Leonardo Electronic Journal of Practices and Technologies
ISSN 1583-1078
Issue 28, January-June 2016
p. 119-136

Effect of used oil contamination and bagasse ash on some geotechnical properties of lateritic soil

Ja'afar A. SADEEQ[1], Joshua OCHEPO[1], and Bunyamin A. SALAHUDEEN[2*]

[1]*Department of Civil Engineering, Ahmadu Bello University, Zaria, Nigeria*
[2]*Samaru College of Agriculture, Division of Agricultural Colleges, Ahmadu Bello University, Zaria, Nigeria*
E-mails: jasadeeq@yahoo.com, ochepo1@gmail.com, muazbj@gmail.com[*]

[*] Corresponding author, phone: +2348063600851

Received: June 3, 2016 / Accepted: July 17, 2016 / Published: July 31, 2016

Abstract

This study was carried out to evaluate the effect of used oil contamination and bagasse ash on some geotechnical properties of northern Nigerian lateritic soils. Laboratory tests were performed on the natural/oil contaminated and bagasse ash treated contaminated soil samples in accordance with BS 1377 (1990) and BS 1924 (1990) respectively. Contaminated specimens were prepared by mixing the soil with oil in steps of 0, 2, 4, and 6 % by weight of the soil while bagasse ash treated specimens were prepared by mixing the oil contaminated soil with bagasse ash in steps of 0, 2, 4, 6 and 8 % by weight of dry soil. The soil is of Group A-6 using AASHTO classification and CL according to Unified Soil Classification System (USCS). The plasticity index of the soil decreased from 15.02 % for the natural soil to 8.16 % at 6 % oil/8 % bagasse ash content. The maximum dry density (MDD) of the soil increased from 1.48 Mg/m^3 for the natural soil to peak value of 1.60 and 1.62 Mg/m^3 at 6 % oil content and 6 % oil/8 % bagasse ash content.. The Optimum Moisture Content (OMC) decreased from a value of 18.5 % for the natural soil to 13.0 and 11.3 % at 6 % oil content and 6 % oil/8 % bagasse ash content. Volumetric shrinkage test was first performed on the soil specimens at their respective optimum moisture contents and then repeated at +2 % and -2 % of the optimum moisture contents. It was observed that used oil and bagasse ash have no adverse effect on the maximum dry density and

volumetric shrinkage of lateritic soil when compacted at optimum moisture content or dry of the optimum moisture content.

Keywords

Geotechnical properties; Bagasse ash; Used oil contamination; Lateritic soil; Atterberg limits; Maximum dry density; Optimum moisture content; Volumetric shrinkage

Introduction

Nigeria is a country in the world that is rich in crude oil production. It has 159 oil fields and 1481 oil wells in operation [1]. The oil and gas export constitute the backbone of the economy of the nation, accounting for more than 98% of export earnings and about 83% of federal government revenue, as well as generating more than 40% of its GDP. It also provides about 95% of foreign exchange earnings, and about 65% of government budgetary revenues. All of these oil operations are concentrated in the Niger Delta area of the country spanning about 70,000 km² of wetlands which is primarily formed by sediment deposition. It makes up about 7.5% of Nigeria's total land mass. The population of the area is about 20 million people [2]. Oil spillage in Nigeria is a common occurrence because of the oil exploration activities. Oil drilling began in the country in 1958. From 1958 to date, an estimated 9 million to 13 million barrels of oil have been spilled. Nigerian government estimates that about 7,000 spills occurred between 1970 and 2000. Between 1976 to 1986 total of 2005 oil spill incidents were reported in Nigeria by oil companies with an estimated total quantity of oil spilled being 2,038,711 barrels [3]. Adepoyigi [4] reported that between January and June, 1998 alone Nigeria recorded three different oil spills of approximately 60,800 barrels of crude oil and Oluremi and Osuolale [2] reported that on 1st May 2010 a ruptured ExxonMobil pipeline in the state of Akwa Ibom spilled more than a million gallons into the delta for over seven days before the leak was stopped. Causes of this spillage include corrosion of pipelines. Tankers accounts for 50% of all spills, sabotage 28%, and oil production operations 21%, with 1% of the spills being accounted for by inadequate or non-functional production equipment.

During the last one and a half decade, the results of a number of studies related to the

physical properties and behaviour of oil and petroleum constituent contaminated soil have been published by [5-7] etc. It does appear, however that further studies are necessary to quantify several parameters of interest to geotechnical engineers. The exploration and exploitation of petroleum hydro-carbons have been have been practiced in Nigeria for decades and their concomitant side effects on the oil producing communities have been quite evident. These activities, though developmental, have elicited all kinds of environmental impacts on the communities where they are found, ranging from the barely tolerable ones to utterly disastrous effects. The exploration activities are known to have decimated terrestrial and aquatic biota, which constitute the peoples' major source of livelihood. The highest incidence of oil spills occurred in the mangrove swamp zones and near off shore areas of the Niger Delta as reported in an analysis of oil spillage statistics in Nigeria during the period of 1976 to 1988 [8]. Any change in engineering properties and behaviour of the soil strata in these areas may lead to functional or structural failure. Used oil was defined as petroleum-derived and synthetic oils spilled into the environment or used for lubrication or cutting oil, heat transfer, hydraulic power or insulation in dielectric transformers (Hazardous Waste Program technical bulletin) [9]. Used oil is any oil that has been refined from crude oil or any synthetic oil that has been used and as a result of such use is contaminated by physical or chemical impurities [10]. Used oil is exactly what its name implies; any petroleum-based or synthetic that has been used.

