GEOTECHNICAL PROPERTIES OF CRUDE OIL INCINERATED LATERITIC SOIL FOR USE IN ROADWORK

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Abstract: Laboratory investigation on crude oil incinerated lateritic soil was undertaken to evaluate its geotechnical properties as connected to roadwork. The lateritic soil was thoroughly mixed with various percent 0, 8, 12, 16 and 20% crude oil by dry weight of the soil. Each of the specimens were incinerated by allowing the crude contaminated soil to burn until the fire goes off. The rate of incineration is directly proportional to the quantity of crude oil content in the soil. Index properties of the crude oil incinerated (COI) soil was determine alongside the compaction characteristic and California bearing ratio test using British Standard light, BSL (or standard Proctor) and British Standard heavy, BSH (or modified Proctor) compaction energies. The result shows that the incineration shifted the aggregate size distribution curve from clayey soil A-7-6(16) to silty soil A-4(1). The liquid limits (LL) and plastic limit (PL) decreases with increased crude oil content and rate of incineration. The liquid limit of not more than 35% recorded, meets the requirement for sub-base material for road construction. The compaction trend showed an initial increase and gradual decrease in the dry density as the percentage incineration increased for BSH compaction level while the optimum moisture content decreases as the crude oil content and incineration rate (COI) increased for both efforts. The CBR (unsoaked) attained a peak value of 70% at 20% COI for BSH compaction energy, while the lower compaction energy (BSL) attained a peak value of 32% at 16% COI. Similarly, the CBR (soaked) attained a peak value of 45% at 12% COI for the higher compaction energy (BSH), while the lower compaction energy (BSL) attained its peak value of 28% at 8% COI. Base on the 30% CBR value recommended for sub-base of lightly trafficked roads by the Nigerian General Specification, 12% COI is recommended for use as a sub-base in road construction.

Keywords: Incineration, Atterberg limit, compaction characteristics, California bearing ratio

Introduction

Soil contamination through oil spillage is a global phenomenon which occurs as a result of wars, accidents, drilling, storage, vandalism, transportation of products, and natural disasters. Singh *et al*. (2008) stated that when oil is released, it resides in the soil system, in the pore space of the soil, modifying the behaviour of the soil. Crude oil was released into the soil when storage tanks and well heads were destroyed in Kuwait during the gulf war (Al-Sanad *et al.*, 1995; Rehman *et al.*, 2007). Also, despite the good oil tanker maintenance culture in the United States of America, oil still leaked from storage tanks to pollute the soil (Patel, 2011). The continued oil exploration activities and in some cases pipeline rupturing and sabotage have crude oil/petrochemicals released to the environment in the Niger Delta of Nigeria, thus exposing the area to environmental degradation.

Oil leakage into soil results in contamination and there is a need for bioremediation (Khamehchiyan *et al.*, 2007). A basic step for effective bioremediation is an understanding on how the geotechnical properties of the soil are affected by the oil contamination. Geotechnical testing of soil aids in finding an alternative usage for the contaminated soil (Al-Duwaisan and Al-Naseem, 2011). A few studies have been performed by experts to evaluate the effects of oil contamination on geotechnical properties of soil (Khosravi *et al*. 2013; Ijimdiya, 2012; Rahman *et al.*, 2010; Khamehchiyan *et al.*, 2007; Rehman *et al*., 2007).

Researchers have suggested several remedial methods for oil-contaminated lands. These included the conversion of oily soil to road base material or topping layers for car parks and roads after mixing with aggregate or consolidation agents. Containment in large burial sites, incineration, biological methods, absorption methods, soil washing methods, and vacuum extraction and separation by centrifuge and screen systems represent other methods of remediating oil-contaminated soil (Al-Sanad *et al*., 1995; Khamehchiyan *et al*. 2007). In contrast to treatment methods that are costly, the utilization of contaminated soil in construction as a road base, surfacing material, a back fill or other engineering applications, such as landfill caps, appears cost-effective. Transporting contaminated soil from one location to another could pose danger and must be noted that moving contaminated soil to other areas could possibly have negative effect on human health and the environment. Incineration is an alternative to bioremediation (Khamehchiyan *et al*, 2007); in this case, the soil is excavated and burnt in an incinerator. This method is similar to what happens when there is a fire outbreak at oil contaminated soil site during/after oil spillage. Hence, an adequate understanding of the geotechnical characteristics of burnt crude oil-contaminated soil is vital.

