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LABORATORY INVESTIGATION OF ENGINEERING USE OF BAGASSE ASH

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ABSTRACT

Bagasse ash (burnt residue from the extraction of juice from sugar cane) is evaluated for use as a stabilizer for an expansive soil, (i.e. black cotton soil). The laboratory study consists of the following tests conducted on soil – bagasse ash mixtures compacted at the British Standard Light (BSL) compactive effort: moisture – density relationships, unconfined compressive strength (UCS), California bearing ratio (CBR) and durability by immersion in water. On stabilizing the black cotton soil with a maximum 12% bagasse by weight of dry soil, peak UCS values of 229, 240, and 286 kN/m^2 were recorded at 7, 14 and 28 days curing periods, respectively, with 10 % bagasse ash content, which is the amount of bagasse ash required for optimal improvement in the UCS of the soil. A peak CBR value of 8 % for the soil – bagasse ash mixture were recorded at 10 % bagasse ash content. The results obtained indicate that for the soil – bagasse ash mixture optimal improvement in strength properties were achieved at 10 % bagasse ash content.

INTRODUCTION

Black cotton soil or tropical black clay is an expansive soil characterized by excessive volume changes, expansive tendencies and low bearing capacities when wet [1, 2, and 3]. The properties of black cotton soil affect the performance of pavements built over such formations. This is because the index properties of these soils indicate a classification that shows inadequacy for use and does not meet the minimum design requirements for sub-grade material. In the north eastern part of Nigeria where these soils are predominant or wherever they occur, they cover an extensive area that avoiding them or finding a suitable replacement is not feasible. As a means of improving the geotechnical properties of black cotton soils lime, cement and admixture stabilization have been used to treat the deficient soil [4, 5, 6, 7, and 8]. Although the properties of this soil are appreciably improved, the cost of incorporating the conventional stabilizers is quite high. This high cost implication has aroused the thinking of research engineers to focus more on the use of potentially cost effective materials that are locally available to improve the properties of deficient soils [8, 9, 10 and 11].

For black cotton soil to be used as a sub-grade material there is need to improve its geotechnical properties. There are several methods for improving the properties of deficient soils; the most common being soil stabilization. Soil stabilization has been used in the construction of roads and aircraft runways, earth dams and embankments, in erosion control [12]. Various stabilizers have been used to stabilize or improve the geotechnical properties of sub-grade soils and the commonest stabilizers used for this purpose in Nigeria are cement, lime and bitumen [6, 9, 13, and 14]. But these materials have become so costly that inadequate quantities are applied than are required, hence defeating the aim. It is in this light that locally available and agricultural waste or industrial waste is sought for use as a replacement or supplement to costly imports .The aim of this study is to evaluate the use of bagasse ash for the improvement of the geotechnical properties of black cotton soil when used as subgrade in road construction. If this is realized it will serve as a "disposal" technique for sugar producing factories.

Bagasse Ash

Bagasse is a residue obtained after the extraction of sugar juice from sugar cane at sugar processing mills. Mohamedbhai and Baguant [15] reported that bagasse ash contains a large quantity of silica and other relevant oxides, such as alumina, and iron oxides which enhance good pozzolanic activity. However, Smith [16] stated that the main reasons why agricultural waste pozzolana (e.g. bagasse ash) have poor pozzolanic activity is due to over burning into the temperature range that favors the development of crystalline (less reactive) rather than the amorphous (more reactive) particles. This is probably the reason for the poor pozzolanic activity of factory produced sugar cane bagasse ash. The oxide compositions of bagasse ash from various countries are summarized in Table I. Bagasse ash is therefore a potential stabilizer since it contains important compounds that produce cementation as in cement. It is crucial to state here that the rate of strength gain of bagasse ash (pozzolana) is very much slower than that of Portland cement.

The utilization of bagasse ash for soil stabilization will lead to demand for more resources (i.e. sugar plantations) and possibly more sugar manufacturing industries that will generate larger bagasse ash into the environment as wastes. The natural environment is the "sink" for the waste and again the "source" for the resources. The recycling of these wastes will lead to a better environment and an improved economy as illustrated in Fig. 1.

