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Stabilization of Makurdi Shale Using Bagasse Ash

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Abstract— *The growing cost of traditional stabilizing agents and the need for the economical utilization of industrial and agricultural wastes for beneficial engineering purposes has prompted an investigation into the stabilizing potential of bagasse ash in highly expansive shale soil. This research work is aimed to evaluate the suitability of bagasse ash for stabilization of expansive shale soil. The laboratory work involved index properties to classify the soil sample. The preliminary investigation of the soil shows that it belongs to A-7-6 class of soil in the AASHTO soil classification system. Soils under this class are generally of poor engineering use. Atterberg limits, compaction and CBR tests were used to evaluate properties of stabilized soil. The soil was stabilized with bagasse ash in stepped concentration of 0 %, 2%, 4 %, 6 %, 8 % and 10 % by dry weight of the soil. Analysis of the results shows that slight improvement on the geotechnical properties of bagasse ash stabilized soil. Bagasse ash reduces plasticity index, maximum dry density with an increase in optimum moisture content and CBR with all higher bagasse ash contents. From this study, improvements observed in the strength properties of bagasseh ash treated shale were below the minimum values specified for road building materials. Hence, it is recommended for use as a modifier, in the stabilization of shale with either cement, lime or other additives for road work.*

Keywords— *Bagasse ash, shale, water, Makurdi.*

I. INTRODUCTION

Shale is the product of highly consolidated clays, silts and sands or a mixture of all the three fractions of soil derived from the weathering of rocks. These fractions of soil were deposited in sea or riverbeds in layers and subjected to high overburden pressures, which lead to consolidation and diagenesis (De Graft - Johnson et al. 1973). According to O'Flaherty, (1974) shale is essentially a clayey material, which is very likely to break down in the presence of moisture and frost. Since shale is highly clayey in nature, it is subject to swelling during the rainy season and shrinkage during the dry season. Shale is a notorious unpredictable material, in which a number of failures have been reported involving cracks on buildings, settlement and shear failure of compacted shale embankments (Abeyesekera et al., 1978; El-Sohby et al. 1987; Williams, 1980). Makurdi town, the headquarters of Benue State is extensively underlain with shale as confirmed by Agbede and Smart, (2007).

Buildings and roads constructed in Makurdi town suffer distress in form of cracks ranging from fraction of millimeters to about 10 mm, thereby reducing the lifespan of these structures and posing threat to lives and properties (Iorliam et al, 2012b). Due to the challenge posed by shale and other expansive soils, many researchers have utilized agricultural or industrial waste to improve the geotechnical properties of these soils. The focus on utilization of waste in soil improvement have received much attention in the recent times due to rising cost of industrial stabilizers such as cement and lime as well as increased cost of waste disposal and environmental constraints caused by waste. The need for economic soil stabilizer is necessary, especially in localities where problem soils are encountered; with shortage of suitable construction materials, avoiding or by- passing them is difficult, thus, prompting engineers to improve the unsuitable natural soils for use in engineering work at economic cost.

The need to bring down the cost of waste disposal and the growing cost of soil stabilizers has led to intense global research towards economic utilization of wastes for engineering purposes. The safe disposal of industrial and agricultural waste products demands urgent and cost effective solutions because of the debilitating effect of these materials on the environment and to the health hazards that these wastes constitute. In order to make deficient soils useful and meet geotechnical engineering design requirements, researchers have focused more on the use of potentially cost effective materials that are locally available from industrial and agricultural wastes in order to improve the properties of poor soils. The over dependence on industrially manufactured soil improving additives (cement, lime, bitumen, etc.) have kept the cost of construction of stabilized road and other engineering structures economically high. This previously have continued to deter the underdeveloped and poor nations of the world from providing accessible roads to meet the need of their rural dwellers who constitute large percentage of their population which are mostly rural farmers.

Bagasse is defined as fibrous residue of sugar cane stalks that remains after extraction of sugar (Rainey, 2009). It is normally deposited as waste and it litters the environment. Most of the bagasse produced, amounting to one-third of all the cane crushed in some cases supplies the fuel for the generation of steam according to Bilba, Arsene, and Ouensanga, (2003) which eventually results in bagasse ash. The resulting ash is deposited in stock piles which are normally dumped in waste landfills and constitute environmental problem to the society. When bagasse is left in the open, it ferments and decays, this brings about the need for safe disposal of the pollutant, which when inhaled in large quantity can result in respiratory disease known as *bagassiosis*

(Laurianne, 2004). The aim of this research work is to investigate the effect of bagasse ash on the engineering properties of shale soil.

