Effect of Bagasse Ash on Lime Stabilized Lateritic Soil

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ABSTRACT

This study was carried out to evaluate the effect of bagasse ash (BA) on lime stabilized lateritic soils. Laboratory tests were performed on the natural and lime/bagasse ash treated soil samples in accordance with BS 1377 (1990) and BS 1924 (1990), respectively. Treated specimens were prepared by mixing the soil with lime and/or bagasse ash in variations of 0, 2, 4, 6 and 8% by weight of the soil. The preliminary investigation carried out on the natural lateritic soil found in Shika, Kaduna State, Nigeria shows that it falls under Silt-Clay material of Group A-6(9) using AASHTO classification and inorganic clay material CL according to Unified Soil Classification System (USCS). The natural soil has a liquid limit value of 36.32, a plastic limit of 21.30% and a plasticity index value of 15.02 %. The maximum dry density (MDD) of the soil was 1.69 kg/m^3 and an Optimum Moisture Content (OMC) value of 16.8 %. Unconfined compressive strength (UCS) values of 269, 404 and 591 kN/m^2 at 7, 14 and 28 days curing periods, respectively, were recorded for the natural soil. Unsoaked and soaked California Bearing Ratio (CBR) values of 13 and 7%, respectively, were recorded for the natural lateritic soil. Peak UCS and CBR values of 698 kN/m^2 and 43% were recorded for soil treated with 8% lime/6% bagasse ash. The peak CBR value met the 20 – 30 % requirement for sub-base reported by Gidigasu and Dogbey (1980) for materials compacted at optimum moisture content, while the peak UCS value fell short of the 1710 kN/m^2 unconfined compressive strength value specified by by Transport and Road Research Laboratory (TRRL) (1977) as a criterion for adequate stabilization using ordinary portland cement.

KEYWORDS: Bagasse ash, Lime, Stabilization, Lateritic soil, Unconfined compressive strength.

INTRODUCTION

Geotechnically, soil improvement could be achieved either by modification or stabilization, or both. Soil modification is the addition of a modifier (cement, lime, cement kiln dust, bagasse ash, rice husk ash, cattle bone ash,… etc) to a problem soil in order to improve its index properties for better workability and usefulness, while soil stabilization is the treatment of problem soils to improve their index properties and

strength characteristics such that they permanently become suitable for construction and meet engineering design standards (Salahudeen and Akiije, 2014).

A lot of laterite gravels, which are good for gravely roads, occur in tropical countries of the world, including Nigeria (Osinubi, 1995). There are instances where laterite may contain a substantial amount of clay minerals that its strength and stability cannot be guaranteed under load, especially in the presence of moisture. These types of laterite are also common in many tropical regions, including Nigeria, where in most cases sourcing for alternative soil may prove

economically unwise but rather to improve the available soil to meet the desired objective (Osinubi, 1994). The needs for good road network are extremely increasing with the increase in population, so also the maintenance of the existing ones. The physical properties of laterite can be improved.

De-Graft (1975) defined laterite as a highly weathered material, rich in secondary oxides of iron or aluminium or both which is nearly void of bases and primary silicates but may contain large amounts of quartz and kaolinite. This definition is more in agreement with that of Osinubi (2003) who defines laterite as soil groups commonly found in tropical, subtropical and temperate regions of the world and formed under weathering conditions that favor laterization (decomposition of ferroalumino silicate minerals, leaching of silica and base and permanent deposition of sesquioxides within a profile). This later definition revealed the possible regions of the world where laterite deposits could be found. However, Hunt (1984) had earlier identified specific regions in the middle latitudes which include much of Brazil, the southern third of Africa, south-eastern Asia and part of India as specified regions where laterite deposits could be found. But, Fletcher and Vernon (1974) described the deceptive nature of laterite that it may appear firm and steep cut; however, when used as a construction material, it may become soft and unstable.

Osinubi (2003) had highlighted factors such as basic or intermediate parent rock material, thick vegetation and high humid residue, permeable profile, heavy rainfall, hot climate and coolish nights, fluctuating water table,… etc. to have been encouraging and affecting the result of laterization. Where all or most of the aforementioned factors occur simultaneously, massive laterite concretions are formed which could possess enough strength and stability to be used as base material for pavement construction (Osinubi and Bajeh, 1994; Hunt, 1984). However, some laterite deposits contain high proportions of clay minerals (mostly kaolinite) so that they are rarely stable for pavement construction as reported by

Fletcher and Vernon (1974). This is because of the colloidal condition conferred upon the kaolinite mineral particles. According to Bridges (1979), properties, which are conferred upon a soil by the colloidal state, are: plasticity, cohesion, shrinkage, swelling, flocculation and dispersion.

Red color is so much associated with laterites that it is included in almost all of their definitions. Zonn (1986), however, stated that red color of whatever shade indicated that the soil is rich in iron or free iron (Fe_2O_3). Yellow is also connected with iron, but indicates the dominance of its hydrated compounds; namely $Fe(OH)_3$. Green or dove gray indicates a high concentration of ferrous compounds (FeO). Black and gray are related to different soil content of humus, and occasionally are due to the color of parent rock or the presence of volcanic ash. White color indicates the presence of quartz, kaolinite or calcium carbonate.

