World Academy of Science, Engineering and Technology
International Journal of Geological and Environmental Engineering
Vol:9, No:10, 2015

Improvement of Deficient Soils in Nigeria Using Bagasse Ash: A Review

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Abstract**—**Review of studies carried out on the use of bagasse ash for the improvement of deficient soils in Nigeria, with emphasis on lateritic and black cotton soils is presented. Although, the bagasse ash is mostly used as additive to the conventional soil stabilizers (cement and lime), the studies generally showed improvement in the geotechnical properties of the soils, either modified or stabilized with the ash. This showed the potentials of using this agricultural waste (bagasse ash) in the improvement of geotechnical properties of deficient soils, thus suggesting that using this material at large scale level in geotechnical engineering practice could help in the provision of stable and durable structures, reduce cost of soil improvement and also reduces environmental nuisance caused by the unused waste in Nigeria.

Keywords**—**Bagasse ash, Black cotton soil, Deficient soil, Laterite, Soil improvement.

I. Introduction

IN geotechnical engineering, deficient soils are soils which do not meet certain criteria required for their intended geotechnical use. The intended use could either be for road or embankment construction, foundation subsoil, clay liners for containment of leachates, etc. In the tropics, these soils could be lateritic soils or any other tropical soils (e.g. black cotton soils). Laterite is a soil group, which is commonly found in the leached soils of the humid tropics and is formed under weathering systems that cause the process of laterization [1]. In Nigeria and other tropical regions of the world, the dominant soil material available for the construction of sub-base and bases courses for both flexible and rigid pavements is the lateritic soil. This is because of its abundance and cost effectiveness [2]. A lot of lateritic gravels and pisoliths are good for gravel roads. There are instances where laterites may contain substantial amount of clay minerals that its strength and stability cannot be guaranteed under load, especially in the presence of moisture. These laterites are also common in many tropical regions including Nigeria where in most cases sourcing for alternative soil may prove economically unwise but rather improve the available soil to meet the desired specifications [3], [4].

Black cotton soils are expansive soils that principally occur in arid and semi-arid regions of the tropical/temperate zones marked with dry and wet seasons, with low rainfall, poor drainage and exceeding great heat [5], [6]. In geotechnical engineering practice, Civil Engineers consider black cotton soils as problematic, because of their unconventional behavior. They show large volume changes with respect to variation of seasonal moisture content and form a major soil group found in North Eastern part of Nigeria [7]. They are characterized by high shrinkage and swelling properties. Because of their swelling and shrinkage characteristics, black cotton soils are challenges to Civil Engineers. It is very hard when dry, but losses its strength when wet. Due to the presence of montmorillonite and illite, they exhibit very low bearing capacity, low permeability and high volume change. In their natural state, these properties make them unsuitable for construction of embankment, highway, building or any other load bearing structure [8].

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Over the times, cement and lime have been the two main materials used for modifying and or stabilizing soils. These materials have rapidly increased in price due to the sharp increase in the cost of energy since 1970s [9]. The over dependent on the utilization of industrially manufactured soil improving additives (cement, lime etc.); have kept the cost of construction of stabilized road high. This hitherto, have continued to deter the underdeveloped and poor nations of the world from providing accessible roads to their rural dwellers who constitute the higher percentage of their population and are mostly, agriculturally dependent [10]. Thus the use of agricultural waste, such as bagasse ash will considerably reduce the cost of construction and as well reducing the environmental hazards the disposal of these waste causes.

Bagasse is the fibrous residue obtained from sugar cane after the extraction of sugar juice at sugar cane mills [11]. Bagasse ash is the residue obtained from the incineration of bagasse in sugar producing factories. The ash has been reported to be a good pozzolanic material [12], [13]. Usman et al. [14] reported a silica and alumina contents of up to 77.29% and 10.95% respectively for ash from bagasse burnt at 700°C. Researches, although still at laboratory levels have recently been focused on the improvement of geotechnical characteristics of soils using bagasse ash. Some of these studies are presented below as a review.

II. Using Bagasse Ash for Improvement of Lateritic Soil

Studies have been carried out on the use of bagasse ash on the improvement of lateritic soils. Mu'azu [15] treated an A-7-6 lateritic soil with 1-4% cement contents and admixed with 2-8% bagasse ash content. Plasticity and particle size distribution characteristic of the bagasse ash on cement treated laterite were evaluated. Reduction in liquid limit and plasticity index was observed (Figs. 1 and 2) while plastic limit increased. Reduction in the percentage of fines as a result of formation of heavier pseudo-particle with percentage passing BS Sieve No. 200 reduced from 63% to almost zero. 4-6% of bagasse was recommended as optimal.

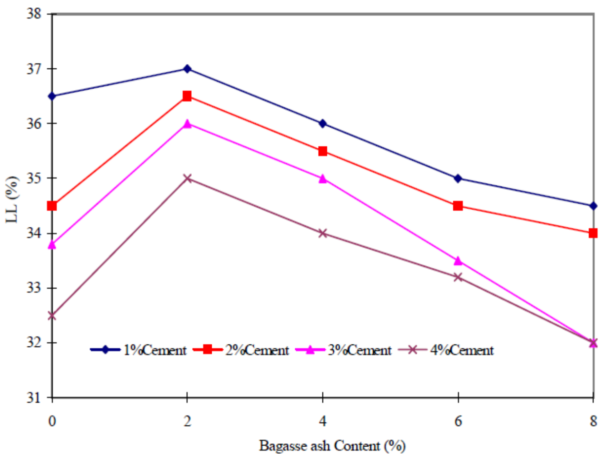

Fig. 1 Variation of Liquid Limit (LL) with bagasse ash content [15]

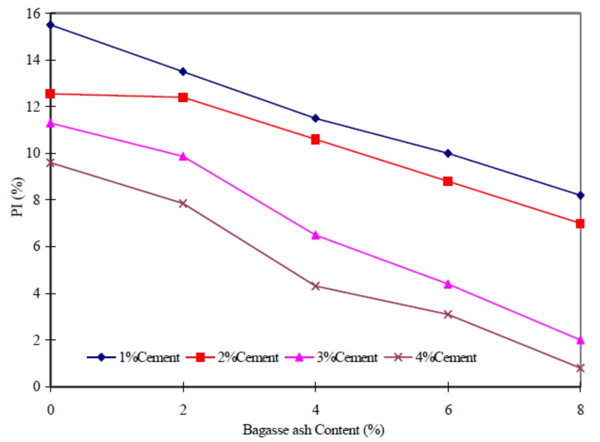

Fig. 2 Variation of Plasticity Index (PI) with bagasse ash content [15]

Mu'azu [16] carried out a study on the influence of competitive effort on bagasse ash with cement treated lateritic soil. An increase in optimum moisture content (OMC) and decrease in maximum day density (MDD) was observed with increase in the percentage of bagasse ash and cement.

Osinubi et al. [17] stabilized lateritic soil with up to 12% bagasse ash. Their study focused on the effect of up to 12% bagasse ash by weight of dry soil on the geotechnical properties of the deficient lateritic soil. Test specimens were subjected to particle size analysis, compaction, unconfined compressive strength (UCS), California bearing ratio (CBR) and durability tests. The compactions were carried out at the energy of the British Standard Light (BSL). The results of the study showed changes in moisture–density relationships resulting in lower maximum dry densities (MDD), higher optimum moisture contents (OMC) (Fig. 3), reduction in fine fractions with higher bagasse ash content in the soil – stabilizer mixtures. A 2% bagasse ash treatment of lateritic soil yielded peak 7 days UCS and CBR values of 836 kN/m^2 (Fig. 4) and 16% (Fig. 5), respectively. They concluded that, since these values are below 1,700 kN/m^2 and 180% for UCS and CBR, respectively, recommended for adequate cement stabilization, it implies that bagasse ash cannot be used as a 'standalone' stabilizer but should be employed in admixture stabilization.

