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Valorization of spent engine oil contaminated lateritic soil with high calcium waste wood ash

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ABSTRACT

Lateritic soils often become contaminated with oil of hydrocarbon origin resulting from anthropogenic activities such as operation of mechanic workshops on lateritic soil deposits, leakage of underground petroleum and oil storage tanks, accidental spillage of crude oil and petroleum products. Whenever such areas will be used either as construction sites or as borrow pits, concern is usually raised on the impact of the oil contamination on the soil. This study therefore examined the impact of waste wood ash on the stabilization of the spent engine oil (SEO) contaminated lateritic soil, by adding 0 - 9% of waste wood ash by mass of soil sample in 3% step intervals. Sieve analysis, consistency limits, compaction and uniaxial compressive strength tests were carried out on the soil specimens. The results revealed that the addition of the waste wood ash improved the liquid, plastic and shrinkage limits but decreased the plasticity index of the lateritic soil. The maximum dry density and uniaxial compressive strength of the lateritic soil significantly increased with the addition of waste wood ash and this gives an indication that waste wood ash is effective up to 6% addition. Based on this study, addition of 6% waste wood ash by weight of the dry soil is therefore recommended for the stabilization of the SEO contaminated soil in order to improve its consistency and strength characteristics for its use as a road construction material.

Keywords: Spent engine oil; lateritic soil; waste wood ash; contamination; stabilization; strength characteristics

INTRODUCTION

Soil contamination is made up of solid or hazardous liquid substances, which are mixed with the naturally occurring soil (Meegoda et al., 1992; Oluremi and Osuolale, 2014). It is formed by the presence of conventional chemicals or other hazardous materials in the natural soil environment. Spent engine oil contamination of soil is very common where motor mechanic workshops are located. According to Euchun and Braja (2001), the bearing capacities of such soils are severely reduced and thereby the soils are rendered unfit as supporting systems for engineering structures and plant growth due to the reduction in nutrients as well as the increase in toxicity levels of the soil. Also, Ameh et al., (2012) stated that the presence of hazardous materials such as chlorinated solvents in spent engine oil makes it a potent contaminant when it is in contact with either water or soil. These contaminants have direct/indirect effects on the various properties of soil due to the interaction between the organic and inorganic pollutants present or generated from contaminants due to the imposed environmental conditions. Interaction between soil and pollutants changes soil behavior and can lead to partial or total immobilization of pollutants (Wang et al., 2000). Civil engineers are often faced with diverse challenges due to oil waste dumping, production, pollution, and spillage resulting into Oil Contaminated Soil (OCS), which if not treated, may cause serious human and environmental problems. Several researchers (Al-Sanad et al., 1995; Mashalah et al., 2006; Ratnaweera and Meegoda, 2006; Khamehchiyan et al., 2007; Ijimdiya, 2007; Al-Aghbari et al., 2011; Ijimdiya, 2013; Akinwumi et al., 2014; Oluremi et al., 2015; Oluremi et al., 2017a) have carried out the stabilization of various contaminated soils in order to improve their engineering properties. According to Oluremi and Osuolale (2014), the re-use of contaminated soil is regarded as one of the effective alternative methods of disposing contaminated soil. However, either the containment or solidification of the contaminants in the soil or effective remediation of the contaminated soil is a precursor to reuse in order to ameliorate the risks of oil contaminated soil. Several technologies are available, which include the conversion of oil contaminated soil into road base layer or a topping layer for motor parks and roads after mixing with stabilizing agents (Colorado Department of Health and Environment, 2003). Other technologies include incineration, vacuum extraction, absorption, soil washing and biological methods. However, these methods are costly and non-economical, considering the volume of contaminated materials to remediate (Ijimdiya, 2011). One good and cost effective method is soil chemical stabilization. Stabilization can be defined as any activity performed on the soil to improve its characteristics for engineering applications. According to Houben and Guillard (1994), stabilizing soil means changing its properties to achieve durable properties suitable for a specific application. In addition, stabilization is an ancient technique, which is not an exact science in spite of various research efforts. One aspect of soil stabilization is the addition of some chemicals and other related materials (usually in powdery form) as either additive or admixture for the improvement of engineering properties of the soil. Studies showed over 130 different stabilizing agents including cement, lime and bitumen, and there has not been any stabilizer that can be used indiscriminately but the cost of these conventional stabilizers is enormous. Hence there are needs for the use of cheap and readily available materials such as ash produced from various agricultural residues, which is regarded as a waste but cost effective material in stabilizing soils (Medjo and Riskowiski, 2004; Osinubi and Stephen, 2006; Alhassan and Mustapha, 2007; Osinubi et al, 2008; Osinubi and Eberemu, 2009; Oluremi et al, 2012; Salahudeen et al, 2014; Raheem et al, 2017a, b). This ash can act as both absorbent and admixture in stabilizing the OCS through various laboratory studies. Several studies (Norton, 1997; Osinubi, 2000; Walker et al, 2005; Alabadan et al, 2006; Oyetola and Abdullahi, 2006; Osinubi et al, 2009; Osinubi et al, 2011; Oluremi et al, 2012; Eberemu, 2015; Oluremi et al, 2016a, b) have investigated the impacts of different stabilizers on the geotechnical characteristics of soils. One good example of these materials is waste wood ash (WWA). Serafimova et al (2011) conducted extensive studies on the characteristics of waste wood ash and concluded that utilization of industrial wastes as secondary raw materials or resources is essential to achieve sustainable technologies. Similarly, Oluremi et al (2017b) investigated the effect of waste wood ash on the plasticity and cation exchange capacity (CEC) of Nigerian lateritic soil and discovered that the plasticity of the soil improved with the liming effect of the ash as well as its CEC. Attempts have been made to stabilize contaminated soils with various additives and test results showed a considerable improvement on the geotechnical properties of the stabilized soils compared to the unstabilized ones (Shah et al., 2003; Al-Rawas et al, 2005; Srivastava et al, 2009; Ochepo and Joseph, 2014). However, the potentials of WWA, which is very cheap and readily available in Nigeria and other African countries, on the stabilization of oil contaminated lateritic soils have not been investigated. This study therefore carried out the stabilization of oil contaminated lateritic soil using WWA for sustainable development and improvement of highway roads.