The common chemical compositions of laterites according to Gidigasu (1976), Ola (1983) and Osinubi (2003) are: silica (SiO_2), sesquioxide of iron (Fe_2O_3) and aluminum (Al_2O_3), and in some few cases, little quantities of manganese (Mn), titanium (Ti), chromium (Cr) and vanadium (V). Though silica is low in most laterite deposits, higher amounts are found in some few laterite deposits where the parent rock contains a lot of quartz. Gidigasu (1976) has reported higher sesquioxide of between 20% and 50% for West African laterite soil deposits as against black clays, which possess less than 20%. The presence of sesquioxide, especially that of iron (Fe_2O_3), imparts on the laterites the property of hardening on firing. This phenomenon was confirmed by Adeyemi et al. (1990) who conducted a study on laterite collected from three different areas in the southern part of Nigeria to evaluate the strength of both air dried and fired bricks made of these laterite deposits. Bases such as calcium oxide (CaO), sodium oxide (Na_2O), magnesium oxide (MgO)… etc. have been observed to be absent in lateritic soil deposits (Gidigasu, 1976).

Over the years, extensive research has been carried out to improve deficient soils. The two most commonly

used stabilizers for expansive clays are cement and lime (Salahudeen et al., 2014). Lime stabilization is generally restricted to warm to moderate climates, since lime stabilized soils are susceptible to breaking under freezing and thawing (Gididgasu, 1976). The action of lime on soil can be reduced to three basic reactions: alteration of water film surrounding the clay minerals, flocculation of the soil particles and reaction of lime with soil components to form new chemical compounds (Gididgasu, 1976).

According to Ola (1975), there is no direct hydration to form cementitious compounds in lime stabilization; rather there are the physical and chemical components to the reaction of lime with clay. The physical reaction is one of cation absorption, where calcium first replaces any other ion present as a base exchange ion. This process is followed by flocculation into coarse particles, which produces an immediate increase in strength. This is in agreement with Osinubi (1999) who referred to this reaction as a short-term reaction. The chemical component of the reaction is the soil-cement hydration. Ola (1975) reported an increase in strength of between 70 to 300 percent on lime stabilized A-7-6 laterite soil. Nevertheless, the stabilized soil was only adequate as a sub-base. Similar results were reported by Singh (1991), Osinubi and Katte (1997), Osinubi (1998), Osinubi (1999) and Adeyemi and Abolurin (1999).

Bagasse is the fibrous residue obtained from sugar cane after the extraction of sugar juice at sugar cane mills (Osinubi and Stephen, 2007). This material usually poses a disposal problem in sugar factories, particularly in tropical countries. Research works have been carried out on the improvement of geotechnical characteristics of soils using bagasse ash (Osinubi and Stephen, 2007). Nowadays, it is common to reutilize sugar cane bagasse as a biomass fuel in boilers for vapour and power generation in sugar factories. Bagasse is rich in amorphous silica which indicates that it has pozzolanic properties, depending on the incinerating condition of the bagasse; the resulting sugar cane bagasse ash may contain high level of silica

(SiO_2) and aluminium oxide (Al_2O_3) enabling its use as supplementary cementitious material. Bagasse ash has been categorized under pozzolans with about 60%-70% silica and about 9% and 3% alumina and iron oxides, respectively (Ogbonyomi, 1998). Silica is substantially contained in amorphous form, which can react with the lime librated during the pozzolanic reaction to further form strength developing compounds.

The pozzolanic reactivity of sugar cane bagasse ash depends strongly on the incinerating temperature. Maximum reactivity occurred at 500°C (Cordeiro, 2008). The main reasons why pozzolans like bagasse ash have poor pozzolalic activity is due to overburning into a temperature range that favors the development of crystalline (less reactive) rather than amorphous (more reactive) particles. Burning of bagasse at a temperature higher than 500ºC causes most amorphous SiO_2 to transform to its crystalline less reactive form called cristobalite, thereby worsening the pozzolanic activity of sugar cane bagasse ash. Based on the pozzolanic characteristics of bagasse ash, it can serve as an attractive waste material to be used as a supplementary cementitious material (SCM), (Sirirat and Supaporn, 2010). Bagasse ash has also shown to be suitable in geo-environmental applications for the treatment of lateritic soil in the construction of compacted clay liners for landfills (Eberemu, 2008).

MATERIALS AND METHODS

Materials

Soil: The soil used in this study is a natural reddish brown laterite which was collected from a borrow pit in Shika village, Zaria Local Government Area, Kaduna State in the northern part of Nigeria (latitude 11° $15^{'}$ N and longitude 7° $45^{'}$ E), by using the method of disturbed sampling at 1m depth from the natural earth surface to avoid organic matter influence. This depth corresponds to the B – horizon usually characterized by the accumulation of material leached from the overlying A – horizon. A study of the geological map

of Nigeria by Akintola (1982) and the soil map of Nigeria by Areola (1982) reveals that the soil belongs to the group of ferruginous tropical soils derived from acid igneous and metamorphic rocks.

Lime: The lime used for this study is hydrated lime obtained at Kaduna central market along Lagos street, Kaduna - Nigeria.

Bagasse Ash: Bagasse was locally obtained from a sugar cane market at Kofar Kansakali area of Gwale local government, Kano State-Nigeria. The sugar cane waste (bagasse) was collected, air-dried and burnt under atmospheric conditions. The residue obtained after burning was the ash that was collected in sacks and transported to the Geotechnical Research Laboratory, Department of Civil Engineering, Ahmadu Bello University, Zaria. The ash was then passed through B.S. sieve no. 200 (0.075 mm) to meet the requirements of both BS 1924 (1990) and ASTM (618-78). The chemical compositions of bagasse ash (BA) and lime were determined at the Center for Energy Research and Training (CERT), A. B. U. Zaria using

the method of Energy Dispersive X-Ray Fluorescence.

