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Compressibility Characteristics of Compacted Lateritic Soil Treated with Bagasse Ash

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ABSTRACT

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. These results show an overall improvement in the consolidation properties suggesting the suitability of the material in fills for embankment and low lying marginal land for foundation works; also solving the environmental problems associated with waste bagasse disposal.

KEYWORDS: Bagasse ash, Coefficient of volume change, Coefficient of volume compressibility, Compression index, Consolidation, Gross yield stress, Swell index.

INTRODUCTION

Utilization of industrial and agro-industrial waste products has been the focus of research lately in the field of geotechnical engineering for economic, environmental and technical reasons (Dermatas et al., 2003; Eberemu, 2008; Osinubi and Eberemu, 2009; Osinubi et al., 2009; Eberemu et al., 2013). Infrastructural development is a major challenge to many developing countries, most of which are located around the tropics. Lateritic soils have been widely interpreted as product of tropical weathering and are widespread around the tropics. Based on field performance, lateritic soils may be classified as problematic and non-problematic types. Lateritic soils that may pose problems during construction works are termed problematic laterite (Gidigasu, 1976; Oyediran, 2001; Osinubi, 1998). Problematic lateritic soils are characterized by high natural water content and liquid limits, low natural densities and friable and/or crumble structures. Lateritic soils are the first choice of material when possible for use in any major construction work; be it roads, bridges, earth dams, embankment… etc. When they are found outside the tropics, they are often cited as evidence of former tropical conditions (Paton and Williams, 1972). Their chemical composition and morphological characteristics are influenced by the degree of weathering to which the parent material has

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been subjected (Gidigasu, 1976).

Some lateritic soils are not problematic, yet in some cases the properties of the soils in the immediate vicinity of the construction work may not meet the required specifications. Such materials need to be modified so as to meet the geotechnical requirements of the correspondent engineering application.

Several agro-industrial wastes, which are pozzolanic in nature, such as bagasse ash, rice husk ash, groundnut husk ash, locust bean waste ash… etc., have been used either as a stand-alone material or admixture in soil modification and stabilization (Osinubi and Stephen, 2005; Eberemu et al., 2009; Osinubi et al., 2011; Eberemu et al., 2011). Factors normally considered in their use include cost, accessibility, availability, location and workability. This process is only economical when the cost of overcoming a deficiency in one material is less than the cost of importing another material which is satisfactory without stabilization.

Bagasse is the residue obtained after the juice is extracted from sugar cane in the sugar milling industry. The ready availability of bagasse as a by-product of sugar production has always made it an attractive fuel for the sugar industry and this practice tends to be the most economical method of disposal. Bagasse ash is the residue remaining after incineration during the bagasse combustion process. Bagasse ash is considered a waste material and is stockpiled; this material is a pozzolan rich in amorphous silica. However, with the advent of increased environmental regulations and the increasing cost of solid waste disposal, the sugar industry will be searching for beneficial ways to use its bagasse ash since it has proved to be a good additive for some engineering works (Eberemu, 2008; Osinubi and Stephen, 2005; Ogbonyomi, 1998; Sujjavanidi and Duangchan, 2004; Osinubi and Mohammed, 2005; Bafau, 2006).

Consolidation theory deals with the response of soil systems to imposed load and predicts stresses and displacements of the loaded soil as a function of space and time. This concept is fundamental to the practice of geotechnical engineering, where the interaction of soil and water dominates (Taha et al., 2008). Consolidation of poorly compacted soils (either natural soil or fill) when loaded with the weight of a foundation (buildings, roads, embankment… etc.) is a major geotechnical challenge. Roads and buildings constructed over them can produce large settlements, which could be differential and hence produce stresses on the structures over them, which could lead to severe cracks and ultimately to failure. To prevent or minimize this effect, engineers use soil consolidation parameters to predict the amount of settlement that will occur due to the weight of overlying structures. In engineering practice, reasonably good predictions of a structure's settlement can be made from the results of carefully run laboratory tests (Lav and Ansal, 2001).

This work aims at understanding the consolidation properties of compacted lateritic soil treated with bagasse ash with a view to enhancing the usage of this material in engineering construction. This work covers the characterization and one-dimensional consolidation test on compacted lateritic soil treated with up to 16% bagasse ash content by dry weight of soil, compacted using the British Standard Light (BSL) compactive effort under varying moisture content between 2% dry of optimum and 2% wet of optimum moisture content, simulating the variation in moisture that might exist in the field.

EXPERIMENTAL DESIGN

Materials Used

Soil: The soil used is a naturally-occurring reddish-brown lateritic soil. Disturbed samples of the soil were obtained from a borrow-pit at 1.0 m depth in Shika area of Zaria (Latitude 11^{o}15'N and Longitude 7^o 45'E), Nigeria. During sampling, a part of the soil was placed in an airtight polythene bag, this was used for determination of the natural moisture in the laboratory. A study of the geological and soil maps of Nigeria (Akintola, 1982; Areola, 1982) shows that the samples belong to the group of ferruginous tropical soils derived from acid igneous and metamorphic rocks. Previous studies by Osinubi (1988) have shown that soil from this area contains kaolinite as the dominant clay mineral. The soil is classified as A-7-6 (10) according to AASHTO soil classification system (AASHTO, 1986) and low plasticity clay (CL) according to the Unified Soil Classification System (USCS) (ASTM, 1992). A summary of the engineering properties of the natural soil obtained according to British Standards is shown in Table 1.