LOCATION AND GEOLOGY OF SOIL SAMPLE

The soil sample used in this study was collected along Numan – Ngurore Road, Lamurde Local Government Area of Adamawa State as a disturbed sample obtained at a depth of 0.85 metres from the ground surface in order to avoid organic matter. Numan – Ngurore is situated between lat. 12° 15', long. 9° 30' and lat. 12° 10', long. 9° 25' lat. The precise borrow pit location is at 0195745N and 1029614 E UTM, obtained in Global Positioning System (GPS) using GARMIN 45 as shown in Fig. 2. The soil is expansive in nature and was classified as A-7-6 in the AASHTO soil classification system and CH in the Unified Soil Classification System (USCS). The index properties and oxide composition of the natural soil are summarized in Tables II and III, respectively. The geology of the black cotton soils of the north eastern Nigeria is shown in Fig. 3. From extensive research works done on soil in this area, the predominant clay mineral is montmorillonite [4, 6 and 16].

Table I: Oxide Compositions of Bagasse Ash from Various Countries

Oxides									
Countries	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	P_2O_5	MnO
Java*	73.5	7.6	2.7	3.0	2.6	7.1		1.7	-
India*	71.0	1.9	7.8	3.4	0.3	8.2	3.4	-	0.2
Southfrica*	82.5	0.5	2.4	4.0	3.5	4.6	-	2.1	0.3
Philipines*	76.8	24.0		4.3	5.1	8.3	-	-	0.1
Hawaii*	56.1	2.2	6.5	5.6	4.6	13.4	1.7	-	0.3
Mauritius*	71.4	1.6	1.9	4.3	3.8	11.0	0.8	3.4	-
Egypt*	65.8	-	0.9	8.2	2.5	10.7	3.3	-	-
Mauritius**	74.2	12.12	12.12	3.93	0.32	1.67	0.36	5.58	0.07
Nigeria***	43.32	2.67	1.17	10.01	1.85	17.41	0.04	-	-

* [19] ** [15] ***[20]

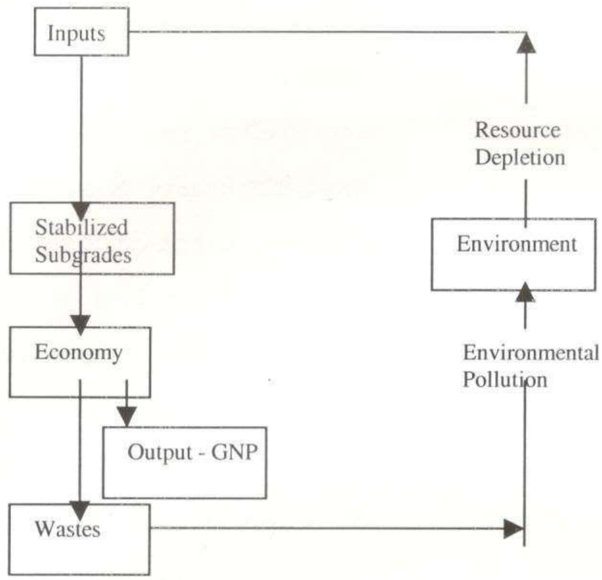

Fig. 1. The economic development process in its environmental context (Adapted from [18]: modified