METHODS

Preliminary Tests: Laboratory tests were performed to determine the index properties of the natural soil and bagasse ash treated lime stabilized soil in accordance with BS 1377 (1990) and BS 1924 (1990), respectively.

Compaction: Compaction tests were performed on the natural and stabilized soils (0, 2, 4, 6 and 8% BA with 0, 2, 4, 6 and 8 % lime treatments by dry weight of natural lateritic soil); using the British Standard Light (BSL) energy.

Strength tests: Strength tests performed were used to determine unconfined compressive strength (UCS) and California Bearing Ratio (CBR) values. The UCS test specimens were compacted at British Standard Light (BSL) energy and cured for 7, 14 and 28 days before testing. CBR tests were carried out in accordance with Nigerian General Specifications (1997) which specify that specimens be dry cured for six days and then soaked for 24 hours before testing.
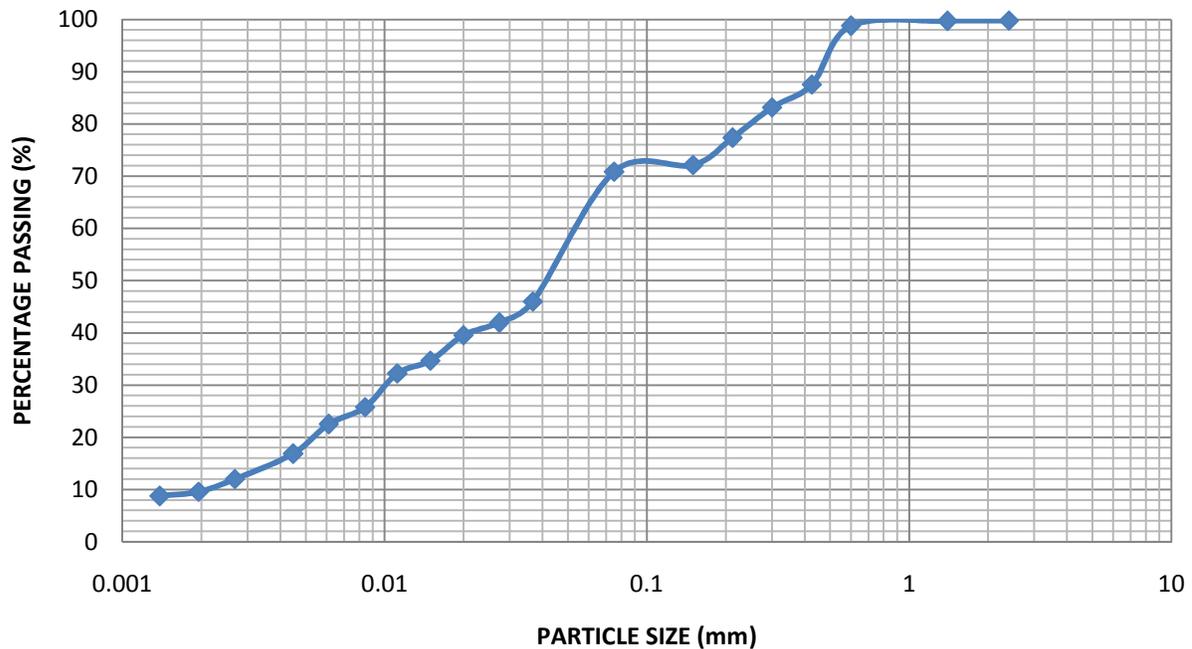

Figure (1): Particle size distribution curve for the natural lateritic soil

RESULTS AND DISCUSSION

Properties of Materials

The index properties of the natural soil show that it is an A-6 soil according to AASHTO classification system and low plasticity clay (CL), using the Unified Soil Classification System (USCS). The soil has a liquid limit value of 36.32%, a plastic limit of 21.30%, a plasticity index of 15.02%, a linear shrinkage of 3.60% and a specific gravity of 2.67 with 70.85 % of the soil particles passing the BS no. 200 sieve (0.075 mm aperture). The predominant clay mineral is kaolinite. The properties of the natural soil are summarized in Table 1, while its particle size distribution curve is shown in Figure 1. The oxide compositions of the bagasse ash and lime are summarized in Table 2.

Table 1. Properties of the natural lateritic soil

Property	Quantity
Percentage passing BS sieve no. 200	70.85
Liquid limit (LL) (%)	36.32
Plastic limit (PL) (%)	21.30
Plasticity index (PI) (%)	15.02
Linear shrinkage (LS) (%)	3.60
AASHTO classification	A-6
USCS	CL
Group index	9.0
Specific gravity	2.67
Natural moisture content (%)	15.8
Color	Reddish brown
Optimum moisture content (OMC) (%)	16.8
Maximum dry density (MDD) (kg/m³)	1.69
Unconfined Compressive Strength (kN/m^2)	
7-Day curing period	269
14-Day curing period	404
28-Day curing period	591
California bearing ratio (%)	
Unsoaked	13
Soaked (24-hour soaking)	7
Dominant clay mineral	Kaolinite

Table 2. Oxide composition of bagasse ash and lime

Oxide	Bagasse ash (%)	Lime (%)
SiO_2	57.95	37.71
Al_2O_3	8.23	11.61
FeO_3	3.96	0.17
CaO	4.52	43.93
MgO	4.47	-
K_2O	2.41	0.18
LOI*	5.0	-

* Loss on Ignition.