Table 1. Engineering properties of the natural soil

Property	Natural Soil
Natural Moisture Content, %	6.5
Liquid Limit, %	43
Plastic Limit, %	17
Plasticity Index, %	26
Linear Shrinkage, %,	6
Percentage Passing BS No. 200 Sieve	57
AASHTO Classification	A-7-6 (10)
USCS Classification	CL
Specific Gravity	2.65
pH Value	6.7
Color	Reddish Brown
Dominant Clay Mineral	Kaolinite

Bagasse Ash: Bagasse ash used for this study was collected from Funtua Local Government Area of Katsina State, Nigeria. The bagasse ash was prepared locally by collecting sugar-cane residues, which were stacked in heaps and burnt in open air, then left for about 24 hours to ash. The ash was then passed through BS no. 200 sieve (75μm aperture). The sieved ash was immediately stored in air-tight containers to avoid pre-hydration during storage or when left in open air. The ash was used to treat the lateritic soil by mixing it in different percentages by dry weight of laterite. The ash treatments considered were 0, 4, 8, 12 and 16%. Oxide composition of the bagasse ash used in this study was obtained through a Compact Energy Dispersive X-ray Spectrometer Method (Mini Pal), designed for elementary analysis of a wide range of samples. The test was carried out at the Center for Energy Research Technology (CERT), Ahmadu Bello University, Zaria, Nigeria. The oxide composition is shown in Table 2.

Table 2. Oxide composition of bagasse ash

Component	Concentration (%)
SiO_2	41.7
Al_2O_3	6.7
P_2O_5	3.2
CaO	5.1
K_2O	17.6
MnO_2	0.4
Fe_2O_3	7.1
Na_2O	-
SO_3	2.8
Rb_2O	11.0
Cl	2.3
TiO_2	1.3

Experimental Program

Index properties and compaction tests were carried out on the treated soils in accordance with the British Standard (BSI, 1990). One-dimensional consolidation tests were performed in general accordance with the procedure described in British Standard (BSI, 1990) and as described by Head (1994). Tests were conducted using rear-loading oedometers, with dial gauges. Oedometer ring diameter of 63.5mm and a height of 18.0 mm were used for all tests. Lateritic soil bagasse ash mixtures were prepared in the remoulded state using standard Proctor compactive effort. The optimum moisture content was first determined from the compaction characteristics. Samples were then mixed with distilled water at moisture content equivalent to 2% dry of optimum (optimum moisture minus 2%), optimum moisture content and 2% wet of optimum (optimum moisture content plus 2%); simulating the variation in moisture that might occur in the field. Compacted specimens were allowed to cure overnight before being cored into the oedometer ring and then placed in the consolidometer setup. Pressure increment was 100, 200, 400 and 800 kN/m^2 during the loading stage and unloaded up to 200 kN/m^2. Compression readings were recorded between 10 sec and 24 hours during the loading stage for each incremental load. The Taylor method (Square Root of Time Method) was used to analyze experimental results. The gross yielding stress was obtained from the void ratio-pressure curve using the procedure proposed by Casagrande (1936) and Burland (1990). In order to check the reproducibility of the test results, consolidation tests evaluating the compressibility characteristics (void ratio, compression index, gross yield stress, coefficient of volume compressibility and coefficient of consolidation) were repeated on six of the fifteen samples, which were chosen at random. The differences in test results between the two tests were within ±10%.

RESULTS AND DISCUSSION

Index Properties

The Atterberg limit results shown in Fig. 1 reveal improved index properties for up to 16% bagasse ash treatment with a decrease in liquid limit (LL) from 43% to 32%, an increase in plastic limit (PL) from 17% to 26%, with a resulting decrease in plasticity index (PI) from 26% to 6%. The linear shrinkage decreased from 6% to 3% with increased bagasse ash content for up to 16% treatment. Atterberg limits are indices of the quantity of clay-sized particles and their mineralogical composition. Typically, higher liquid limits and plasticity indices are associated with soils having a greater quantity of clay particles or particles having higher surface activity.

These changes are probably due to physico-chemical reaction (i.e., cation exchange) that depends on particle surface ion hydration and inter-particle attractive forces. Bagasse ash has the potential to provide multivalent cations (Ca^{2+}, Al^{3+}, Fe^{3+}, Mg^{2+}... etc.) which promote flocculation of clay particles by cation exchange. This caused a reduction in the repulsive forces and also an increase in the effective grain size due to aggregation of the clay and silty particles thus increasing the shear strength (Mitchell, 1976). Also, this could be attributed to the addition of bagasse ash that increased the angle of internal friction of the clay-ash matrix and hence reduced the cohesion within the matrix thus producing a much more silty material. These results are in agreement with the work of other researchers (Osinubi et al., 2007). The decreases in PI and LL with increased bagasse ash treatment show that the workability of the material is improved and hence the engineering properties.

The specific gravity of bagasse ash is 2.10. This led to a decrease in specific gravity of the treated soils from 2.65 to 2.51 for up to 16% bagasse ash treatment.