Laterite was defined by Alexander and Cady [11] as highly weathered material rich in secondary oxides of iron, aluminium or both. It is mostly of bases and primary silicates, but it may contain large amount of quartz and kaolinite. It is either hard or capable of hardening on exposure to wetting and drying. Laterite is a highly weathered tropical soil, rich in secondary oxides of any or a combination of iron, aluminium and manganese. Most tropical laterites are composed predominately of kaolinite clay mineral with some quartz. In some cases they contain swelling clay mineral type (e.g., vermiculite, hydrated halloysite and montmorillonite). When laterite contains swelling clay mineral type, they are known as problematic lateritic soils [12]. Lateritic soils are the product of intensive weathering that occurs under tropical and subtropical climatic condition resulting in the accumulation of hydrated iron and aluminium oxides [11, 13]. Lateritic soil as a soil group rather than well-defined materials is most commonly found in the leached soils of the humid tropics where they were first studied. Lateritic soils are formed under weathering systems productive of the

process of laterization [13]. The most important characterization is the decomposition of ferro-aluminium silicate minerals and the permanent deposition of sesquioxide (i.e., oxides of iron and Aluminium - Fe_2O_3 and Al_2O_3) within the profile to form the horizon of materials known as laterite [14]. The term “laterization” describes the processes that produce laterite soils [15]. Construction Industry Research and Information Association (CIRIA) [16] proposed the following definition for lateritic soils which states that ‘laterite in all its form is a highly weathered natural material formed by the concentration of the hydrated oxides of iron and aluminium. This concentration may be by residual accumulation or by solution, movement and chemical precipitation [17]. Sugarcane is one of the major crops grown in over 110 countries and its total production is over 150 million tons [18]. After the extraction of the sugar juice from sugarcane, about 40-45% fibrous residue is left, this is reused in the same industry as fuel in boilers for heat generation leaving behind 8-10% ash as waste. This ash is known as sugarcane bagasse ash (SCBA). However, results of various studies conducted on the properties of bagasse ash shows that the ash possess some pozzolanic properties [18].

Bagasse is the fibrous residue generated after the juice has been extracted from the sugar cane plant. It is normally deposited as waste and it litters the environment. Most of the bagasse produced, amounting to one-third of all the cane crushed in some cases supplies the fuel for the generation of steam which eventually results in bagasse ash. The resulting ash is deposited in stockpiles which are normally dumped in waste landfills and constitute environmental problems to the society. When bagasse is left in the open, it ferments and decays; this brings about the need for safe disposal of the pollutant, which when inhaled in large doses can result in respiratory disease known as *bagassiosis* [19]. There is a growing demand for fine amorphous silica materials in the construction industry today, hence it is economical for industrial waste materials such as bagasse to be recycled and reconverted into useful materials which can be used as additives to improve the engineering properties of deficient soils and making it suitable as a construction material. According to Misari et al [19] the estimated land under sugarcane cultivation in Nigeria is between 25,000 to 30,000 hectares. However, there is a potential land under sugarcane cultivation to be expanded to 147,000 hectares. Also sugarcane yield in Nigeria was estimated at 80 tonnes per hectare, which leaves the amount of sugarcane produced in today at between 2 million tones and 2.4 million tones. According to Ogbonyomi [20] the estimated average amount of bagasse from sugarcane is 30% and the ash content from bagasse is 2.48%, which leaves the amount of

bagasse produced in Nigeria annually to lie between 600,000 tonnes and 720,000 tonnes while the amount of bagasse ash lies between 14880 tonnes and 17,856 tonnes. Some of this bagasse is burnt to generate steam at the factories for the production processes. But this still leaves the problem of disposing the bagasse ash. As mentioned earlier the ash has been found to contain a substantial amount of silica and alumina and has been categorized under pozzolanas [20]. These oxides in their reactive form can take part in cement-like setting reactions with lime or ordinary Portland cement. In Mauritius, research has shown that a 20-30% replacement of ordinary Portland cement with bagasse ash yielded a useful cement strength value, which at upwards of 4 months compared favorably with OPC mixes [21]. Other uses of bagasse as reported by Ogbonyomi, [20] include for paper production, ceiling, wallboards, alpha cellulose, plastics and cattle bedding. The volumetric shrinkage or volume change of a soil is the change in volume of the soil expressed as a percentage of the dry volume when the water content is reduced from a given value to the shrinkage limit.

The aim of this research is to investigate the effects of bagasse ash, used oil contamination and the combination of these two materials on some geotechnical properties of lateritic soil when the soil is used for flexible pavement construction.

