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Influence of Compactive Efforts on Cement-Bagasse Ash Treatment of Expansive Black Cotton Soil

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Abstract**—**A laboratory study on the influence of compactive effort on expansive black cotton specimens treated with up to 8% ordinary Portland cement (OPC) admixed with up to 8% bagasse ash (BA) by dry weight of soil and compacted using the energies of the standard Proctor (SP), West African Standard (WAS) or "intermediate" and modified Proctor (MP) were undertaken. The expansive black cotton soil was classified as A-7-6 (16) or CL using the American Association of Highway and Transportation Officials (AASHTO) and Unified Soil Classification System (USCS), respectively. The 7day unconfined compressive strength (UCS) values of the natural soil for SP, WAS and MP compactive efforts are 286, 401 and 515kN/m^2 respectively, while peak values of 1019, 1328 and 1420kN/m^2 recorded at 8% OPC/ 6% BA, 8% OPC/ 2% BA and 6% OPC/ 4% BA treatments, respectively were less than the UCS value of 1710kN/m^2 conventionally used as criterion for adequate cement stabilization. The soaked California bearing ratio (CBR) values of the OPC/BA stabilized soil increased with higher energy level from 2, 4 and 10% for the natural soil to Peak values of 55, 18 and 8% were recorded at 8% OPC/4% BA 8% OPC/2% BA and 8% OPC/4% BA, treatments when SP, WAS and MP compactive effort were used, respectively. The durability of specimens was determined by immersion in water. Soils treatment at 8% OPC/ 4% BA blend gave a value of 50% resistance to loss in strength value which is acceptable because of the harsh test condition of 7 days soaking period specimens were subjected instead of the 4 days soaking period that specified a minimum resistance to loss in strength of 80%. Finally An optimal blend of is 8% OPC/ 4% BA is recommended for treatment of expansive black cotton soil for use as a sub-base material.

Keywords**—**Bagasse ash, California bearing ratio, Compaction, Durability, Ordinary Portland cement, Unconfined compressive strength.

I. INTRODUCTION

PROBLEMATIC soils such as expansive soils are normally encountered in foundation engineering designs for highways, embankments, retaining walls backfills, etc. Expansive soils are normally found in semi – arid regions of tropical and temperate climate zones and are abundant, where the annual evaporation exceeds the precipitation and can be found anywhere in the world [1]–[4]. Expansive soils are also referred to as "black cotton soils" in some parts of the world because the cotton plant thrives well on them. Black cotton soils have colors ranging from light grey to dark grey and black.

Two groups of parent rock materials have been associated with the formation of expansive soils. The first group comprises sedimentary rock of volcanic origin, which can be found in North America, South Africa and Israel [5], while the second group of parent materials is basic igneous rocks found in India, Nigeria and South Western U.S.A. [6]. The mineralogy of this soil is dominated by the presence of montmorillonite, which is characterized by large volume change from wet to dry seasons and vice versa Deposits of black cotton soil in the field show a general pattern of cracks during the dry season of the year. Cracks measuring 70mm wide and over 1m deep have been observed and may extend up to 3m or more in case of thick deposits as described by [7]. Reference [8] gives the engineering definition for tropical black clay as dark grey to black soil with a high content of clay, usually over 50% in which montmorillonite is the principal clay mineral.

Various researchers [3]–[4] and [9]–[12] have attempted to stabilize the Nigerian black cotton soil. High compaction energy levels are normally used in soils in order to achieve the desired densification and strength improvement of soils. Thus, it is expected that increased compactive effort will produce an increase in strength of the soil. However, the behaviors of highly expansive clays do not follow the regular pattern of soils due to their mineralogical compositions.

Bagasse is a fibrous residue obtained from sugar cane plant after the extraction of sugar juice. Northern Nigeria has many active sugar producing local cottage industries with a capacity to produce bagasse residues to the tune of 270,000 tons annually [13]. The resulting ash from the incineration of bagasse possesses pozzolanic substances in the form of oxides of silicon, aluminum and iron. The use of bagasse ash as admixture in cement stabilization of black cotton soil makes it necessary to understand the mechanism of reaction and the effect of different compaction energies on strength gain.

Various attempts have been made to improve the strength of soils using different chemical additives in conjunction with lime and cement. Recent trend in research works in the field of geotechnical engineering and construction materials [14]–[20] focuses more on the search for cheaper and locally available materials. In geotechnical engineering terms, any process which improves the engineering properties of deficient soils and subsequently enables them to perform and sustain their intended engineering use is referred to as stabilization [21]–

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[23]. Primarily, the objectives of soil stabilization are to improve the soil strength, decrease permeability and water absorption, improve soil bearing capacity and the durability under adverse weather condition.

Agricultural waste is increasingly becoming a focus of researchers because of the pozzolanic properties of such wastes when oxidized by burning. The ash from sugarcane production has been categorized under pozzolanas [24]. Thus, this study was aimed at evaluating the strength gain of black cotton soil treated with cement and bagasse ash admixture when compacted at various energy levels.