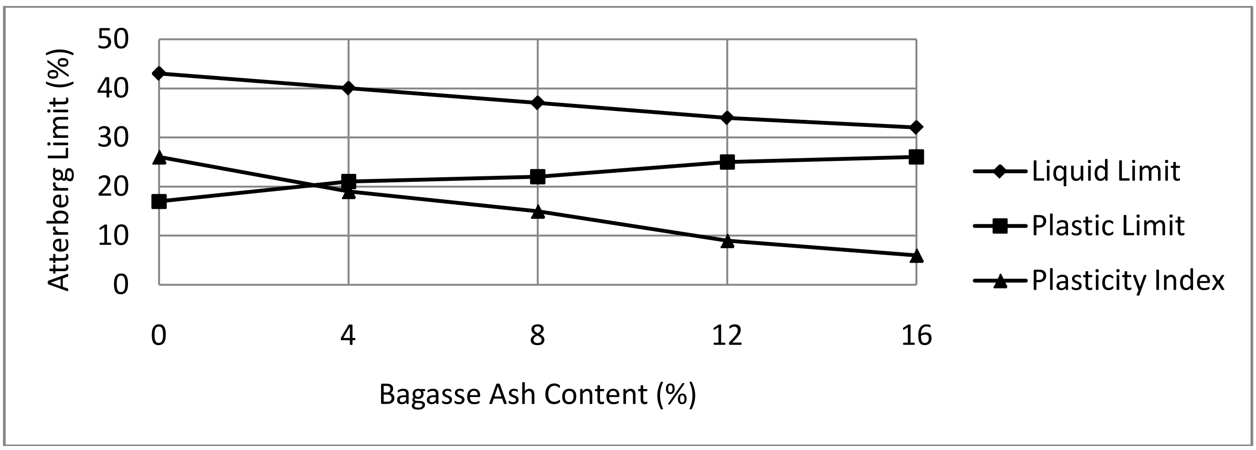

Figure (1): Variation in Atterbeg limits with bagasse ash content

Compaction Characteristics

The effect of bagasse ash content on the maximum dry density (MDD) and optimum moisture content (OMC) of the lateritic soil-bagasse ash mixture is shown in Fig. 2.

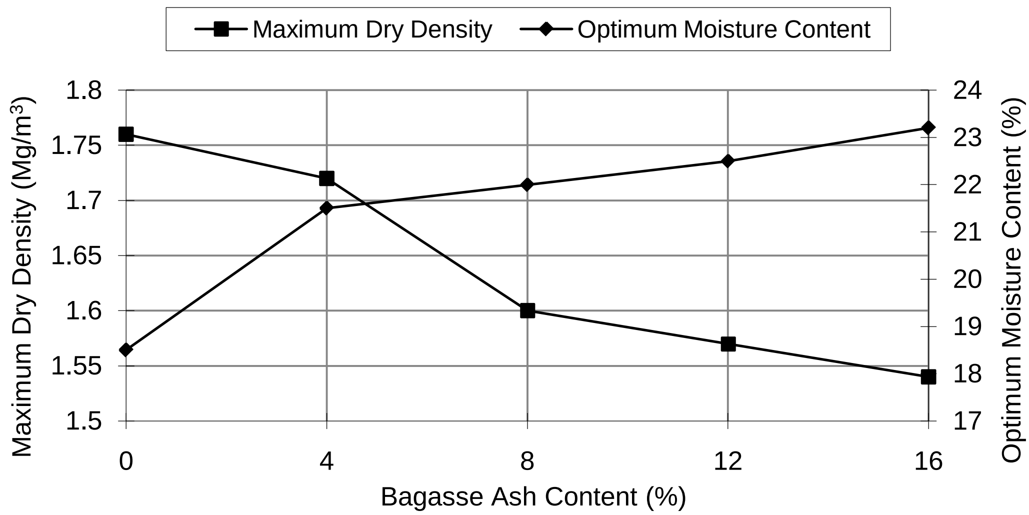

Figure (2): Variation of maximum dry density and optimum moisture content with bagasse ash content

The maximum dry density (MDD) decreased from 1.76 kg/m^3 to 1.54 kg/m^3 and the optimum moisture content (OMC) increased from 18.5% to 23.2%, respectively, as the bagasse ash content increased from 0 to 16%. The decrease in MDD with higher bagasse ash content is associated with the initial simultaneous flocculation and agglomeration of clay particles caused by cation exchange leading to an increase in volume and a decrease in dry density. Also, this could probably be due to the comparatively lower specific gravity of 2.10 for the bagasse ash to that of the soil which is 2.65. This is in agreement with the works of other researchers (Osinubi et al., 2007; Ferguson, 1993; Nicholson and Kashyap, 1993). On the other hand, the OMC increased with higher bagasse ash treatment due to the increase in fines from the bagasse ash with larger surface areas that require more water for hydration.

Consolidation Characteristics

The consolidation characteristics of the various soil-bagasse ash mixtures compacted at different moulding water contents were observed through the void ratio, gross yield stress, compression index, coefficient of volume compressibility and coefficient of consolidation. These are discussed under the effect of the bagasse ash content, moulding water content and applied pressure.

Void Ratio, e

Results showing the relationship between void ratio and pressure are shown in Fig 3. The results shown give a pattern similar to that of natural clay. For all cases of ash treatment, the void ratio decreased as pressure is increased from 100 to 800 kN/m^2 during loading stage, and the void ratio increased as pressure is released during the unloading stage. The result showed the same variation for specimens compacted on the dry side of optimum moisture content, optimum moisture content and on the wet side of optimum moisture content. The reason for this variation is the adjustment of the soil particles to fill up any voids present in response to the applied pressure.