Materials and methods

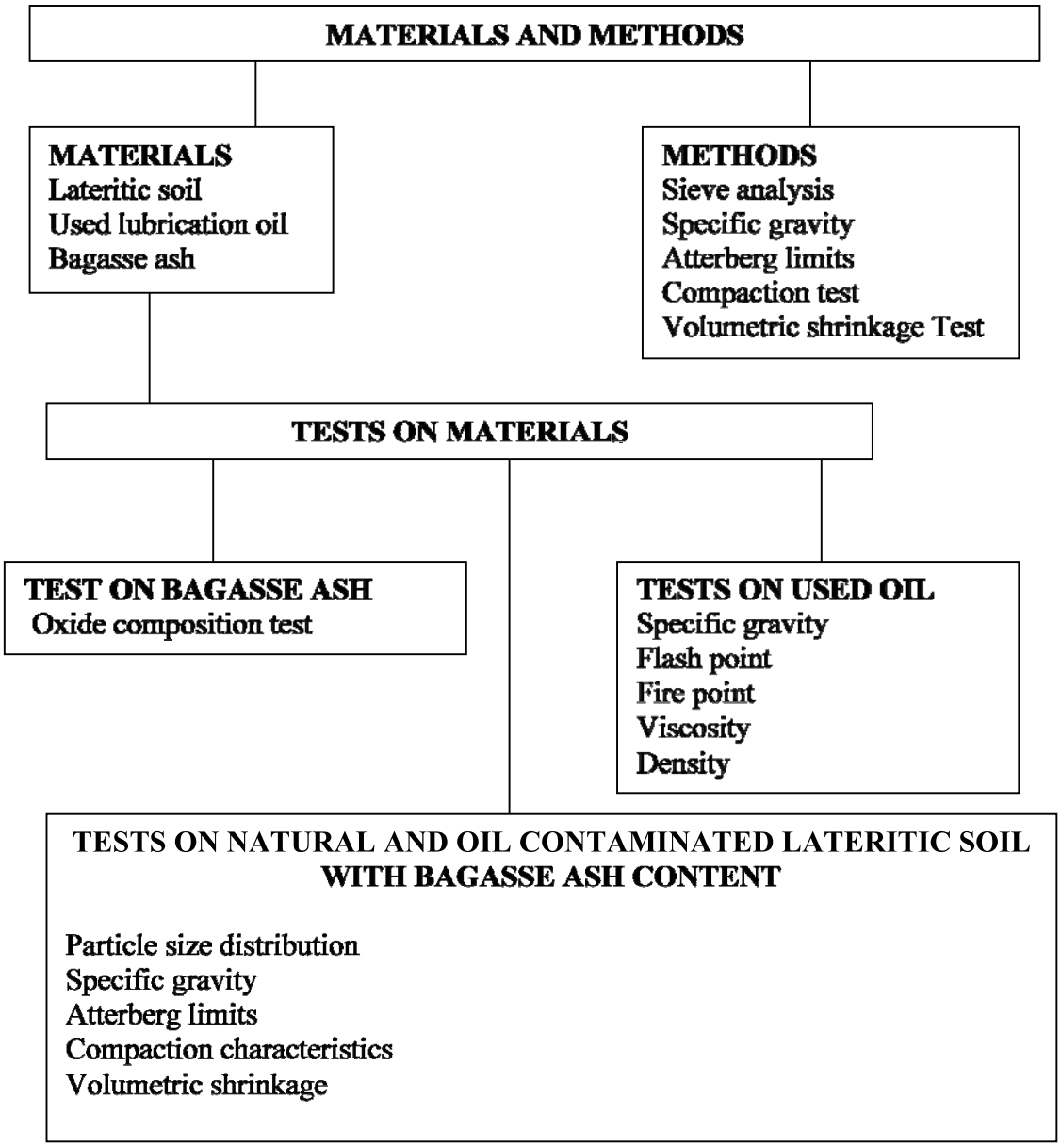
The soil used in this study is a natural reddish brown laterite which was collected from a borrow pit in Shika village, Zaria Local Government Area, Kaduna State in Northern part of Nigeria, (latitude 11°15' N and longitude 7°45' E), by using the method of disturbed sampling at 1m depth from the natural earth surface to avoid organic matter influence.

The used oil was collected from Oando lubrication workshop adjacent Ahmadu Bello University main gate, Samaru Campus, Zaria Kaduna state. It is used motor oil, black in colour with petrol and engine oil chocking smells and feels greasy on the palm.

The Bagasse was obtained locally from a sugarcane processing plant situated in Gaskiya, Zaria local government area in Kaduna State. The sugarcane 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 Geothechnical research laboratory, department of civil engineering of Ahmadu Bello University, Zaria. The ash was

then passed through B.S. sieve No. 200 (0.075mm) to meet the requirements of ASTM (618-78). The specific gravity of the Bagasse ash (BA) is 2.34. The chemical composition of the Bagasse ash (BA) was determined at the Center for Energy Research and Training (CERT), A. B. U. Zaria using the method of Energy Dispersive X-Ray Fluorescence.

The flowchart bellow present a schematic about materials and methods used in the present study:



The lateritic soil used in this research was thoroughly mixed after been contaminated with used engine oil using 0, 2, 4 and 6 percentages by dry weight of each soil sample in order to simulate the ideal field conditions.

Laboratory tests were performed on the natural and used oil contaminated lateritic soil

samples in accordance with BS 1377 [22] and bagasse ash treated samples in accordance with BS 1924 [23].

The compaction tests were performed on the natural, contaminated and bagasse ash (BA) treated soils (at 0, 2, 4, 6 and 8 % BA treatment by dry weight of soil.); using the British Standard light (BSL) energy.

The volumetric shrinkage strains of various specimens were observed for a period of 40 days in order of 5, 10, 15, 20, 25, 30, 35 and 40 days. The volumetric shrinkage strain tests were conducted on the samples at their respective OMC and then at +2% and -2% of the OMC.

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 [24] and low plasticity clay (CL), using the Unified Soil Classification System, USCS (ASTM) [25]. The soil has a liquid limit value of 36.32 %, plastic limit of 21.30 %, plasticity index of 15.02 %, linear shrinkage of 3.60 % and specific gravity of 2.61 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.

Table 1. Properties of the natural lateritic soil

Properties	**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	107.74
Specific gravity	2.61
Natural moisture content (%)	15.8
Colour	Reddish brown
Optimum moisture content (OMC) (%)	18.50
Maximum dry density (MDD) (kg/m³)	1.48
Dominant clay mineral	Kaolinite

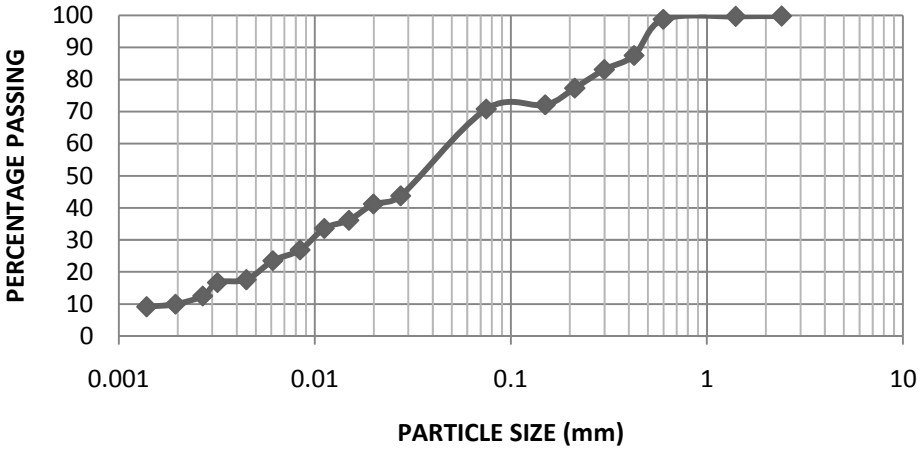


***Figure 1**. Particle size distribution curve for the natural lateritic soil*

The properties of the used oil are given in Table 2 while the oxide compositions of the bagasse ash are summarized in Table 3.