The study of Khosravi *et al*. (2013) on the effect of oil contamination on Atterberg limits of low plasticity clay showed that the liquid limit and the plasticity index of the soil increased as the oil content increased in the soil from 0 to 12% and reduced with further oil content (12 to 16%). They attributed this behaviour to reduction in cohesion of the soil due to oil content. Also, Atterberg limits and plasticity index of oil contaminated high plasticity clay increased because oil gave additional cohesion to the clay particles Rehman *et al.* (2007). The Atterberg limits of oil contaminated basaltic grade V and VI soils shows that liquid limit and the plastic limit reduced with increased oil content because oil filled more space without adding more increase to cohesion tendency of soil (Rahman *et al*, 2010). Similar trend in Atterberg limits reduction with increased oil content were reported for oil contaminated granitic sandy loam and meta sedimentary soils, respectively (Rahman *et al*., 2011). Ijimdiya (2012) reported that 2 percent oil content reduced the plasticity index of lateritic soil deposit of Shika, Zaria in Nigeria from 16 to 15.5 percent. He also confirmed that clods were formed, hence, crude oil could form adhesion in soil particles, thereby reducing the effect of water on the soil particles. The increase in oil content shifted the particle size distribution curve from finer to coarser grain Ijimdiya (2011). The findings of Oluremi *et al*. (2017) indicated that clay and silt size of aggregate size distribution decrease with increase in the spent engine oil (SEO) content without any optimum and conclude that 4% SEO content could be used to improve the particle size distribution. Contamination of soft clays by crude oil account for 17.9% increase in the liquid limit, 6.9% increase in plastic limit and 37.5% increase in plasticity index (Elisha, 2012). Liquid limit and plastic limit increased as oil contamination increased in the soil mixtures. The plasticity index of the soils also increased as oil contamination increased (Daka, 2015).

Soil compositional factors such as clay mineralogy and chemical compositions account for the variations in its engineering property. The variations in compaction characteristics of oil contaminated soils differed because the soil composition varied. The effect of oil contamination on the compaction characteristics of various kind of soil have been investigated in several studies (Rehman *et al*., 2007; Rahman *et al*., 2010; Rahman *et al*., 2011; Al-Sanad *et al*., 1995; Khamehchiyan *et al*., 2007). The variation of compaction characteristics in a compacted oil-contaminated soil containing high plasticity clay showed that the maximum dry density (MDD) increased with increase in oil content (Rehman *et al*., 2007). This trend is consistent with the investigation of Rahman *et al* (2011) who used metasedimentary soil contaminated with oil. Also, MDD values decrease with increase in spent engine oil contents (SEO) but increased with higher compaction energies but no general trend was observed for OMC values with higher SEO content Oluremi *et al*. (2017). In another study, the MDD decreased with an increase in oil content, when a variety of soils such as poorly graded sand, sand with 5 to 15% silt, low plasticity clay and basaltic soils were studied under various level of oil-contamination (Al-Sanad *et al*. 1995; Khamehchiyan *et al*. 2007; Rahman *et al*. 2010; Rahman *et al*. 2011). Elisha (2012) report a test that a marked increase in MDD at relatively low OMC in contaminated soft clay against the uncontaminated. Furthermore, as the oil contamination increases from 0 to 12% (0 to 120000 ppm), the MDD increases from 1.65 to 1.73 g/cm^3, and the optimum water content decreases from 19.2 to 10.1% (Mohammad and Taghi 2012). Ur-Rehman *et al*. (2007) report that the improvement in compaction characteristics is attributed to the lubricating effects of the oil, which is due to the oil coating on the individual clay particles and the clay groups.