II. MATERIALS AND METHODS

Materials

Bagasse Ash

Bagasse is the fibrous residue obtained from sugarcane after the extraction of juice at sugar mill factories and is burnt as a means of solid waste disposal. However, as the cost of fuel oil, natural gas and electricity has increased, bagasse has become a major source of fuel rather than refuse in the sugar mills. The fibrous residue used for this purpose leaves behind about 8-10% of bagasse ash, Hailu, (2011). Since there is no Sugar producing factory in Benue State, the bagasse ash used in this research work was obtained from randomly collected Bagasse in some parts of Makurdi Town. This bagasse was properly burnt in the open air and the bagasse ash obtained was sieved through 425µm sieve to obtain the fine powdery ash. The ash was then put into polythene bags in order to keep it air-tight and to maintain its moisture. This ash was then stored until when it was required for tests.

Water

Water conforming to the requirements of water for concreting and curing as per IS; 456-2009 was used throughout in this research work.

Shale Soil

The soil used for this study was obtained from a borrow pit at a depth of 1.5 metres of shale outcrop located in College of Engineering, University of Agriculture Makurdi. Makurdi town is located on 7^{o}43’50’’N and 8^{o}32’10’’E, on the geographical map of Nigeria (http://en.wikipedia.org/wiki/Makurdi, 2012).

Methodology

Basic laboratory tests (Moisture Content, Specific Gravity, Attenberg limits, Grading test, compaction test and California bearing ratio) were carried out on shale soil sample, and on combination of soil and bagasse ash to determine the engineering properties of the soil sample. Then the stabilization of shale soil with bagasse ash was carried out by blending the soil with different percentages of bagasse ash (0 %, 2 %, 4 %, 6 %, 8 % and 10 %) and then the optimum percentage of Sugarcane Bagasse Ash were determined.

Determining the effect of Bagasse Ash on the Physical Properties

The research investigated the physical properties of clay which included the following; moisture content, compaction test, atterbeg test, specific gravity.

Moisture Content

The test was conducted in accordance with BS 1377:1990. Small representative sample of the natural soil and soil-bagasse ash mixture specimen was obtained and oven-dried at 105 ± 5°C for at least 12 hours. The samples was then reweighed, and the difference in weight was the weight of the water driven off during drying. The difference in weight was divided by the weight of the dry soil, giving the water content of the soil a dry weight basis.

Specific Gravity Test

Specific gravity which is the measure of heaviness of the soil particles was determined by using the density bottle method. Empty flask (density bottle) was weighed as M_1, about 5 g of the soil plus different percentage of bagasseh ash passing through 20 mm BS test sieve was transferred to the density bottle and weighed as M_2, Sufficient water was added to the soil in the bottle and shaken vigorously to expel air, the bottle was filled with more water and the stopper was replaced. The bottle was wiped dry and the whole content was weighed as M_3. The bottle was emptied of its content and completely filled with water; the stopper was replaced and the whole content was weighed as M_4. The procedure was repeated for different admixtures, the specific gravity was calculated using equation below.

$$Gs = \frac{(M_2 - M_1)}{(M_4 - M_1) - (M_3 - M_2)}$$

where,
Gs = specific gravity
M_1 = weight of empty flask, (g)
M_2 = weight of empty flask + weight of the soil mixed with bagasseh ash, (g)
M_3= weight of empty flask + weight of the soil mixed with bagasseh ash + water, (g) M_4 = weight of empty flask + water, (g)

Atterberg Limits

The test included the determination of the liquid limits, plastic limits and the plasticity index for the natural soil and the soil-bagasse ash mixtures. The tests were conducted on soil samples in accordance with BS 1377:1990.

Liquid Limit

The soil sample for liquid limit was air-dried and 300g of the material passing through No. 40 sieve (425µm aperture) was obtained and thoroughly mixed with water to form a homogeneous paste on a flat glass plate. A portion of the soil-water mixture was then placed in the cup of the Casagrande apparatus, leveled off parallel to the base and divided by drawing the grooving tool along the diameter through the centre of the hinge. The cup was then lifted up and dropped by turning the crank until the two parts of the soil come into contact at the bottom of the groove.

The number of blows at which that occurred were recorded. A little quantity of the soil was then taken from the sample and its moisture content was determined. The test was performed for well spaced out moisture content from the drier to the wetter states. The values of the moisture content (determined) and the corresponding number of blows were then plotted on a graph and the liquid limit was determined as the moisture content corresponding to 25 blows. The same procedure was carried out for the treated soil with increment of bagasse ash content.

