showed that the soil stabilized with cement improved the soil strength and CBR in comparison to the soil samples stabilized with bagasse ash alone and the composite mixture. Despite the variation in performance, there was good improvement in the stabilized subgrade soil using bagasse ash, cement or their composite. Therefore, cement, bagasse ash as single, or their combination can be effectively use for soil stabilization, particularly for road pavement and load bearing soil. The study also established that the optimum performance of stabilizing materials occurred at 8% proportion. Therefore, 8% of bagasse ash processed from *Costus adolphi-friderici Loes* with, cement or their composites, is recommended to be used during soil stabilization.

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