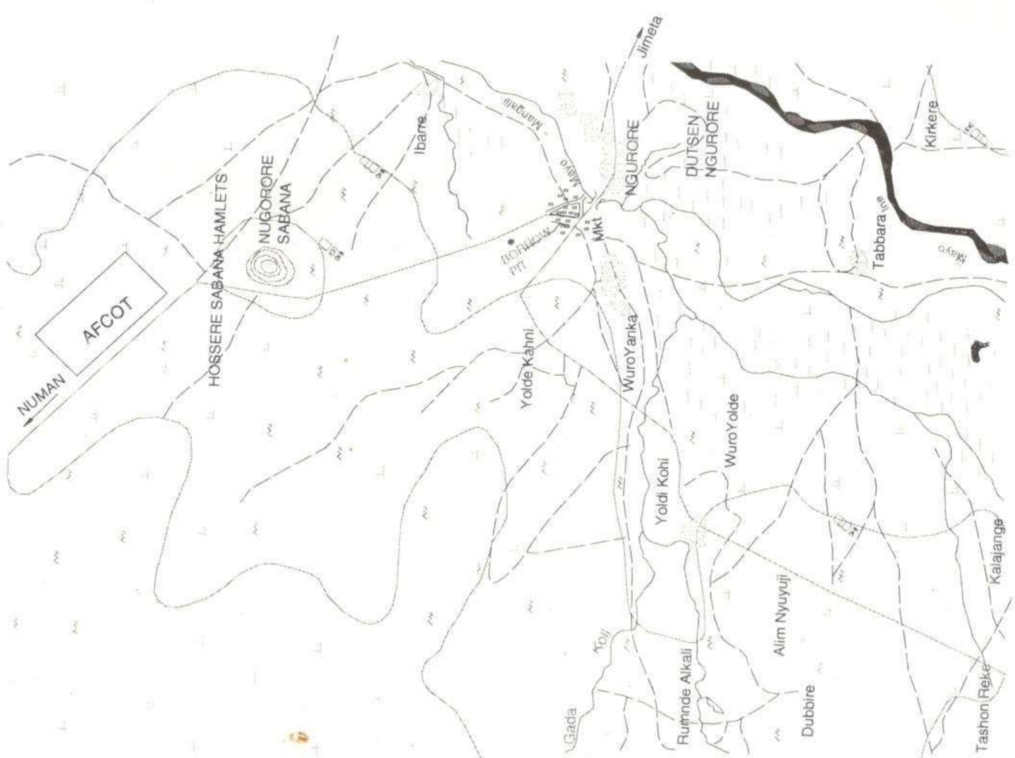

Fig. 2: Topographical Map of Ngurore showing Borrow pit of Black Cotton Soil in Global Positioning System

Table II Index Properties of the Natural Soil

Property	Quantities
Natural moisture content, %	8
Percentage passing BS Sieve No. 200	71
Liquid Limit, %	52
Plastic Limit, %	15
Plasticity Index, %	37
Linear shrinkage, %	15
AASHTO Classification	A-7-6
Group Index	13
Unified Soil Classification System (USCS)	CH
Maximum Dry Density (MDD), Mg/m^3	1.75
Optimum Moisture Content, (OMC) %	18.4
Unconfined Compressive Strength (UCS), kN/m^2	120
California bearing ratio (CBR), %	3
Specific Gravity	2.37
Swelling Pressure, N/mm^2	55.6
pH	7.7
Colour	Dark grey

Table III Detectable Oxide Compostion of the Natural Black Cotton Soil

Oxide	Concentration by weight (%)
CaO	-
SiO_2	31.01
Fe_2O_3	4.74
Al_2O_3	16.19
MnO	0.13
TiO_2	1.34

CEMENT RATING OF BAGASSE ASH

The cementing characteristic of bagasse ash is dependent on its chemical/oxide composition. It is evident from Table IV, that except for the calcium oxide (CaO), which is very low in the bagasse ash, it could be a good cementing agent. The basic chemistry of hydrated cement paste shows that the silicates, tricalcium silicate (C_3S) and dicalcium silicate (C_2S) are the most important compounds which are responsible for strength gain. However, due to the low calcium content of bagasse ash, these cementitious compounds are non-existent. The presence of tricalcium aluminate (C_3A) in the cement though undesirable is about 1/6th the quantity in bagasse ash. From earlier work carried out, it was observed that the presence of tricalcium aluminate (C_3A) does not contribute to the strength gain at early ages and it reacts with sulphates to form the expansive compound calcium sulphoaluminate (enttrigite) responsible for the so called "sulphate attack" or "sulphate-induced heaving" [10]. The tetracalcium silicate does not contribute to strength gain. The calculated compound composition of bagasse ash and a typical ordinary Portland cement used for comparism based on Bogue's equation [21] are summarized in Table V.