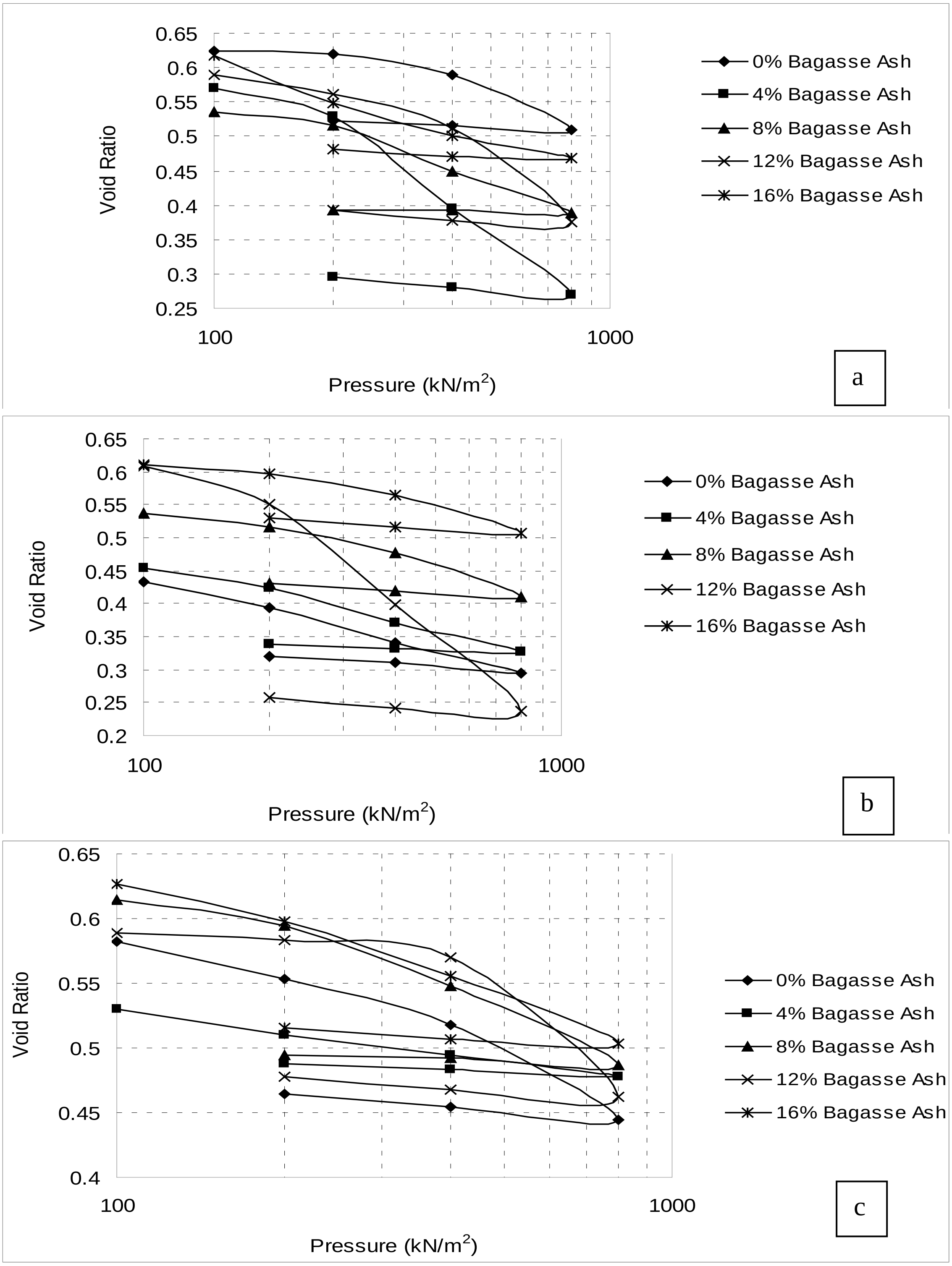

Figure (3): Variation of void ratio with pressure for specimens prepared at (a) 2% dry of optimum (b) optimum moisture content and (c) 2% wet of optimum