II. MATERIALS AND METHODS

A. Soil

The dark grey soil used in this study was obtained along Gombe – Biu road in Yamatu Deba Local Government Area of Gombe State using the method of disturbed sampling. The location lies within latitude 10° 19’N and longitude 11° 30’E. In terms of extent of deposit, black cotton soils are not restricted to the area of study but are wide spread throughout north – eastern Nigeria

B. Bagasse Ash

The bagasse ash utilized in this work was obtained from Makarfi Local Government Area of Kaduna State, Nigeria. Bagasse (i.e. the residue obtained after extraction of the sugar juice) was openly incinerated with in a temperature range of 500^0-700^0C measured using a thermo-couple.

C. Cement

The ordinary Portland cement used for the study was obtained from the open market.

D. Properties Test

Index properties tests on the natural and treated soils were carried out in accordance with [25], [26], respectively. Stepped percentages of cement (i.e., 0, 2, 4, 6 and 8%) were admixed with 0, 2, 4, 6 and 8% of bagasse ash by dry weight of soil.

E. Compaction

All the compactions involving moisture-density relationships, CBR and UCS were carried out using energies derived from the standard Proctor (SP), West African Standard (WAS) and modified Proctor (MP) energies. The SP compactions was carried out using energy derived from a rammer of 2.5kg mass falling through a height of 30cm in a $1000cm^3$ mould. The soil was compacted in three layers, each receiving 27 blows. The soaked CBR tests were conducted in accordance with the [27] which stipulates that specimens be cured dry for six days, then soaked for 24 hours before testing. The CBR compaction involved the use of the same rammer weight and drop height with each layer receiving 62 blows in a $2360cm^3$ mould.

The WAS compaction, was carried out using energy derived from a rammer of 4.5kg mass falling through a height of 45cm in a $1000cm^3$ mould. The soil was compacted in five layers, each layer receiving 10 blows. For the CBR compaction, the same rammer weight and drop height was adopted with each layer receiving 30 blows in a $2360cm^3$ mould. Finally, the MP compaction moisture density relationships were determined using energy derived from a hammer of 4.5kg mass falling through a height of 45cm in a $1000cm^3$ mould. The soil was compacted in 5 layers, each receiving 27 blows. The CBR compaction involved the same hammer weight and drop height with each layer receiving 62 blows in a $2360cm^3$ mould.

UCS test specimens were compacted at the SP, WAS and MP energy levels. Specimens were cellophane cured for 7, 14 and 28 days before testing.

III. RESULTS AND DISCUSSION

A. Index Properties

Results of tests carried out on the natural soil are summarized in Table I. The soil is classified as A – 7 – 6 (16) in the AASHTO classification system. Liquid limit and plasticity index values of 93 and 72%, respectively, suggest that the soil is highly plastic. Thus, from the results obtained, the soil falls below the standard recommended for most geotechnical construction works [17].

TABLE I
INDEX PROPERTIES RESULTS OF NATURAL BLACK COTTON SOIL

Property	Quantity
Percentage passing BS No 200 sieve	87.0
Natural moisture content,%	15.0
Liquid limit,%	93.0
Plastic limit, %	21.0
Plasticity index, %	72.0
Linear shrinkage, %	21.0
Free swell, %	90.0
Specific gravity	2.5
AASHTO classification	A-7-6 (16)
USCS	CL
NBRRI classification	High swell potential
Maximum dry density, Mg/m^3	
Standard Proctor	1.41
West African Standard	1.52
Modified Proctor	1.63
Optimum moisture content, %	
Standard Proctor	30.6
West African Standard	25.2
Modified Proctor	20.0
Unconfined compressive strength, kN/m^2	286
Standard Proctor	
West African Standard	401
Modified Proctor	515
California bearing ratio, %	
Standard Proctor	2
West African Standard	4
Modified Proctor	10
pH	7.2
Color	Dark grey

B. Compaction Characteristics

Maximum Dry Density

The variation of maximum dry density (MDD) with bagasse ash content for soil-cement-bagasse ash mixes are shown in Fig. 1. Generally the SP compaction showed a decrease in MDD with higher OPC content in agreement with findings reported by [21]. The decrease in MDD for SP compaction can be attributed to the presence of large, low density aggregate particles. Generally there was an increase in the MDD with increasing bagasse ash content due to the void within the coarse aggregate becoming occupied by cement-ash particles. Furthermore, above 2 % BA content there was a possibility of formation of new compounds that were responsible for the increase in MDD values.

The MDD for the WAS compactive effort (see Fig. 2) is in conformity with the trend of decreasing OMC/increasing MDD. This is as a result of cement/bagasse occupying the void within the soil matrix and in addition, the flocculation and agglomeration of the clay particle due to cation exchange. The decrease in MDD can be attributed to bagasse ash with specific gravity of 2.2 replacing the soil particles which has a higher specific gravity of 2.5.

The variation of maximum dry density (MDD) with bagasse ash content for soil-cement-bagasse ash mixes are shown in Fig. 3. Generally the MP compaction showed a decrease in MDD with higher OPC content in agreement with findings reported by [21]. The decrease in MDD for MP compaction can be attributed to the presence of large, low density aggregate particles. Generally there is an increase in the MDD with increasing bagasse ash content due to the void within the coarse aggregate becoming occupied by cement-ash particles. Furthermore, above 2% BA content there was a possibility of formation of new compounds that were responsible for the increase in MDD.