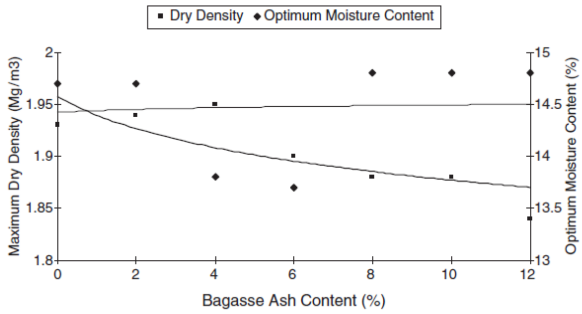

Fig. 3 Variation of maximum dry density and optimum moisture content with bagasse ash content [16]

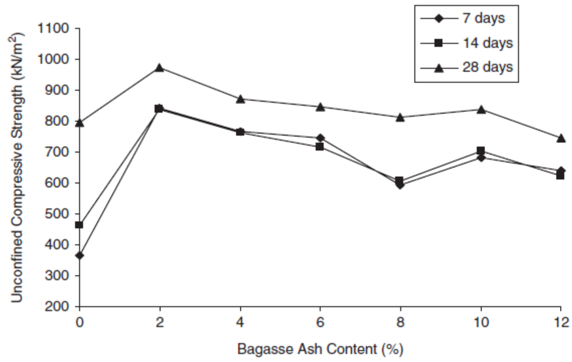

Fig. 4 Variation of unconfined compressive strength with bagasse ash content [16]

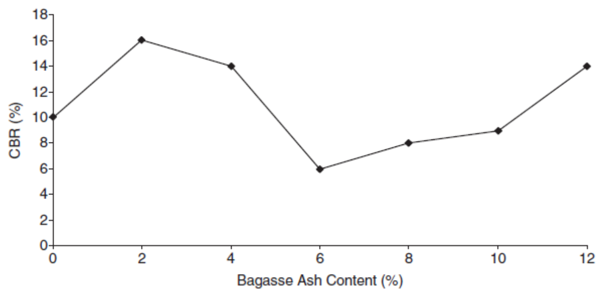

Fig. 5 Variation of California bearing ratio with bagasse ash content [16]

Osinubi and Alhassan [12] investigated the use of lime and bagasse ash in the modification of laterite, using an A-7-6 lateritic soil collected from Shika area of Zaria, Nigeria. The soil was modified with up to 4% lime content by dry weight of the soil. Effect of bagasse ash on the modified soil was studied with respect to particle size distribution, plasticity characteristics, compaction characteristics and shear strength parameters, using British standard light compaction energy. The results obtained indicated increase in the particle sizes, improvement in the plasticity of the soil with decrease in liquid limit and increase in plastic limit. The maximum dry density decreased when treated with 1% lime/6% bagasse ash from 1.79 to 1.76 Mg/m^3, while the optimum moisture content increased from 16.25 to 18.40%. The shear strength parameters also generally improved with decrease in cohesion from 130 to 80 kN/m^3, while angle of internal friction increased from 19 to 23° at 1% lime/6% bagasse ash contents (Figs. 6 and 7). On the bases of the compaction and shear strength parameters results, 6% bagasse ash content was recommended as optimal for admixing with 1% lime for modification.

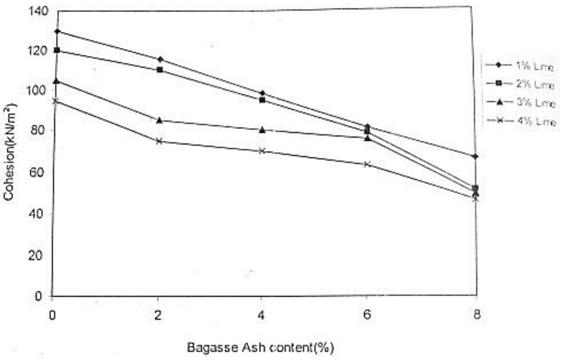

Fig. 6 Variation of cohesion of soil-lime mixtures with bagasse ash content [12]

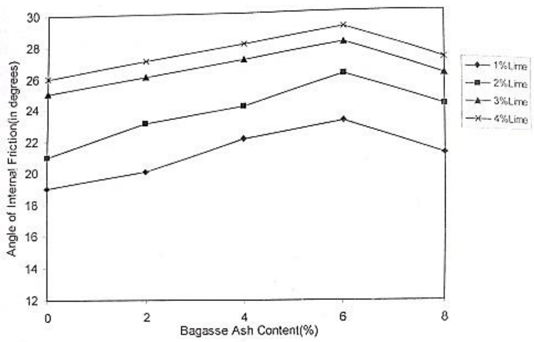

Fig. 7 Variation of angle of internal friction of soil-lime mixtures with bagasse ash content [12]

Osinubi and Mustapha [18] investigated the optimal use of bagasse ash on cement stabilized laterite, by treating A-7-6 lateritic soil classified as CL on AASHTO with up to 8% each content for of both cement and bagasse ash. California bearing ratio and unconfined compressive strength were used as evaluation criteria for the treated specimen compacted at British Standard Heavy (BSH) energy level. Substantial improvement in the strength and durability values of the treated specimens was observed up to 6% bagasse ash content at specific cement contents. Based on durability assessment of the treated specimens, they recommended 6% cement/6% bagasse ash and 2% cement/6% bagasse ash as optimal additives for the stabilization of CB1 (heavy trafficked) and CB2 (lightly trafficked) roads respectively.

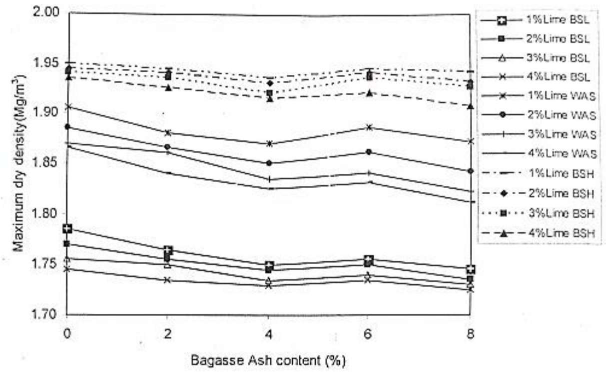

Fig. 8 Variation of maximum dry density with bagasse ash content for the different compaction energy levels [13]

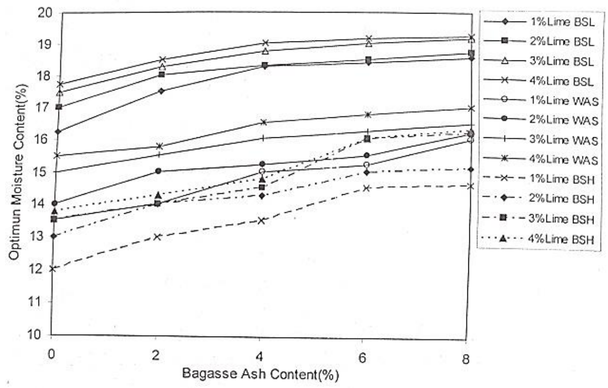

Fig. 9 Variation of optimum moisture content with bagasse ash content for the different compaction energy levels [13]