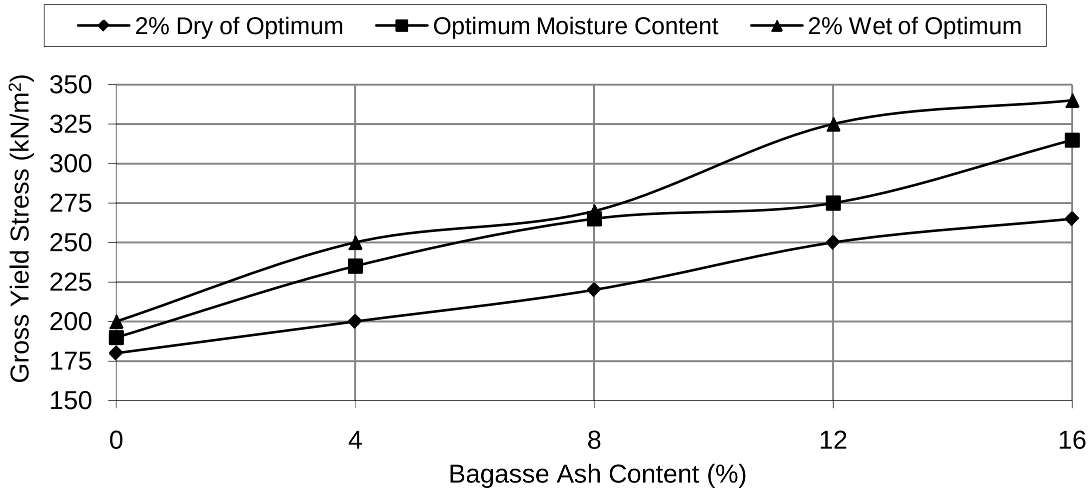

Figure (4): Variation of gross yield stress with bagasse ash content

On the dry side of optimum moisture content, the loading part of e-log p curve of all treated soils is located below that of untreated soil. With increasing bagasse ash content, the amount of water required to obtain the OMC increased due to the increase in fines from the bagasse ash with larger surface areas that require more water for hydration. Compaction with higher moulding water contents results in soils that are devoid of macro-pores hence reduced void ratio. The increasing water will also help in deflocculating the particle structure of the soils reducing voids during compaction; hence the arrangement of individual particles influenced by moulding water content will control the nature of voids formed (Acar and Oliveri, 1989). Furthermore, soft wet clods of soil are easier to remould resulting in smaller interclod voids and hence a plot lower than that of untreated soil (Olsen, 1962; Mitchell et al., 1965; Garcia-Bengochea et al., 1979).

At the optimum moisture content, the void ratio of lower bagasse ash treatment generally plots below those of higher bagasse ash treatment. On the wet side of optimum moisture content, no clear trend could be established for void ratio pressure plots. These results show that the particle state of the soil resulting from the placement condition (moulding water content) seriously affects the void ratio pressure plot irrespective of the bagasse ash treatment. Similar results were obtained in a similar work on black cotton soil but with rice husk ash (Eberemu, 2013).

Gross Yield Stress, σ_{yv}

Effect of Bagasse Ash Content

Burland (1990) suggested using Gross Yield Stress (σ_{yv}) to describe the critical stress separating small to moderate strains from large strains for non-structured soils (reconstituted or remoulded soils); which encompasses the stress history of the soil resulting from mechanical compaction, cementation or binding of the soil particles due to physico-chemical changes; instead of pre-consolidation pressure which is an effect of the stress history of a soil that can be established from geological processes (Liu and Carter, 1999). The relationship between gross yielding stress and bagasse ash content is shown in Fig 4. The results show that there is a continuous increase in gross yield pressure as the bagasse ash content of the lateritic soil is increased from 0 to 16%. The increasing bagasse ash content changes the soil matrix, reducing the MDD and hence making the MDD easier to be attained by the compactive effort. This increases the effect of the applied stress during compaction on the soil. The increasing applied stress results in closer alignment of soil particles along the compaction plane. This could probably be a result of increase in effective stress in the soil during compaction or cementation due to the pozzolanic reaction in the presence of water with increased bagasse ash treatment. This results in the formation of calcium silicate hydrates and increased inter-particle stress. Osinubi and Eberemu (2006) reported increased unconfined compressive strength for up to 8% treatment with the same material. Dermatas et al. (2003) recorded a similar trend although they used cement in treating dredged sediment.

Effect of Moulding Water Content

The effect of water content relative to optimum on the gross yield stress is shown in Fig. 5. As the moulding water content increased from the dry to the wet side of optimum moisture content irrespective of the bagasse ash treatment, the gross yield stress increased. Compaction under increasing moulding water from the dry to the wet side of optimum moisture content will result in soils devoid of macro-pores. The increasing water helps in deflocculating the particle structure reducing the size of the voids (Acar and Oliveri, 1989). Soft wet clods of soils are easier to remould resulting in smaller inter-clod voids (Benson and Daniel, 1990). This could also be a result of the hydration and pozzolanic reactions that evolved between the bagasse ash and water present in the soil matrix. This means that the higher the water content in the matrix, the more the hydration effect caused by bagasse ash, and hence the more the gross yield stress will continuously increase from the dryer side to the wetter side of optimum.

Since the gross yield stress is the critical stress separating small to moderate strains from large strains, pressures applied to the foundation soil that exceed the gross yield stress may cause substantial settlement (Engineer Manual, 1990). This means that as the gross yield stress increases with increasing bagasse ash content, potential settlement decreases because the applied pressure will become relatively more difficult to exceed the increasing gross yield stress.

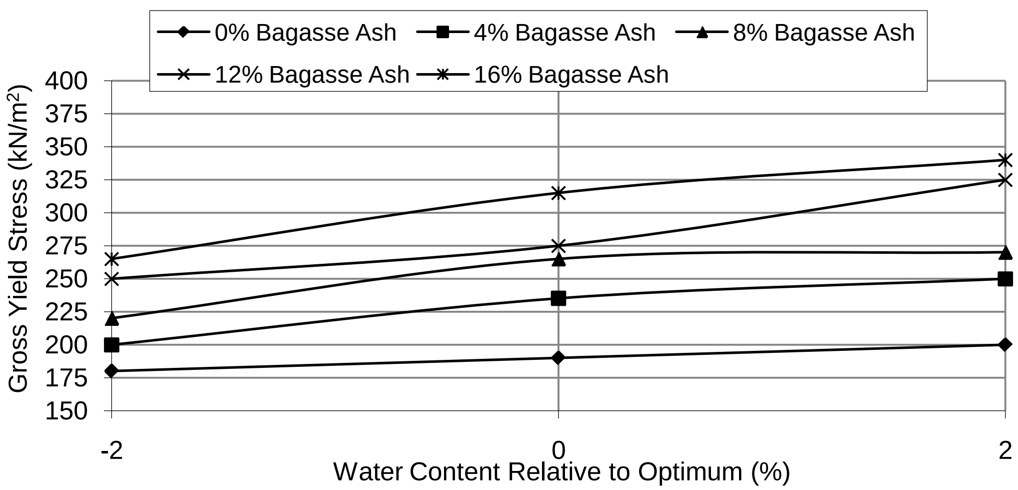

Figure (5): Variation of gross yield stress with water content relative to optimum

Compression Index, C_c

Effect of Bagasse Ash Content

Compression index which is the slope of the virgin portion of the void ratio – pressure plot is an important consolidation characteristic. It is very useful in determination of consolidation settlement of clayey soils. The effect of bagasse ash content on compression index is shown in Fig. 6.

