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STABILIZATION OF CRUDE OIL CONTAMINATED LATERITIC SOIL USING COMPOSITE MIXTURE OF BIOCHAR AND CEMENT

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Abstract
This work studied the effects of composite mixture of cement and biochar in the stabilization of crude oil contaminated lateritic soil to ascertain its suitability as earthwork construction material. Disturbed lateritic soil sample was artificially contaminated with 10% crude oil obtained from Olomoro-Oleh Oil and Gas Field, Isoko South Local Government Area, Delta State, Nigeria. The natural and contaminated soil specimens were subjected to geotechnical tests to determine the Specific gravity (SG), Plasticity Index (PI), Percentage Passing Sieve No 200, Maximum Dry Density (MDD), Optimum Moisture Content (OMC), unsoaked and soaked California Bearing Ratio (CBR). Results indicated that the contamination of the soil with 10% crude oil increased its plasticity and generally reduced its workability and strength. Stabilization of the crude oil contaminated soil with biochar increased the plasticity index of the soil. However, addition of cement decreased the PI of the crude oil contaminated soil. The percentage passing sieve No 200 increased with increasing contents of cement and biochar. The addition of cement improved the MDD and CBR, but there was reduction MDD and CBR with the addition of biochar. Two-way Analysis of Variance (ANOVA) performed on the results showed that cement and biochar had statistically significant effects on all the parameters. Based on this research, the use of 15% cement with 4% biochar improved the strength of crude oil contaminated lateritic soil and is therefore recommended for the use of crude oil contaminated soil as subgrade material in earthworks construction.

Keywords
Biochar, Crude oil, Geotechnical properties, Lateritic soil Soil-contamination, Soil stabilization

1. INTRODUCTION

Lateritic soil is a soil variety rich in iron and aluminum, typically found in wet and hot tropical areas. Almost all laterite soils are rusty red due to iron oxides present in them [1]. They accumulate by thorough and long-lasting weathering of the core parent rock. Lateritic soils are broadly used as fill resources for different construction works in most tropical countries. These soils are weathered under circumstances of elevated temperatures and humidity with definite irregular wet and dry seasons ensuing in poor engineering features such as high permeability, affinity to hold moisture and high natural water content [1]. The efficient use of lateritic soil is consequently often mired by complexity in handling under moist and damp conditions typically of tropical regions and can only be used after adjustment and or stabilization [2]. The soil that is going to be suitable for highway building must meet up with the existing local requirement for index properties as well as certain criteria. Generally, a compressible soil with great amount of clayey material and low bearing capability to resist load is unsuitable for highway construction. Therefore, such soil with large quantity of clayey materials and low bearing capability needs to be steadied to raise its strength to make it suitable for highway construction. Lateritic soil is a compressible soil with great amount of clayey material and low bearing capability to resist load. It varies in colour but usually brightly coloured [2].

Soil is a primary recipient, either by design or accident of farmyard of waste products and chemicals used in modern society. Soil can be generally contaminated by natural crude oil in the soil, and also soil can be polluted artificially by oil spillage [3] and other human activities in processing of crude oil into diverse valuable product and other anthropogenic activities such as positioning of mechanic shop on laterite deposit, leakage of underground petroleum tank. Crude Oil contamination can affect soil physical and chemical properties [4]. The effect of crude oil on the soil depends on the amount and grade of oil spilled. Crude oil contamination significantly alters the physical, chemical and mechanical characteristics of soil leading to deterioration in soil quality and engineering performance. Crude oil spillage decreases the porosity of the soil, this owing to the reality that oil tends to compel the soil constituent part to stick together, thus decrease the pore in the soil. Crude oil can also form a coat covering the soil surface to conserve carbon dioxide from the respiration of soil organism [5, 6].

Technically, cement is any material which, if added in a suitable form to a non-coherent assemblage of particles, will subsequently harden by physical or chemical means and bind the particles into a coherent mass. This broad definition allows such diverse materials as bitumen, tar and lime to be termed cementitious materials. In general, however, the term is most often associated with Portland, slag, pozzolanic, and high alumina cements, all of which are finely-ground powders which, in the presence of water, have a chemical reaction (hydration) and after setting and hardening produce a very tough and long-lasting binding material. Cementitious materials play vital role in construction and soil stabilization. Portland cement is a hydraulic binder obtained by grinding clinker composed mainly of calcium silicates with gypsum added to control setting time [7]. Slag cement is produced from granulated blast furnace slag and exhibits latent hydraulic properties when activated by water or Portland cement. Pozzolanic materials are siliceous or aluminous substances that react with calcium hydroxide in the presence of moisture to form cementitious compounds. High-alumina cement, on the other hand, is manufactured by fusing limestone and bauxite to produce clinker rich in calcium aluminates [7].

The application of stabilizers such as normal Portland cement, lime, ash, etc. or a combination of these frequently results in the alteration of the soil texture. Previously, the most normally used additive for soil stabilization is the usual Portland cement, but recent researches have shown that several of the soil problems can be enhanced by the addition of some industrial, environmental and agro-wastes [8 - 11].

Soil stabilization is any treatment applied to a soil to develop its power and reduce its susceptibility to water. If the treated soil is able to endure the stresses forced on it by traffic under all-weather condition without twist, then it is commonly considered as firm. This description applies regardless of whether the treatment is applied to soil in-situ or after the soil has been removed and placed in a pavement or embankment and this can be achieved by mechanical means and by the adding of chemical such as cement, lime etc. or addition of ash gotten from agricultural waste that possess pozzolanic properties [12].

Feedstock is the term generally used for the type of biomass that is pyrolysed and turned into biochar. Pyrolysis is the thermal degradation of biomass in the absence of oxygen leading to the manufacture of condensable vapour, liquid and charcoal (solid). In standard, any organic feedstock can be pyrolysed, while the give up of solid residue (biochar) regarding liquid and gas yield differs significantly along with physico-chemical characteristics of the ensuing biochar [13]. Biochar is commonly defined as charred organic matter which is a carbon-rich material produced from biomass through thermochemical decomposition under oxygen-limited conditions, commonly known as pyrolysis formed with the goal to intentionally pertain to soils to confiscate carbon and develop soil properties [14, 15]. The single variation involving biochar and charcoal is in its useful intention; charcoal is formed for other reasons (e.g. heating, barbeque, etc.) than biochar. In a physicochemical sense, biochar and charcoal are essentially the same material [13]. It could be argued that biochar is a term that is used for other purposes other than scientific, i.e. to re-brand charcoal into something more attractively sounding for commercial purpose. Concerted efforts have been made to stabilize contaminated soils with different stabilizers and results indicated a significant improvement on the geotechnical properties of these soils [16, 1]. However, the potentials of biochar, which is very cheap and readily available in Nigeria and most developing countries, on the stabilization of crude oil contaminated lateritic soils have not been efficiently examined. Therefore, this research investigated the effect of composite mixture of cement and biochar in the stabilization of crude oil contaminated lateritic soil to ascertain its suitability as earthwork construction material for sustainable development and improvement of highway roads.