MATERIALS AND METHODS

Materials

Lateritic soil samples used are naturally reddish brown in color and were collected from Aroje burrow pit located along Ogbomoso–Ilorin express way in Ogbomoso (Lat. 080 10.249'N and Long. 004o15.118'E). Disturbed soil specimens were collected at a depth of 100 cm below the ground surface. These specimens were air-dried, pulverized and then sieved through British Standard sieve No. 4 (4.63mm) prior to its use.

Spent engine oil (SEO) was collected from Lutonia Tech. Ltd. Orita Naira Junction, Ogbomoso, Oyo state, Nigeria. It was a bulk sample of engine oil drained during the services of different car engines.

Waste Wood Ash (WWA) was produced by the open combustion of wood residues collected from saw mill along Abogunde road, Ogbomoso, Oyo State. The wood residue consisted of sawdust and wood shavings/chips and was burnt closer to the forest to act as carbon sink. The ash obtained was sieved through British Standard sieve size 75 μm and the content obtained was mixed with the SEO contaminated soil in increments of 0, 3, 6, and 9% by weight of soil sample to obtain the required specimens for testing. The chemical composition of this ash showed that it is a pozzolana of Class F in relation to ASTM C 61898- (ASTM, 1992).

Methods

The lateritic soil was contaminated with 10% SEO because it has been established that oil contamination beyond 8% by weight of its dry mass will adversely affect the geotechnical properties of the soil (Ijimdiya, 2007; Oluremi et al, 2015). The appearance of the lateritic soils before and after contamination was presented in Figures 1 and 2 respectively. The contaminated soil was then stabilized with WWA in varying percentages (0 to 9%). Sieve analysis, consistency limits, compaction and uniaxial compressive strength tests were conducted on the contaminated specimens in accordance with British Standards (BS 1377, 1990; BS 1924, 1990) and Head (1992) so as to assess the influence of WWA on the geotechnical properties of the contaminated soil. The test procedures are described as follows:

Fig. 1. Appearance of the soil before contamination.