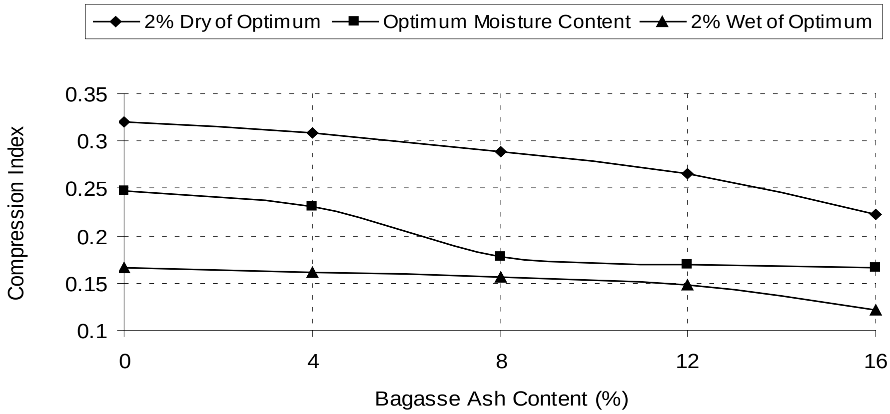

Figure (6): Variation of compression index with bagasse ash content

Results show that there is a continuous decrease in compression index as bagasse ash content increases for up to 16% ash treatment. It decreased from 0.32 to 0.222, 0.247 to 0.167 and 0.166 to 0.122, respectively for samples prepared at 2% dry of optimum, optimum and 2% wet of optimum. This decrease in compression index could be a result of increased formation of pozzolanic products within the pore spaces from physico-chemical changes (Osinubi and Eberemu, 2006) which leads to a reduction in compression index. Similar results were obtained by other researchers (Anagnostopoulos, 2006; Kazemian and Huat, 2009) for soft soils with increased cement ratio. Practically, decreasing compression index will lead to reduced potential settlement of the material under load.

Effect of Moulding Water Content

Furthermore, as the moulding water content increased between 2% dry of optimum and 2% wet of optimum, the compression index generally decreased irrespective of the bagasse ash treatment. Fig. 7 shows a variation in compression index with water content relative to optimum. It decreased from 0.32 to 0.166, 0.309 to 0.162, 0.288 to 0.157, 0.266 to 0.148 and 0.222 to 0.122, respectively for 0, 4, 8, 12 and 16% bagasse ash treatment.

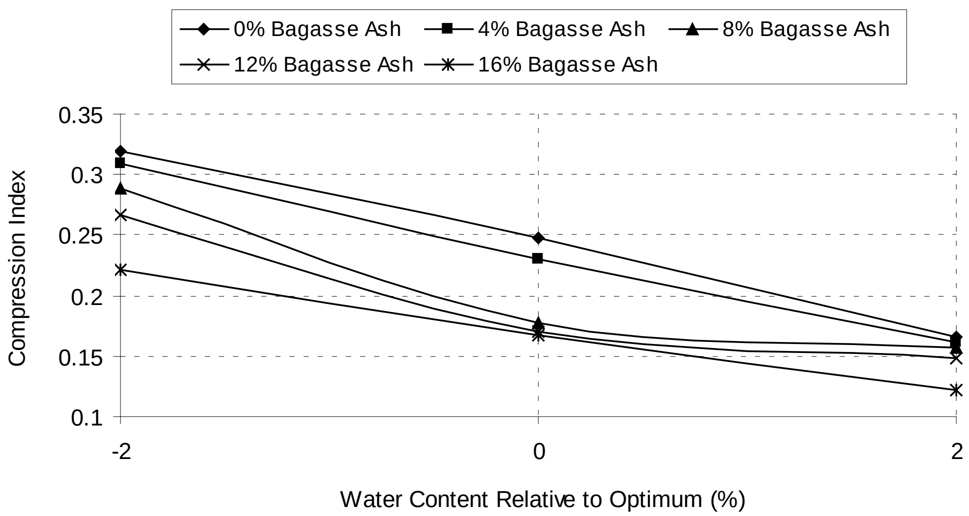

Figure (7): Variation of compression index with water content relative to optimum