Plastic Limit

A portion of the natural soil and the soil–bagasse ash mixture used for the liquid limit test was retained for the determination of plastic limit. The ball of the natural soil and the soil– bagasse ash mixture were moulded between the fingers and rolled between the palms of the hand. Each of the parts was rolled into a thread between the first finger and the thumb. The thread was then rolled between the tip of the fingers of one hand and the glass plate. This continued until the diameter of the thread was reduced to about 3mm. The soil–bagasse ash mixture were then put in the moisture container and the moisture content was determined. The same procedure was also carried out for the treated soil with increment of bagasse ash content.

Plasticity Index

The plasticity index of the samples is the difference between the liquid limits and their corresponding plastic limits.

$$PI = LL-PL$$

Where PI – Plasticity index LL – Liquid Limit
PL – Plastic Limit

Determining the effect of Bagasse Ash on the Mechanical Properties

The tests included the determination of the sieve analysis test, maximum dry density, optimum moisture content and CBR for the natural soil and the soil stabilized by bagasse ash. The tests were conducted in accordance with BS 1377:1990 testing procedures.

Sieve Analysis

The particle size distribution of the clay samples were determined by the hydrometer method of sedimentation as specified by British Standard BS 1377:1990. 500 g of the sample was washed through a 75 µm sieve and the soil sample retained on the sieve was dried in an oven at 105 ^oC for 24 hours. The dried sample was then quartered and 50 g of each sample was transferred into a 600 ml brass container. 125 ml of a dispersant solution, made from 40 g/L of sodium hexametaphosphate $(NaPO_3)_6$ was added to the distilled water. The suspension was agitated with a stirrer for 15 minutes and the sample was later transferred to a 1 litre measuring cylinder. The contents were made up to 1 litre with distilled water and left to stand undisturbed for 24 hours to effect the decoagulation of the various particles. The cylinder was agitated manually by holding the measuring cylinder containing the suspension between the palms and turning it upside-down for a minute to disperse the particles and placed on a bench. The timer was switched on immediately. The hydrometer readings were first taken after elapsed time of 2, 5, 8, 15, 30, 60 minutes and 24 hours. After the hydrometer readings, The dried samples in the oven was passed through 3.35 mm, 2.36 mm, 1.70 mm, 1.18 mm, 0.85 mm, 0.6 mm, 0.425 mm, 0.3 mm, 0.15 mm and 0.075 mm standard sieves and the soil retained on each sieve were recorded.

Maximum Dry Density

The maximum dry density was conducted for both the natural and soil-bagasse ash mixture of about 2.5kg, by varying the moisture content. The sample was then compacted into three layers of approximately equal mass with each layer receiving 27 blows. The blows were uniformly distributed over the surface of each layer. The collar was removed and the compacted sample leveled off at the top of the mould with a straight edge. The mould containing the leveled sample was weighed to the nearest 1g. One small representative sample was taken from the compacted soil for the determination of moisture content. The same procedure was repeated until minimum of six sets of samples were taken for moisture content determination. The values of the dry densities were plotted against their respective moisture contents and MDD was deduced as the maximum point on the resulting curves.

Optimum Moisture Content

The corresponding value of moisture contents at maximum dry densities, which was deduced from the graph of dry density against moisture content, gave the optimum moisture content of the soil.

California Bearing Ratio

The CBR test was conducted in accordance with BS 1377:1990 for the natural soils and soil- bagasse ash mixture. The CBR was expressed by the force exerted by the plunger and the depth of its penetration into the specimen; it is aimed at determining the relationship between force and penetration. 6.0kg of the natural soil and the soil-bagasse ash mixture was mixed at their respective optimum moisture contents in 1000 cubic centimeters mould. The samples was compacted in five layers with 62 blows from the 4.5 kg rammer. The CBR test indirectly measures the shearing resistance of a soil under controlled moisture and density conditions. The CBR was obtained as the ratio of load required to affect a certain depth of penetration of a standard penetration piston into a compacted specimen of the soil at some water content and density to the standard load required to obtain the same depth of penetration on a standard sample of crushed stone. In equation form, this is:

CBR= (test load on the sample/ standard load on the crushed stone)*100 %

Determining the Optimum CBR Value at Varrying Percentages of Bagasse Ash.

The study was carried out by mixing shale soil sample with (2-10) % of varying quantities of bagasse ash and water

III. RESULTS AND DISCUSSIONS

The relevant engineering property of the soil is evaluated both for natural and stabilized soil samples separately. The tests include Sieve analysis, Atterberg limits, compaction specific, gravity and California bearing ratio (CBR).