Fig. 2. Appearance of the soil after contamination.

Sieve analysis: 300 g each of the contaminated soil samples was mixed with varying percentages of WWA (0 to 9%) and soaked in water for twenty four (24) hours. Wet sieving was then used to obtain the dried sample sieved in accordance with British Standard 1377 (British Standard Institution, 1990). Sieving was carried out with the aid of mechanical sieve shakers containing set of sieves. The samples retained on each sieve were collected, weighed and recorded. The data obtained was then used in determining percentage passing each sieve.

Liquid limit: 200 g of soil sample passing through BS Sieve No. 40 (425 μm) was thoroughly mixed with water until a thick homogeneous paste was formed. The paste was placed in the Casagrande apparatus cup and the crank rotated. The number of drops (blows), which closes the opened grove, was recorded. A portion of the tested soil samples was taken for the determination of moisture content.

Plastic limit: 200 g of the soil sample passing the 425 μm sieve was measured and mixed with water until it was homogenous and plastic to be rolled to a ball. The soil sample was then rolled on a glass plate under palm until the thread cracked at nearly 3 mm diameter. The water content of the sample at this point was determined.

Shrinkage limit: The paste formed during liquid limit was collected, placed and leveled in a shrinkage mould. The mould and its content were oven-dried for 24 hours and the linear difference before and after oven drying was calculated and used in determining the percentage shrinkage values of the soil sample.

Compaction: Air-dried oil contaminated soil samples were mixed with waste wood ash in varying percentages (0 to 9%) by weight of soil sample. The samples were subjected to three energy levels of compactions (i.e. British Standard Light (BSL), West African Standard (WAS) and British Standard Heavy (BSH)) to determine their maximum dry density and optimum moisture content (similar to that of Ijimdiya and Elaigwu, 2011).

Uniaxial compressive strength: The test was conducted by extruding the test sample from the sampling tube. A cylindrical specimen of the length-to-diameter ratio of 2:1 was trimmed such that the ends are reasonably smooth and was then placed in a loading frame on a metal plate. By turning a crank, the load was gradually increased for sample shearing to occur. The readings of the applied force and the corresponding deformation were taken periodically until the soil developed obvious shearing planes or the failures become excessive. The data obtained were used to determine the strength of the soil specimen and the stress-strain characteristics. In addition, the sample was then oven-dried to determine its water content. The results of this test were used to plot the stress-strain relationship for the sample and corresponding unconfined compressive strength was determined.