Compaction Characteristics

Maximum Dry Density

The variation of maximum dry density (MDD) of lime stabilized lateritic soil with bagasse ash content is shown in Fig. 2. The MDD decreased with the increase in both lime and bagasse ash contents. This observed decrease in MDD is probably due to the flocculation and agglomeration of clay particles due to cation exchange leading to corresponding decrease in dry density (Ochepo and Salahudeen, 2013). Decrease in MDD of the soil was reported by Meegoda et al. (1998). The low MDD may be attributed to the dispersed structure of the soil in the presence of the polar organic liquid, which consequently leads to reduced MDD (Meegoda et al., 1998). Decrease in maximum dry density (MDD) of the treated soils with increased lime and bagasse ash contents may also be due to the low specific gravity value of both lime and bagasse ash compared to that of the natural lateritic soil.

Optimum Moisture Content

The variation of optimum moisture content of lime stabilized lateritic soil with bagasse ash content is shown in Figure 3. The OMC increased continuously with the increase in both lime and bagasse ash contents. This trend is in conformity with results reported by Ola (1978), Gidigasu (1976) and Osinubi (1999). An increase in OMC may be due to increased demand for water which commensurates with the higher amount of lime/BA required for hydration

reaction and dissociation needed for cation exchange reaction (Salahudeen et al., 2014).
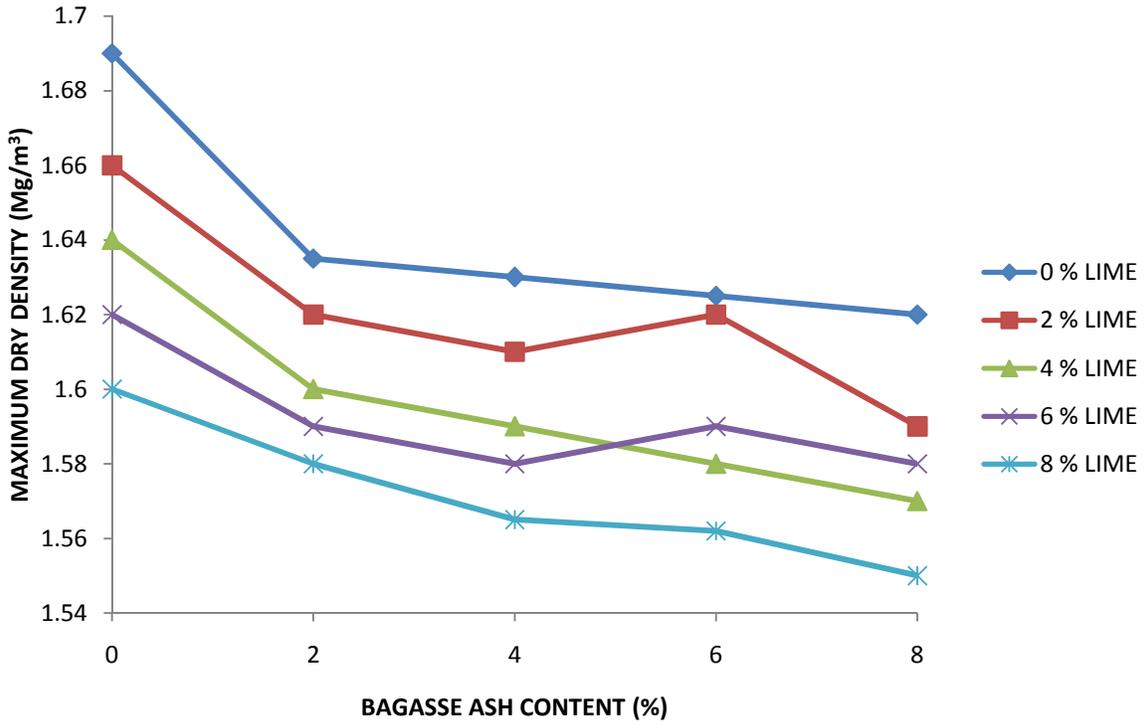

Figure (2): Variation of maximum dry density of lime stabilized lateritic soil with bagasse ash content
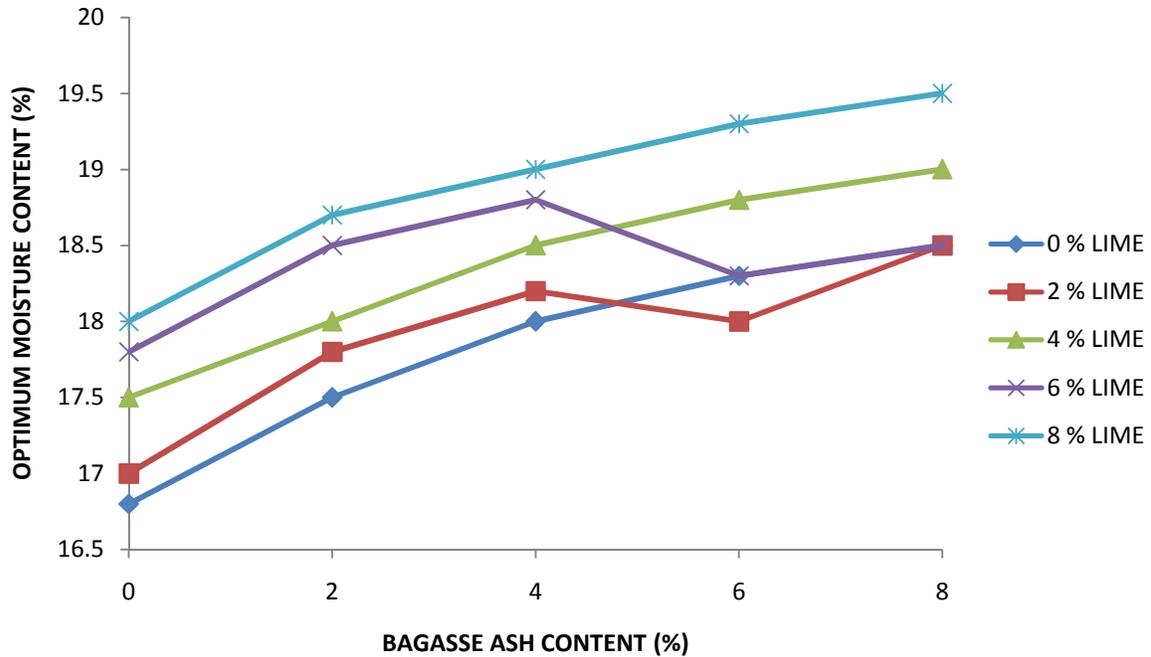