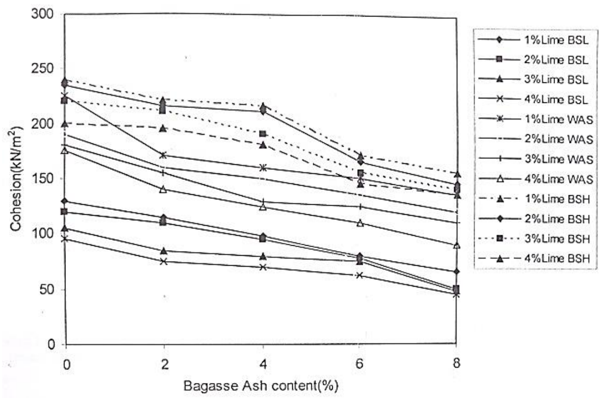

Fig. 10 Variation of cohesion with bagasse ash content for the different compaction energy levels [13]

Using an A-7-6 lateritic soil collected from Shika area of Zaria, Nigeria, [13] investigated the effect of three energy levels-British Standard Light (BSL), West African Standard (WAS) and British Standard Heavy (BSH) and bagasse ash admixtures on lime modified laterite. The soil was modified with up to 4% lime content by dry weight of the soil and up to 8% bagasse ash content. The results obtained indicated increase in the particle sizes with higher dosage of the additives; the particle sizes decreases with higher compaction energy. Decrease in the maximum dry density and increase in optimum moisture content with higher dosage of the additives and compaction energy was observed (Figs. 8 and 9). There was also improvement in the shear strength parameters with dosage of the additives and compaction energy (Figs. 10 and 11). The results showed that the soil modified with 1% lime and 6% bagasse ash admixture meets the Highway Research Board limits, Millard and O'Reilly free flow criteria as well as the limits set by Nigerian General Specification for Roads and Bridge Works, at all the compaction energy levels considered.

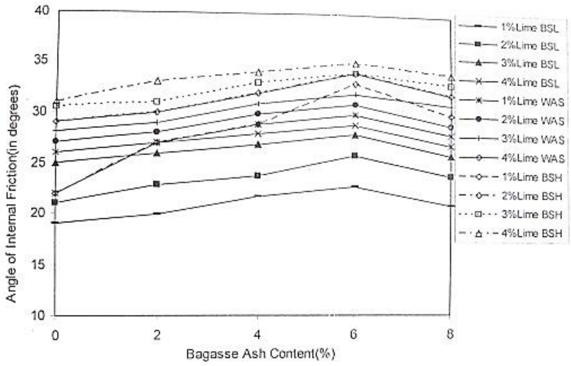

Fig. 11 Variation of angle of internal friction with bagasse ash content for the different compaction energy levels [13]

Osinubi and Mustapha [19] investigated the effect of energy level on cement-sugar cane bagasse ash admixture on laterite. They treated A-7-6 lateritic soil with cement and sugar cane bagasse ash admixture (SCBA) by compacting the specimens at three energy level-British Standard Light (BSL), West African Standard (WAS) and British Standard Heavy (BSH). They observed a general increase in the maximum dry density, California bearing ratio and unconfined compressive strength with higher compaction energies and dosages of the additives (Figs. 12 and 13). They also observed an improvement in durability of the treated soil, and recommended 2% cement/6% bagasse ash as optimal.

Osinubi [20] studied the effect of up to 12% bagasse ash by weight of dry soil on the geotechnical properties of deficient lateritic soil and concluded that bagasse ash cannot be used as a 'standalone' stabilizer but should be employed as admixture.

Amu et al. [21] carried out a study to determine the geotechnical properties of lateritic soil modified with sugarcane straw ash with a view to obtaining a cheaper and effective replacement for the conventional soil stabilizers. Preliminary tests were performed on three samples, A, B and C for identification and classification purposes followed by the consistency limit tests. Strength tests: compaction, California bearing ratio (CBR), unconfined compression test and triaxial were also performed on both unstabilized and stabilized samples adding 2, 4, 6, and 8% sugarcane straw ash. The results of the study showed that sugarcane straw ash improved the geotechnical properties of the soil samples. Optimum moisture content increased from 19.0 to 20.5%, 13.3 to 15.7% and 11.7 to 17.0%, CBR increased from 6.31 to 23.3%, 6.24 to 14.88% and 6.24 to 24.88% and unconfined compression strength increased from 79.64 to 284.66 kN/m^2, 204.86 to 350.10 kN/m^2 and 240.4 to 564.6 kN/m^2 for samples A, B and C respectively. They therefore concluded that Sugarcane straw ash is an effective stabilizing agent for lateritic soils.

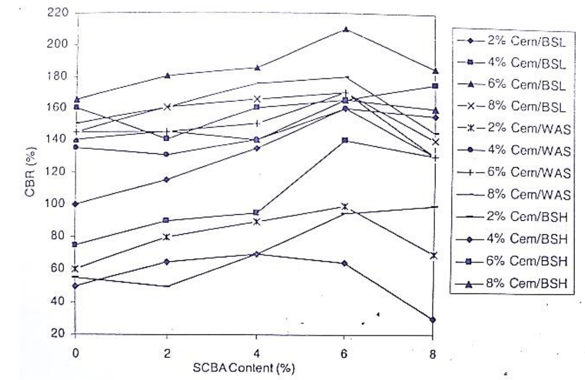

Fig. 12 Variation of CBR with SCBA content at the different compaction energy levels [19]

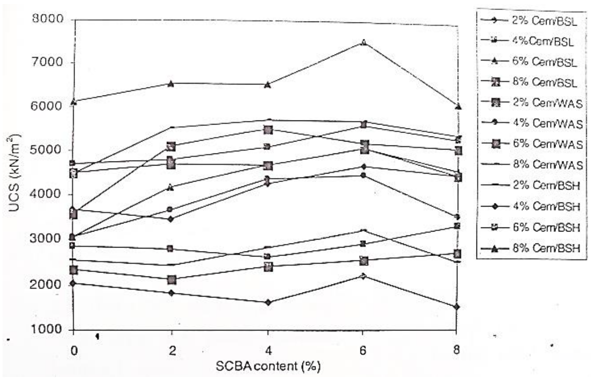

Fig. 13 Variation of UCS with SCBA content at the different compaction energy levels [19]

Onyelowe [22] collected A-2-6 lateritic soil from a borrow site in Ukwa East Local Government Area of Abia State, and stabilized it using 4% and 6% cement with various content of bagasse ash ranging from 0% (control), to 10% by weight of the dry soil at 2% variation. Effect of bagasse ash on the soil was investigated with respect to compaction characteristics and California bearing ratio (CBR). The results obtained indicated a decrease in maximum dry density (MDD) with 4% cement content and an increase with 6% cement content. An increase in optimum moisture content (OMC) for both 4% and 6% cement content all with increase in bagasse ash content of 0, 2, 4, 6, 8, and 10% by weight of the soil was also observed. CBR of the soil also showed improvement. The study showed potential of using bagasse ash as admixture in cement stabilized lateritic soil.