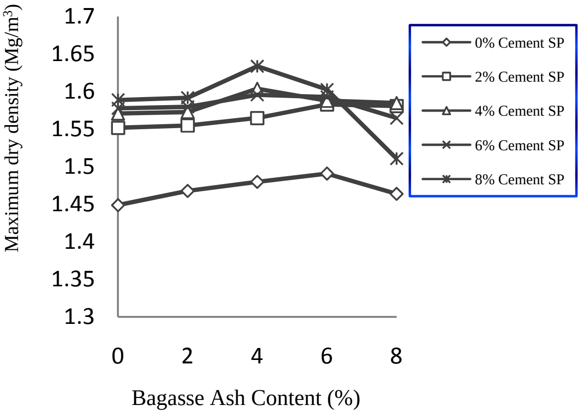

Fig. 1 Variation of maximum dry with bagasse ash content for soil-cement-bagasse ash mixtures (Standard Proctor compaction)

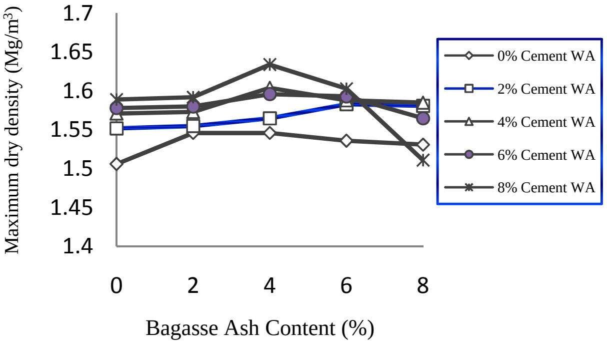

Fig. 2 Variation of maximum dry density for with bagasse ash content for soil-cement-bagasse ash mixtures (West African Standard compaction)

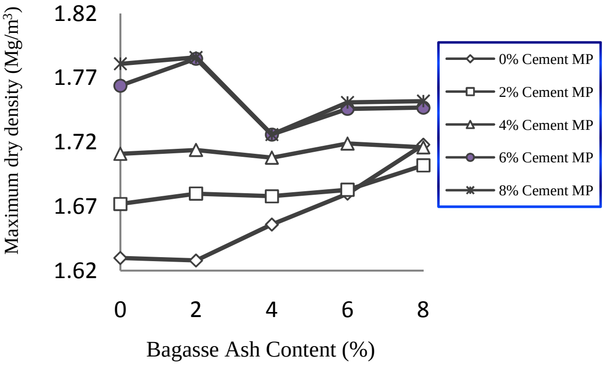

Fig. 3 Variation of maximum dry density with bagasse ash content for soil-cement-bagasse ash mixtures (Modified Proctor compaction)

Optimum Moisture Content

The variation of OMC with OPC/BA blends for SP, WAS and MP compaction are shown in Figs. 4-6 respectively.

There was an initial increase in OMC with higher OPC/BA contents for the standard Proctor and modified Proctor compactive efforts. The initial increment could have been as a result of increasing demand for water by various cations and the clay mineral particles to undergo hydration reaction.

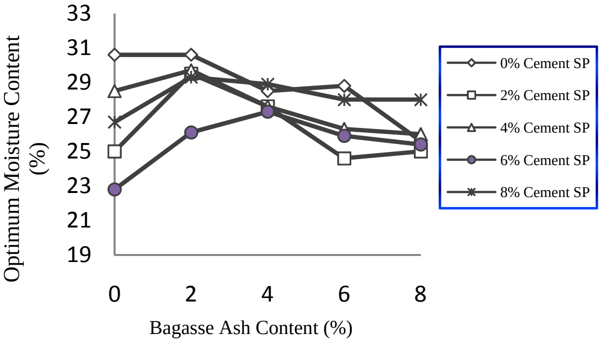

Fig. 4 Variation of optimum moisture content with bagasse ash content for soil-cement-bagasse ash mixtures (Standard Proctor compaction)

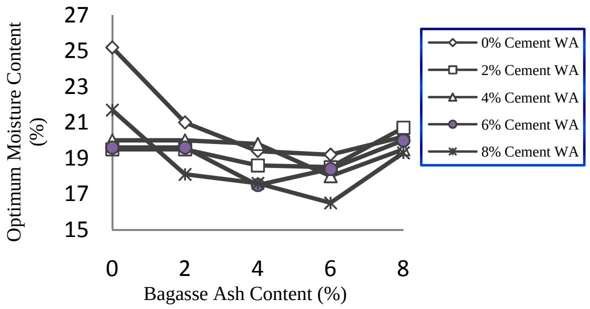

Fig. 5 Variation of optimum moisture content with bagasse ash content for soil-cement-bagasse ash mixtures (West African Standard compaction)

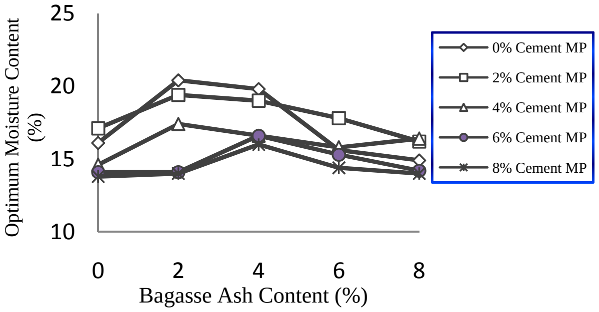

Fig. 6 Variation of optimum moisture content with bagasse ash content for soil-cement-bagasse ash mixtures (Modified Proctor compaction)

The subsequent decrease might have been due to cation exchange reaction that caused the flocculation of clay particles. For specimens compacted with West African Standard energy, the initial decrease in OMC recorded was probably due to self – desiccation in which all the water was used, resulting in low hydration. When no water movement to or from cement – paste was permitted, the water is used up in the hydration reaction, until too little is left to saturate the solid surfaces and hence the relative humidity within the paste decreases. The process described above might have affected the reaction mechanism of the stabilized soil [15].