Figure (3): Variation of optimum moisture content of lime stabilized lateritic soil with bagasse ash content
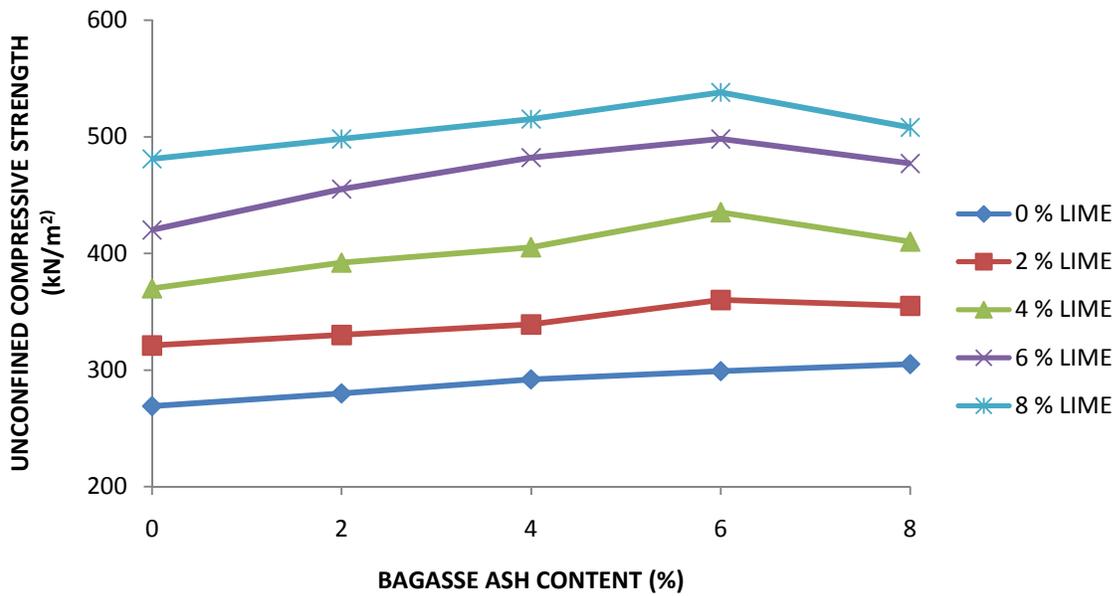
Figure (4): Variation of unconfined compressive strength of lime stabilized lateritic soil with bagasse ash content (7-day curing period)
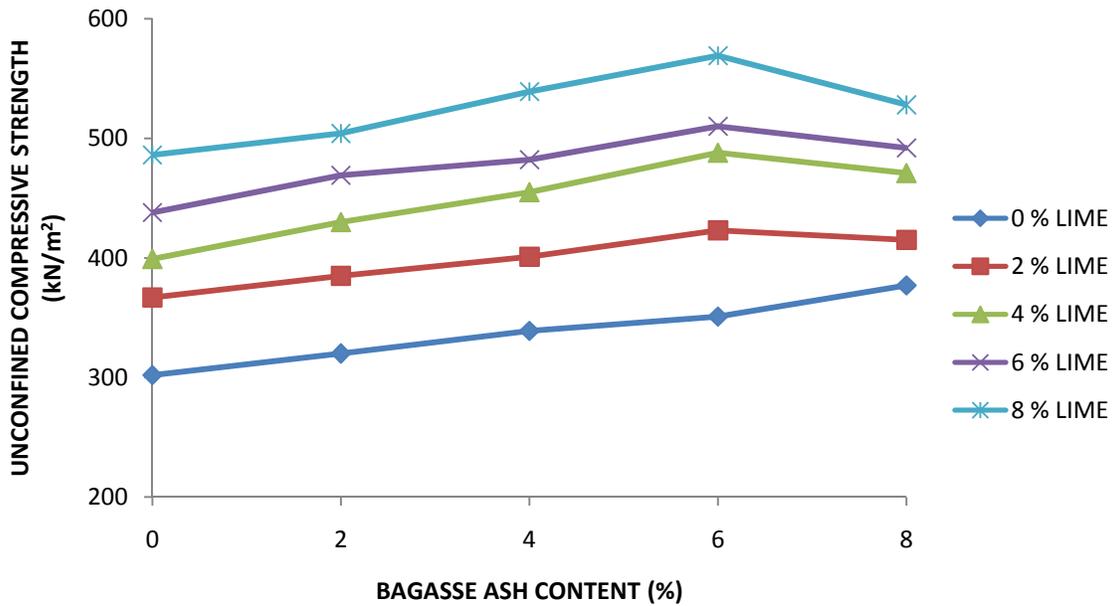