A laboratory study, aimed at evaluating the strength of laterite soil stabilized with recycled asphalt pavement (RAP) and sugarcane bagasse ash (SCBA) was carried out by Ochepo [23]. The laterite soil was mixed with RAP in 40/60 ratio and treated with SCBA at 0, 2, 4, 6, 8 and 10% by weight of the soil-RAP mixture. Particle size analysis, compaction test, unconfined compressive strength, (UCS), and California bearing ratio (CBR), tests were carried out on the prepared specimens. The results obtained showed that addition of RAP reduces the optimum moisture content, (OMC), and increases the maximum dry density (MDD) of the sample as compared with the natural soil, while the addition of SCBA up to 4% resulted in further increase in the MDD after which the values reduced, whereas OMC increased with increasing SCBA. UCS and CBR increased with SCBA treatment and curing period respectively. Soaking of the specimens for 24 hours resulted in reduced CBR values. Based on the laboratory results obtained and based on the strength criteria for soil-lime, it was observed that 6 to 8% SCBA treatment of the soil-RAP mixture yielded the best results meeting the requirement for sub base course and 10% SCBA treatment gives the best results meeting the requirement for base course for light trafficked roads.

Ochepo et al [2] carried out a study to evaluate the strength of laterite soil mixed with recycled asphalt pavement RAP and sugarcane bagasse ash, SCBA. The soil was mixed with RAP in 60/40 ratio and treated with SCBA at 0, 2, 4, 6, 8 and 10% by weight of the soil-RAP mix. Particle size analysis, compaction test, unconfined compressive strength and California bearing ratio tests were carried out on the prepared specimens. The results showed that addition of RAP reduces the optimum moisture content and increases the MDD of the sample as compared to the natural soil while addition of bagasse ash up to 4% after which the MDD reduced (Fig. 14). The OMC increased with increasing SCBA. UCS and CBR increased with increased in SCBA content and curing period (Fig. 15). Soaking of the specimens for 24 hour resulted in reduced CBR values. Based on the results of their study and on the strength criteria for soil-lime, the authors recommended that the soil-RAP-SCBA mix can be used for sub-base course for light and heavy traffic using 6 to 8% and 10% SCBA treatments respectively.

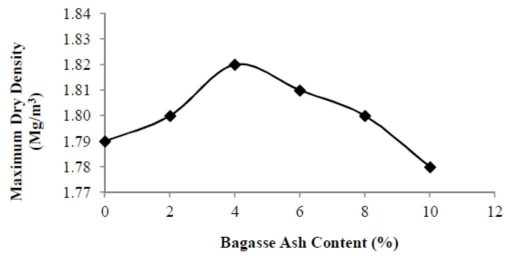

Fig. 14 Variation of MDD with bagasse ash treatment for soil-RAP mix [2]

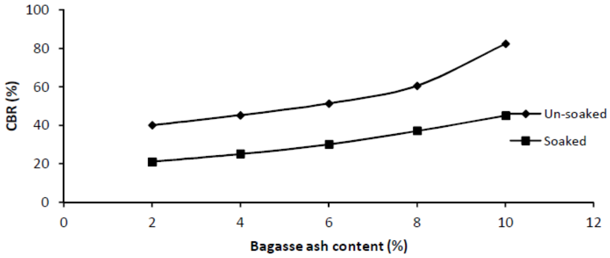

Fig. 15 Variation of CBR with bagasse ash treatment for soil-RAP mix [2]

Eberemu [24] studied the compressibility characteristics of compacted lateritic soil treated with bagasse ash. Compacted lateritic soil treated with up to 16% bagasse ash content was subjected to one-dimensional consolidation test using the British Standard Light (BSL) compactive effort; prepared at -2%, 0% and +2% of the optimum moisture content (OMC). The study showed improvement in index properties, lower maximum dry density (MDD) and higher optimum moisture content (OMC) with increased ash treatment. In a pattern similar to natural clay, the void ratio decreased and increased with pressure increase and decrease, respectively. An increase in the gross yield stress was recorded with increased bagasse ash content and water content relative to optimum; a reduction in compression index was recorded with increase in bagasse ash treatment and water content relative to optimum. Coefficient of volume compressibility decreased with increased loading pressure, while bagasse ash content did not show any established trend. The coefficient of consolidation decreased with increased loading pressure and bagasse ash treatment. The results of the study (Fig. 16) showed an overall improvement in the consolidation properties, suggesting the suitability of the bagasse ash in fills for embankment and low lying marginal land for foundation works; and solving the environmental problems associated with waste bagasse disposal.

Sadeeq et al. [25] carried out a study 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 [26] and BS 1924 [27], respectively for unstabilized and stabilized soils. 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 lateritic soil classified as A-6(9) and inorganic clay material CL using AASHTO and Unified Soil Classification System respectively was obtained from Shika area of Kaduna State, Nigeria. The natural soil has a liquid limit, plastic limit and plasticity index values of 36.32, 21.30 and 15.02% respectively. The maximum dry density (MDD) and Optimum Moisture Content (OMC) of the soil was 1.69 kg/m^3 and 16.8% respectively. 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, while 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 (Figs. 17 and 18). The author concluded that the recorded peak CBR value met the 20–30% requirement for sub-base reported by [28] 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 Transport and Road Research Laboratory (TRRL) [29] as a criterion for adequate stabilization using ordinary Portland cement.

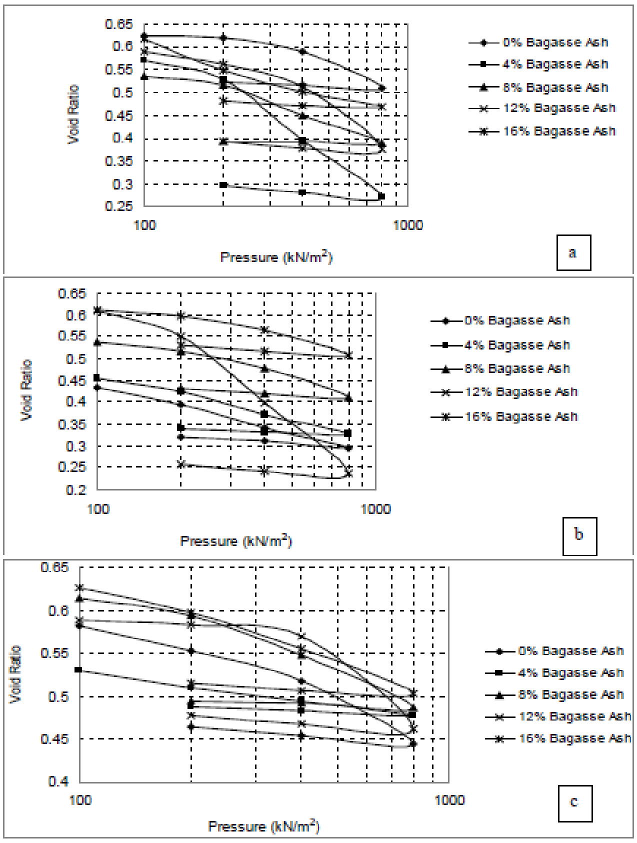

Fig. 16 Variation of void ratio with pressure for specimens prepared at (a) 2% dry of optimum (b) optimum moisture content and (c) 2% wet of optimum [24]

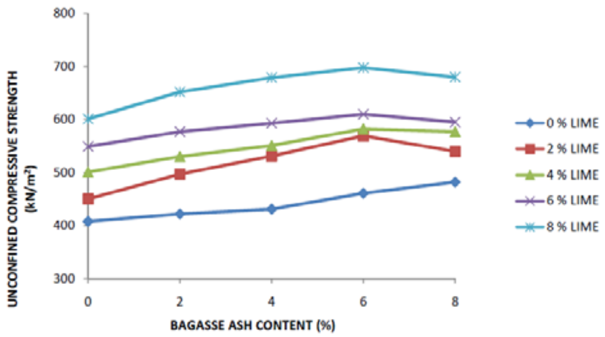

Fig. 17 Variation of 28-days unconfined compressive strength of lime-bagasse ash stabilized lateritic soil [25]

III. Using Bagasse Ash for Improvement of Black Cotton Soils

Studies have also been carried out on the use of bagasse ash on the improvement of black cotton soils. Osinubi and Stephen [30] carried out a study whose result showed that bagasse has positive effect on particle size distribution and plasticity characteristics of black cotton soil.