RESULTS AND DISCUSSION

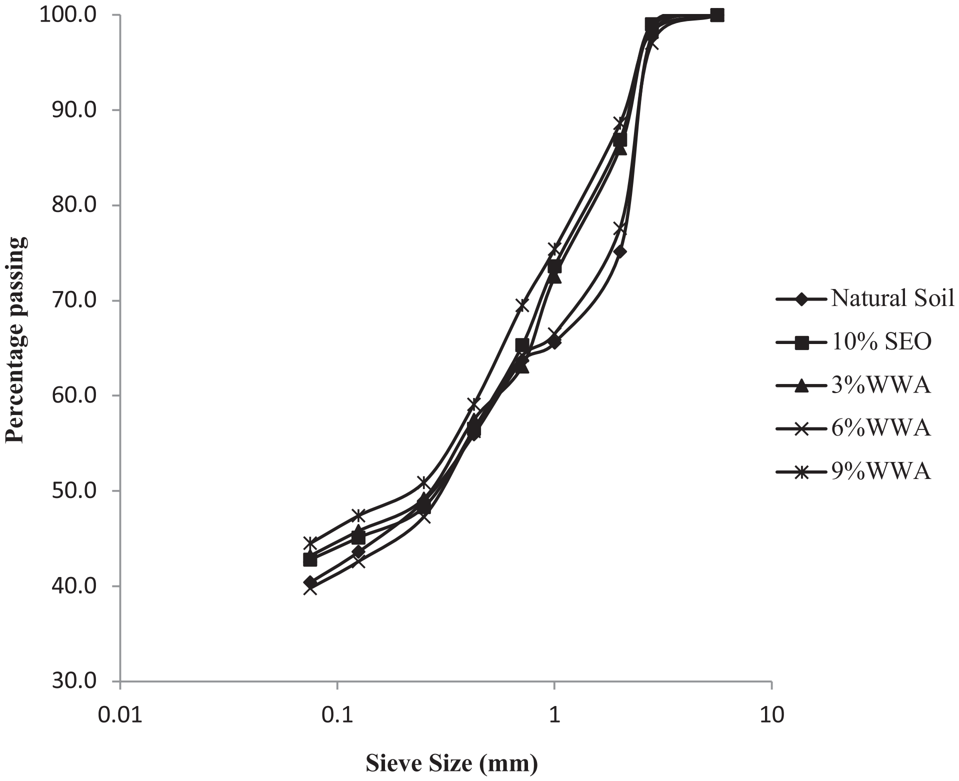
Sieve analysis

Figure 3 and Table 1 show that the percentages passing BS sieve No. 200 were less than 2.6% for all the stabilized soil samples. This result meets the required limits of 35% or less for its use as road construction material in accordance to Road and Bridges Specification Revised Edition of Federal Ministry of Works, Nigeria (Federal Ministry of Works and Housing, 1997). This indicates that the contamination itself has significant influence in reducing the fine content of the soil sample, that is, percentage passing No. 200 BS sieve size.

Table 1. Summary of the geotechnical tests.

Ash Composition		Natural soil	10% SEO	3% WWA	6% WWA	9% WWA
% Passing 0.075 µm		40.4	42.80	43.20	39.80	44.50
Liquid Limit (%)		58	50	54	60	60
Plastic Limit (%)		50	33.33	50	50	50
Plastic Index (%)		8	16.67	4	10	10
Shrinkage Limit (%)		10.2	6.25	7.94	7.94	8.59
BSL	**OMC (%)**	18.1	2A0	15	13.5	18
	MDD (g/cm³)	1.61	1.5	1.55	1.62	1.58
WAS	**OMC (%)**	16	14	12	14	15
	MDD (g/cm³)	1.66	1.52	1.54	1.67	1.67
BSH	**OMC (%)**	15	13.5	10	13	16
	MDD (g/cm³)	1.74	1.60	1.63	1.76	1.66
UCS (kN/m²)	**BSL**	149	75	80	84	122
	WAS	269	142	144	199	176
	BSH	285	236	257	299	325

**SEO = Spent Engine Oil, WWA = Waste Wood Ash, OMC = Optimum Moisture Content, MMD = Maximum Dry Density, BSL = British standard Light, WAS = West African Standard, BSH = British Standard, UCS = Uniaxial Compressive Strength*

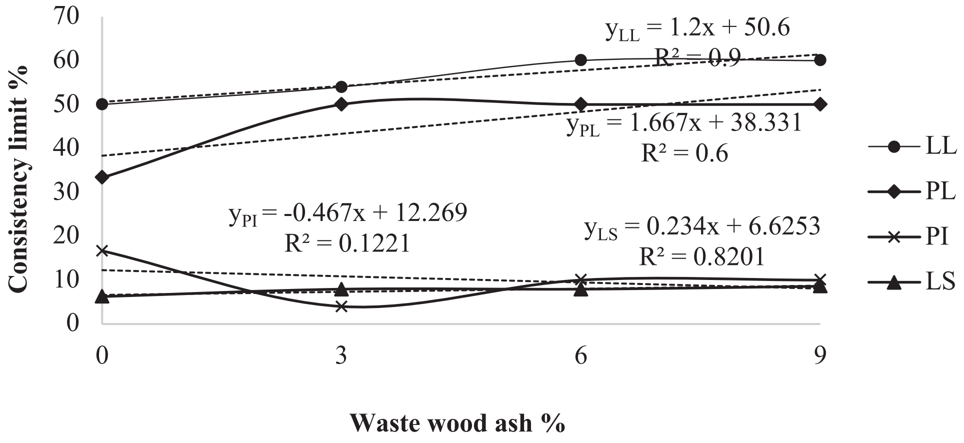


*SEO = *Spent Engine Oil, WWA= Waste Wood Ash*

Fig. 3. Grading curves of soil - waste wood ash mixtures.