2. MATERIALS AND METHOD

Materials used in conducting this research are the crude oil samples, lateritic soil samples, biochar and cement. The methods adopted in preparing the samples for different experimental tests are in conformity with the procedures outlined in [17, 18].

2.1. Materials

Lateritic soil: lateritic soil samples used are naturally reddish brown in colour and were collected from a burrow pit located at Ajinapa Orire Local Government Area, Ogbomoso, Oyo State Nigeria (Latitude 80 17' N and Longitude 40 14' E). Disturbed soil specimens were obtained 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. Crude oil: Crude oil used was obtained from Olomoro-Oleh Oil and Gas Field, Isoko South Local Government Area, Delta State, Nigeria. Feedstock: This comprised of wood chips, wood shaving, sawdust, wood trims and wood barks (Biomass). It was collected from Anuoluwapo Sawmill, Pakiotan, Layout, Abogunde road, Ogbomoso, Nigeria. Cement: Ordinary Portland cement was purchased from one of the retail shops in Ogbomoso metropolis in Oyo State, Nigeria.

2.2. Methods

2.2.1. Biochar production: A laboratory-scale slow pyrolyzer was used for biochar production at Renewable Resources Center, Department of Environmental Health Science, Faculty of Public Health, College of Medicine, University of Ibadan. The batch reactor was filled with feedstock which comprised of wood chips, wood shaving, sawdust, wood trims and wood barks covered with a fitting lid, and pyrolyzed under oxygen-limiting conditions at 500^0C which was measured by K type temperature controller until the desired biochar was obtained. After pyrolysis, biochar in the reactor was allowed to cool overnight to room temperature. Then it was air-dried, pulverized and then sieved through British Standard sieve No. 200 (75 micron) prior to its use.

2.2.2. The chemical characterization: The chemical characterization of Laterite, Biochar and Crude Oil Soil (Contaminated soil) was carried using X-Ray Fluorescence as specified in [19] at Lafarge Cement Plant, Ewekoro, Ogun state, Nigeria. Equations 1 and 2 were used to determine the Total Reactive Oxide Content (TROC) and the Hydration Modulus (HM) of the biochar to determine its pozolanic nature.

$$HM = \frac{CaO}{(SiO_2 + Al_2O_3 + Fe_2O_3)} \quad 1$$

$$TROC = \left(CaO + MgO - LOI - (Na_2O + K_2O)\right) \quad 2$$

2.2.3. Sample preparation: The collected lateritic soil samples were air-dried, pulverized and then sieved through British Standard sieve No. 4 (4.75 mm) prior to their use without addition of any additive. This was done in agreement to [17], so as to have a uniformly colour and texture natural lateritic soil sample for geotechnical tests. Then, the lateritic soil was polluted with 10% crude oil to obtain crude oil polluted lateritic soil and left inside a covered container in the laboratory for 12 weeks to be saturated before geotechnical tests were done on it. According to [20] oil pollution beyond 8% by weights of its dry mass and left for saturation for at least a week, will negatively affect the geotechnical features of the soil. The cement proportions were varied from 0 to 15% of dry weight of the soil at 5% interval while biochar proportions varied from 0 to 12% of dry weight of the soil at 4% step concentration. The various percentages of cement and biochar were then combined together to stabilize the soil. For instance, combination of 5% cement and 4% biochar would give rise to 9%, then 9% was deducted from 100% lateritic soil used initially and 5% cement and 4% biochar were added to replace it. These mixed proportions are shown in Table 1. After the mixing, various geotechnical tests were conducted on each of the combinations and their results were noted.

Table 1: Composition of biochar and cement by percentage in the soil sample

Biochar (%) / **Cement (%)**	**0**	**4**	**8**	**12**
0	0,0	0,4	0,8	0,12
5	5,0	5,4	5,8	5,12
10	10,0	10,4	10,8	10,12
15	15,0	15,4	15,8	15,12

2.3. Experimental tests

The laboratory tests carried out on the natural lateritic soil, crude oil contaminated lateritic soil and crude oil contaminated lateritic soil admixed with varied percentage of cement and biochar samples are described as follows:

2.3.1. Specific gravity: The specific gravity of any substance is defined as the unit weight of the material divided by the unit weight of distilled water at the standard temperature of 27° C. The specific gravity (usually given the notation Gr) of the soil is often used in relating the weight of soil to its volume. A value of precise gravity is essential to calculate the void ratio of a soil. The specific gravity of soil was determined using the relation below in accordance with [17] Clause 8 using the density bottle method.

$$G = \frac{M2 - M1}{(M2 - M1) - (M3 - M4)} \quad 3$$

Where:

M_1 = mass of empty pycnometer,
M_2 = mass of pycnometer with dry soil,
M_3 = mass of pycnometer with soil and water,
M_4 = mass of pycnometer filled with water only,
G = specific gravity of soil.

2.3.2. Particle size distribution: This test was carried out to determine the various sizes of soil particles in a given sample of soil and also the percentage of the total weight represented by various range of grain sizes. The particles were divided into groups in agreement with [17]. Contaminated soil samples of 300 g mixed with varying percentages of cement and biochar and soaked in water for twenty-four (24) hours. Wet sieving was then used to obtain the dried sample sieved. 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.

2.3.3. Liquid limit: Soil sample of 200 g 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. This is conducted following the procedure outlined in [17].

2.3.4. Plastic limit: Soil sample of 200 g 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. This is conducted following the procedure outlined in [17].

2.3.5. Plasticity index: The plasticity Index was computed as the difference between the liquid limit and the plastic limit as given in Equation 3.2. This is conducted following the procedure outlined in [17].

$$PI = LL - PL \quad 4$$

LL: The liquid limit is the water content at which soil changes from plastic to liquid state.
PL: This is the water content at which soil changes from the semi-solid state to plastic state.
PI: This is the range of moisture content over which soil remains plastic.