Properties of Material Used in the Study

Natural Soil

The results of the tests conducted for identification and/or determination of properties of the natural soil before applying bagasse ash are presented in Table 1. The soil is grayish black in color. As shown in Figure 1 on the particle size distribution curve almost 98.8% of the soil is passing through No. 200 sieve; it exhibits a liquid limit of 47.20 %, a plastic limit of 31.0 % and plasticity index of 16.20 %. Liquid limit less than 35% indicates low plasticity, between 35% and 50% intermediate plasticity, between 50% and 70% high plasticity and between 70% and 90% very high plasticity (Whitlow, R., 1995). Hence, these values indicate that the soil is low plastic.

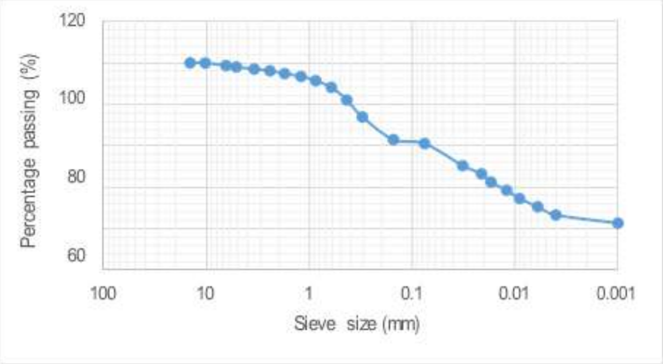

Fig. 1. Particle Size Distribution Graph

Table 1: Geotechnical Properties of the Natural Soil.

Parameters	**Quantity**
Natural Moisture content	10.30
Liquid limit	47.20
Plastic limit	31.00
Plasticity index	16.20
Linear shrinkage	12.10
Specific gravity	2.43
AASHTO Class	A-7-6
USCS	CH
MDD	1.61
OMC	17.53
CBR	7.29

Accordingly the soil falls under the A-7-6 and CH soil class based on AASHTO and USCS soil classification system respectively. Soils under this class are generally classified as a material of poor engineering property to be used as a sub-grade material. The soil has a maximum dry density of 1.61 g/cm3, optimum moisture content of 17.53 % and CBR value of 7.29 %. The general relationship between CBR values and the quality of the subgrade soils used in pavement applications is as follows:

Table 2: Showing CBR values and the quality of the subgrade

CBR-values (%)	**Quality of subgrade**
0-3	very poor subgrade
3-7	poor to fair subgrade
7-20	fair subgrade
20-50	good subgrade
> 50	excellent subgrade

Source: (Bowles, J., 1992).

Hence, the soil was found to be low plastic expansive shale with low bearing capacity and its fell below the standard recommendations for most geotechnical construction works especially highway construction. Therefore, the soil requires initial modification and/or stabilization to improve its workability and engineering properties.

Atterberg Limit Test

Table 3: Summary of Atterberg Limit Results

Percentage Bagasse	**Liquid Limit (%)**	**Plastic Limit (%)**	**Plasticity Index (%)**	**Shrinkage Limit (%)**
0	47.20	31.00	16.20	12.10
2	45.06	31.57	13.49	10.70
4	44.96	33.02	11.94	10.28
6	45.32	34.28	11.04	9.71
8	45.95	35.59	10.26	9.12
10	45.54	36.43	9.11	8.81

The natural soil shows a low liquid limit (i.e. 35.50 % < 50.00 %). The liquid limit was observed to range from 44.96 % to 47.20 % Bagasseh Ash, Whereas Plastic Limit (PL) was seen to increase from 31.00 % at 0 % Bagasseh Ash to a maximum value of 36.43 % at 10 % Bagasseh Ash. Plasticity index decreases with increase in Bagasseh Ash. The Plasticity Index (PI) experienced a reduction from 16.20 % at 0 % Bagasseh Ash to a minimum value of 9.11 % at 10% Bagasseh Ash. According to ASHTO and Unified soil classification system (USCS) classification, the soil is classified as A-7-6 and CH soil respectively. Plasticity index is a parameter which can be used as a preliminary indicator of the swelling characteristics of a soil. The following values were proposed by Chen, (1988) to relate soil expansivity and plasticity index.

Table 4: Soil Classification Based on Plasticity Index

Soil Expansivity	**Plastic index**
Low	<15
Medium	15-30
High	20-50
Very high	>50

Source: Chen, 1988

Relating the plasticity index of the study soil with the above given range reveals that the soil falls in the range of medium swell potential. It was observed that the linear shrinkage decreases from

12.10 % at 0 % to a minimum value of 8.81 % at 10 % Bagasseh Ash. The increase in Bagasseh Ash content experience a considerable decrease in volume change which shows a sign of improvement in the soil.