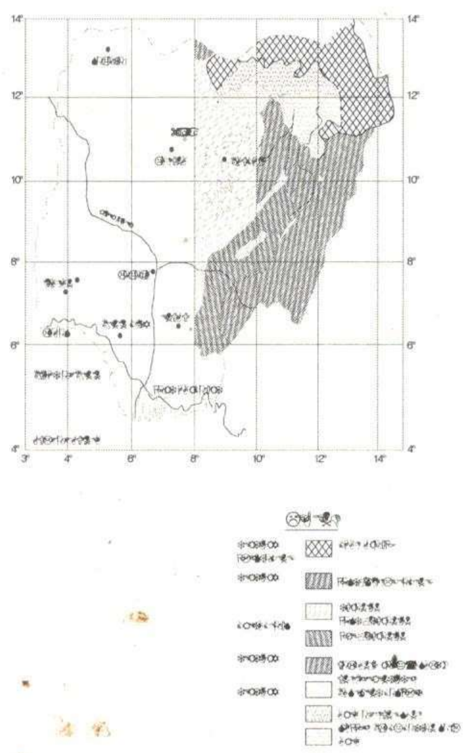

Table IV Oxide Composition of Bagasse ash and Ordinary Portland Cement

Oxide	*Bagasse ash (%)	**Cement (OPC) (%)
CaO	3.23	63
SiO_2	57.12	20
Al_2O_3	29.73	6
Fe_2O_3	2.75	3
Mn_2O_3	0.11	-
$Na_2O + K_2O$	-	1
K_2O	8.72	-
SO_3	0.02	2
TiO_2	1.10	-
Loss on ignition	17.57	2

* [22] ** After [23]

Table V Calculated Compound Composition of Bagasse ash and typical Ordinary Portland Cement

Compound	Content (%)	
	Bagasse ash	Portland cement
C_3S	-	54.1
C_2S	-	16.6
C_3A	74.13	10.8
C_4AF	8.36	9.1

METHODS OF TESTING

Preparation of Test Specimens

Remoulded sample

The soil first air dried, pulverized and passed through sieve size 4.75 mm in order to remove the clods in the soil as specified [24]. The exact quantity of dry soil required to make a sample of definite height in the mould at its required density was calculated and the corresponding weight of the soil is taken in a basin. The soil was mixed thoroughly at stepped percentages of the stabilizer and then compacted in the mould with the aid of a 2.5 kg compaction rammer falling through 300 mm, providing the British Standard Light (BSL) compaction energy.

Potential Volume Change

The potential volume change test was`carried in accordance with the procedure outlined in [2 and 25]. The potential volume change test apparatus consists of a device by which the

The water bath containing the mould is placed on the base of the framework. A plunger piece is placed on the top porous stone and then attached to the proving ring which is adjusted so that it comes in contact with the plunger piece. Pressure exerted by the soil sample is transmitted to the proving ring, the deflection of which is recorded in the dial gauge. The relationship between load and the deflection of the proving ring is determined by calibration and therefore, the applied pressure due to swelling is determined.

Moisture – Density Relationships

Moisture density relationships were determined using soil samples air-dried for one day. Compaction of natural and treated soil were at the energy of the BSL (BSL) in accordance with the procedures outlined in [26 and 27], respectively. The BSL compactive effort was used because this is easily achieved in the field.

Strength Tests

Unconfined Compressive Strength

The black cotton soil with and without the stabilizer was compacted into the unconfined compressive strength moulds with dimensions 70 x 70 x 70 cm^3. Each cube was produced by using predetermined weights of soil obtained from the density – volume relationship and at different moisture contents and different percentages of the stabilizer. The pulverized natural soil or treated soil was thoroughly mixed with water at the optimum moisture content and compacted into the mould with the BSL compactive effort. The compacted samples were carefully removed from the moulds, placed in sealed transparent plastic bags and cured for 7, 14, and 28 days respectively. The strength of the cured samples were determined by placing them on platens of a universal testing machine and crushed to failure.