2.3.6. Compaction: Compaction of soil is the procedure through which the solid particles are packed more strongly together, usually by mechanical means thereby increasing the dry density of the soil. The dry density which can be achieved depends on the degree of compaction applied and on the amount of water present in the soil. For a given compaction of a given cohesive soil, there is an optimal moisture content at which the dry density obtained reaches a maximum value. The objective of the compaction test is to obtain the Maximum Dry Density (MDD) and the corresponding optimal Moisture Content (OMC) of the soil from the connection between the compacted dry density and the soil moisture content. The compaction characteristics of the soil, namely Maximum Dry Density (MDD) and the corresponding optimal Moisture Content (OMC), were determined [17]. In order to assess the soil samples as subbase material, the compaction efforts or energy level that was adopted for this project was West African Standard (WAS). Air-dried oil contaminated soil samples were mixed with cement and biochar in varying percentages by weight of soil sample (Figure 1). The samples were subjected to West African Standard (WAS) energy level of compaction to determine their maximum dry density and optimum moisture content.

2.3.7 California bearing ratio test (CBR): The CBR value of compacted soil is an indicator of soil strength and bearing ability and is widely used in the design of thickness of each of the courses of pavement [17].

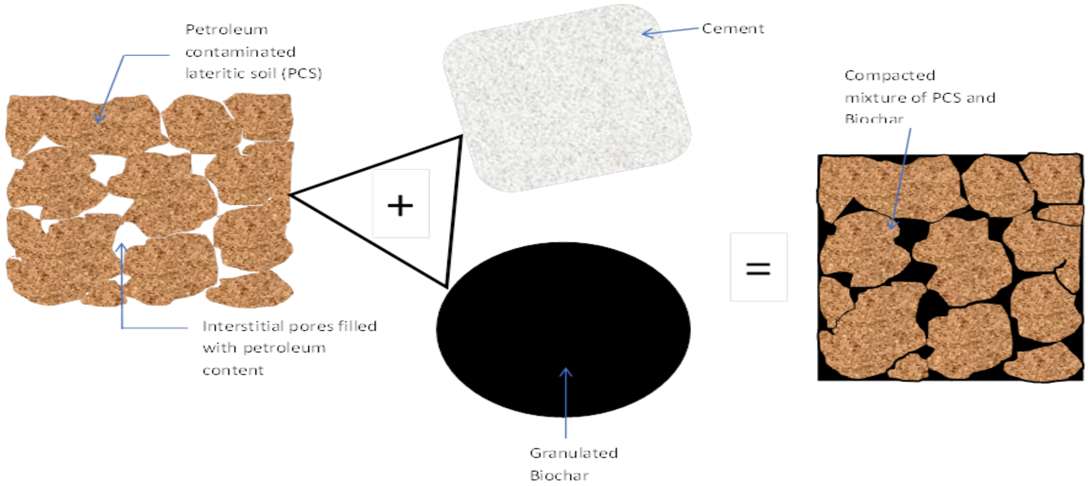

Figure 1: Schematic appearance of the components before and after mixing

3. RESULTS AND DISCUSSION

The results and discussion of experimental tests conducted in this study are comprehensively presented in this section.

3.1. Chemical characterization

Table 2 presents the results of the oxide compositions of the laterite soil and biochar. The biochar used in this study can be classified as Class C pozzolan [21]. The sum total of the combination of the chemical compounds (SiO_2 +Al_2O_3+Fe_2O_3) was 61.44% and the loss of ignition (LOI) of 0.2% as shown in Table 2. The hydration modulus (HM), [22] as determined from Equation 1 for the biochar is 0.323, which is extremely low and outside the range for the HM of 1.7 (Alite) to 2.4 (Belite) for active cementitious material such as cement and cement kiln dust. The low HM value reveals the non-cementitious property of biochar. The total reactive oxide content (TROC) computed from Equation 1 is 15.36, which further buttresses the non-cementitious characteristics of the biochar.

Table 2: Oxide composition of the biochar and laterite soil

Chemical	Biochar (%)	Laterite (%)	Contaminated soil (%)
SiO_2	48.86	59.91	57.58
Al_2O_3	6.95	11.16	12.32
Fe_2O_3	5.63	17.77	15.12
CaO	19.98	0.38	0.21
MgO	3.35	0.02	0.04
SO_3	0.20	0.00	0.00
K_2O	7.61	0.39	0.32
Na_2O	0.00	0.00	0.00
M_2O5	0.18	0.45	0.38
P_2O_5	4.91	0.08	0.07
TiO_2	0.61	0.97	0.94
Loss on Ignition (LOI)	0.2	8.63	12.79
Total	98.32	99.77	99.76

3.3. Geotechnical properties of the natural and contaminated lateritic soil

The particle size distributions of both the natural and crude oil contaminated lateritic soils are shown in Figure 2. For the natural soil, the sample contained coarse silt, fine medium coarse sand and medium gravel. The soil is reddish-brown in colour as a result of the presence of iron oxide. The soil had percentage passing BS No. 200 (75 µm) sieve of 18%, the LL of 40 (≥40 %) and PI of 12% (>10 %). Based on these results, the soil was classified as clayey A-2-6 soil with Group Index (GI) of 0 according Soil Classification System [23].

Also, the soil was clayey gravels, poorly graded gravel-sand-clay mixtures (GC, SC) on the Unified Soil Classification System [24]. The MDD and OMC are 1.92 g/cm^3 and 16.5%, respectively, and the specific gravity is 2.64. The soaked and unsoaked CBR values are 27% and 44%, respectively. For the crude oil contaminated lateritic soil, the sample contained coarse silt, fine medium coarse sand and medium gravel. The soil is dark- reddish-brown; the change in colour was as a result of the crude oil used for its contamination. The percentage passing BS Sieve 75 µm (Sieve No. 200) increased from 18% for the natural soil to 35.25% for the crude oil contaminated soil, LL increased to 53 (>40 %) and PI reached 18% (>10%). Based on these results, the contaminated soil can be classified as clayey A-2-7 soil with GI of 2 Soil Classification System [23]. Also, the soil is clayey gravels, poorly graded gravel-sand-clay mixtures (GC, SC) on the USCS [24].