Table 2. Properties of the used oil

Characteristics	**Quantity**
Specific gravity	0.70
Flash point (ºC)	168
Fire point (ºC)	220
Viscosity (cP)	1.17
Density (g/cm³)	0.76

Table 3. Oxide composition of bagasse ash

Oxide	**Composition**
SiO_2	57.95
Al_2O_3	8.23
FeO_3	3.96
CaO	4.52
MgO	4.47
K_2O	2.41
Loss on Ignition (LOI)	5.0

Variation of specific gravity of oil contaminated soil with bagasse ash content is shown in Figure 2. The specific gravity of solid particles is the ratio of the mass of a given volume of solids to the mass of an equal volume of water. Specific gravity an important parameter used for the determination of the void ratio and particle size of any soil particle [26]. The value of the specific gravity of the oil contaminated soil-bagasse ash mixes decreased steadily from a value of 2.61 for the untreated lateritic soil to 2.11 at 8 % BA/6 % Oil contents. The specific gravity decreased with increase in both oil and BA contents. This decrease in specific gravity is due to the lower specific gravity values of both bagasse ash

(2.34) and used oil (0.70) compared to that of the natural soil.

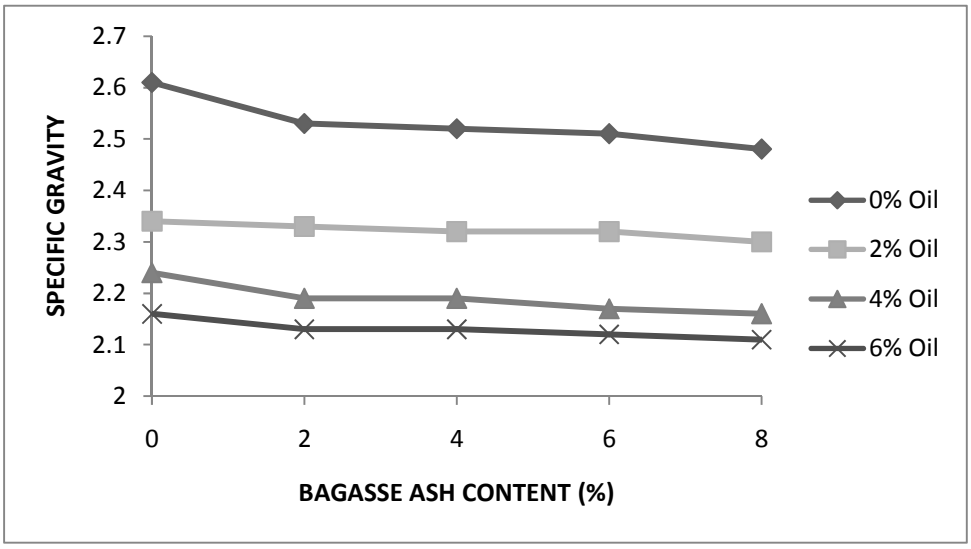


***Figure 2**. Variation of specific gravity of oil contaminated soil with bagasse ash content*

The variations of Atterberg limits of oil contaminated lateritic soil with bagasse ash content are shown in Figures 3 - 6. The liquid and plastic limits of the lateritic soil increased with increased used oil content. This increase in liquid limit is an indication of increasing value of compression index and higher proneness of the soil towards settlement [27]. An increase in plastic limit (PL) was also observed as oil content increased. This may be due to the lubricating effect of oil making the particles to roll over one another hence the increased plastic behaviour.

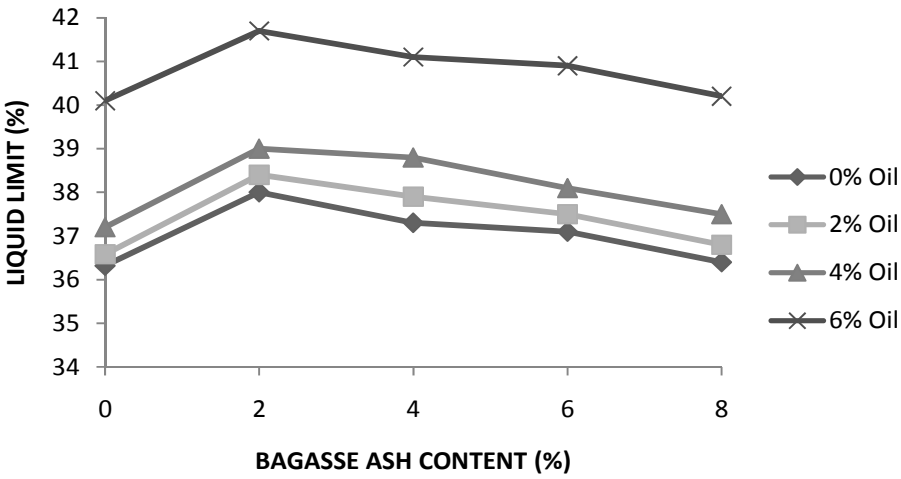


***Figure 3.** Variation of liquid limit of oil contaminated soil with bagasse ash content*

The plasticity index (PI) decreased with increase in oil content while the linear shrinkage (LS) increased then decreased.