Humans are intentionally/unintentionally contaminating soils from different sources. The contaminated soils are not only a challenge for the environmentalist but for the geotechnical engineer. The surface environment is becoming increasingly contaminated because of disposal of chemicals and waste materials produced as a result of rapid industrialization and various human activities. All types of pollution have direct/indirect bearing on soil/subsoil. Oil exploration, production, processing, and transportation from one end to refining, storage (surface and subsurface) transportation and distribution leads to the chance of leakage and spillage. The physical properties of oil contaminated soils will also control the stability of slopes and also the bearing capacity of foundation and other structures. Bearing capacity changes have far reaching effects on foundation. It can result in functional and structural failure of existing structures, this is particular when contamination causes significant increase in soil plasticity; loss of bearing capacity, increases the soils settlement and prevent drainage of water and other liquids. Oil contamination of soils can lead to total abandonment of proposed project sites, reduce scope of projects or increase project cost. Fire outbreak as a result of spillage/contamination can have adverse effects on the soil structure and its engineering properties. As a contribution to knowledge, it becomes necessary to carry out further investigations on Aggregate size distribution, Atterberg limit and some geotechnical evaluations on incinerated fine grain lateritic soil. Therefore, this study makes a major contribution to research on incinerated lateritic fine grain soil by demonstrating its potentials as sub-grades or sub base construction material through geotechnical testing and chemical characterization. The study also offers some important insights into the gap created in previous report which are based on only oil-contamination.

The lack of compromise on the influence of oil on compaction characteristics, Atterberg limit, particle size distribution and strength properties necessitates a different approach of study wherein after varied level of crude oil contamination, soil is further incinerated and its effect on the engineering properties investigated. In the light of the aforementioned, this study investigated the geotechnical properties of crude oil incinerated soil (COI) limited to 20 % crude oil content before burning

Materials and Methods

Soil: The soil used in this research work 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, by using the method of disturbed sampling at 1m depth from the natural earth surface to avoid organic matter influence.

Crude oil: The crude oil used was Escravos light crude from Kaduna Refining and Petrochemical Company (KRPC). The sample of the crude oil used in shown in Fig. 1.

Fig. 1: Weighing of crude oil

Crude oil specimen

Specimen preparation

The lateritic soils used in this research was thoroughly mixed after been contaminated with crude oil using, 0, 8, 12, 16 and 20 percentages, respectively by dry weight of each soil sample in order to simulate the ideal field conditions where crude oil spillage in an open field. The soil is completely burned until the fire goes off on its own without any interference. The duration of incineration of the contaminated soil increased with increased percentage contamination. This is expected because the higher the hydrocarbon contents the greater and longer will be the combustion period because more time is required to oxidize much quantity of hydrocarbon to carbon dioxide and water during burning in the presence of oxygen for a complete combustion. The incinerated soil was allowed to cool before being packed into sacks and labeled. The picture of the contamination and burning process is shown in Fig. 2.

(a) Uncontaminated (b) burning contaminated soil (c) after burning and cooling

Fig. 2: Crude oil contamination and burning process

Methods of testing

Grain size distribution of the natural soil was determined using hydrometer analysis (ASTM D422) and grain size analysis by dry sieving (mechanical sieving) of coarse fraction (ASTM D422).

Atterberg limit: The experiments for Atterberg limits are also known as consistency tests. They include liquid limit, plastic limit plastic limit, and plasticity index tests. The liquid limit (LL) and plastic limit (PL) experiments were conducted with the requirement of ASTM D4318 and ASTM D4318 standards, respectively, and plastic index was calculated as PI=LL−PL.

Compaction: The compaction tests was performed on the natural and contaminated soils using the British Standard light (BSL) and British Standard heavy (BSH) compactive energy in accordance with BS 1377 Part 4 (1990). The BSL and BSH compactions are the British Standard (BS) equivalents of the Standard (ASTM Test Designation D-698 (ASTM, 2007); AASHTO Test Designation T-99 (AASHTO, 1982)) and Modified Proctor compactions (ASTM Test Designation D-1557 and AASHTO Test Designation T-180). Compaction experiments were done on the uncontaminated and various level of 8, 12, 16 and 20% crude oil contaminated and incinerated (COI) fine grain soils. Maximum dry density value in (Mg/m^3) which correspond to the optimum moisture contents value in % was obtained for the various specimen on compaction graph showing the relationship between dry density and water content.