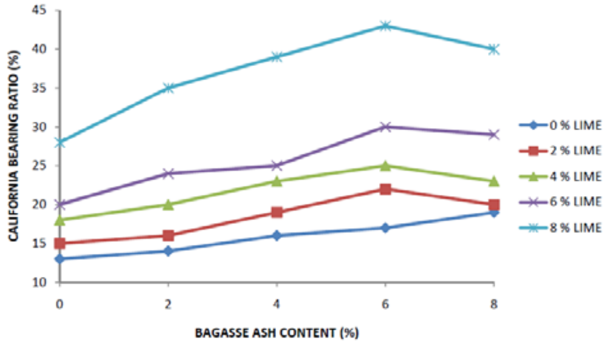

Fig. 18 Variation of unsoaked California bearing ratio of lime stabilized lateritic soil with bagasse ash content [25]

Moses and Osinubi [31] carried out a laboratory study on the influence of compactive effort on A-7-6 expansive black cotton soil specimens treated with up to 8% ordinary Portland cement admixed with up to 8% bagasse ash by dry weight of soil and compacted using the energies of the standard Proctor (SP), West African Standard (WAS) and modified Proctor (MP). The 7 day, unconfined compressive strength values of the natural soil for SP, WAS and MP compactive efforts were found to be 286, 401 and 515 kN/m^2 respectively, while the peak values (Fig. 19) of 1019, 1328 and 1420 kN/m^2, recorded at 8% cement/ 6% bagasse ash, 8% cement/2% bagasse ash and 6% cement/4% bagasse ash treatments, respectively were less than 1710 kN/m^2 conventionally used as criterion for adequate cement stabilization (Fig. 8). They observed increase in the soaked California bearing ratio values of the cement/bagasse ash stabilized soil with higher energy level from 2, 4 and 10% for the natural soil to Peak values of 55, 18 and 8% at 8% cement/4% bagasse ash, 8% cement/2% bagasse ash and 8% cement /4% bagasse ash, treatments when SP, WAS and MP compactive effort were used, respectively. The durability of specimens was also evaluated by immersion in water, were soils treated with 8% cement/4% bagasse ash gave a value of 50% resistance to loss in strength after 7 days soaking period (Fig. 20). They recommended an optimal blend of is 8% cement/4% bagasse ash for treatment of expansive black cotton soil for use as a sub-base material. A similar study on the influence of compactive efforts on bagasse ash treated black cotton soil has earlier been conducted by [32].

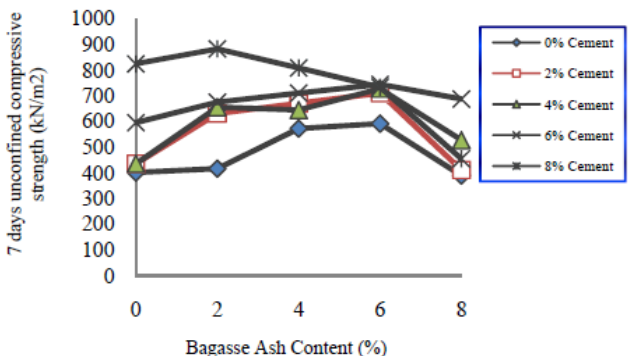

Fig. 19 Variation of 7 days unconfined compressive of soil-cement-bagasse ash mixtures at West African Standard compaction [31]

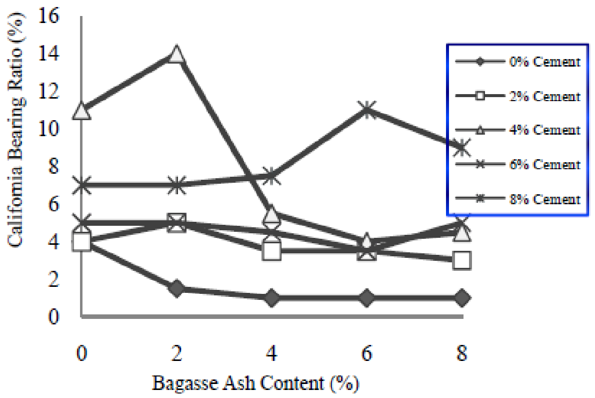

Fig. 20 Variation of soaked California bearing ratio of soil-cement-bagasse ash mixtures at West African Standard compaction [31]

Ochepo and Osinubi [33] carried out a study to investigate the effect of compactive efforts and elapse time on strength and durability of black cotton soil-lime-bagasse ash mixes. The authors obtained soil from Gombe, Nigeria and treated it with lime and bagasse ash in stepped concentration of 0, 2, 4, 6 and 8% by dry weight of the soil. The results they obtained shows that the peak values of unconfined compressive strength were obtained at 6% lime/ 8% bagasse ash contents regardless of compactive effort used. They also observed a general increase in unconfined compressive strength of the specimens with higher compactive efforts and curing age, while there was a decreased in unconfined compressive strength with elapse time for all compactive efforts. Durability assessment of the soil-lime-bagasse ash mix showed resistance to loss in strength of tested specimens to fell far short of the acceptable conventional 80%. They observed that sample stabilized with 6% lime/8% bagasse ash did not achieve the required unconfined compressive strength value of 1034.25 kN/m^2 normally used as criterion for adequate lime stabilization after 7 days. They concluded that from the unconfined compressive strength value at 28 days curing age showed that the strength development of lime/bagasse ash is a slow process and a longer period is required to attain the specified strength.