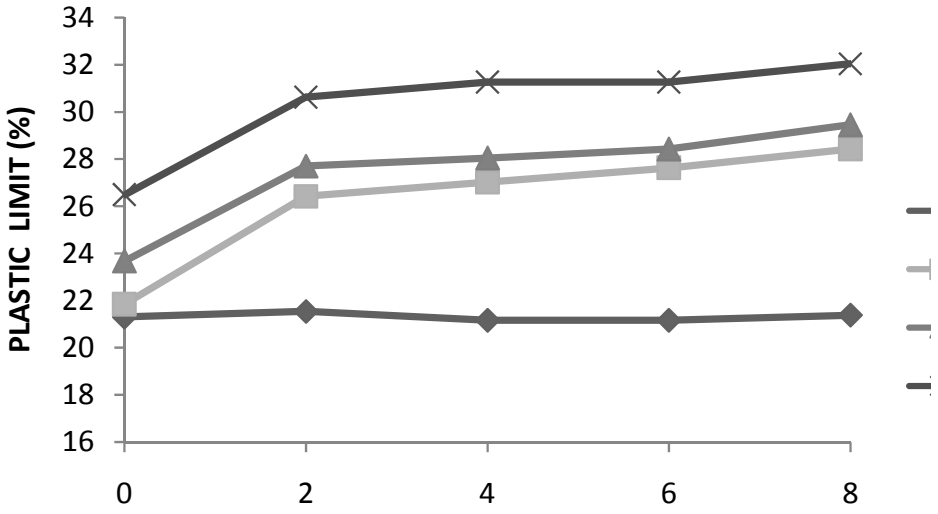


***Figure 4**. Variation of plastic limit of oil contaminated soil with bagasse ash content*

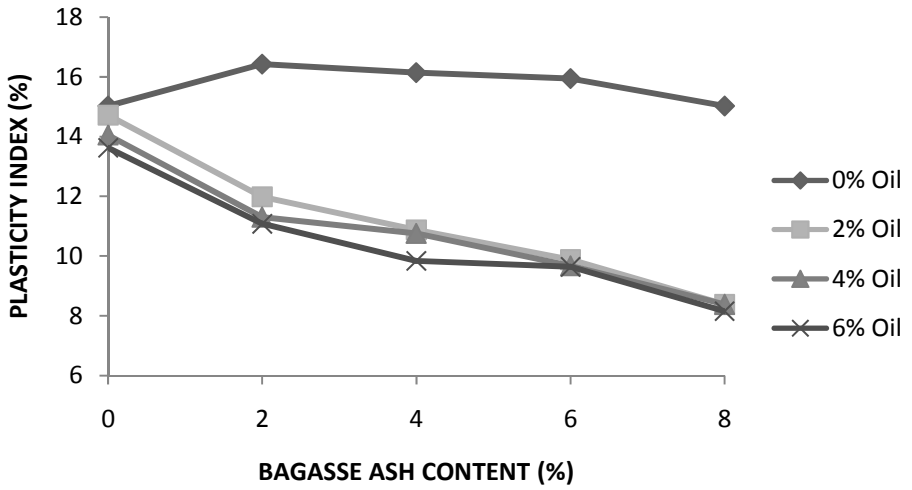


***Figure 5**. Variation of plasticity index of oil contaminated soil with bagasse ash content*

The introduction of bagasse ash into the oil contaminated soil first caused an increase in the Atterberg limits to a peak value at 2 % bagasse ash treatment and thereafter decreased. The increase can be attributed to addition of bagasse ash which introduced more pozzolanic substance into the specimen that required more water for hydration to be completed. The subsequence decrease can be associated with the agglomeration and flocculation of the clay particles which is as a result of exchange ions at the surface of the clay particles. This observed trend is in agreement with Ramzi et al. [28]. Venkaramuthyalu et al. [29], Suhail et al. [30] and Ramzi et al. [28] reported that the reduction in plasticity index with chemical treatment could be attributed to the depressed double layer thickness due to cation exchange

by potassium, calcium and ferric ions.

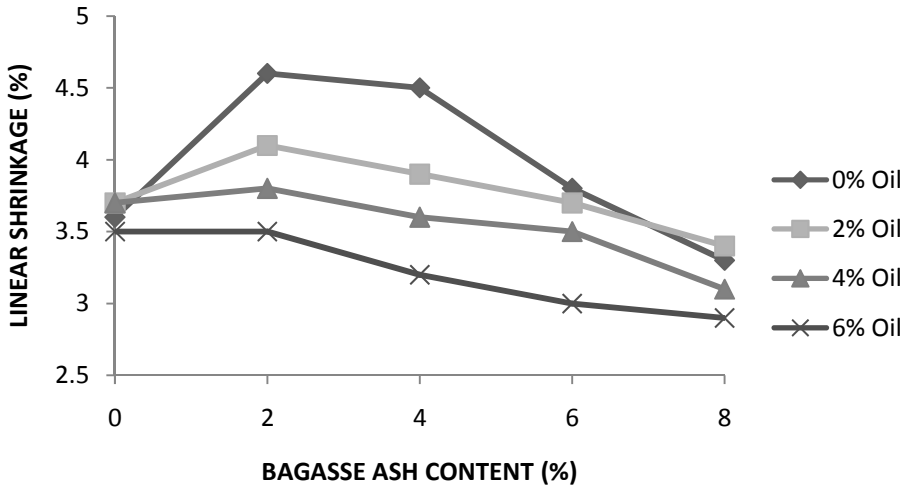


***Figure 6**. Variation of linear shrinkage of oil contaminated soil with bagasse ash content*

The variations of maximum dry density (MDD) and optimum moisture content (OMC) of used oil contaminated lateritic soil with bagasse ash content are shown in Figures 7 and 8. The MDD steadily increased with increase in both oil and BA contents. The continuous increase in MDD was attributed to the lubricating effect due to the presence of oil which facilitates compaction and reduced the amount of water needed to reach maximum density. This increase in dry density with addition of oil may also be due to cation exchange reactions and it could also be due to oil being a fluid occupying the voids within the soil matrix[31]; [32].