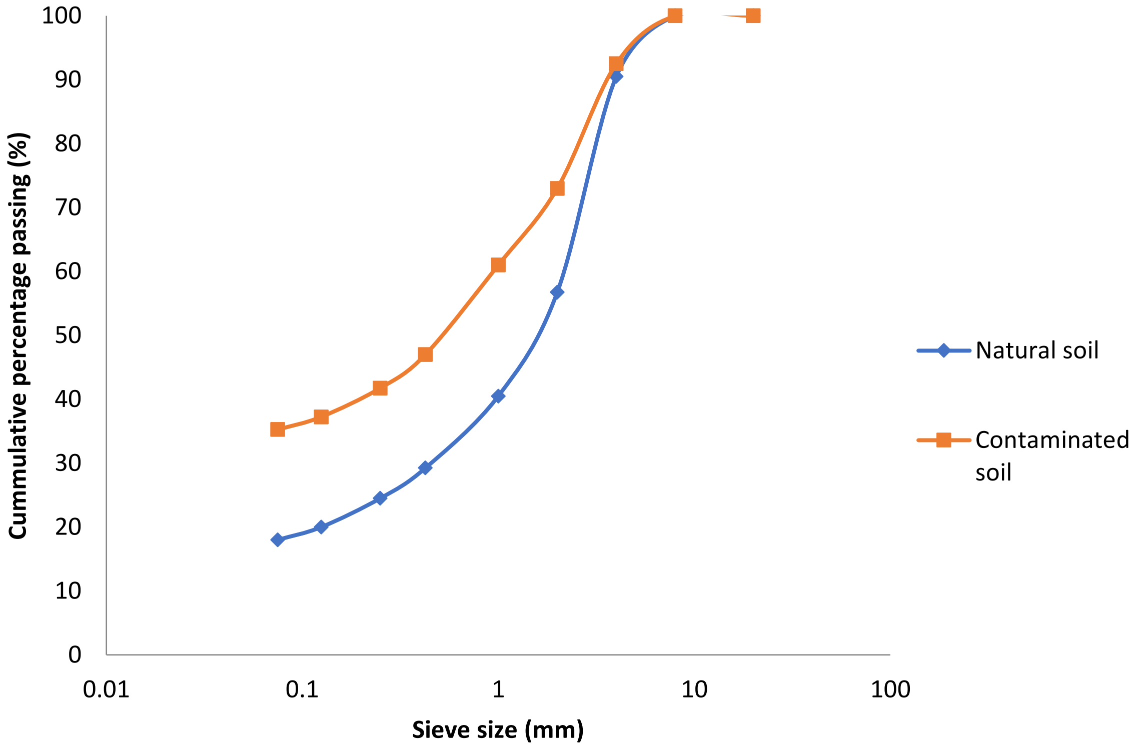

Figure 2: Particle size distribution curves for the natural and crude oil contaminated soils

The MDD decreased from 1.92 for natural soil to 1.73 g/cm^3 for the contaminated, while OMC increased from 16.5% to 20.23%. The specific gravity decreased from 2.64 to 2.27. The unsoaked CBR value of the crude oil contaminated soil fell from 44 to 35% and soaked from 27 to 21% as a result of the presence of crude oil in the soil. Although this soil could be used as subgrade material as it is based on this classification [25], the contamination limits its use which makes it liable for stabilization. These results clearly showed that crude oil contamination can greatly affect the geotechnical properties of the lateritic soil which also noted [6].

3.4. Effect of biochar and cement on specific gravity of crude oil contaminated lateritic soil

Figure 3 shows the effect of the biochar and cement on the specific gravity of the crude oil contaminated lateritic soil. The specific gravity value of natural soil is 2.64. When lateritic soil was contaminated with 10% of crude oil by weight of its dry mass, the specific gravity value dropped from 2.64 to 2.27. This reveals that the addition of crude oil of 10% weight of the soil to the soil reduced the specific gravity of the soil. This result is in agreement with one reported in previous study [20]. For the crude oil contaminated soil stabilized with cement and biochar, the specific gravity values as presented in Figure 3 ranged from 1.59 to 2.47. It is evident from the result that the specific gravity of the treated soil is raised as the percentage of cement was increasing but decreased with increasing biochar content. This occurs as a result of volumetric replacement of cement which has higher specific gravity and is heavier than the crude oil contaminated soil and also volumetric replacement of biochar which is lighter than the crude oil contaminated soil as also noted by (Akinwumi *et al.*, 2016).