California bearing ratio

The California bearing ratio (CBR) test was carried out as a measure of strength of the natural and the stabilized soils in conformity with [26, 27 and 28]. Predetermined weights of the soil sample with or without the stabilizer were placed into the 2360 cm^3 mould and compacted at the optimum moisture content (OMC) and at the BSL compactive effort. The soil samples were compacted in three (3) layers each receiving 62 blows from the 2.5 kg rammer. The specimens were cured for six (6) days and then later soaked in water for 24 hours before testing in accordance with the specification given in [28]. The plunger was then made to penetrate the specimen at a uniform rate. The dial reading indicating, force were taken each at 0.25 mm interval of penetration until the maximum of 7.50 mm was attained or alternatively until failure was reached. The bottom of the specimens was also tested in like manner.

DISCUSSION OF TEST RESULTS

Unconfined Compressive Strength

For the BSL compactive effort at 7 days curing period, it is observed from Fig.4 that the UCS of the stabilized soil increased from 120.21 kN/m^2 for the natural soil to a peak value of 228.98 kN/m^2 at 10% bagasse ash content. Higher bagasse ash content led to a reduction in UCS to a value of 114 kN/m^2 at 12% bagasse ash content. Early increases in UCS values observed between 2% and 4% bagasse ash content can be attributed to ion exchange at the surface of clay particles as the Ca^{2+} in the stabilizer reacted with the lower valence metallic ions in the clay microstructure which resulted in agglomeration and flocculation of the clay particles. The reduction in UCS at the 6% bagasse ash content was probably due to excess of lower valence cations that could not be neutralized with the available higher valence cations. This reaction increased the affinity for H^+ that caused a reduction in UCS to a minimum value of 103.04kN/m^2, less than the UCS of the unstabilized soil sample. With increase in bagasse ash content the amount of cations increased and were able to balance the net negative disequilibrium or in other words caused a reduction in the zeta potential of the clay minerals and bagasse ash mixture; that resulted in a reduction in the affinity for H^+ [29]. This consequently led to the increase in UCS to the maximum value of 228.98 kN/m^2 at 10% stabilizer content, which is about twice the UCS value of the unstabilized soil sample. The variation of UCS with bagasse ash content for the 14 days cured specimens is also depicted in Fig.4. The UCS for the natural soil specimen comparatively increased from 120.21kN/m^2 at 7 days curing period to 206.08 kN/m^2 at the 14 days curing period. The reason for the low increment in UCS was probably due to the formation of very weak bonds between the soil particles and the available water molecules. When all the water was used up, there was a gradual depletion of water molecules that consequently led to a reduction in UCS. However, the increase in strength could also be attributed to the presence of the iron oxide (goethite) which dehydrated with time to yield higher strength in agreement with [30, 31 and 32]. Peak UCS value of 228.98 kN/m^2 was recorded at 10% bagasse ash content. Further addition of bagasse ash caused a reduction in UCS. The variation of UCS with bagasse ash content at 28 day curing period is also illustrated in Fig.4. The UCS of the natural soil is 194.63 kN/m^2 which is comparatively lower than the UCS value of the natural soil sample cured for 14 days. The reason for the reduction in UCS is attributable to variability in the composition of soil specimen. At the 10% bagasse ash content peak UCS value of 286.22 kN/m^2 was recorded. Generally, there was marked increase in UCS values with curing periods as expected. The gain in strength of specimens with age is

Generally, there was marked increase in UCS values with curing periods as expected. The gain in strength of specimens with age is shown in Fig.4 was primarily due to the long term hydration reaction that took place in the presence of water. This reaction led to the formation of cementitious compounds that enhanced strength development with time. Drop in strength beyond 10 % bagasse ash is probably due to the replacement of soil particles of higher specific gravity of 2.37 with bagasse ash of lower specific gravity of 1.66.