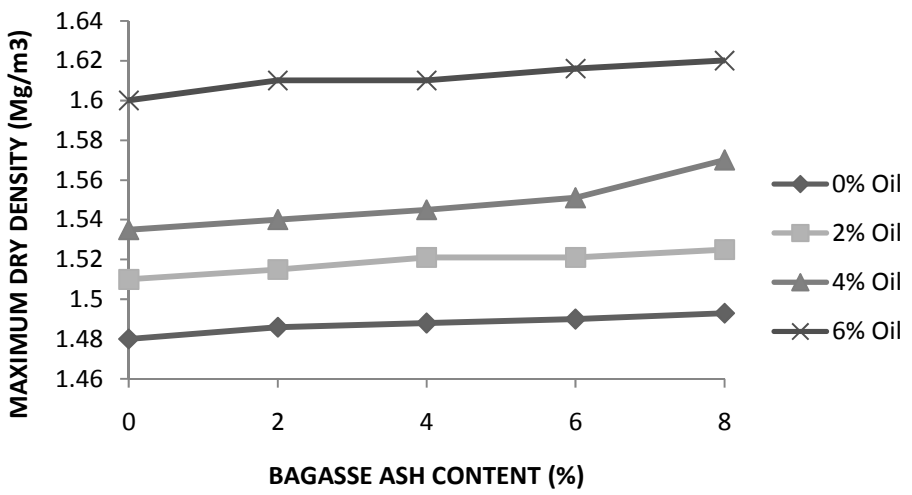


***Figure 7**. Variation of maximum dry density of oil contaminated soil with bagasse ash content*

The decrease in OMC as oil content increases may be due to the fact that oil being a fluid with lubricating characteristics tends to facilitate slippery of the soil particles relative to each other which resulted in reaching higher densities at lower moisture content. The trend observed in MDD and OMC is in agreement with findings of Lees et al [1, 27 and 33-37].

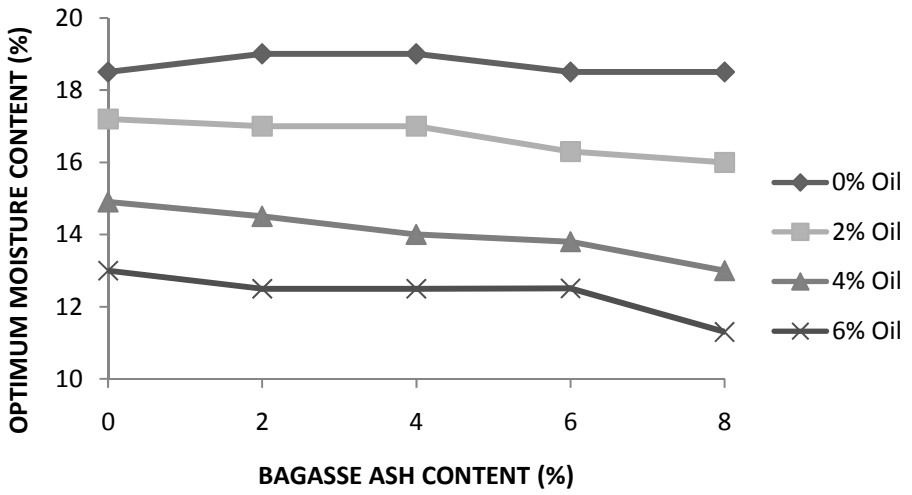


***Figure 8**. Variation of optimum moisture content of oil contaminated soil with bagasse ash content*

The OMC decreased continuosely with increased used oil content, but with respect to BA content, it increased to a peak value at 2 and 4 % BA contents and thereafter decreased. This trend is in conformity with results reported by Ola [38], Gidigasu [39] and Osinubi [40]. An explanation given to this trend was that the increased demand for water commensurate with the higher amount of admixture required for its hydration reaction and dissociation needed for cation exchange reaction. The subsequent decrease in OMC with increase in BA content might be due to cation exchange reaction that caused the flocculation of clay fractions of the soil. The variations of volumetric shrinkage of used oil contaminated lateritic soil with bagasse ash content using 0 %, +2 % and -2 % OMC as moulding water content are shown in Figure 9 - 11. A general decrease in volumetric shrinkage with increase in oil content was observed with 0 % and -2 % OMC variations of moulding water contents, while the volumetric shrinkage increased with increased oil and BA content when moulded with +2 % OMC. The decrease in volumetric shrinkage with oil contamination may be due to the penetration of the liquid oil into the soil matrix which lubricated the surfaces of the soil fabrics resulting into reactions between the hydrocarbon compounds in the oil and the calcium silicate gel in the soil [1].

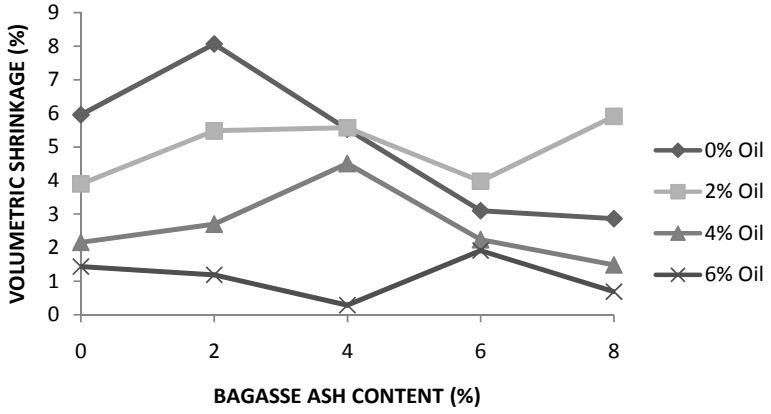


***Figure 9**. Variation of volumetric shrinkage of oil contaminated soil with bagasse ash content using the OMC as moulding water content*