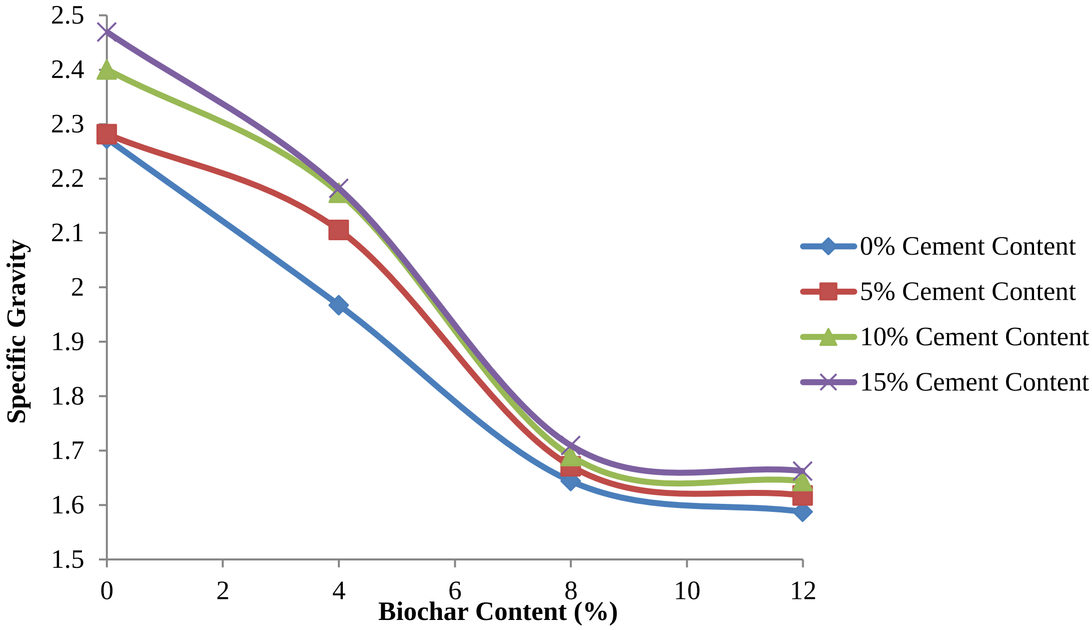

Figure 3: Variation of specific gravity with cement and biochar content

3.5. Effect of biochar and cement on particle size distribution of crude oil contaminated lateritic soil
The influence of the biochar and cement on the particle size distribution of the crude oil contaminated lateritic soil is presented in Figure 4. The percentages passing BS sieve No. 200 of natural soil was 18.00%. When lateritic soil was contaminated with 10% of crude oil by weight of its dry mass, the percentages passing BS sieve No. 200 increased to 35.25%, this showed that the sample is silty-clay according t0 classification system [18]. This sample will not be suitable for subgrade construction because it has low quality of soil strength as their percentage weight passing through sieve No. 200 is greater than 35%, as a result of influence of crude oil present in the sample. Hence, the soil needs to be stabilized. For the crude oil contaminated lateritic soil stabilized with cement and biochar, as shown in Figure 4, the percentage passing through Sieve No. 200 (75 micron) ranged from 28.5 – 46%. The percentage passing through Sieve No. 200 (75 micron) increased when the percentage of cement and biochar increased and this occurs as result of fines of cement and biochar.

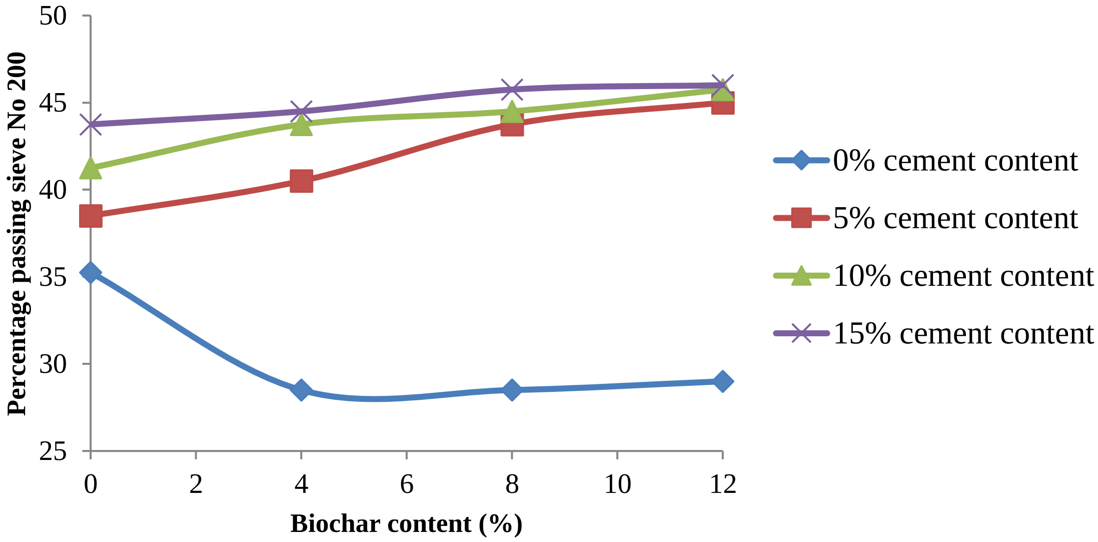

Figure 4: Variation of particle size distribution with cement and biochar content

3.6. Effect of biochar and cement on the consistency limits of crude oil contaminated lateritic soil
The impact of the biochar and cement on the consistency limits (LL, PL and PI) are presented in Figures 5-7, respectively. Natural lateritic soil has LL, PL and PI of 40.0, 28.0 and 12.0%, respectively while the corresponding values for crude oil contaminated lateritic soil were 53%, 35% and 18%. This shows that the addition of crude oil of 10% makes the soil unfit geotechnically in relation to the increase in the consistency

limits of the soil. This corroborates an established fact that oil contamination beyond 8% by weight of its dry mass will negatively have an impact on the geotechnical features of the soil [20].

For the crude oil contaminated lateritic soil stabilized with cement and biochar, the LL, PL and PI ranged between 40.0 and 66.0%, 18.0 and 35.0%, and 13.0 and 21.0%, respectively as shown in Figures 5-7. Stabilization of the oil contaminated soil with cement and biochar shows that as the percentage of the cement increased, the LL, PL and PI decreased in values. This is in conformity with earlier findings of [26] which noted that the decrease in plasticity might result from the depressed double layer thickness due to cation exchange between the added admixtures and soil minerals. However, when percentage of the biochar increased, LL, PL and PI increased. The results also revealed that the stabilization of crude oil contaminated soil for improvement in workability is only effective with the addition of cement but not as effective with the addition of biochar. However, this does not imply that solidification achieved with the use of cement might lead to the decrease in the concentration of crude oil. These results imply that crude oil contaminated soil might be able to regain its workability after addition of cement, which aligned with the previous findings reported by [20, 27].