California bearing ratio (CBR)

The California bearing ratio (CBR) experiments were conducted in accordance with BS 1377 (1990) and BS 1924 (1990) for the natural and incinerated soils, respectively. However, the test was modified in accordance to the Nigerian General Specification (1997) Clause 6223. The aim of the CBR test was to determine the relationship between force and penetration. For the standard Proctor compaction, about 3.5 kg of the incinerated soil sample was mixed at OMC. The mixture was then compacted in 3 equal layers in the CBR mould, with 62 blows of the 2.5 kg rammer was applied to each layer while for modified proctor 5 equal layers each receiving 62 blows using a 4.5 kg rammer. The extension collar was removed and the top of the compacted sample trimmed carefully and wrapped in a polyethylene bag. The samples were kept in the humidity room at a temperature of 20 ± 2°C and 100% relative humidity for 6 days. Durability assessment of CBR specimen entails immersion of the 6 days cured specimens in water for about 24 h before testing; this is in accordance with the Nigerian General Specification (1997). In testing the specimens, the mould containing the compacted soil with the base plate in place were positioned on the lower plate of the machine. The plunger was then made to penetrate the specimen at a rate 1.3 mm/min until the specimen failed. The mould was then inverted base plate removed and the procedure repeated for the base of the specimen. The value of the force at each 0.25 mm interval was recorded until failure of the specimen. From the values of penetration and force recorded, a curve of force against penetration was obtained. The CBR value was calculated at penetration of 2.5 and 5.0 mm. The greater of the two values was taken as the CBR of the soil for the soil in question. However, where the values are within 10% of each other, the mean value of the two readings was considered, otherwise the higher value was recorded as the CBR of the specimen

The CBR was calculated using the relationship;

$$CBR = \frac{\text{Test load}}{\text{Standard load}} \times 100\% \qquad 1$$

Standard Load = 13.24 kN at 2.5 mm penetration

= 19.96 kN at 5.0 mm penetratio

Results and discussion

Chemical characteristic of materials used

The oxide composition of the natural and crude oil incinerated Soil (COI) carried out at National Geo-science research laboratories center Kaduna are presented in Tables 1 and 2. Table 3 shows the typical property of crude oil used in this study. The ratio of sesquioxides [SiO_2/ (Al_2O_3 + Fe_2O_3)] for the natural soil was calculated to be 1.29, which indicates that the soil is laterite. Whereas the ratio of sesquioxides (SiO_2/ (Al_2O_3 + Fe_2O_3)) for the varying percentages of incinerated soil (8, 12, 16 and 20%) where calculated to be 1.90, 1.65, 1.66 and 1.19, respectively. This result is an indication that the soil change to lateritic as a result of the contamination and incineration of the laterite soil (COI).

Table 1: Oxide composition of lateritic soil

Oxide	Concentration (%)
SiO_2	47.1
Al_2O_3	17.40
K_2O	0.48
CaO	0.17
TiO_2	3.69
V_2O_5	0.070
Cr_2O_3	0.035
Fe_2O_3	19.04
MnO	0.054
CuO	0.065
ZrO	0.966

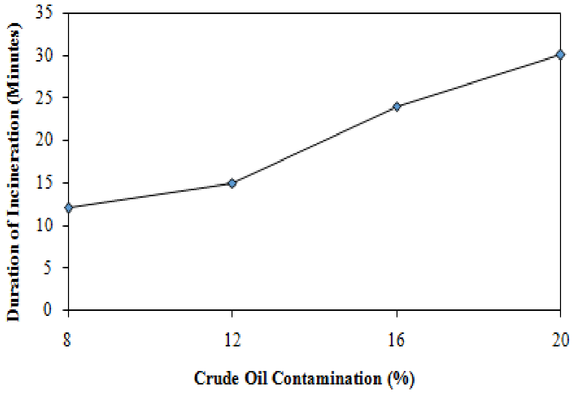

Fig. 3: Variation of incineration time with crude oil content

The natural laterite contains the highest amount of Fe_2O_3 more than the various crude oil contaminated incinerated lateritic soil as indicated by the oxide composition in the Table 1 and 2. The high content Fe_2O_3 is responsible for the reddish-brown colour of laterite soils (Nnochiri *et al*., 2010). The natural and crude oil incinerated soil (COI) content are majorly composed of the following components: SiO_2, Al_2O_3, and Fe_2O_3 these components account for the strength of the soil. At 8 and 12% COI, percentage composition SiO_2 and Al_2O_3 appreciated with a significant reduction in the composition of Fe_2O_3 while at 16 and 20% COI, SiO_2 and Al_2O_3content slightly decreased with corresponding decrease in Fe_2O_3 content. These variations are likely to have influence on the geotechnical properties of specimens when deployed as sub grade construction material in road works.