Figure (5): Variation of unconfined compressive strength of lime stabilized lateritic soil with bagasse ash content (14-day curing period)
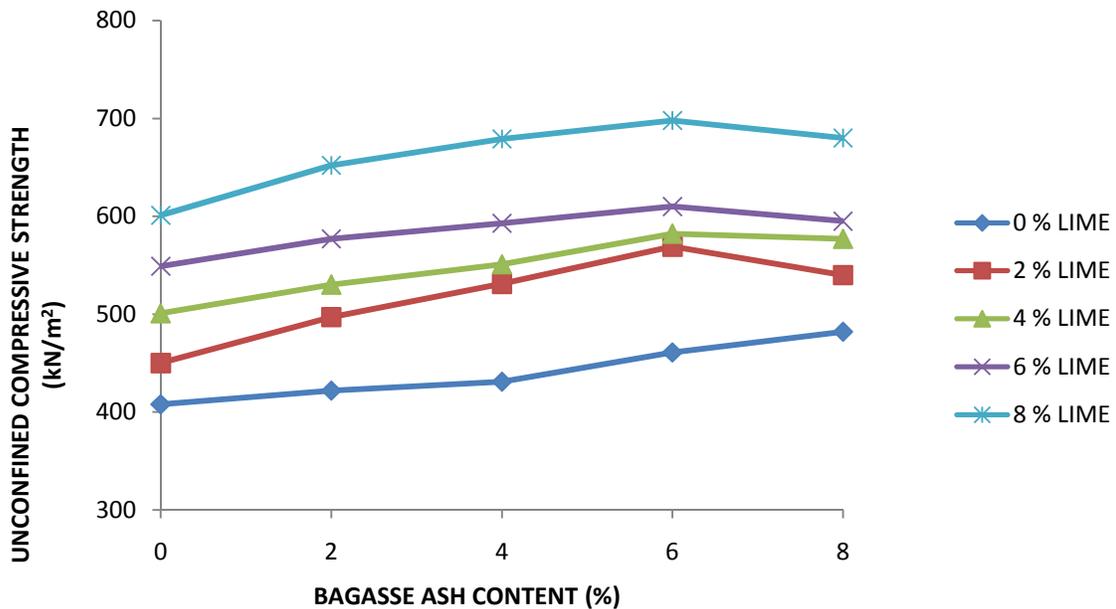
Figure (6): Variation of unconfined compressive strength of lime stabilized lateritic soil with bagasse ash content (28-day curing period)

Strength Characteristics
Unconfined Compressive Strength

The variation of unconfined compressive strength (UCS) of lime stabilized lateritic soil with bagasse ash content for 7-, 14- and 28-day curing periods are shown in Figures 4, 5 and 6. The UCS values increased with the increase in both lime and bagasse ash contents having peak values at 6% bagasse ash content and decreasing thereafter. The observed trends can be attributed to ion exchange at the surface of clay particles. The Ca^{2+} in cement kiln dust (CKD) reacted with the lower valence metallic ions in the clay microstructure which resulted in agglomeration of the clay particles (Moses and Saminu, 2012; Salahudeen et al., 2014). The increase in the UCS values was primarily due to the formation of various compounds such as calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH) and micro fabric changes, which are responsible for strength development (Jones and Holtz, 1973; Osinubi et al., 2011). The subsequent decrease in the unconfined compressive strength (UCS) values above 6% bagasse ash treatment may be due to

insufficient water to meet the amount of moisture required for complete hydration reaction.

Although the strength of the lateritic soil improved with both lime and bagasse ash treatment, none of the values at all additive contents met the 1710 kN/m^2 unconfined compressive strength value specified by TRRL (1977) as a criterion for adequate stabilization using Ordinary Portland Cement.

California Bearing Ratio (CBR)

The variation of unsoaked and soaked (24-hour soaking) California Bearing Ratio (CBR) values of the soil with lime and bagasse ash contents is shown in Figures 7 and 8. Generally, the CBR values recorded increased with higher lime content. Increase in CBR values was also recoded with bagasse ash content having its peak value at 6% BA content. This increase could be due to the presence of adequate amounts of calcium required for the formation of calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH), which are the major compounds responsible for strength gain. All the unsoaked CBR values at 6% lime

and also at 2 and 4% BA/2 and 4% lime contents and above met the 20-30% requirement for sub-base reported by Gidigasu and Dogbey (1980) for materials compacted at the optimum moisture content. The soaked CBR value at 6 % BA/6 % lime contents also met this requirement.
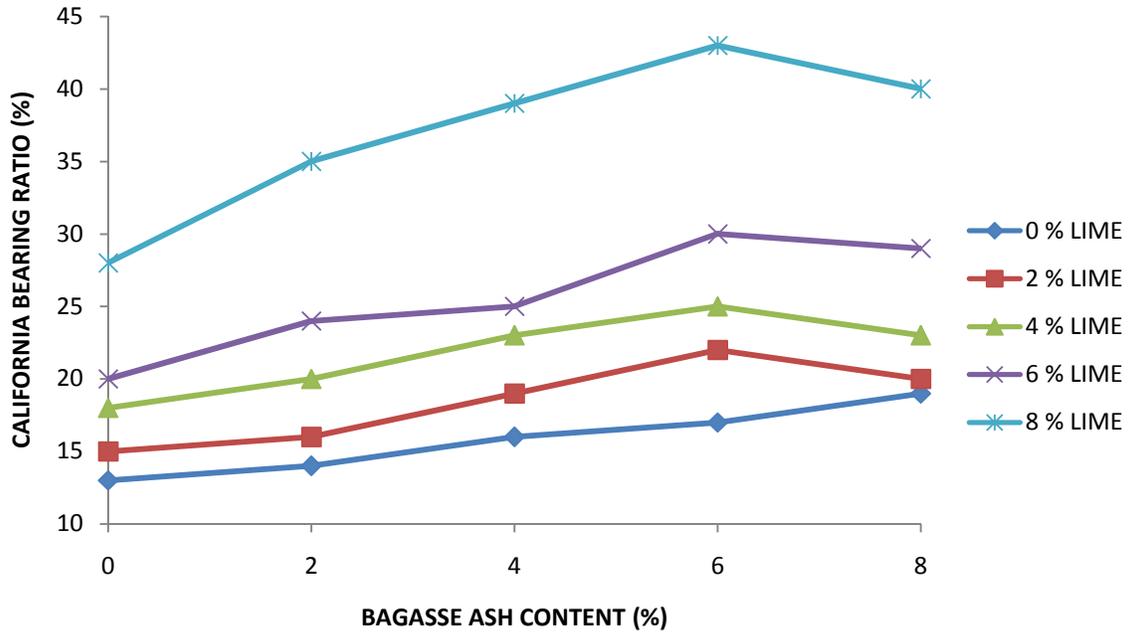