Consistency limits

The liquid limit (LL) ranged between 50% and 60%, plastic limit (PL) ranged between 33.33% and 50%, plasticity index (PI) was between 4% and 16.67%, and shrinkage limit (SL) ranged between 6.25% and 8.59% as shown in Figure 4. This shows that stabilization of the oil contaminated soil with WWA decreased the plasticity index but increased the liquid, plastic and shrinkage limits of the lateritic soil. This decrease is due to the agglomeration and flocculation of the clay minerals due to the isomorphous substitution of cations at the top of the clay soil particles. This is in agreement with previous findings (Ramzi et al, 2001; Salahudeen and Akiije, 2014; Salahudeen and Ochepo, 2015). In addition, Venkaramuthyalu et al. (2012), Ramzi et al (2001) and Salahudeen and Ochepo (2015) noted that reduction in plasticity might result from the depressed double layer thickness, due to cation exchange between the added admixtures and soil minerals. The results also indicate that the effect of stabilizing contaminated soil is only significant up to 6% addition of WWA. This shows that contamination has an early effect on the consistency limits but soil regained its strength back after biodegradation and volatilization, which is in line with the previous findings reported by Ijimdiya (2011), Oluremi et al (2012), and Oluremi et al (2015). According to Federal Ministry of Works and Housing (1972) for road works, the results of the consistency limits (liquid limit, plastic limit and plasticity index) fall outside the limit of 30% maximum, 18% maximum and 12% maximum recommended for sub-base and base materials. So, the stabilized soil sample could only be used as fill or subgrade material. Both liquid limit (LL) and linear shrinkage (LS) linearly fitted very well with R2 value of 0.9 and 0.82, respectively while plastic limit (PL) linearly fitted moderately with R2 value of 0.6. This implies the numerical simulation of these properties will be consistent with the experimental results. However, the non-fitting of plasticity index (PI) might be connected with the fact that it is from deterministic results and not really experimental results.

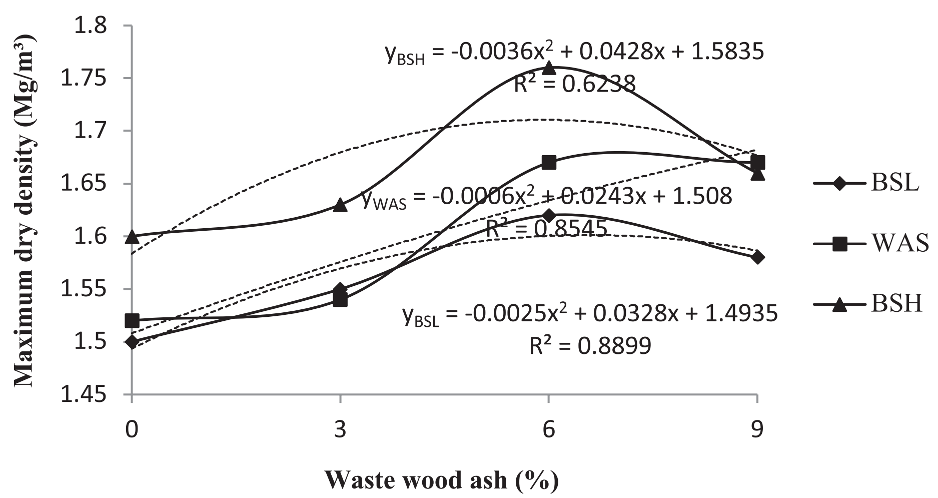


**LL= Liquid Limit, PL= Plastic Limit, PI= Plastic Index, LS= Linear Shrinkage*

Fig. 4. Relationship between consistency limits and waste wood ash.