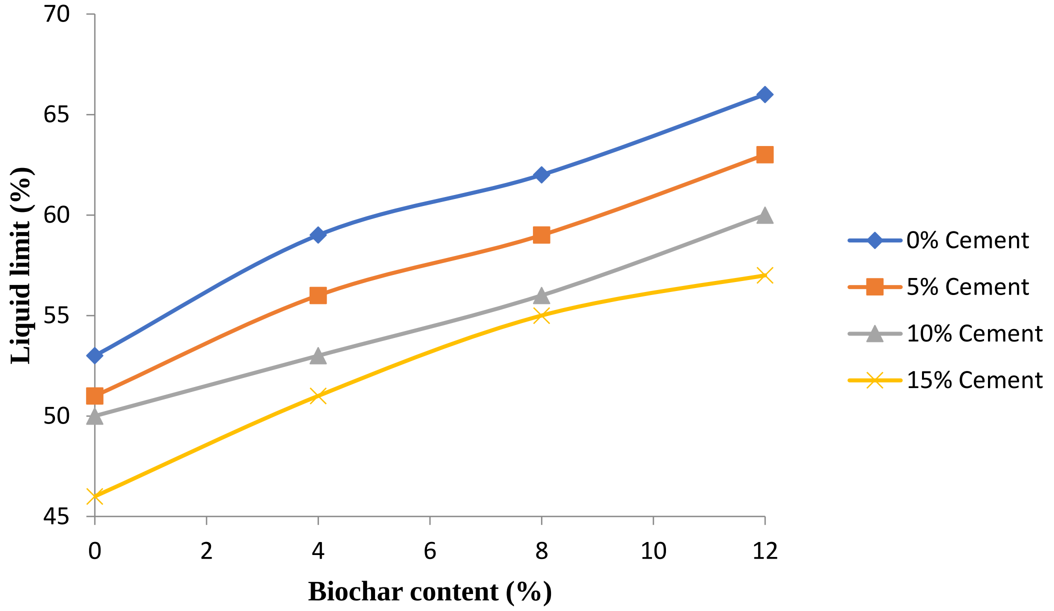

Figure 5: Variation of Liquid Limit with cement and biochar content

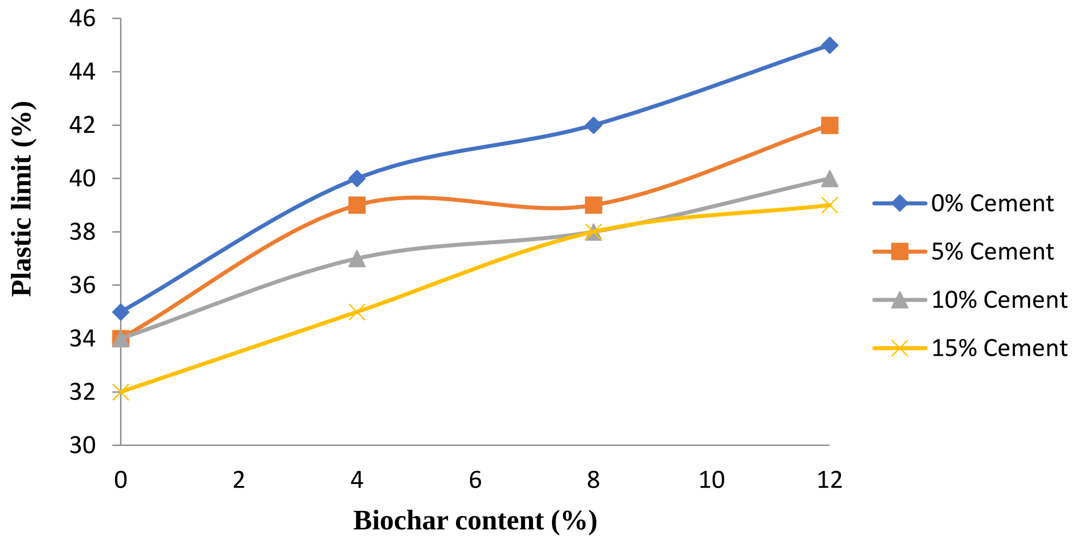

Figure 6: Variation of plastic Limit with cement and biochar content

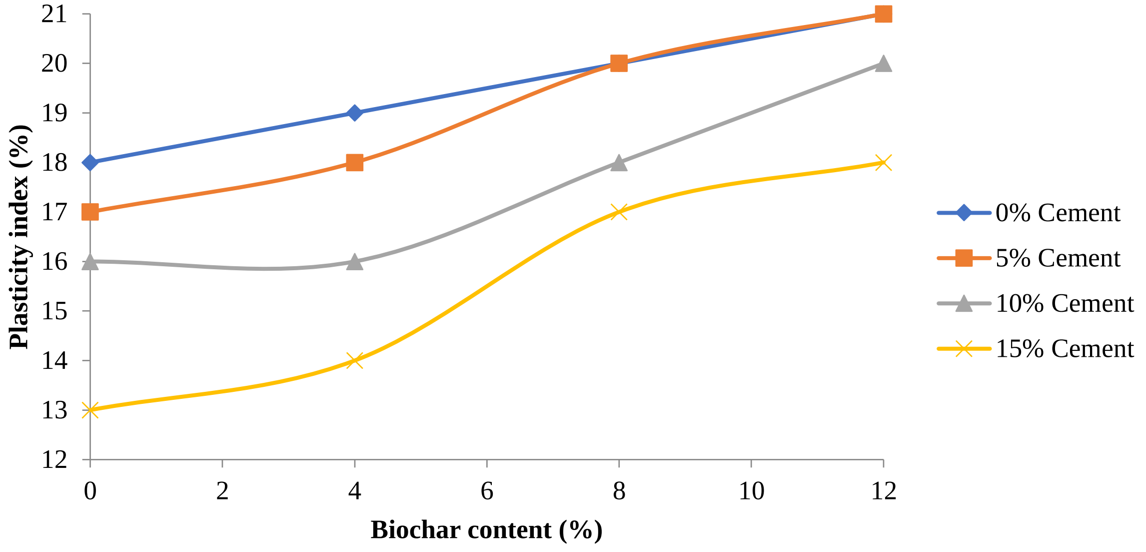

Figure 7: Variation of plasticity index with cement and biochar content

3.7. Effect of biochar and cement on the compaction parameters of the crude oil contaminated lateritic soil

The effect of biochar and cement on the compaction parameters (MDD and OMC) of the crude oil contaminated soil are presented in Figures 8 and 9. The MDD and OMC of the natural lateritic soil were 1.92 g/cm^3 and 16.52%, respectively while lateritic soil contaminated with 10% of crude oil by weight of its dry mass, has MDD of 1.73 g/cm^{3}and OMC of 20.23%. There was decrease in MDD with equivalent increase in OMC upon contamination which affects negatively the compaction properties of the soil as stated in [20]. For the crude oil contaminated soil stabilized with cement and biochar as presented in Figures 8 and 9, the MDDs ranged from 1.37 to 1.89 g/cm^3 while the OMCs ranged from 20.23 to 34.38%.