Sani et al. [34] developed a reliability estimates of strength characteristic values from laboratory results for specimens of black cotton soil stabilized with bagasse ash and compacted at British Standard Light (BSL), West African Standard (WAS) and British Standard Heavy (BSH) energy levels for compacted bagasse ash treated black cotton soil using cement kiln dust (CKD) as an activator, by incorporating data obtained from Unconfined compressive strength (UCS) test gotten from the laboratory test to produce a predictive model. The obtained data were incorporated into a FORTRAN-based first order reliability program to obtain reliability index values. They observed that variable factors such as water content relative to optimum (WRO), hydraulic modulus (HM), bagasse ash (BA), cement kiln dust (CKD), Tri-calcium silicate (C3S), Di-calcium silicate(C2S), and maximum dry density (MDD) did not produced acceptable safety index value of1.0 at the three energy levels at coefficient of variation (COV) ranges of 10-100% for the Unconfined compressive strength but they produces acceptable safety index value at the three energy level at coefficient of variation (COV) ranges of 10-100% for both California bearing ratio and resistance to loss in strength. Observed trends indicate that for unconfined compressive strength WRO, HM, CKD and MDD are greatly influenced by the COV and therefore must be strictly controlled in CKD/BA treated black cotton; California bearing ratio indicated that the CKD, C3S, C2S and MDD were greatly influenced by the COV and therefore must be strictly controlled in CKD/BA treated black cotton; resistance to loss in strength indicated that the WRO, CKD, C3S, C2S and MDD were greatly influenced by the COV and therefore must be strictly controlled in CKD/BA treated black cotton. Stochastically, the authors concluded that none of the compactive efforts can be used to model the 7 days unconfined compressive strength of compacted CKD/BA treated black cotton soil as a subbase material for road pavement at all COV ranges because the safety index were lower than the acceptable 1.0 value. All the compactive efforts can be used to model both California bearing ratio and resistance to loss in strength of compacted CKD/LBWA treated black cotton soil as sub-base material for road pavement at the variable ranges of COV between 10-100%.

Osinubi and Ijimdiya [35] carried out a laboratory investigation on black cotton soil treated with bagasse ash, which showed that the treated soil has desiccation characteristics.

IV. Using Bagasse Ash in the Improvement of Soils for Leachate Containment

Ijimdiya and Osinubi [36] presented results of an investigation into the potential use of black cotton soil treated with bagasse ash for the attenuation of cationic contaminants in municipal solid waste (MSW) leachate. They performed batch equilibrium adsorption tests at various soil-bagasse ash mixtures. They mixed the bagasse ash with the soil to form four different soil-bagasse ash mixtures in stepped increment of 4% from 0 to 12% by weight of dry soil. The results of the study showed that with higher bagasse ash contents, there was an increased sorption of the contaminant species. They concluded that pollutants represented by calcium, magnesium, potassium and sodium can be effectively attenuated by using black cotton soil-bagasse ash mixtures containing an optimum 8% bagasse ash by weight of dry soil.

Osinubi and Eberemu [37] investigated the effect of bagasse ash on the hydraulic properties of laterite. Laboratory studies on lateritic soil treated with up to 10% bagasse ash was carried out to access the effect of bagasse ash treatment and curing periods on the hydraulic properties of the soils. Compacted specimens at standard Proctor effort were cured for 1, 7, 14, 28 and 56 days, respectively before permeability tests were conducted. The compacted specimens showed a decrease in maximum dry density (MDD) and increase in Optimum moisture content (OMC) with increment in bagasse ash treatment (Fig. 21). The coefficient of permeability reduced with increase in bagasse ash treatment up to 8% and with increased curing periods (Fig. 22). The coefficient of permeability also decreased with corresponding decrease in void ratio irrespective of the bagasse ash treatment. A reduction in the void ratio values was recorded with increased curing periods and a decrease was also recorded from 0 to 8% bagasse ash treatment before an increase. The highest coefficient of permeability of 8.42 x 10-10 m/s at 10% bagasse ash treatment was obtained for the 1 day curing period and the lowest value of 9.72 x 10-11 m/s was recorded at 8% bagasse ash treatment for 56 days curing period showing the suitability of the material in hydraulic system for up to 8% bagasse ash treatment. Similar study also earlier conducted by [38], on evaluation of bagasse ash treated black cotton soil as hydraulic barrier in waste containment systems.

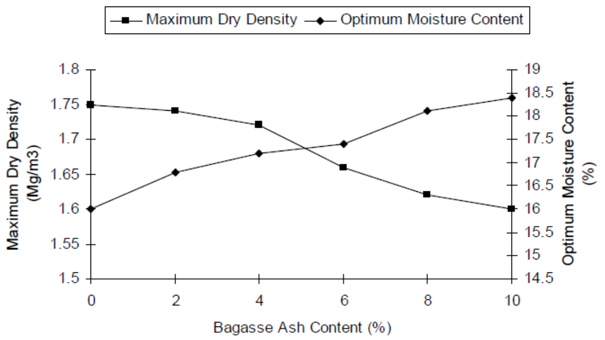

Fig. 21 Variation of maximum dry density and optimum moisture content with bagasse ash content [37]

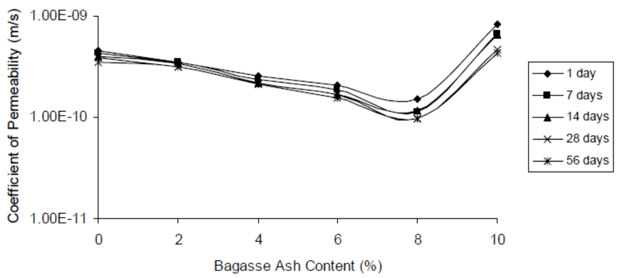

Fig. 22 Variation of coefficient of permeability with bagasse ash content [37]

Osinubi et al. [39] conducted a study on the compatibility of compacted lateritic soil treated with bagasse ash and Municipal Solid Waste leachate. The compatibility tests were carried out on lateritic soil treated with up to 12% bagasse ash compacted at about 2% wet of their respective optimum moistures using the standard Proctor energy. The samples were sequentially permeated with distilled water (Fig. 23) and municipal solid waste (MSW) leachate for 22 and 69 days, respectively, until steady flows were established. The final hydraulic conductivity values were about 1.2–1.48 orders of magnitude higher than the initial values after 91 days of permeation (Fig. 24). They concluded that the treated soil is compatible with leachate studied and suitable for use as liner.

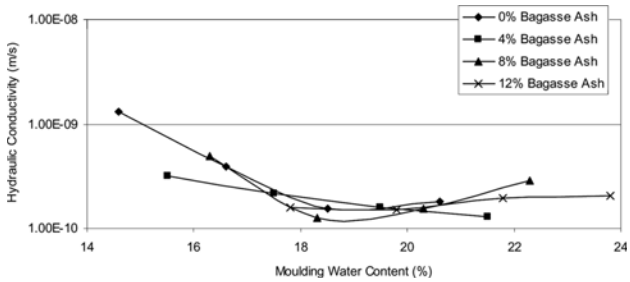

Fig. 23 Variation of hydraulic conductivity with moulding water content time [39]

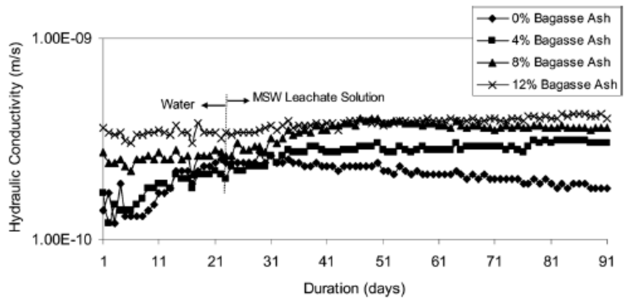

Fig. 24 Variation of hydraulic conductivity with [39]

In their study, Eberemu et al. [40] investigated diffusion of municipal waste contaminants in compacted lateritic soil treated with bagasse ash. In the study, compacted lateritic soil treated with up to 12% bagasse ash and municipal solid waste (MSW) leachate sourced from a domestic waste land fill were used in diffusion test studies to access the diffusion characteristics of some inorganic species present in the municipal solid waste leachate. Diffusion set-up were prepared containing 0, 4, 8 and 12% bagasse ash—soil mixes compacted at 2% wet of optimum using the modified proctor effort. They saturated set up with water for 30 days before the introduction of MSW leachate and initiation of diffusion test for another 90 days. After diffusion testing, a decrease with depth of water content within the soil column was observed. The diffusion test results generally showed that diffusion is an active means of transport of chemical species even at very low flow rates in the compacted soil-bagasse ash mixes, and the effective diffusion coefficient was affected by the bagasse ash. The pore fluid concentration profile for the various chemical species tested showed that the compacted soil-bagasse ash mix has the capacity to attenuate Ca2+, Pb2+ and Cr3+ ions.