Compaction Test

Table 5: Showing Compaction Test Result

Percentage Bagasseh Ash	**Optimum Moisture Content (%)**	**Maximum Dry Density (g/cm^3)**
0	17.53	1.61
2	17.68	1.57
4	17.71	1.49
6	17.76	1.45
8	17.84	1.43
10	17.90	1.40

From the test results, the maximum dry density (MDD) of the sample ranges from 1.61 to 1.40 g/cm^3 and the optimum moisture content ranges 17.53 to 17.90 percent. The decrease in the maximum dry density is mainly due to;

i. the partial replacement of comparatively heavy soils with the light weight bagasse ash;
ii. comparatively low specific gravity value (1.95) of bagasse ash than that of replaced soil (2.43);
iii. it may also be attributed to coating of the soil by the bagasse ash which result to large particles with larger voids and hence less density

The increase in the optimum moisture content was mainly due to;

i. The optimum moisture content of soil increase with the increase in bagasse ash. Bagasse ash is finer than the soil. The more fines the more surface area, so more water is required to provide well lubrication.
ii. The bagasse ash forms coarser materials, which occupy larger spaces for retaining water.
iii. The increase of water content may also be attributed by the pozzolanic reaction of bagasse ash with the soil.
iv. The increase in OMC due to addition of bagasse ash caused by the absorption of water by bagasse ash. This implies that more water is needed in order to compact the soil with bagasse ash mixture. So, bagasse ash effectively dries wet soils and provides an initial rapid strength gain, which is useful during construction in wet, unstable ground conditions. In general it can be utilized in improving the workability of wet soils.

Specific Gravity Test

The effect of bagasse ash on the specific gravity of the expansive soil is shown in table 5. Specific gravity decreased from 2.43 to 2.22 with increased bagasse ash content from 0% to 10%. As it is shown in the table, the reduction in specific gravity is directly proportional to the quantity of bagasse ash. This decrease in specific gravity of the soil bagasse ash mix is due to the lower value of specific gravity of bagasse ash.

Table 6: Specific Gravity Test

Percentage Bagasseh Ash	Specific Gravity
0	2.43
2	2.40
4	2.37
6	2.34
8	2.25
10	2.22

California Bearing Ratio

The CBR value of the shale soil increase with increase in bagasse ash contents but the increment is insignificant. The optimum CBR value of soil treated with 2% bagasse ash is 1.79 % higher than the untreated soil sample of shale. While those of 4%, 6%, 8% and 10% bagasse ash are 6.18%, 8.16%, 9.08% and 11.09% respectively.

Table 7: California Bearing Ratio Result

Percentage Bagasseh Ash	CBR Value (%)
0	7.29
2	9.08
4	13.47
6	15.40
8	16.37
10	18.38

Bowles, (1992), specified the general relationship between CBR values and the quality of the subgrade soils used in pavement applications which were shown in table 4.2. Relating the CBR of the study soil with the above given range reveals that the soil falls in the range of fair subgrade which shows that the baggasseh can be combined with other additive in other to stabilized the soil.

IV. CONCLUSION

The following conclusions can be drawn from the results of the study/investigation carried out within the scope of the study.

i. The plasticity index slightly reduced with increased in bagasse ash content. However, the addition of bagasse ash alone has a minor effect on the plasticity index of shale soil.
ii. The optimum moisture content increased while the maximum dry density values decreased with increment of bagasse ash content.
iii. CBR values slightly increased with the addition of bagasse ash. The increment for bagasse ash was insignificant compare with the set standard by Road design manual part
iv. Bagasse ash alone cannot be used for stabilization of shale as a subgrade material.

Addition of bagasse ash alone does not improve the strength of soils due to presence of only reactive silica with low amount of calcium content in bagasse ash.

Recommendations

Based on the findings of this research, the following recommendations were forwarded:

i. Sugarcane bagasse ash as investigated in this research work can only be used as a soil stabilizing agent when combined other stabilizing agents. Therefore sugar industries should impress the new finding regarding the usage of bagasse ash to solve their disposal problem.
ii. The sugar factories in collaboration with higher education organizations in the country should work together and establish a research team to further study the use of bagasse ash as a soil stabilizing material on different types of soils.
iii. Further study should be done using finely grinded unburnt bagasse and compare with the existing results.
iv. The study of bagasse ash as agricultural fertilizer should be investigated.

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