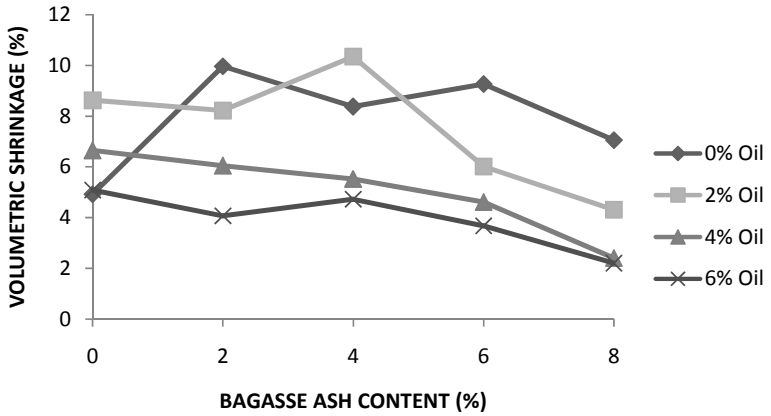


***Figure 10**. Variation of volumetric shrinkage of oil contaminated soil with bagasse ash content using +2 %OMC as moulding water content*

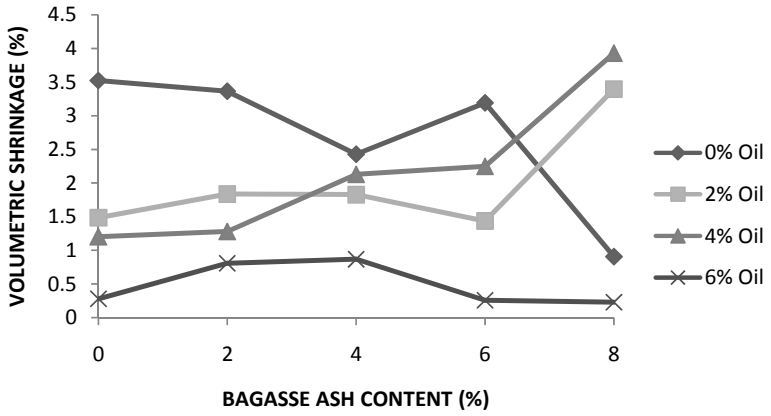


***Figure 11**. Variation of volumetric shrinkage of oil contaminated soil with bagasse ash content using -2 % OMC as moulding water content*

This reaction might have attenuated the bonds between the soil particles thereby

preventing the shrinkage of the soil. The decrease in volumetric shrinkage with BA content may be due to the penetration of the BA into the soil matrix which covered the surfaces of the soil fabrics resulting into reduced shrinkage.

Conclusions

The following conclusions were drawn from the results of tests conducted on the used oil contaminated lateritic soil treated with bagasse ash:

1. The lateritic soil used in this study is an A-6 soil using the AASHTO classification system and CL using the Unified Soil Classification System (USCS).
2. The properties of the natural soil improved with used oil contamination and bagasse ash treatment. The plasticity index decreased from 15.02 % for the natural soil to 13.62 % when contaminated with 6 % oil content. This value is very close to the 12 % plasticity index specified by clause 6201 of the Nigerian General Specifications (1997) for subbase type 1 materials. However, the 8.16 % plasticity index value obtained at 6 % oil/8 % bagasse ash content met the 12 % plasticity index requirement by the Nigerian General Specifications [41] for subbase type 1 materials. The specific gravity decreased steadily with increase in both oil and BA contents which indicates decrease in voids and hence higher densities.
3. The maximum dry density of the soil increased with increase in both oil and BA contents and the volumetric shrinkage decreased. The lowest values of volumetric shrinkage of 0.279 and 0.231 % were observed respectively at 6 % oil content and 6% oil/8 % BA content when the moulding water was reduced by 2 % of the optimum moisture content.
4. Used oil and bagasse ash have no adverse effect on the maximum dry density and volumetric shrinkage of lateritic soil when compacted at optimum moisture content or dry of the optimum moisture content.

References

1. Ochepo J., Salahudeen A. B., *Effect of oil contamination on lime and cement stabilized soil for pavement structures*, 2013 Conference Proceedings, Nigerian Institution of Civil

Engineers, 2013, p. 43-53.

2. Oluremi J. R., Osuolale O. M., *Review of the Potential Reuse of Oil Contaminated Soil as Engineering Material*, Book of Abstract for *Alexander von Humboldt Conference*, University of Ibadan, Ibadan Nigeria 11-15 October 2011, p. 12-13.
3. Ifeadi C. N., Nwankwo J. N., *Critical analysis of oil spill incidents in Nigerian petroleum industry*, *Seminar Proceedings of Petroleum Industry and the Nigerian Environment*, FMNH and NNPC, Lagos, 1987, p. 104-114.
4. Adepoyigi T., *Oil and Energy Insurance in Nigeria: Effects, Problems and Prospects, A paper presented at 1998 Seminar of Actuarial Science and Insurance Student's Associations*, University of Lagos, Lagos, Nigeria, 1998, 16 p.
5. Evgin E., Das B. M., *Mechanical Behaviour of Oil-Contamniated Sand. In: Environmental Geotechnology*, Usmen, M.A. and Y.B. Acar (Eds.). Balkema Publishers, Rotterdam, Netherlands, 1992, pp. 101-108.
6. Al-Sanad H. A., Shagoor F. M., Hencher S. R., Lumsden A. C., *The influence of changing groundwater levels on the geotechnical behaviour of desert sands*, Quarterly Journal Engineering Geology, 1990, 23, p. 357-364.
7. Puri A., Saxana R. P., Saxana K. C., Srivastava V., Tanden J. S., *Immuno stimulant activity of Nyctanthes Arbortristis*, Journal of Ethnopharmacology, 1994.
8. Madaki G. Y., *Effect of used oil contamination on the volumetric shrinkage of lateritic soil*, Unpublished project, Department of Civil Engineering, Ahmadu Bello University, Zaria, 2009.
9. Hazardous Waste Program technical bulletin, Missouri Department of Natural Resources, www.dnr.mo.gov/env/hwp, 2006 (retrieved 25th October 2015).
10. Environmental Protection Agency (EPA) United States, Managing used oil: advice for small businesses, 2012.
11. Alexander L. T., Cady J. G., *Genesis and Hardening of Laterite Soils*, U. S Department of Agriculture Technical Bulletin 1282, 1962, p. 90.
12. Osula D. O. A., *Cement stabilization using hydrated lime as an admixture*, An Unpublished M.Sc. Thesis Civil Engineering Department Ahmadu Bello University Zaria,

1984.