Figure (7): Variation of unsoaked California bearing ratio of lime stabilized lateritic soil with bagasse ash content
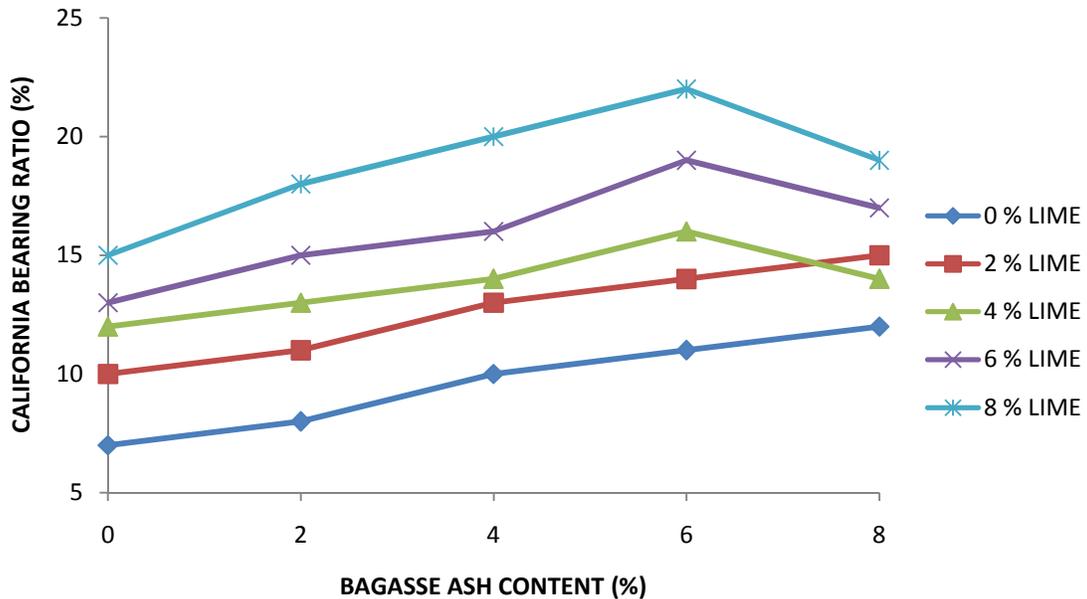

Figure (8): Variation of soaked California bearing ratio of lime stabilized lateritic soil with bagasse ash content

CONCLUSIONS

The lateritic soil was classified as an A-6 (9) soil using the AASHTO classification system and CL using the USCS.

Peak UCS and CBR values of 698 kN/m^2 and 43% were recorded for soil treated with 8% lime/6% BA. The Peak CBR value met the 20-30% requirement for sub-base reported by Gidigasu and Dogbey (1980) for materials compacted at optimum moisture content.

Although the properties of the natural soil improved, peak UCS value fell short of the 1710 kN/m^2 unconfined compressive strength value specified by TRRL (1977) as a criterion for adequate stabilization using Ordinary Portland Cement.

In lateritic soil treatment, 8% lime / 6%BA contents will satisfactorily modify the soil.

REFERENCES

AASHTO. (1986). Standard Specifications for Transport Materials and Methods of Sampling and Testing. 14th Edition. American Association of State Highway and Transport Officials (AASHTO), Washington, D.C.

Adeyemi, G.O., and Abolurin, S.B. (1999). "Strength characteristic of a chemically stabilized laterite soil from kilometer 4, Ile – Ife / Sokona road south – west Nigeria". Journal of Mininig and Geology, 36 (1), 113-119.

Adeyemi, G.O., Ojo, A.A., and Omidiran, M.O. (1990). "Relationship between some index properties and crushing strengths of three south – eastern Nigeria laterites clay deposits." Nigerian Journal of Technical Research, 1 (2).

Akintola, F. A. (1982). "Geology and geomorphology". In: Nigeria in maps, edited by K.M. Barbour, Hodder and Stoughton, London, UK.

Areola, O. (1982). "Soils". In: Nigeria in maps, edited by K.M. Barbour, Hodder and Stoughton, London, UK.

ASTM. (1992). Annual Book of Standards, Vol. 04.08, American Society for Testing and Materials, Philadelphia.

Bridges, E.M. (1979). "World Soils". 2nd Edition. Cambridge University Press, Cambridge, 14-21.