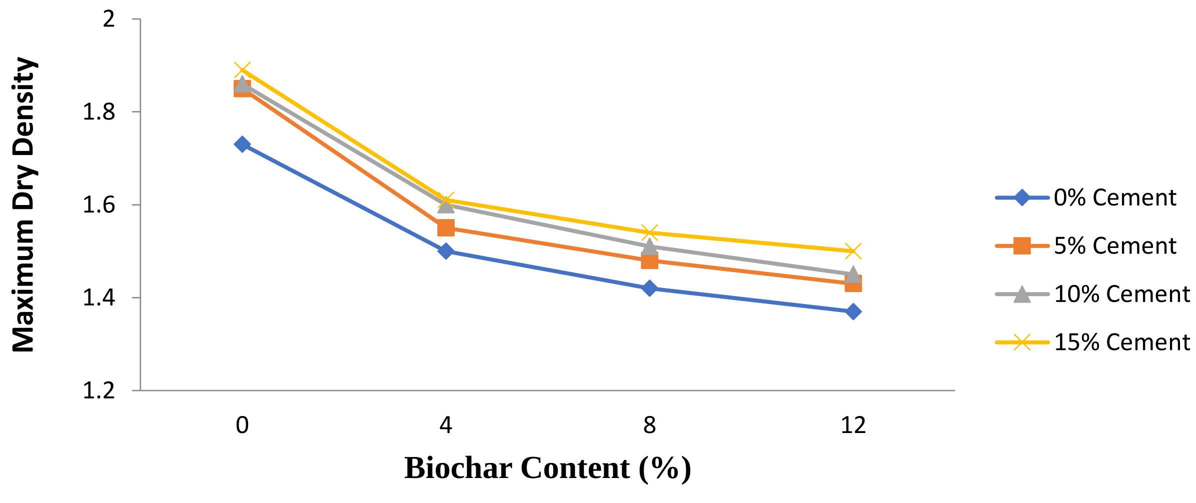

Figure 8: Variation of Maximum Dry density with Biochar and Cement

As the cement content in the polluted soil sample increased, its OMC was decreasing while MDD increased, respectively. The higher specific gravity of cement (typically 3.15), compared with that of the crude oil polluted soil, 2.27, is accountable for increasing maximum dry unit weight of the stabilized-contaminated soil as its cement content increases. As the cement content increases in the contaminated soil, there is increasing cementation of some of the particles of the contaminated soil which led to a decrease in the volume of the stabilized-contaminated soil which also have contributed to the increase in its dry unit weight as also noted by [27]. On the other hand, the addition of biochar obviously increased OMC and decreased the MDD, with larger decrease occur at highest percentage of biochar mixtures. Changes in the MDD are due to volumetric replacement of the heavier crude oil contaminated soil with the significantly lighter biochar as noted [28].

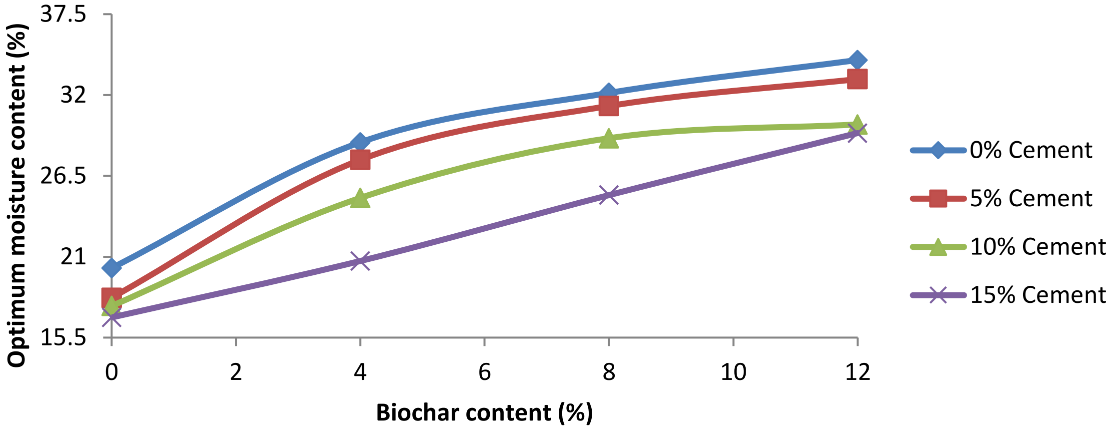

Figure 9: Variation of optimum moisture content with cement and biochar content

3.8. Effect of biochar and cement on the California bearing ratio of the crude oil contaminated lateritic soil

Figure 10 shows the effect of biochar and cement on the unsoaked CBR of the crude oil contaminated lateritic soil. The unsoaked CBR value of natural soil was 44%. When lateritic soil was contaminated with 10% of crude oil by weight of its dry mass, the CBR dropped from 44 to 35%. This reveals that the crude oil contamination of the soil beyond 8% adversely affect the strength properties of the soil as established [20]. The reduction in CBR might results from the slippery of the soil grains over one another due to the lubricating effect of crude oil in the presence of water. For the crude oil contaminated soil stabilized with cement and biochar, the CBR values as shown in Figure 10 ranged from 22 to 40%. It is evident from the result that the CBR of the treated soil was increasing as the percentage of cement was increasing.

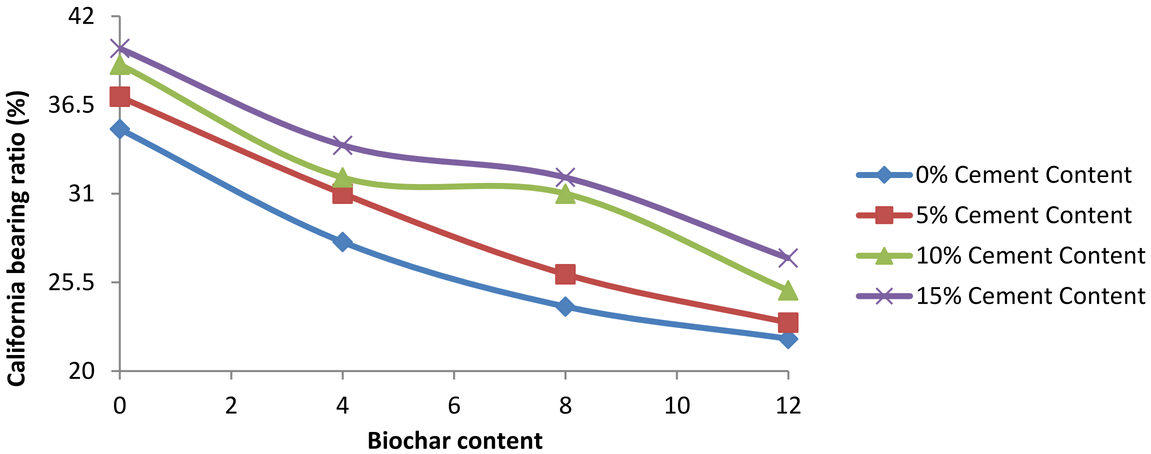

Figure 10: Variation of Unsoaked California bearing ratio with cement and biochar content

The formation of cementitious compounds such as calcium-silicate-hydrates and calcium-aluminate-hydrates in the cement-stabilized contaminated soil is responsible for the improvement in its unsoaked CBR values as also noted [29, 30]. However, the addition of biochar noticeably decreased the unsoaked CBR; with larger decrease occur at highest percentage of biochar mixtures. This reduction in the CBR was because of volumetric replacement of the heavier soil sample with the significantly lighter biochar as noted [28].