Moses et al. [41] investigated the influence of compactive effort on long term hydraulic performance of compacted foundry sand treated with bagasse ash, with specimens permeated with municipal solid waste (MSW) landfill leachate in sequence. Based on the hydraulic conductivity, results obtained for bagasse ash treated foundry sand at optimum molding water content of only 2 and 4% treatment level met specification requirements at the four energy levels of reduced British standard light (RBSL), British standard light (BSL), West African Standard (WAS), and British Standard heavy (BSH). Therefore, foundry sand specimens at 2 and 4% bagasse ash content and compacted at the four energy levels and at 100% relative compaction, were permeated with municipal solid waste (MSW) landfill leachate in sequence at 2% wet of optimum moisture content to assess the influence of the compactive efforts on the long term hydraulic performance of compacted bagasse ash treated foundry sand. The falling head testing method was used, while the experiments were terminated after 90 days when steady flows were reached. At 2% bagasse ash content, lower energy levels recorded more decrease in the final hydraulic conductivity values by factors of 1.46, 1.33, 1.08 and 1.00 for RBSL, BSL, WAS and BSH compactive efforts, respectively. 4% bagasse ash treated specimens gave factors of 1.61, 1.32, 1.17 and 0.70 for RBSL, BSL, WAS and BSH compactive efforts, respectively. Less pore or voids was observed with lower energies levels after long period of hydration reaction due to products hydrations (cementitious compounds) filling the pores (bigger pores experience greater impact on their pores due to hydration reaction products filling up the available pores than specimen at higher compactive effort). They concluded that the final hydraulic conductivity values recorded greater changes than those of specimens compacted at higher energy levels. They noted that the pores of pozollana-soil mixtures if cured for longer period's decreases and hydration products decrease void space with curing times. It was therefore concluded that hydraulic conductivity of compacted foundry sand treated with bagasse ash in the long term, is more affected at lower energy level than that at higher energy levels. Thus, for bagasse ash treated foundry sand, the lower energy levels are the most suitable to adopt in the construction of liners and covers based on the experimental results recorded.

Osinubi and Eberemu [42] studied the adsorption and diffusion of inorganic chemical species from municipal solid waste leachate in compacted lateritic soil treated with Bagasse ash. They compacted lateritic soil treated with up to 12% bagasse ash and municipal solid waste (MSW) leachate sourced from a waste landfill were used in batch equilibrium and diffusion test studies to assess the adsorption and diffusion characteristics of some inorganic species present in the municipal solid waste leachate. Batch equilibrium test was carried out on five lateritic soils - bagasse ash mixtures prepared at stepped bagasse ash treatments of 0, 4, 8, 12 and 100% by dry weight of soil in a 1:4 soil-solution ratio. Soil – bagasse ash mixtures were prepared at 2% wet of optimum moisture content and compacted using the modified Proctor energy level; saturated with tap water before the introduction of MSW leachate and initiation of diffusion test after steady flow had been established. Batch equilibrium test results for all bagasse ash treated lateritic soil show trends of chemical sorption by the soil-bagasse ash mixtures for zinc (Zn2+), Calcium (Ca2+), Chlorine (Cl-), Chromium (Cr2+) and Lead (Pb4+). After diffusion testing, water content within the soil column showed a decrease with depth. The pore fluid concentration profile for the various chemical specie tested showed that the compacted soil-bagasse ash mixture has the capacity to attenuate Ca2+, Pb2+ and Cr3+ ions. They concluded that the diffusion test results generally showed that diffusion is an active means of transport of chemical species even at very low flow rates in the compacted soil-bagasse ash mixes, and the effective diffusion coefficient is affected by compositional factor such as bagasse ash content.

V. Conclusion

The paper generally reviewed studies carried out on the use of bagasse ash in the improvement of deficient soils in Nigeria, with emphasis on lateritic and black cotton soils. The reviewed studies generally showed potentials of using this agricultural waste (Bagasse Ash) in the improvement of geotechnical properties of deficient soils. This suggest that using this material at large scale level, in geotechnical engineering practice in Nigeria will help in the provision of stable and durable structures, reduce cost of soil improvement and also reduces environmental nuisance the unused waste causes.

References

[1] M. D. Gidigasu, "*Laterite Soil Engineering: Pedogenesis and Engineering Principles*", Elsevier Scientific Publication Company. Amsterdam, 1976.

[2] J. Ochepo, A. B. Salahudeen and I. Iliyasu, "Strength Evaluation of Laterite Soil Mixed With Reclaimed Asphalt Pavement and Bagasse Ash for Sub-Base Construction, 2014. Retrieved from at: http://www.researchgate.net/publication/265832414.

[3] K. J. Osinubi and I. Bajeh, "Bituminous stabilization of laterite." *Spectrum Journal*, Vol. 1, No. 2, 1994, pp. 104-112.

[4] M. A. Mustapha, "*Effect of Bagasse Ash on Cement Stabilized Laterite*". Unpublished M. Sc. thesis Department of Civil Engineering, Ahmadu Bello University, Zaria, 2005.

[5] F. H. Chen, *Foundations on Expansive Soils*, Elsevier Scientific Pub. Co. Amsterdam, 1988.

[6] J. D. Nelson and D. J. Miller, *"Expansive Soils: Problem and Practice in Foundation and Pavement Engineering"*, Wiley, New York, 1992.

[7] A. O. Eberemu, A. A. Amadi and M. Lawal, "The Geotechnical Properties of Black Cotton Soil Treated with Glass Cullet", *Nigeria Journal of Engineering*, 2012, pp. 23-30

[8] M. B. Das, *"Principles of Geotechnical Engineering"*, 4th edition PWS Publishing Division of International Thomas Publishing, 1998.

[9] A. M. Neville, *"Properties of Concrete"*, 4th edition. Pearson Education Asia Ltd, Malaysia, 2000.

[10] M. Alhassan and A. M. Mustapha, "Effect of Rice Husk Ash on Cement Stabilized Laterite", *Leonardo Electronic Journal of Practices and Technologies*, Romania, vol. 6(11), July – December, 2007, pp. 47 – 58.

[11] K. J. Osinubi and T. A. Stephen, "Economic utilization of an agro-industrial waste–Bagasse ash," *Proceedings of the 4th Nigerian Materials Congress "NIMACON 2005"*, Zaria. Nigeria, 17 – 19 November, 2005, pp. 36 - 40.

[12] K. J. Osinubi and M. Alhassan, *"Use of Lime and Bagasse Ash in the Modification of Laterite", Nigerian Journal of Engineering, A. B. U. Zaria, Nigeria*, vol. 14(1), (2008). pp. 70-80.