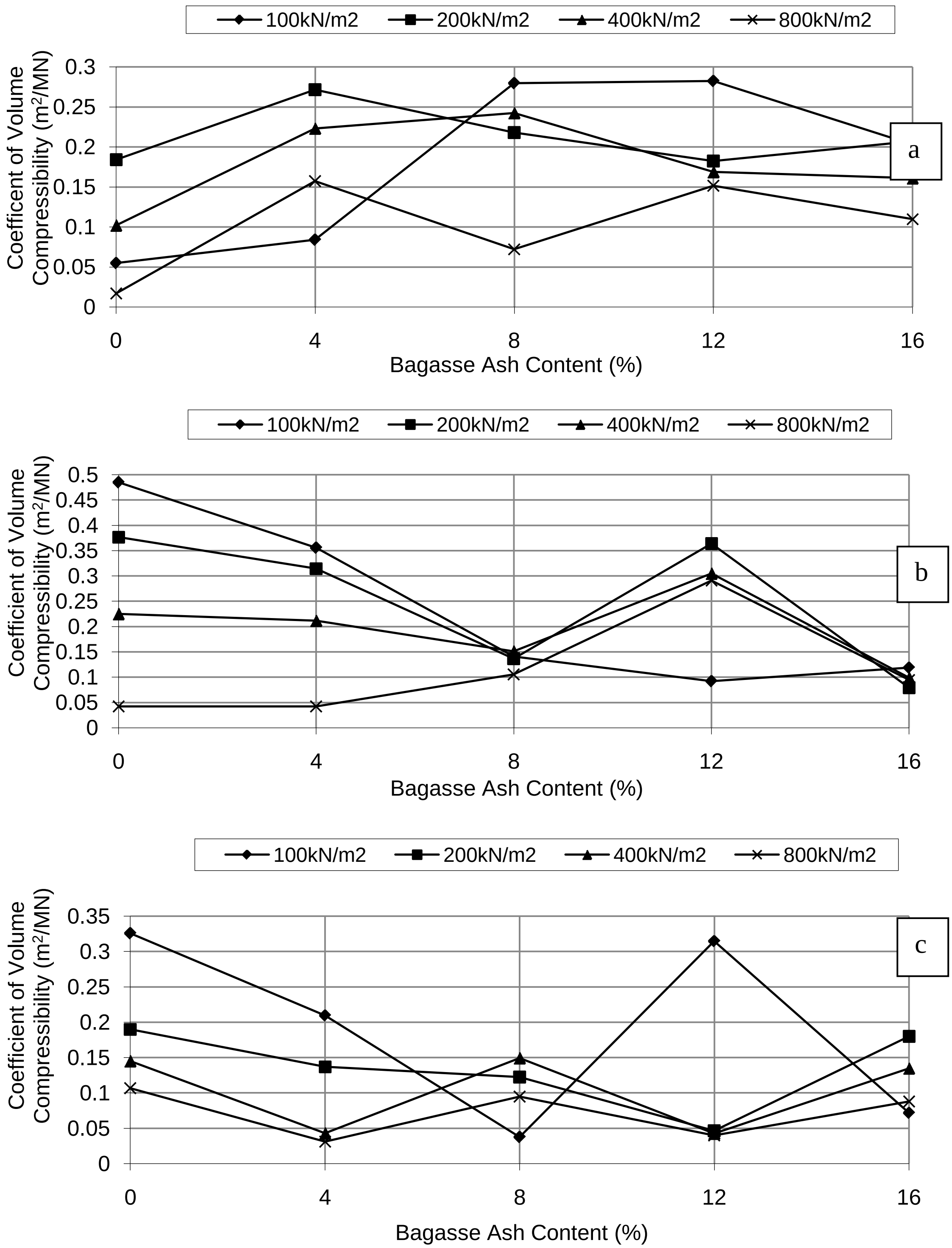

Figure (8): Variation of coefficient of volume compressibility with bagasse ash content for specimens prepared at (a) 2% dry of optimum (b) optimum moisture content and (c) 2% wet of optimum