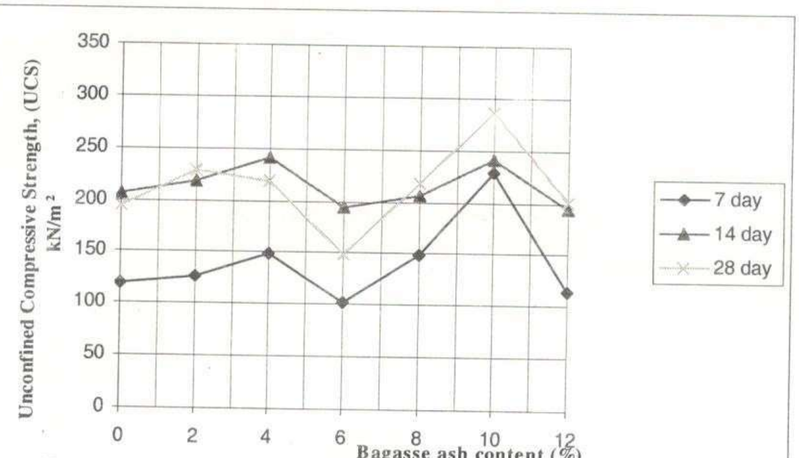

Fig. 4 Variation of UCS with Bagasse ash content for British Standard Light (BSL) compaction

California Bearing Ratio Test

The CBR values obtained from the results of bagasse ash stabilization of black cotton soil marginally increased from 3% for the natural soil prepared at the BSL compaction energy to 8% optimum at 10% bagasse ash content (see Fig. 5). The reason for the slight increase in strength could be due to inadequate amounts of calcium required for the formation of CSH, which is the major element for strength gain. [28] recommends that a CBR value of 180 % should be attained in the laboràtory for cement-stabilized material to be constructed by the mix-in-place method. But usually, a minimum CBR value of 20% to 30% for sub-base , 60% to 80% is required for bases both when compacted at optimum moisture and 100% intermediate/West African Standard [33, 34 and 32]. Although, there is no existing specification for bagasse ash stabilization, the optimum CBR value for the BSL compactive effort does not meet the minimum specified by [28] but can be used as an evaluation criterion.

Potential Volume Change

The potential volume change device was used to measure the swelling pressures of both the contents is shown in Fig. 6. The swelling peak pressure recorded was 55.5 N/mm^2 for the natural soil and on addition of 2 % bagasse ash, the swelling pressure decreased to 54.55 N/mm^2. Higher bagasse ash contents also resulted in lower swelling pressures with the minimum value recorded at 12 % bagasse ash contents. The reduction in swelling pressure could probably be due to the alkalinity of the mixture in the presence of water which increased from 7.7 to a value of 9.6 at 12 % bagasse ash content.

The silicates and aluminates compounds dissolve in an environment of pH above 10 [35]. On the dissolution of the silicates and aluminates compounds, they probably reacted with Ca^{2+} to produce cementitious compounds as it is expected. This caused a decrease in the negative charges or the lowering of the zeta potential that led to flocculation and consequent decrease in the swelling pressures [29]. With higher bagasse ash content, the swelling pressures decreased consistently with the minimum value recorded at the 12% bagasse ash content; the decrease is probably due to the same reasons as stated above.