C. *Strength Characteristics*

Unconfined compressive strength

The unconfined compressive strength (UCS) test is recommended for use for determining the required amount of additive to be used in the stabilization of soils [28]. The 7day UCS test results (see Figs. 7-9) show peak values for SP, WAS and MP energy levels as 1019, 1328 and 1420kN/m^2 at 8% OPC/ 6% BA, 8% OPC / 2% BA and 6% OPC/ 4% BA treatments, respectively. The trend of the UCS for the WAS compactive energy level shows a marked difference from those of SP and MP compaction energies probably because of inadequate amount of water available for the pozzolanic reaction to take place. The optimal blend of cement and bagasse ash treated soil was attained at 8% OPC/ 6% BA content at SP compactive effort with a peak 7 day UCS value of 1019kN/m^2. This value falls short of 1710kN/m^2 specified by [29] for base materials stabilization using OPC. However, this value meets the requirement of 687–1373kN/m^2 for sub-base as specified by [30].

The variation of UCS with BA at different OPC contents for 14 and 28 days curing period are shown in Figs. 10–15. The peak 14 day UCS values for SP, WAS and MP compactive efforts are 1111, 1923 and 1498kN/m^2 at 8% / 2%, 8% / 2% and 6% / 4% OPC/BA contents treatments, respectively. The peak 28 day UCS values for SP, WAS and MP compactive efforts are 1464 , 2290 and 2313kN/m^2 at 8% OPC / 4% BA, 8% OPC / 0% BA and 6% OPC / 2% BA contents treatments, respectively. This conforms to the trend of increasing strength with higher compaction energy. The trend of increased compressive strength with curing period can be attributed to time dependent strength gain action of the pozzolanas.

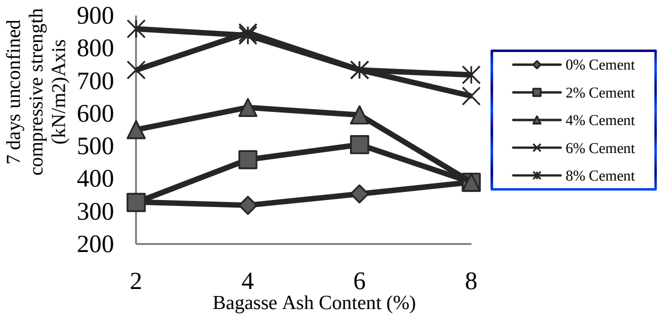

Fig. 7 Variation of unconfined compressive strength (7 days curing) with bagasse ash content for soil-cement-bagasse ash mixtures (Standard Proctor compaction)

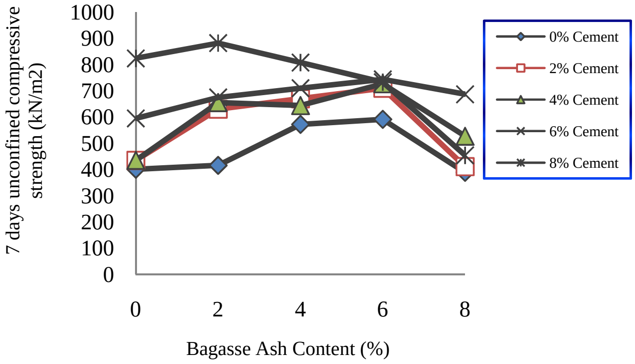

Fig. 8 Variation of unconfined compressive strength (7 days curing) with bagasse ash content for soil-cement-bagasse ash mixtures (West African Standard compaction)

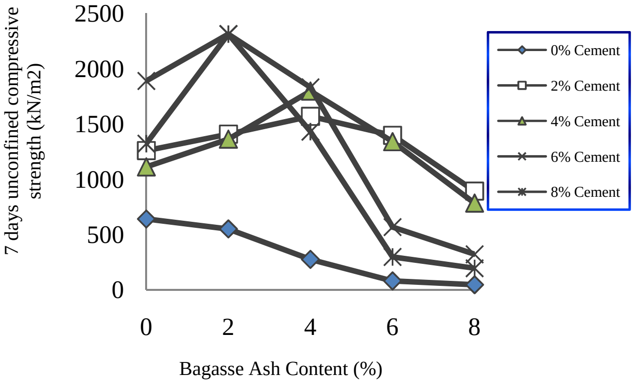

Fig. 9 Variation of unconfined compressive strength (7 days curing) with bagasse ash content for soil-cement-bagasse ash mixtures (Modified Proctor compaction)