13. Gidigasu M. D., *Mode of Formation and Geotechnical Characteristics of Laterite Materials of Ghana in Relation to Soil Forming Factors*, Engineering Geology, 1972, 6, p. 79-150.
14. Ijimdiya T. S., Igboro T., *The Compressibility Behavior of Oil Contaminated Soils*, Electronic Journal of Geotechnical Engineering, 2012, 17, p. 3653-3662.
15. Gidigasu M. D., Dogbey J. L. K., *Geotechnical characterization of laterized decomposed rocks for pavement construction in dry sub-humid environment*, 6th South East Asian Conf. on Soil Engineering, Taipei, 1980, 1, p. 493-506.
16. Construction Industry Research and Information Association (CIRIA), Laterite in Road Pavements, Special publication 47, 1988, Transportation Road Research Laboratory, London.
17. Ijimdiya T. S., *The Effects of Oil Contamination on the Consolidation Properties of Lateritic Soil*, Development and Applications of Oceanic Engineering (DAOE), 2013, 2, p. 53-59.
18. Ajay G., Anwar A. M., Hattori K., Ogata H., *Properties of Sugarcane Bagasse Ash and its Potential as Cement-pozzolana Binder*, 12th International Colloquim on Structural and Geotechnical Engineering, Cairo, Egypt, 2007.
19. Misari S. M., Busari I. O., Gbiore S., *Current Status of Sugar Cane Research and Development in Nigeria., Proceedings of The Inaugural Meeting and Planning Workshop for Collaborations of National Co-Ordinated Research Program on Sugar Cane (NCRPSC)*, 1998, p. 2-12.
20. Ogbonyomi T. D., *Possible Uses of Bagasse Ash as an Alternative Cement*, Unpublished M.Sc Thesis, Ahmadu Bello University, Zaria, Nigeria, 1998.
21. Smith R. G., *Alternatives to Ordinary Portland cement*, British Building Society Journal, 1992, 25, p.1-17.
22. British Standard (BS) 1377, *Methods of Test for Soils for Civil Engineering Purposes*, 1990.
23. British Standard (BS) 1924, *Methods of Tests for Stabilized Soils.* British Standards

Institute, London, 1990.

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

25. ASTM C618-93 specification, Fly Ash and Raw or Calcined Natural Pozzolan for use as Mineral Admixture in Portland Cement Concrete, 1992.

26. Arora K. R., *Soil mechanics and foundation engineering*, 2011, 7th edition, p. 19.

27. Meegoda N. J., Chen B., Gunasekara S. D., Pederson P., *Compaction Characteristics of Contaminated Soils - Reuse as a Road Base Material*, Recycled Materials in Geotechnical Applications, GSP 79, ASCE, 1998, p. 195-209.

28. Ramzi T., Amer A., Ali A., Hilia A., *Use of Cement Kiln Dust in Soil Stabilization*, EJUQ, 2001, 14, p. 61-76.

29. Venkaramuthyalu P., Ramu K., Prasada R. G. V. R., *Study on performance of chemically stabilized expansive soil*, IJAET, 2012, 2(1), p. 139-148.

30. Suhail A. A. A., Khawla A. K. A., Ibrahaim M. A. A., *Strength Durability And Hydraulic Properties of Clayey Soil Stabilized with Lime and Industrial Waste Lime*, Al-Rafidain Engineering. 2008, 16(1), p.102-116.

31. Osinubi K. J., *Laboratory trial of soil stabilization of Nigerian black cotton soils*, Nigerian Society of Engineers Technical Transactions, 2000, 35(4), p. 13-21.

32. Oriola F., Moses G., *Groundnut Shell Ash Stabilization of Black Cotton Soil*, Electron Journal of Geotechnical Engineering, 2010, 15, p. 415-428.

33. Lees G., Abdelkader M. O., Hamdani S. K., *Sodium chloride as additive in lime- soil stabilization*, Journal Institute of Highway Engineers, 1982, 29(11), p. 8-16.

34. Ola S. A., *Laboratory testing and geotechnical characterization of black cotton soil and expansive shales in Nigeria*, Proceedings 9th Regional Conference for Africa on Soil Mechanics and Foundation Engineering, Balkema, Rotterdam, 1991, p. 991-995.

35. Iorliam A. Y., Agbede I. O., Joel M., *Effect Of Cement Kiln Dust On Some Geotechnical Properties Of Black Cotton Soil*, EJGE, 2012, 17, p. 967-976.

36. Salahudeen A. B., Akiije I., *Stabilization of highway expansive soils with high loss on*

ignition content kiln dust, NIJOTECH, 2014, 33(2), p. 141-148.

37. Salahudeen A. B., Eberemu O. A., Osinubi K. J., *Assessment of cement kiln dust-treated expansive soil for the construction of flexible pavements*, Geotechnical and Geological Engineering, Springer, 2014, 32(4), p. 923-931.
38. Ola S. A., *The geology and geotechnical properties of the black cotton soils of North Eastern Nigeria*, Engineering Geology, 1978, 12, p. 375-391.
39. Gidigasu M. D., *Laterite Soil Engineer-ing: Pedogenesis and Engineering Principles*. Elsevier, Amsterdam, the Netherlands, 1976.
40. Osinubi K. J., *Evaluation of admixture stabilization of Nigerian black cotton soil*, Nigerian Society of Engineers Technical Transactions, 1999, 34(3), p. 88-96.
41. Nigerian General Specification, Road Works and Bridges, Federal Ministry of Works and Housing, Abuja, Nigeria 1997.