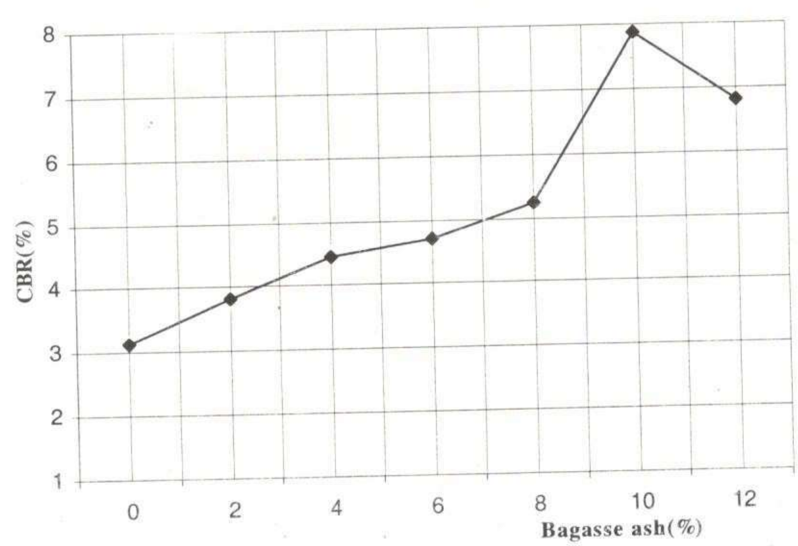

Fig. 5 Variation of CBR with Bagasse ash content

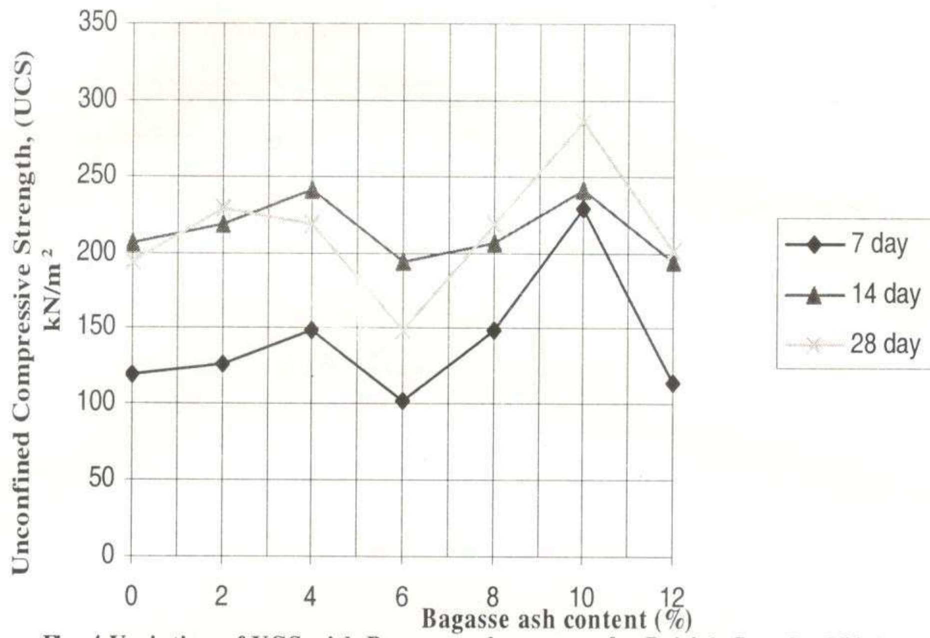

Fig. 4 Variation of UCS with Bagasse ash content for British Standard Light (BSL) compaction