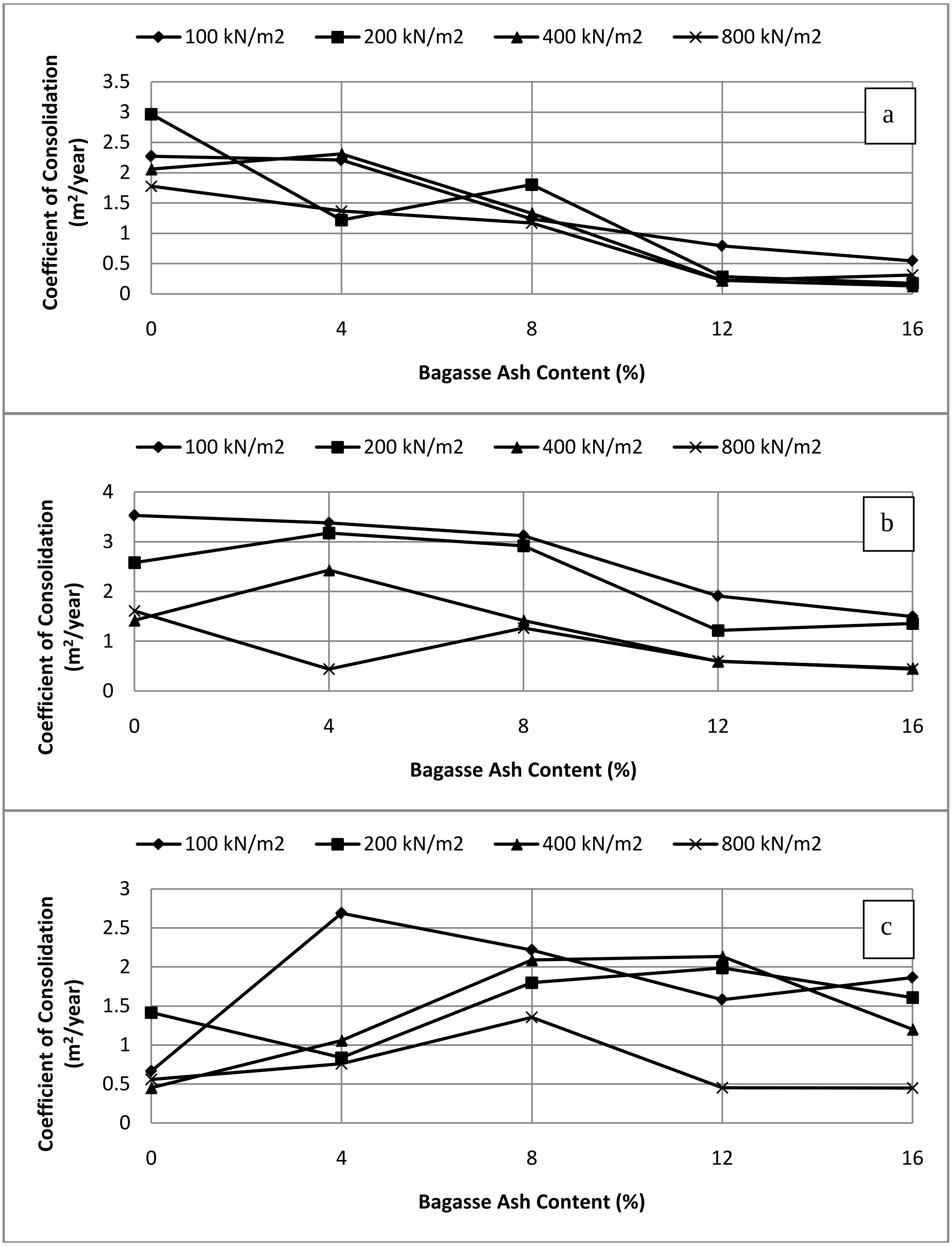

Figure (9): Variation of coefficient of consolidation with bagasse ash content for specimens prepared at (a) 2% dry of optimum (b) optimum moisture content (c) 2% wet of optimum

This decrease could be a result of increased moisture needed for the formation of hydration products within the pore spaces resulting in better strength gain. This is in agreement with the properties of pozzolans which gain strength as a result of the reaction with reactive silica and alumina compounds that combine with water to form pozzolanic products (Osinubi and Eberemu, 2006).

Coefficient of Volume Compressibility, m_v

The coefficient of volume compressibility is sometimes known as the modulus of change. It is defined as the change in volume per unit volume per unit pressure as a result of consolidation due to that pressure change (Head, 1994).

The influence of bagasse ash treatment on the coefficient of volume compressibility for specimens consolidated at the different soil states (dry of optimum, optimum and wet of optimum) is shown in Fig. 8. On the dry side of optimum, the coefficient of volume compressibility generally increased with increased bagasse ash treatment before reducing from 12% ash treatment; but no clear trend could be established due to high scattering of the data for up to 16% ash treatment between the OMC and the wet state of soil specimens. These results show that the soil particle orientation which varies greatly between the dry and wet side of optimum (Lambe, 1958) has more influence on the coefficient of volume compressibility than the bagasse ash treatment.

Coefficient of Consolidation, c_v

The relationship between consolidation coefficient and bagasse ash content is shown in Fig 9. Previous studies (Robinson and Allam, 1998; Olson and Mesri, 1970) have shown that the coefficient of consolidation in clays is influenced by mechanical and physico-chemical factors that govern compressibility effects. Results show that the coefficient of consolidation generally decreased as the bagasse ash content increased from 0 to 16% at the dry side of optimum and optimum moisture content, while on the wet side there was no clear trend of variation of c_v as a function of bagasse ash content for all the applied forces, whereas it could be stated that values were three times and twice higher for 16% compared to natural soil under pressures of 100 kN/m^2 and 400 kN/m^2, respectively, and approximately the same for 16% and for natural soil under pressures of 200 kN/m^2 and 800 kN/m^2. The range of variation of c_v observed at the several investigated conditions, however, is very low when compared to the variation of c_v values among different materials. This shows that the soil particle state could affect the coefficient of consolidation. The variation could be due to the formation of increased pozzolanic products from the bagasse ash (Osinubi and Eberemu, 2006). This result implies that the rate at which the specimen will undergo one-dimensional consolidation particularly when compacted on the dry side and optimum moisture content is gradually reduced as bagasse ash content is generally increased for up to 16% treatment.

CONCLUSIONS

Bagasse ash affects the index properties by improving the workability of the material. The void ratio decreased and increased with pressure increase and decrease, respectively. The gross yield stress increased with increased bagasse ash treatment (between 47% and 70%) and water content relative to optimum from the dry side of optimum to the wet side. The compression index decreased as bagasse ash content increased (between 36% and 48%). Moreover, as the moulding water content increased between 2% dry of optimum and 2% wet of optimum, the compression index generally decreased.

No clear trend could be established for the coefficient of volume compressibility with increased bagasse ash treatment. The coefficient of consolidation generally decreased on the dry side and optimum moisture with increased bagasse ash treatment, while on the wet side it showed no clear trend.

The results reveal that bagasse ash improves the compressibility characteristics of lateritic soil irrespective of the moulding water content. The observed improvement occurred immediately after compaction, and the improvement is expected to continue with time due to the pozzolanic nature of bagasse ash, although further research is suggested in this area. It is clear that the material will be suitable for fills in embankment and reclaiming of low lying marginal lands for foundation works. This will ultimately help to reduce the environmental problems associated with the disposal of waste bagasse, although there is need for more study on the *in situ* leaching of components from the soil-bagasse ash mixture.

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