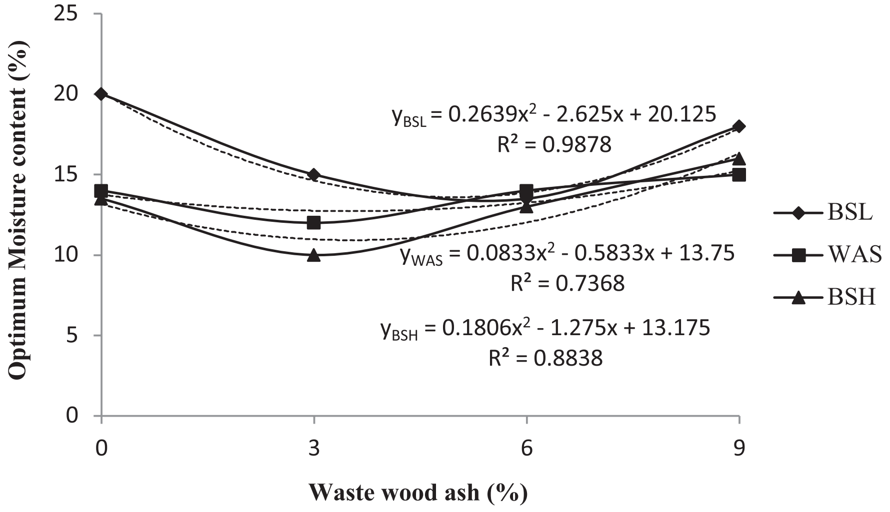
Compaction

Figures 5 and 6 show variations of maximum dry densities and optimum moisture content respectively. The maximum dry densities (MDD) as shown in Figure 5 ranged from 1.5 to 1.62 g/cm3, 1.52 to 1.67 g/cm3, and 1.6 to 1.76 g/cm3 for British Standard Light (BSL), West African Standard (WAS) and British Standard Heavy (BSH) respectively. In addition, the optimum moisture contents (OMC) as shown in Figure 6 ranged from 13.5 to 20% for BSL, 12 to 15% for WAS and 10 to 16% for BSH. Also, maximum dry density of the waste wood ash stabilized SEO contaminated soil, which is best fitted using polynomial trend line of order 2, increased with a corresponding decrease in OMC and increase in compactive effort. The effect of the stabilization on MDD and OMC is quite significant up to 6% of waste wood ash addition. In addition, it is evident from the results that increasing energy level leads to increasing soil density due to dehydration of the soil sample and increased compaction, which accumulated the formation to large pseudo size clods with increased density. This shows that both the density and strength characteristics of the soil samples can be improved through compactive efforts.



**BSL= British Standard Light, WAS= West African Standard, BSH= British Standard Heavy*

Fig. 5. Relationship between maximum dry density and waste wood ash for various compactive energy levels.



**BSL= British Standard Light, WAS= West African Standard, BSH= British Standard Heavy*

Fig. 6. Relationship between optimum moisture content and waste wood ash for various compactive energy levels.

Unlike consistency limits which fit linearly, Maximum dry densities (MDDs) and optimum moisture contents (OMCs) as compaction properties of the stabilized soil can only be fitted using polynomial of order two. This shows that the optimum content of the stabilizer has to be determined. Both MDDs and OMCs fitted very well with R2 values of (0.89, 0.86, 0.62) and (0.99, 0.74, 0.84) for BSL, WAS and BSH respectively.

The result of two–way ANOVA (analysis of variance) test on the results of compaction characteristics (MDD and OMC) shows that both compactive energy level (FCAL = 12.29097< FCRIT = 5.1433) and waste wood ash (FCAL = 14.83612< FCRIT = 4.7571) have effects that are statistically significant on the waste wood ash stabilized lateritic soil. However, only compactive effort has statistically significant effect on the stabilized soil as shown in Table 2. This means that addition of waste wood ash may not necessary control the effect of moisture content in the stabilization of the spent engine oil contaminated lateritic soil and hence moisture content of the soil should be monitored closely during field compaction.