Table 2: Oxide composition of crude oil incinerated soil (COI)

Oxides	8% COI	12% COI	16% COI	20% COI
Al_2O_3	22.17	24.78	18.37	19.30
SiO_2	57.93	57.18	45.48	35.59
K_20	0.12	0.02	0.01	0.06
Ti_20	0.86	1.24	1.18	0.70
MnO	0.03	0.05	0.05	0.03
Fe_2O_3	8.32	9.79	9.05	10.59
Sr_2O_3	0.004	-	-	-
Zr_2O	0.070	0.039	0.017	0.014
Nb_2O_5	0.012	0.012	0.011	0.012
MoO_2	0.001	-	-	-
Na_2O	0.007	0.005	0.004	0.004
Cd_2O_5	0.027	0.024	0.006	0.006
Hf_2O_3	0.0002	0.0006	-	-
PbO	0.0037	-	-	-

Table 3: Characteristics of escravos light crude used in this study

Analysis/Parameters	Crude oil sample result	Crude oil specification
Specific gravity@ 15/4^{O}C	0.8167	0.840-0.860
API in degree	42	30 min
Sulphur content, % wt	0.138	0.150max
Viscosity at 40^{O}C	1.90	5.50max
BS & W, % VOL	Trace	1.00max

Index properties characteristic

The particle size distribution plots for the natural soil and crude oil incinerated soil (COI) mixtures are shown in Fig. 4. Summary of the index properties is shown in Table 4. The particle size distribution of the soils showed that 96.2, 60.00, 57.00, 53.00 and 40.2% particle sizes pass through sieve 75 µm aperture, for 0, 8, 12, 16 and 20% COI, respectively. The particle size distribution curves of the soil indicate a shift from a finer to coarser particles.

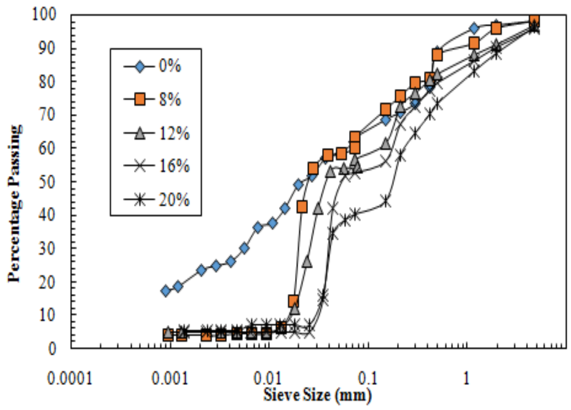

Fig. 4: Particle size distribution curve

The liquid limits result shown in Table 4 show a decrease in liquid limit (LL) and also a relatively low plastic behaviour of the soil as percentage COI increase. This is because the addition of crude oil to the soil before incineration causes an alteration in the cohesive bonds and as a result of reduced intermolecular cohesive forces that existed between the soil particles Jesna *et al.* (2015). The reduction in liquid limit can be explained by the nature of water in clay mineral structure. Water is polar (i.e., it can have a positive charge at one side and negative at the other) the dipolar water is both attracted by the negatively charged clay particles and by the cation double layer. All the water held to clay particles by force of attraction is called double layer water. The inner most layer of double layer water, which is held very strongly by clay is known as absorbed water. This orientation of water around clay particles gives clayey soil their plastic property (Das, 2010). Dry clay soils and clays with non-polar fluids have no plasticity properties (Gillot, 1987). Crude oil is a non-polar fluid this further affects its plasticity, the incineration of the soil has modified the classification of the soil from a clayey soil to a silty clay, leading to a reduction in the plasticity. Therefore, incineration of the soil makes it hydrophobic thus reducing the water reaction with the soil particles. As a result, the thickness of the double layer water reduces and we observed a decrease in the Atterberg limit (Khamehchlyan *et al.*, 2007).