B.S. 1377. (1990). Methods of testing soil for civil engineering purposes". British Standards Institute, London.

B.S. 1924. (1990). "Methods of testing for stabilized soils". British Standards Institute, London.

Cordeiro, G.C., Toledo Filho, Tarvares, L.M., and Fairbairn. (2008). "Pozzolanic activity and filler effect of sugar cane bagasse ash in Portland cement and lime mortars".

De-Graft Johnson, J.W.S. (1975). "Laterite soil in road construction". Proceedings of Regional Conference for Africa on Soil Mechanics and Foundation Engineering, Durban, South, 89-97.

Eberemu, A. O. (2008). "Evaluation of compacted lateritic soil treated with bagasse ash as hydraulic barriers in municipal solid waste containment system". Unpublished PhD Thesis, Department of Civil Engineering, Ahmadu Bello University, Zaria, Nigeria.

Fletcher, G.A., and Vernon, A.S. (1974). "Construction guides for soils and foundation". John Wiley and Sons, Inc. New York.

Gidigasu, M.D. (1976). "Laterite soil engineering: pedogenesis and engineering principles". Elsevier Scientific Publication Company, Amsterdam.

Gidigasu, M.D., and Dogbey, J.L.K. (1980). "Geotechnical characterization of laterized decomposed rocks for pavement construction in dry sub-humid environment." Proceedings of the 6th South-East Asian Conf. on Soil Engineering, Taipei, 1, 493-506.

Hunt, R.E. (1984). "Geotechnical engineering manual". McGraw Hill Book Company, New York.

Jones, D., and Holtz, J. (1973). "Expansive soils: hidden disaster". Civil Engineering, ASCE, 43, 54.

Meegoda, N.J., Chen, B., Gunasekara, S.D., and Pederson, P. (1998). "Compaction characteristics of contaminated soils – reuse as a road base material". Recycled Materials in Geotechnical Applications, GSP 79, ASCE, 195-209.

Moses, G.K., and Saminu, A. (2012). "Cement kiln dust stabilization of compacted black cotton soil". IRJI Journal of Research in Engineering, 17, 826-834.

Nigerian General Specification. (1997). "Roads and bridge works". Federal Ministry of Works, Lagos, Nigeria.

Ochepo, J., and Salahudeen, A. B. (2013). "Effect of oil contamination on lime and cement stabilized soil for pavement structures". 2013 Conference Proceedings, Nigerian Institution of Civil Engineers, 43-53.

Ogbonyomi, T.O. (1998). "Possible uses of bagasse ash as alternative cement". Unpublished MSc Thesis. Ahmadu Bello University, Zaria, Nigeria.

Ola, S.A. (1975). "Stabilization of Nigeria laterite soils with cement, bitumen and lime". Proceedings of 6th Regional Conference for Africa on Soil Mechanics and Foundation Engineering. Durban, South Africa, 145-152.

Ola, S. A. (1978). "The geology and geotechnical properties of the black cotton soils of north-eastern Nigeria." Engineering Geology, 12, 375-391.

Ola, S.A. (1983). "Geotechnical properties and behavior of some Nigerian lateritic soil". In: Tropical Soils of Nigeria in Engineering Practice". A.A. Balkema/Rotterdam, 61-85.

Osinubi, K. J. (1995). "Lime modification of black cotton soils." Spectrum Journal, 2 (1, 2), 112-122.

Osinubi, K.J. (1998). "Influence of compactive efforts and compaction delay on lime-treated soil". Journal of Transportation Engineering, 124 (2), 149-155.

Osinubi, K.J. (1999)." Evaluation of admixture stabilization of Nigeria black cotton soil." Nigerian Society of Engineers (NSE) Technical Transactions, 34 (3), 88-96.

Osinubi, K.J. (2003). "Laterite soils and other problem soils of Africa". Unpublished MSc lecture Note, Ahmadu Bello University, Zaria.

Osinubi, K.J., and Bajeh, I. (1994). "Bituminous stabilization of laterite." Spectrum Journal, 1 (2), 104-112.

Osinubi, K.J., and Katte, V.Y. (1997). "Effect of elapse time after mixing on grain size and plasticity characteristics, I: soil-lime mixes". Nigerian Society of Engineers Technical Transactions, 32 (4), 65-77.

Osinubi, K.J., and Stephen, A.T. (2007) "Influence of compactive efforts on bagasse ash treated black cotton soil". Nigerian Journal of Soil and Environment Research, 7, 92-101.

Osinubi, K.J., Eberemu, A. O., and Oyelakin, M.A. (2011). "Improvement of black cotton soil with ordinary Portland cement - locust bean waste ash blend". Electronic Journal of Geotechnical Engineering, Bund. F, 16, 6199-627.

Salahudeen, A. B., and Akiije, I. (2014). "Stabilization of highway expansive soils with high loss on ignition content kiln dust". NIJOTECH, 33 (2), 141-148.

Salahudeen, A. B., Eberemu O. A., and Osinubi, K. J. (2014). "Assessment of cement kiln dust-treated expansive soil for the construction of flexible pavements". Geotechnical and Geological Engineering, Springer, 32 (3).

Singh, G. (1991). "Highway engineering". 3rd Edition.Standard Publishers Distributors, 599-619.

Sirirat, J., and Supaporn, W. (2010). "Pozzalanic activity of industrial sugar cane bagasse ash". Suranaree Journal of Science and Technology, 17 (4), 349-357.

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, H. M. S. O., London.

Zonn, S.V. (1986). "Tropical and sub-tropical soil science". Mir Publishers, Moscow.