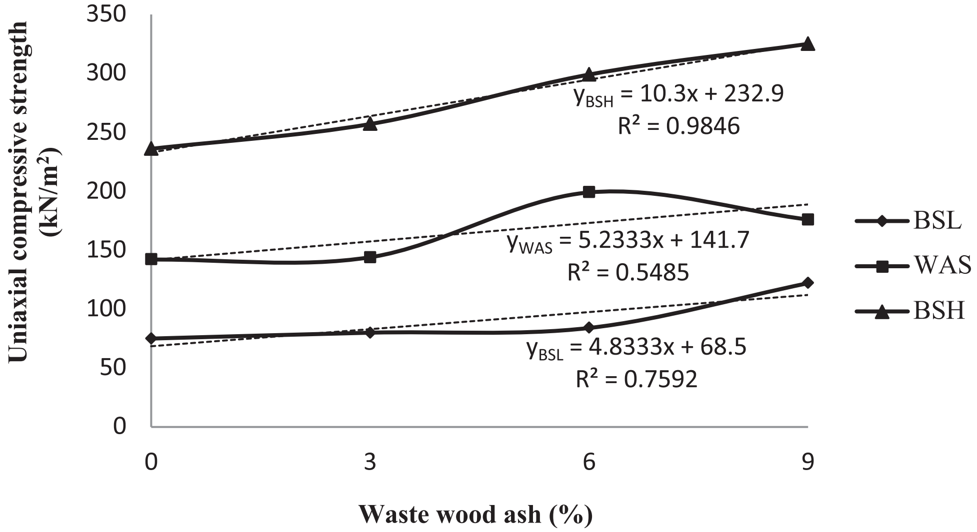
Table 2. Two–way Analysis of Variance of compaction characteristics of waste wood ash stabilized SEO contaminated lateritic soil.

Properties	*Source of Variation*	*Degree of freedom*	F_{Cal}	*P-value*	F_{Crit}	*Remark*
Maximum dry density	Compactive efforts	2	12.29097	0.007552	5.143253	SS
	Waste wood ash	3	14.83612	0.0035	4.757063	SS
Optimum moisture content	Compactive efforts	2	5.186047	0.04922	5.143253	SS
	Waste wood ash	3	4.031008	0.069085	4.757063	NSS

**FCAL* = Ratio of variance after treatment; *FCRIT* = Stipulated ratio of variance; *P-value* = probability value; SS = Statistically Significantly; NSS = Not Statistically Significantly

Uniaxial compressive strength (UCS)

Figure 7 is the variation of the uniaxial compressive strength of the SEO contaminated lateritic soil stabilized with varying content of WWA. It shows that the UCS increased with increasing percentage of waste wood ash content from 75-176-142 ,122 and 236325- kN/m^2 with R2 values of 0.7592, 0.5485 and 0.9846 for BSL, WAS and BSH respectively. This reveals that compressive strengths increased with increasing compactive effort, which is an indication that the density and strength characteristics of the samples can be increased through compactive efforts. The results gave a good linear fitting with R2 value of 0.76, 0.55 and 0.98 for BSL, WAS and BSH respectively. The increase in strength according to Galiano et al (2011), Huang et al (2013) and Wang et al (2015) is connected with the agglomeration of the soil particles under the influence of cementitious materials of calcium silicate hydrate (CSH) and alumina silicate hydrate (ASH) formed from pozzolanic reaction of the waste wood ash with siliceous materials in the soil after the lubricating effect of the spent engine oil has been overcome. However, the values of UCS were not up to 1710 kN/m^2 specified by TRRL (1977) and Iorliam et al (2012) as a gauge for adequate stabilization using Ordinary Portland Cement (OPC).



**BSL= British Standard Light, WAS= West African Standard, BSH= British Standard Heavy*

Fig. 7. Relationship between uniaxial compressive strength and waste wood ash for various compactive energy levels.

Based on the result of two–way ANOVA test on the results of uniaxial compressive strength shown in Table 3, both compactive energy level (FCAL = 111.5089< FCRIT = 5.1433) and waste wood ash (FCAL = 6.7007< FCRIT = 4.7571) exerted statistically significant effects on the waste wood ash stabilized lateritic soil.