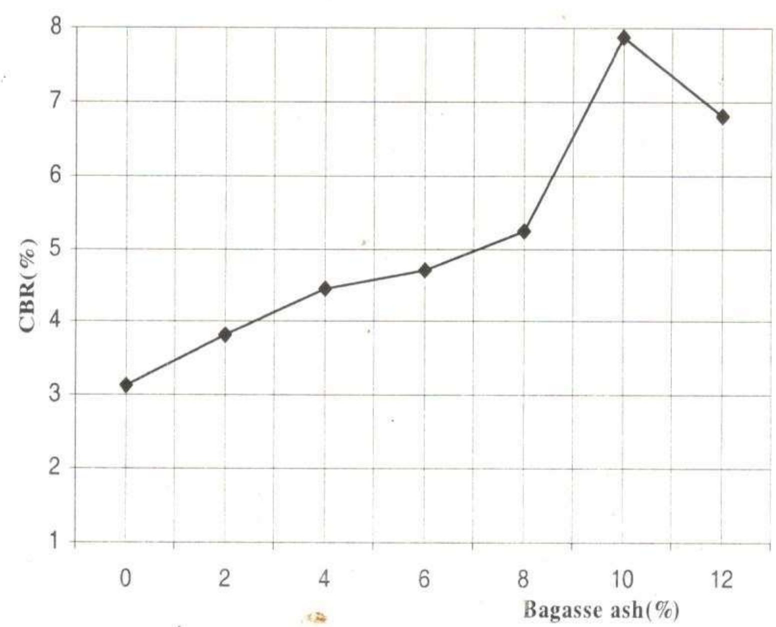

Fig. 5 Variation of CBR with Bagasse ash content

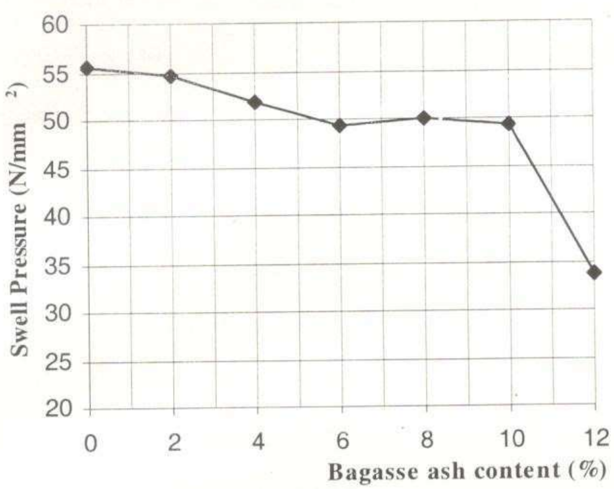

Fig. 6 Swell Pressure versus Bagasse ash content

Durability of Bagasse Ash Stabilized Black Cotton Soil

The durability assessment of the specimens were carried out by determining the resistance to loss in strength due to complete immersion of the 70 x 70 x 70 cm3 samples in water. A set of specimens were initially cured in sealed transparent plastic bags for 7 days under controlled conditions. The cured specimens were then removed from the plastic bags, dewaxed top and bottom and totally immersed in water for another 7 days in order to measure resistance to loss in strength. The resistance to loss in strength was calculated as a ratio of the UCS of the specimens cured for 7 days and soaked for another 7 days to the UCS of another set of specimens, which were earlier cured under controlled conditions for 14 days in accordance with [27]. The resistance to loss in strength at 10 bagasse ash is 16.7 % (i.e. 83.3 % loss in Strength (UCS) value strength). The values obtained (see Table VI) are more than the maximum 20 % allowable loss in strength for a 7 – day curing dry and 4 – day soaking period specified by conventional specifications.

CONCLUSION

The black cotton soil used in this study was classified as A-7-6 (13) [36] or CH [37]. The natural soil had 58 % fines passing the BS sieve No. 200, with high liquid limit, plastic limit, plasticity index, and swelling pressures while UCS and CBR were very low. From the results of the potential volume change test, the swelling pressures steadily reduced as bagasse ash was added to the soil and the least swelling pressures of 34 N/mm2 was recorded at 12 % bagasse ash content. Reduced swelling pressures indicate that the treated soil would not heave under foundation loads. The unconfined compressive for BSL compactive efforts obtained for the natural soil after 7 days curing was 120 kN/m^2, and the optimum UCS value obtained after the 7 day curing was 229 kN/m^2 at 10% bagasse ash content. This value does not meet the minimum requirement of 1720 kN/m^2 for cement stabilized soil [28]. The CBR values for the natural soil at the BSL energy level was 3 % while the optimum CBR value obtained for the stabilized black cotton soil was 8 % at 10 % bagasse ash content. The value obtained does not meet the minimum specification by [28] of 15 % CBR for a subgrade material. The strength tests results of bagasse ash treated black cotton soil gave values that are below those recommended for pavement materials. It implies that bagasse ash cannot be used as a 'stand-alone' stabilizer but need to be admixed with more potent additives. However, for this study 10 % bagasse ash content yields peak strength values that can be used to evaluate this form of stabilization.

Table VI Effect of immersion in water on UCS of bagasse ash stabilized black cotton soil (BSL)

Bagasse ash (%)	P_i (kN/m^2)	P_c (kN/m^2)	R (%) $= P_i/P_c \times 100\%$
0	17	206	8.3
2	29	218	13.3
4	40	240	16.7
6	46	195	23.6
8	46	206	22.3
10	40	240	16.7
12	46	195	23.6

P_i – UCS (kN/m^2) of specimens cured dry for 7 days and soaked in water for another 7 days.

P_c – UCS (kN/m^2) of specimens cured dry for 14 days.

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