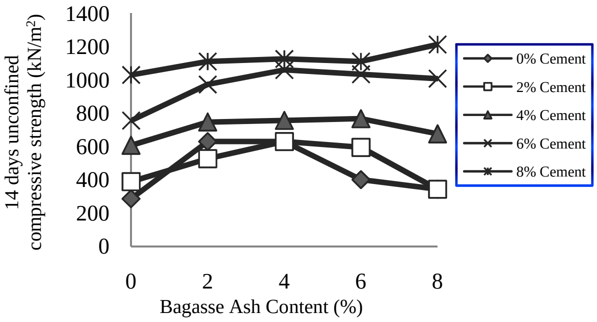

Fig. 10 Variation of unconfined compressive strength (14 days curing) with bagasse ash content for soil-cement-bagasse ash mixtures (Standard Proctor compaction)

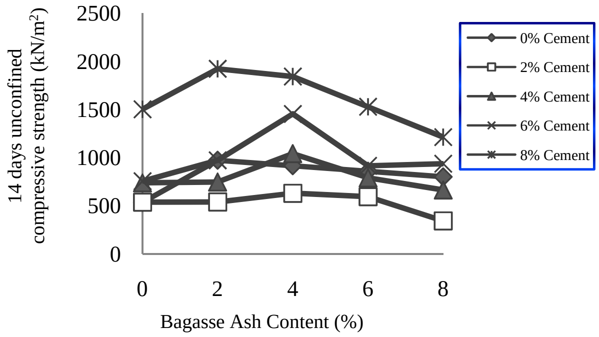

Fig. 11 Variation of unconfined compressive strength (14 days curing) with bagasse ash content for soil-cement-bagasse ash mixtures (West African Standard compaction)

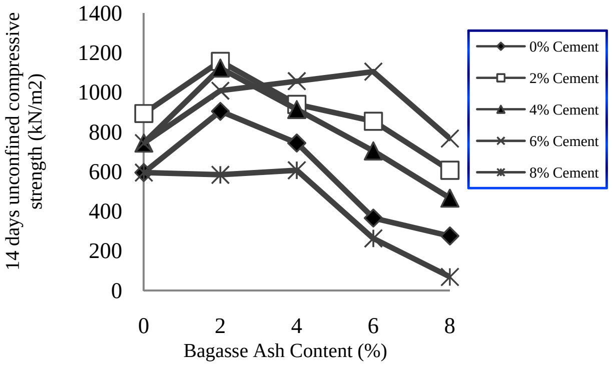

Fig. 12 Variation of unconfined compressive strength (14 days curing) with bagasse ash content for soil-cement-bagasse ash mixtures (Modified Proctor compaction)

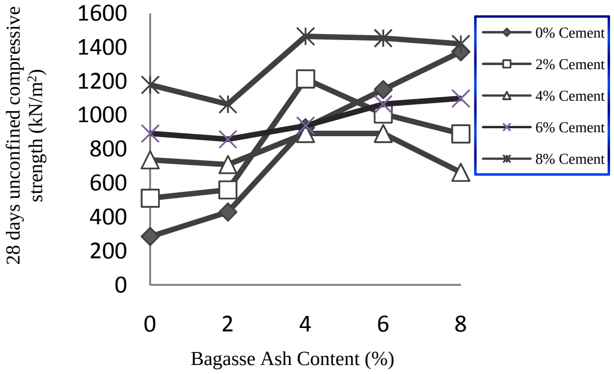

Fig. 13 Variation of unconfined compressive strength (28 days curing) with bagasse ash content for soil-cement-bagasse ash mixtures (Standard Proctor compaction)

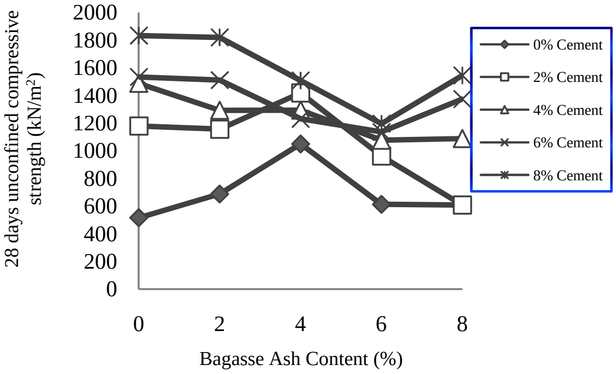

Fig. 14 Variation of unconfined compressive strength (28 days curing) with bagasse ash content for soil-cement-bagasse ash mixtures (West African Standard compaction)

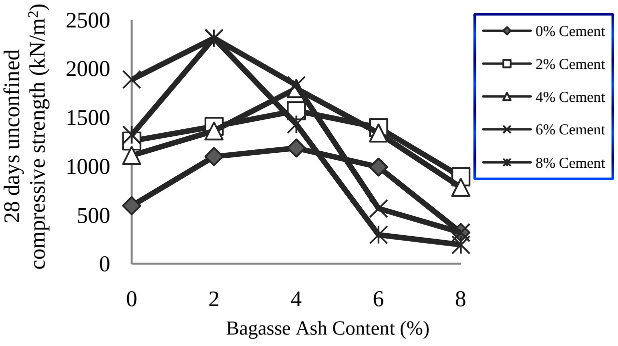

Fig. 15 Variation of unconfined compressive strength (28 days curing) with bagasse ash content for soil-cement-bagasse ash mixtures (Modified Proctor compaction)

C. California Bearing Ratio

The California bearing ratio (CBR) value, of the stabilized soils is an important parameter in assessing its suitability for use as a road construction material. It gives an indication of the strength and bearing ability of the soil; which will assist the designer in recommending or rejecting the soil as suitable for base or sub-base for a flexible road pavement.