Table 4: Physical properties of the natural soil and incinerated soils used

Property	Percentage Crude Incineration (%)				
	Natural soil	8% COI	12% COI	16% COI	20% COI
Natural moisture content, %	2	-	-	-	-
Liquid limit, %	53	39.9	33.7	29.8	29.8
Plastic limit, %	30	24.5	22	19.6	20
Plasticity index, %	27	15.4	11.7	10.2	9.8
Percentage passing BS No. 200 sieve	63	63	57.00	53.00	40.00
ASSHTO classification	A-7-5(16)	A-6(8)	A-6(4)	A-5(3)	A-4(1)
Specific gravity	2.72	2.40	2.00	1.92	1.51
Maximum dry density, Mg/m^3(BSL)	1.70	1.70	1.68	1.61	1.61
Maximum dry density, Mg/m^3(BSH)	1.86	2.13	1.77	1.76	1.70
Optimum moisture content, %(BSL)	15.40	15.40	21.02	16.5	16.7
Optimum moisture content, %(BSH)	15.72	14.2	16.3	12.6	13.65
USCS classification	CH	CL	CL	CL	SC
Colour	Brown	Grey	Grey	Grey	Grey

Compaction characteristics

Maximum dry density

The BSH compaction level in Fig. 5 show an initial MDD increase at the initial crude oil incineration (COI) before showing a consistent decrease with increase in COI, this could possibly be because at 8% COI the hydrophobic nature of soil is at its least, therefore water can interact with the soil molecules producing higher bonding leading to increased MDD. Subsequently the hydrophobic nature of the soil plays out causing the decrease in MDD. Also from the particle size distribution curve, the incinerated soil shifted from a clayey soil to a silty clay soil affecting the rate of bonding on interaction with water leading to a decrease in the maximum dry density. The MDD in the case of BSL compaction level, show a continuous decrease with increasing COI.

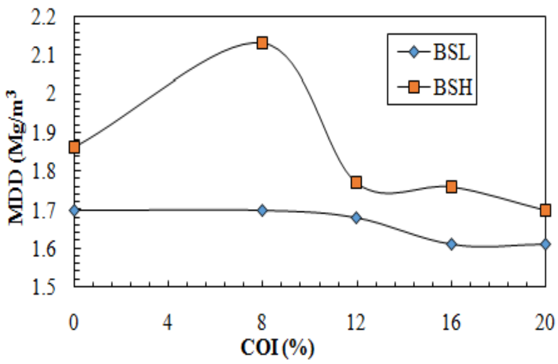

Fig. 5: Variation of MDD with COI for BSL and BSH compaction energies

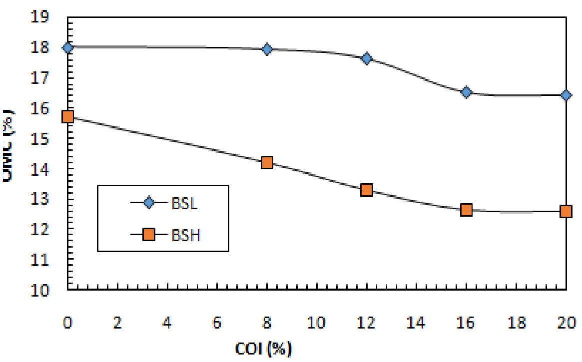

Fig. 6: Variation of OMC with COI for BSL and BSH compactive efforts

Optimum moisture content

The effect of crude oil incineration on the OMC is presented in Fig. 6 below. The graph showed a decrease in the OMC as crude oil incineration content in the contaminated soil increased. Crude oil is hydrophobic and as it coats itself around individual clay particles, even after incineration the soil remains hydrophobic, disallowing free water (water other than the adsorbed water) from interacting with the soil particles, this phenomenon results in the decreased optimum water content (OMC).