[13] K. J. Osinubi and A. M. Mustapha, "Effect of Energy Level on Cement-Sugar Cane Bagasse Ash Admixture on Laterite," *NSE Technical Transaction*, vol. 43 (2), 2008, pp.33-46.

[14] A. M. Usman, A. Raji, N. H. Waziri and M. A. Hassan, "A Study on Silica and Alumina Potential of the Savannah Bagasse Ash", IOSR Journal of Mechanical and Civil Engineering, vol. 11, Issue 3 Ver. V, pp. 48-52.

[15] M. A. Mu'azu, "Evaluation of Plasticity and Particle Size Distribution Characteristics of Bagasse Ash on Cement Treated Lateritic Soil," *Leonardo Journal of Sciences*, Issue 10, January-June, 2007, pp. 137-152.

[16] M. A. Mu'azu, "Influence of Compactive Effort on Bagasse Ash with Cement Treated Lateritic Soil," *Leonardo Journal of Sciences*, Issue 10, January-June, 2007, pp. 79-92.

[17] K. J. Osinubi, V. Bafyau, and A. O. Eberemu, "Bagasse ash stabilization of lateritic soil", *Proc. of the First Inter. Conf. on Environ*. Res., Techn. and Policy "ERTEP 2007"under the auspices of International Society of

Environmental Geotechnology, Accra, Ghana, 16 -19 July, Category E: State-of-the-Art Technologies for Environmental Performance and Protection, 2007, pp.1 - 17.

[18] K. J. Osinubi, and A. M. Mustapha, *"Optimal Use of Bagasse Ash on Cement Stabilized Laterite,"* NSE Technical Transaction, vol. 44 (2), 2008, pp.1-16.

[19] K. J. Osinubi and M. Alhassan, "Influence of Compactive Efforts and Bagasse Ash on Lime Modified Laterite," *Nigerian Journal of Engineering,* A. B. U. Zaria, Nigeria, vol. 14(1), 2008, pp. 81-89.

[20] K. J. Osinubi, Bagasse Ash Stabilization of Lateritic Soil. *Springer Link Sciences and Business Media*, USA, 2009.

[21] O. O. Amu, S. A. Ogunniyi and O.O. Oladeji, "Geotechnical properties of lateritic soil stabilized with sugarcane straw ash", *American Journal of Scientific and Industrial Research,* vol. 2(2), 2011, pp. 323-331.

[22] K. C. Onyelowe, "Cement Stabilized Akwuete Lateritic Soil and the Use of Bagasse Ash as Admixture," *International Journal of Science and Engineering Investigations,* vol. 1(2), 2012, pp. 16-20.

[23] J. Ochepo, "Stabilization of Laterite Soil Using Reclaimed Asphalt Pavement and Sugarcane Bagasse Ash for Pavement Construction", *Journal of Engineering Research*, vol. 2, No 4, 2014.

[24] A. O. Eberemu, "Compressibility Characteristics of Compacted Lateritic Soil Treated with Bagasse Ash," *Jordan Journal of Civil Engineering*, vol. 9(2), 2015, pp. 214 – 228.

[25] J. A. Sadeeq, J. Ochepo, A. B. Salahudeen and S. T. Tijjani, "Effect of Bagasse Ash on Lime Stabilized Lateritic Soil," *Jordan Journal of Civil Engineering*, vol. 9(2), 2015, pp. 203-213.

[26] B. S. 1377, "*Methods of testing soil for civil engineering purposes*", British standards institute London, 1990.

[27] B. S. 1924, *"Methods of testing for stabilized soils",* British standards institute, London, 1990.

[28] M. D. Gidigasu and J. L. K. Dogbey, "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, vol. 1, 1980, pp.493-506.

[29] TRRL, "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, 1977,

[30] K.J. Osinubi and T.A. Stephen, "Effect of Bagasse Ash Content on Particle Size Distribution and Plasticity Characteristics of Black Cotton Soil," *Proceedings of the 5th Nigerian Materials Congress "NIMACON 2006"*, Abuja, Nigeria, 15-18 November, 2006, pp. 214 -220.

[31] G. Moses and K. J. Osinubi, "Influence of Compactive Efforts on Cement-Bagasse Ash Treatment of Expansive Black Cotton Soil," *World Academy of Science, Engineering and Technology*, vol.7, 2013, pp. 1841-1848.

[32] K. J. Osinubi and A. T. Stephen, "Influence of Compactive Efforts on Bagasse Ash Treated Black Cotton Soil", *Nigerian Journal of Soil and Environmental Research,* vol. 7, 2007, pp. 92 – 101.

[33] J. Ochepo and K. J. Osinubi, "Effect of Compactive Effort and Elapse Time on the Strength of Lime-Bagasse Ash Stabilized Expansive Clay from Gombe", *EJGE,* vol. 18 (2013), Bund. B, 2013, pp. 219-233.

[34] J. E. Sani, A. O. Bello and C. P. Nwadiogbu, "Reliability Estimate of Strength Characteristics of Black Cotton Soil Pavement Sub-Base stabilized with Bagasse Ash and Cement Kiln Dust", *Civil and Environmental Research*, vol. 6, No.11, 2014, pp. 115-135.

[35] K. J. Osinubi and T. S. Ijimdiya, "Laboratory Investigation of Desiccation Characteristics of Black Cotton Soil Treated with Bagasse Ash," *Proceedings of Bi-monthly Meetings/Workshops organized by Zaria Chapter of Materials Society of Nigeria*, 2009, pp. 61 - 68.

[36] T. S. Ijimdiya and K. J. Osinubi, "Attenuative Capacity of Compacted Black Cotton Soil treated with *Bagasse* Ash", *EJGE*, vol. 16, Bund. D, 2011, pp. 419-429.

[37] K. J. Osinubi and A. O. Eberemu, "Effect of Bagasse Ash on the Hydraulic Properties of Laterite", 2012. Retrieved from at: http://www.researchgate.net/publication/233969725.

[38] T. S. Ijimdiya, "*Evaluation of Bagasse Ash Treated Black Cotton Soil as Hydraulic Barrier in Waste Containment Systems*. Unpublished Ph.D. Dissertation. Ahmadu Bello University, Zaria, Nigeria, 2010.

[39] K. J. Osinubi and A. O. Eberemu, "Compatibility of Compacted Lateritic Soil Treated with Bagasse Ash and Municipal Solid Waste Leachate", *Int. J. Environment and Waste Management*, vol. 10(4), 2012, pp. 365-376.

[40] A. O. Eberemu, A. A. Amadi and J. E. Edeh, "Diffusion of Municipal Waste Contaminants in Compacted Lateritic Soil Treated With Bagasse Ash," *Environmental Earth Science*, vol. 70(2), 2013, pp. 789-797.

[41] G. Moses, F.O.P. Oriola and J.O. Afolayan, "The Impact of Compactive Effort on the Long Term Hydraulic Conductivity of Compacted Foundry Sand Treated with Bagasse Ash and Permeated with Municipal Solid Waste Landfill Leachate", *Frontiers in Geotechnical Engineering (FGE)*, vol. 2(1), 2013, pp. 7-15.

[42] K. J. Osinubi and A. O. Eberemu, "Adsorption and Diffusion of Inorganic Chemical Species from Municipal Solid Waste Leachate in Compacted Lateritic Soil Treated with Bagasse Ash," *Proceedings of 10th International Symposium on Environmental Geotechnology and Sustainable Development*, 2009, pp. 1-9.