The soaked CBR values (see Figs. 16-18) changed from the regular trend by showing a marked decrease with higher compaction energy level with peak values of 55% for 8% OPC/ 4% BA treatment at SP compaction, 18% for 8% OPC/ 2% BA treatment at WAS Compaction and 8% at 8% OPC/ 4% BA treatment at MP compactive effort. This behavior of decreasing CBR values at higher compactive efforts can be attributed to the OMC. At lower energy levels less water is available to meet hydration demand, therefore, the ability of the stabilized expansive clay to complete its hydration reaction is unlikely, which consequently leads to weak bonds formation due to the strength failing to be fully mobilize. Furthermore, the 24 hours soaking that specimens are subjected to before testing as specified [27], facilitates the loosening up of the weak bonds formed by the incomplete pozzalanic input of the cement and bagasse ash treated highly expansive clay at lower energy levels [31].

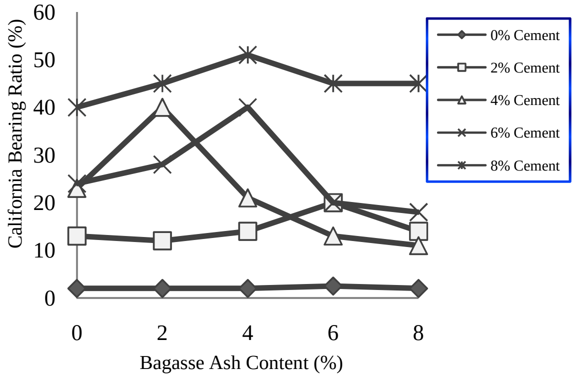

Fig. 16 Variation of soaked California bearing ratio with bagasse ash content for soil-cement-bagasse as (Standard Proctor compaction)

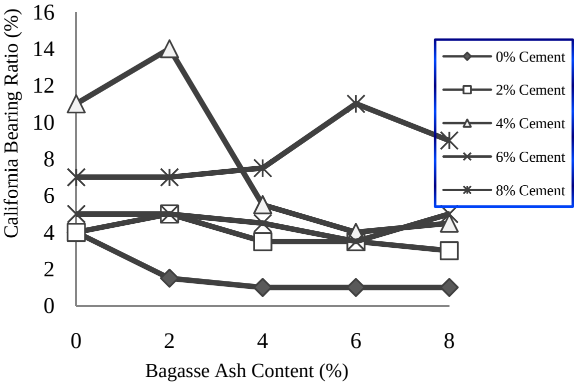

Fig. 17 Variation of soaked California bearing ratio with bagasse ash content for soil-cement-bagasse ash mixtures (West African Standard compaction)

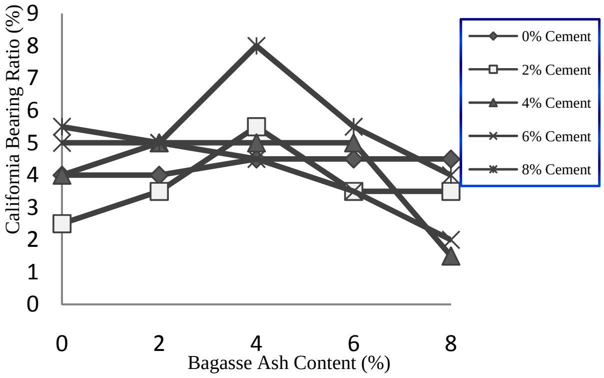

Fig. 18 Variation of soaked California bearing ratio with bagasse ash content for soil-cement-bagasse ash mixtures (Modified Proctor compaction)

D. Durability Assessment of Specimens

In order to simulate some of the worst conditions that can be attained in the field for any soil to be used for engineering purposes, immersion of the cured specimen in water before testing its compressive strength is employed to ensure that the stabilized material do not fail under adverse field conditions. The UCS values obtained under these conditions are analyzed in conjunction with the 14 days curing period UCS test results. Cured specimens are normally soaked for 7 days before testing to obtain the percentage resistance to loss in strength of the stabilized material as recommended for tropical countries by [5].

The peak resistance to loss in strength values for SP, WAS and MP (Figs. 19-21) compactive energy levels are 61.8%, 5.1% and 50.7% at OPC/BA contents of 8%/6%, 8%/6% and 8%/8% respectively, the tested specimens fell short of the acceptable conventional 80% accepted as minimum resistance to the loss of strength by [5]. However 61.8% resistance to loss in strength for SP compaction at 8% OPC/ 6% BA content seems almost acceptable since the loss of strength limiting value obtained [5] was based on a 4 day soaking period and not the 7 days soaking period that the specimens were subjected to in this work.