Table 3. Two–way Analysis of Variance of uniaxial compressive strength of waste wood ash stabilized SEO contaminated lateritic soil.

Properties	*Source of Variation*	*Degree of freedom*	F_{Cal}	*P-value*	F_{crit}	*Remark*
Uniaxial compressive strength	Compactive effort	2	111.5089	1.8E-05	5.1433	SS
	Waste wood ash content	3	6.7007	0.0242	4.7571	SS

**FCAL = Ratio of variance after treatment; FCRIT = Stipulated ratio of variance; P-value = probability value; SS = Statistically Significantly*

CONCLUSIONS

Experimental analyses of the geotechnical properties of the SEO contaminated lateritic soil admixed with varying contents of waste wood ash were conducted in accordance with British Standards 1377 and 1924. The following itemized conclusions were established from the results of the various soil tests conducted.

Waste wood ash had significant influence on the Atterberg limits, compaction and unconfined compressive strengths of the spent engine oil contaminated lateritic soil. Stabilization of the SEO contaminated soil with waste wood ash increased the liquid, plastic and shrinkage limits with corresponding decrease in the plasticity index of the SEO contaminated lateritic soil. The liquid and plastic limits increased from 0 to 6% addition of waste wood ash.

Maximum dry density of the lateritic soil increased from 0 to 6% of waste wood ash, which gives an indication that waste wood ash is significantly effective up to 6% addition. It was also observed that maximum dry density increased with increasing compactive efforts, that is, from British Standard Light (BSL) to West African Standard (WAS) to British Standard Heavy (BSH) method of compaction. This indicates that the density and strength of the lateritic soil can be improved through compactive efforts.

Uniaxial compressive strength (UCS) increased with increasing percentage of waste wood ash. In addition, the UCS of the WWA stabilized SEO contaminated lateritic soil increased as the compactive energy level increased from BSL to WAS and then to BSH.

Based on this study, waste wood ash up to 6% addition by weight of the soil is therefore recommended for the stabilization of the SEO contaminated lateritic soils of low density and strength characteristics, and to increase and decrease the liquid limit and plasticity index of soils, respectively. The stabilized soils can thereby be used as a subgrade material in the construction of both the low and high traffic roads.

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تثمين تربة اللاتريت الملوثة بزيت المحركات برماد الخشب المحتوي على نسبة عالية من الكالسيوم

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الخلاصة

غالباً ما تتلوث تربة اللاتريت بالزيت ذو الأصل الهيدروكربوني الناتج عن الأنشطة البشرية، مثل تشغيل الورش الميكانيكية، وتسرب النفط تحت الأرض ومن خزانات النفط، والانسكاب العرضي للنفط الخام والمنتجات النفطية. وحينما تُستخدم هذه المناطق إما كمواقع بناء أو مواقع تجهيز للحفر، يثُار القلق عادة بشأن تأثير التلوث النفطي على التربة. اختبرت هذه الدراسة تأثير رماد الخشب على استقرار تربة اللاتريت المُلوثة بزيت المحركات، وذلك بإضافة 0 - 9 ٪ من رماد الخشب على عينة من التربة عن طريق إضافة 3 ٪ على 3 فترات. تم إجراء تحليل الغربال، واختبارات حد التناسق، والضغط، وقوة الانضغاط أحادي المحور على عينات التربة. وأظهرت النتائج أن إضافة رماد الخشب عمل على تحسين كل من حدود السائل والبلاستيك والانكماش، ولكنه عمل على تقليل مؤشر اللدونة لتربة اللاتريت. وزادت الكثافة الجافة القصوى ومقاومة الانضغاط أحادية المحور للتربة بشكل كبير من خلال إضافة رماد الخشب، مما يعطي مؤشراً على أن رماد الخشب فعال عند إضافة 6 ٪ منه على التربة. وبناءً على هذه الدراسة، يُوصَى بإضافة 6 ٪ من رماد الخشب بوزن التربة الجافة لتثبيت التربة المُلوثة بزيت المحركات لتحسين خصائص الاتساق والقوة لاستخدامها كمواد لبناء الطرق.