Figure 11 presents the effect of biochar and cement on the soaked CBR of the crude oil contaminated lateritic soil. The soaked CBR value of the natural soil was 27%, and this value decreased to 21% when the natural lateritic soil was contaminated with 10% of crude oil by weight of its dry mass. This reveals that the crude oil contamination of the soil beyond 8% negatively have a significant effect on the strength properties of the soil as established [20].

For the crude oil contaminated soil stabilized with cement and biochar, the CBR values as shown in Figure 11 ranged from 12 to 21%. It is obvious from the result that the CBR of the treated soil was increasing with increasing percentage of cement in the samples. The formation of cementitious compounds such as calcium-silicate-hydrates and calcium-aluminate-hydrates in the cement-stabilized contaminated soil is also responsible for the improvement in its soaked CBR values as also noted [28]. However, the addition of biochar distinctly decreased the soaked CBR, with larger decrease occur at the highest percentage of biochar mixtures. This reduction in the CBR was because of volumetric replacement of the heavier soil sample with the significantly lighter biochar as noted [28].

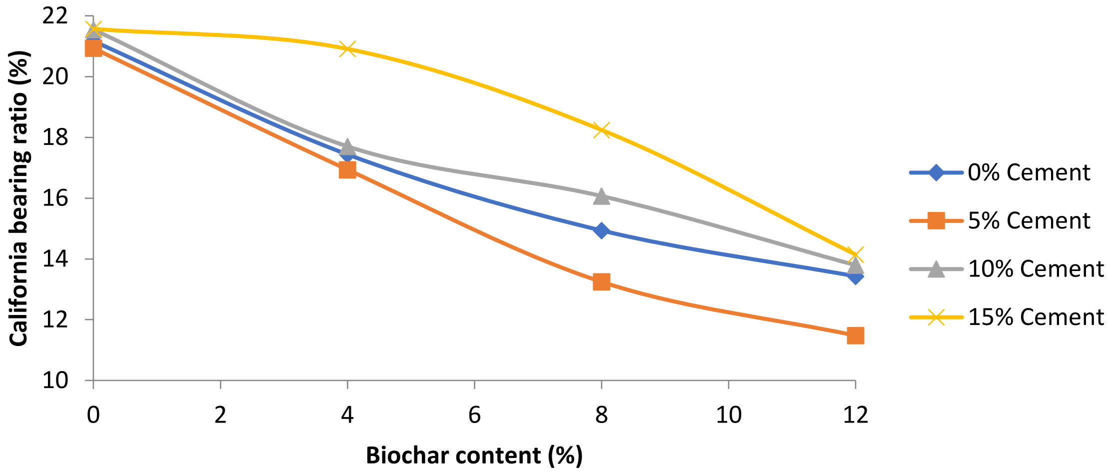

Figure 11: Variation of Soaked California bearing ratio with cement and biochar content

3.9. Statistical evaluation of the results

Two-way Analysis of Variance (ANOVA) was performed at 5% level of significance to analyze the effect of cement and biochar on the crude oil contaminated lateritic soil. Two-way ANOVA revealed that cement and biochar had statistically significant effects on PI, MDD, OMC, CBR (soaked and unsoaked) respectively. The p-values of cement and biochar for PI, MDD, OMC, CBR (soaked and unsoaked) are (1.25E-05 and 1.07E-05), (3.96E-06 and 1.58E-10), (0.00032 and 2.99E-07), (0.008617 and 4.25E-06), (4.59E-05 and 6.9E-08), respectively as it is shown in table 3.

Table 3: Analysis of Variance Results

Parameters	*Source of Variation*	*SS*	*Df*	*MS*	*Fcal*	*P-value*	*Fcrit*
Plasticity Index	Cement	38.75	3	12.91667	42.27273	1.25E-05	3.862548
	Biochar	40.25	3	13.41667	43.90909	1.07E-05	3.862548
	Error	2.75	9	0.305556			
	Total	81.75	15				
Maximum Dry Density	Cement	0.037119	3	0.012373	55.50467	3.96E-06	3.862548
	Biochar	0.371369	3	0.12379	555.3178	1.58E-10	3.862548
	Error	0.002006	9	0.000223			
	Total	0.410494	15				
Optimum Moisture Content	Cement	78.08092	3	26.02697	18.87052	0.00032	3.862548
	Biochar	418.276	3	139.4253	101.0885	2.99E-07	3.862548
	Error	12.41316	9	1.37924			
	Total	508.77	15				
California Bearing Ratio	Cement	78.08092	3	26.02697	18.87052	0.00032	3.862548
	Biochar	418.276	3	139.4253	101.0885	2.99E-07	3.862548
	Error	12.41316	9	1.37924			
	Total	508.77	15				
Soaked CBR	Cement	19.52562	3	6.508539	7.34045	0.008617	3.862548
	Biochar	145.2255	3	48.4085	54.59599	4.25E-06	3.862548
	Error	7.980009	9	0.886668			
	Total	172.7311	15				
Unsoaked CBR	Cement	84.75	3	28.25	30.81818	4.59E-05	3.862548
	Biochar	388.75	3	129.5833	141.3636	6.9E-08	3.862548
	Error	8.25	9	0.916667			
	Total	481.75	15				

4. CONCLUSION

Experimental analyses of the geotechnical features of the crude oil contaminated soil admixed with varying contents of cement and biochar were conducted in conformity with BS [17]. The following itemized conclusions were established from the results of the various soil tests conducted.

i. The contamination of the soil with 10% crude oil increased its plasticity and generally reduced its workability and strength. Cement and biochar had significant influence on the specific gravity, particle size distribution, Atterberg limits, compaction and CBR of the crude oil contaminated soil.
ii. Stabilization of the crude oil contaminated soil with biochar increased the plasticity index of the crude oil contaminated soil., Stabilization of the crude oil contaminated soil with cement decreased the plasticity index of the crude oil contaminated soil.
iii. The addition of cement improved the MDD and CBR. However, there was reduction in MDD and CBR with the addition of biochar. But none of the samples passed the minimum requirement of soaked CBR of 30% as the criteria for a soil to be used as subbase material. Therefore, the crude oil contaminated soil stabilized with 5% cement upward cannot be used as a subbase material; however, the samples can be used as subgrade material or fillings.

The use of 15% cement with 4% biochar improved the strength of crude oil contaminated lateritic soil and is therefore recommended for the use of the crude oil contaminated lateritic soil as a subgrade material in earthworks construction.

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