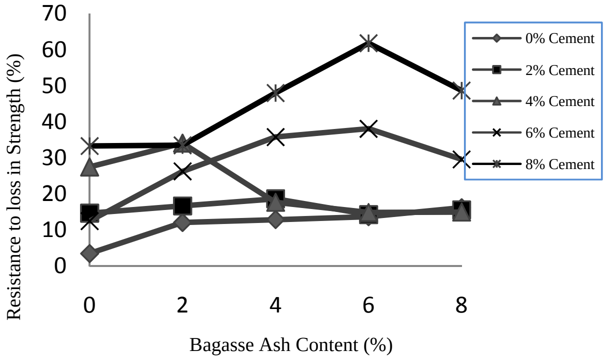

Fig. 19 Variation of resistance to loss of strength of soil treated with bagasse ash content for soil-cement-bagasse ash (Standard Proctor compaction)

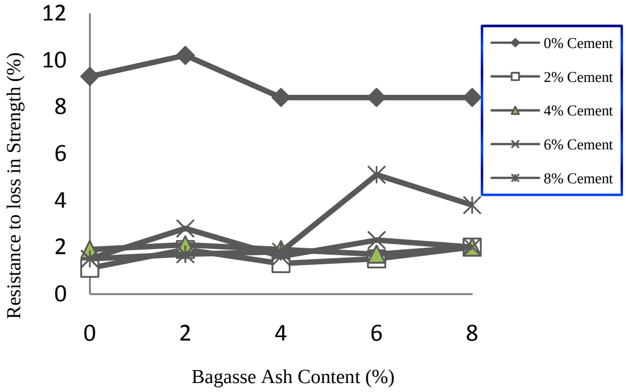

Fig. 20 Variation of resistance to loss of strength of soil treated with bagasse ash content for soil-cement-bagasse ash (West African Standard compaction)

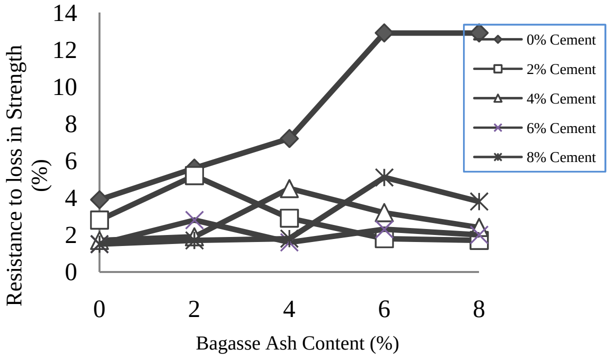

Fig. 21 Variation of resistance to loss of strength of soil treated with bagasse ash content for soil-cement-bagasse ash (Modified Proctor compaction)

IV. CONCLUSION

The natural black cotton soil was classified as A – 7 – 6 or CL in the AASHTO and Unified Soil Classification System (USCS), respectively. Soils under these groups are of poor engineering benefit. The soaked CBR values changed from the regular trend by showing a marked decrease with increasing compactive energy level with a peak value of 55% at 8% OPC/ 4% BA content at SP, 18% at 8% OPC/ 2% BA content at WA and 8% at 8% OPC/ 4% BA content at MP compactive effort, respectively. Furthermore, the OMC at lower energy levels are higher than at higher energy levels, at higher OMC enough water is available for the hydration process thus giving stabilized expansive soils at lower energy level higher strength gain. Treatment of natural the soil with cement and bagasse ash gave a 7 days UCS value of 839kN/m^2 at 8% OPC/ 4% BA content. This value falls short of 1710kN/m^2 specified by TRRL (1977) for base materials stabilization using OPC. However, this value meets the requirement of 687–1373 kN/m^2 for sub-base. The C.B.R value of 55% obtained at 8% OPC/ 4% BA content meet the specification for sub-base materials as recommended by the Nigerian General Specifications (1997). The durability of the specimen at 8% OPC/ 4% BA content is acceptable on the bases of the 7 days soaking test period results recorded from the resistance to loss in strength test. Thus higher compactive effort did not impact positively on the strength and durability assessment of the black cotton soil. Thus, an optimal blend of 8% OPC/ 4% BA at SP is recommended for use as sub-base material.

REFERENCES

[1] Chen, F. H. (1988). Foundations on Expansive Soils. Elsevier Scientific Pub. Co. Amsterdam, Netherlands.

[2] Warren, K.W. And Kirby, T.M. (2004): “Expansive Clay Soil A Wide Spread And Costly Geohazard”, Geostra, Geoinstitute of The American Society Of Civil Engineers.

[3] Osinubi, K.J., Ijimdiya, T. S. and Nmadu, I. (2008b). “Lime stabilization of black cotton soil using bagasse ash as admixture.” Advanced Materials Research, Vol. 62-64, pp3-.10. In Advance Materials Systems Technologies 11. Online http://www.scientific net Trans Tech. Publications, Switzerland.

[4] Osinubi, K. J. (2000). “Influence of compaction energy levels and delays on cement treatedSoil.” Nigerian Society of Engineers Technical Transactions, Vol. 36, No. 4, pp 1 – 13.

[5] Ola, S. A. (1974): Need for estimated cement requirement for stabilization of laterite soils. J. Transp. Engrg. Div., ASCE, Vol. 100, No. 2, pp. 379 – 388

[6] So, El – Kon (1992): “Research on the optimum secondary additives to granulated clay – stabilized soils,” In: T. Mise et al., (eds.) Soil Improvement, Current Japenese Materials Research, Vol. 9. Elsevier Science Publishers, London and New York.

[7] Adeniji F. A. (1991). “Recharge function of vertisolic vadose zone in sub-sahelian Chad Basin”. Proc. Ist Inter. Conf. on Arid Zone Hydrogeology Hydrology and Water Resources, Maduguri, pp. 331 – 348.