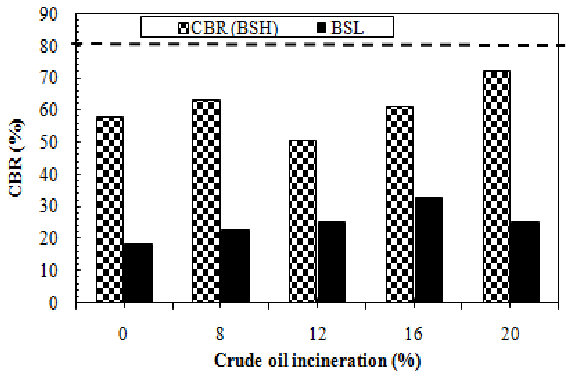

Fig. 7: Unsoaked CBR for BSH & BSL against COI (%)

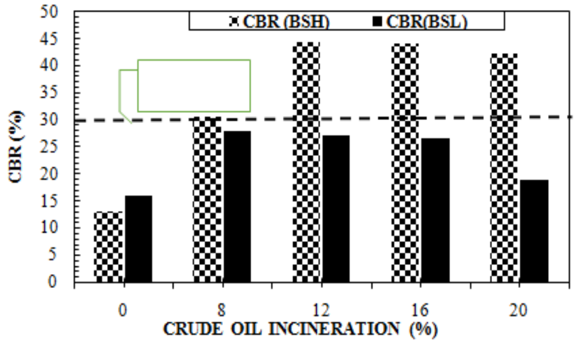

Fig. 8: Soaked CBR for both BSH and BSL against COI(%)

California bearing ratio

California Bearing Ratio tests were carried out on the crude contaminated incinerated soil using both the BSH and BSL efforts at varying percentage incineration. The effect of crude oil incineration on the California Bearing Ratio for both Unsoaked and Soaked CBR are presented in Figs. 7 and 8, respectively. This is in connection with the possibility of using the incinerated soil as sub base or base material in road pavement construction. The unsoaked CBR attained a peak value of 70% at 20% COI for the higher compactive effort (BSH), while the lower compactive effort (BSL) attained a peak value of 32% at 16% COI. The soaked CBR which is the worst case scenario consider in design of pavement. 45% peak soaked CBR was attained at 12% COI for BSH compaction, while peaked 28 % value was obtained for BSL at 8% COI. The soaked CBR value at higher compactive effort meet the recommended 20 - 30% value for sub-base of lightly trafficked roads (Nigerian General Specification, 1997). Therefore, this material can be used as a sub base material in pavement construction. In addition, as the results of Atterberg limits tests reflect a relatively low plasticity due to burning of crude oil contaminated soil. The low-plasticity of the burnt soil may lead to enhanced compaction which is reflected in MDD compaction variable for BSH compactive energy obtained at 8% COI (Fig. 5). This change in properties will heighten the use of such soil in embankments for road or other geotechnical construction.

Conclusion

This research investigated the geotechnical properties of crude oil incinerated lateritic soil. The study generated data on particle size distribution, Atterberg limits, compaction and California bearing ratio (CBR). The research showed that the incineration shifted the aggregate size distribution curve from clayey soil A-7-6(16) to silty soil A-4(1). This implied that the incineration has modified the soil clay minerals reducing the quantity of clay in the soil. The classification of the soil showed a shift from a clayey soil to a silty soil, The Atterberg limits results show a decrease in liquid limit (LL) and as well revealed a relatively lower-plastic behaviour of the soil as the percentage COI increases. The liquid limit of not more than 35% meets the requirement for use as sub-base material. The compaction showed an initial increase as in the maximum dry density before a gradual decrease in the dry density as the percentage incineration increased. The moisture content reduced as the (COI) increased. This is in connection with the possibility of using the incinerated soil as sub base or base material in road pavement construction as reflected in the CBR values obtained in this study. The unsoaked CBR attained peak value of 70% at 20% COI for BSH compaction level, while the lower compaction energy (BSL) attained peak value of 32% at 16% COI. The soaked CBR which is the worst case scenario consider in design of pavement attained a peak value of 45% at 12% COI for the higher compaction energy (BSH), while the lower compaction level (BSL) attained its peak value of 28% at 8% COI. The soaked CBR value at higher compaction energy meets the recommended 30% value for sub-base of lightly trafficked roads in Nigeria. Therefore, CBR value at 12% COI is recommended for use as a sub base in road construction. Also, tests such as unconfined compressive strength (UCS), durability and scan electron microscope (SEM) which limit this study are recommended for further investigation so as to establish new findings that will guide engineers and researchers in the potentials of crude oil contaminated soil in geotechnical applications.

Conflict of Interest

Authors declare no conflict of interest.

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