[8] Maclean, D. J. (1953) “Investigation of some problems in soil stabilization”. Proc. of the 3rd Int. Conf. On soil Mech. and found, Engineering, Switzerland, 263 – 267.

[9] Ola, S. A. (1983). “The geotechnical properties of black cotton soils of North Eastern Nigeria.” In: S. A. Ola (Editor). Tropical Soils of Nigeria in Engineering Practice, A. A. Balkema, the Netherlands, Rotterdam, pp155 – 171. soil.” The Nigeria Engineer, Vol. 26 No., pp. 15 – 24.

[10] Balogun, L. A. (1991). “Effect of sand and salt additives on some geotechnical properties of lime stabilized black cotton soil.” The Nigeria Engineer, Vol. 26 No., pp. 15 – 24.

[11] Osinubi, K.J., (1995). "Lime modification of black cotton soil" Spectrum Journal, Kaduna, Vol.2, Nos. 1 and 2, pp, 112 – 122.

[12] Osinubi K. J. (1999). "Evaluation of admixture stabilization of Nigerian black cotton soil." Nigeria Society of Engineers Technical Transactions, Vol 34, No. 3, pp 88 – 96.

[13] Misari S. M., Busari L.O. and Agboire S. (1998). "Current status of sugarcane research and development in Nigeria." Proceedings of the Inaugural Meeting and Planning Workshop for Collaborators of National Coordinated Research program on Sugarcane (NCRP – SC).pp 2 – 12.

[14] Osinubi K.J. and Medubi A.B. (1997). "Evaluation of cement and phosphatic waste admixture on tropical black clay road foundation." Proceedings of the 4th Conference in Structural Engineering Analysis and Modelling (SEAM), Vol. 2. pp. 297 – 307.

[15] Umar S.Y. "The Stabilization of Black Cotton Soil with Ordinary Portland Cement and Blast Furnace Slag". Unpublished MSc. Thesis Dept.of Civil Engineering Ahmadu Bello University Zaria.

[16] Osinubi,K.J. and Stephen, T.A. (2007). 'Influence of compactive efforts on bagasse ashtreated black cotton soil.' Nigerian Journal of Soil and Environmental Research, Vol. 7, pp. 92-101

[17] Osinubi, K.J., Eberemu, A.O. (2006a). Hydraulic conductivity of lateritic soils treated with blast furnace slag. Electronic Journal of Geotechnical Engineering. EJGE, Vol 11, Bundle D Paper 0693.

[18] Medjo Eko and Riskowiski, G. (2004). "A procedure for processing mixtures of soil, cement, and sugar cane bagasse". Agricultural Engineering International. The Journal of Scientific Research and Development. Manuscript BC 990. Vol. III. pp 1-5.

[19] Osinubi, K. J and Eberemu. A. O. (2006b) "Effect of bagasse ash on the strength of stabiized lateritic soil" Book of Abstracts 5th Nigerian Material Congress (NIMACON), Nov 15th – 18th 2006. Abuja, Nigeria. pp. 24 – 25.

[20] Osinubi, K. J., Eberemu, A.O. and Aliu, O.S (2007). "Stabilization of laterite with cement and bagasse ash admixture." Proc of the First Inter. Conf. on Environ. Res., echn. and Policy "ERTEP 2007" under the auspices of International Society of Environmental Geotechology, Accra, Ghana, 16 – 19 July, Category B: Mining and Environment, pp. 1-14

[21] Yoder, E. J.; and Witczak, M. W. (1975): Principles of Pavement Design. John Wiley and Sons. Inc, New York, pp 300–321.

[22] Gillot J.E. (1987). Clay in Engineering Geology. Elsevier Scientific Publishing Company Amsterdam, Netherlands.

[23] Nicholas, J.G. and Lester, A.H.(1999): Traffic and Highway Engineering, 2nd edition. Books/Cole Publishing Company.

[24] Mohammedbhai, G.T.G. And Baguant, B.K. (1985). "Possibility of using bagassae ash and other furnace residue as partial substitute for cement in Maurice". Vol. 64, .No. 3 Sept-Dec.

[25] BS 1377 (1990). "Methods of testing soils for civil engineering purposes". British Standard Institute, London, Great Britain.

[26] BS 1924 (1990). "Methods of tests for stabilized soils." British Standard Institute, London, Great Britain.

[27] Nigerian General Specification (1997): Bridges and Road Works. Federal Ministry of Works, Abuja, Nigeria.

[28] Singh, G. (1991). Highway Engineering, 3rd Edition, Standard Publishers Distributors. pp 599 – 619.

[29] TRRL (1977). A Guide to the Structural Design of Bitumen Surfaced Roads in Tropical and Sub – tropical Countries. Transport and Road Research Laboratory, Road Note 31, Her Majesty Statemey 0ffice, London. geohazard", Geostrate, Geo-Institute of the American Society of Civil Engineers

[30] Ingles, O.G. and Metcalf, J. B. (1972). Soil Stabilization Principles and Practice, Butterworths, Sydney, Australia.

[31] Moses, G. (2012). Hydraulic and contaminant transport performance of compacted bagasse ash treated foundry sand for use in waste containment facilities. Unpublished Ph.D Dissertation submitted to the Department of Civil Engineering, Ahmadu Bello University, Zaria.