



Lime Stabilization of Vermi-Remediated Crude Oil Contaminated Lateritic Soil for Road Base Material

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ABSTRACT

This research is aimed at stabilizing vermi-remediated crude oil contaminated soil using lime for application as highway base material. 250kg of lateritic soil sample was contaminated with crude oil at a rate of 75cl of crude per 10kg of the soil sample and mixed with 1000 ml of water. The mixture was allowed for a period of one month for full saturation. The total petroleum hydrocarbon (TPH) present in the soil was then determined as 4500mg/kg. Atterberg test: liquid Limit (LL), Plastic Limit (PL) and Plasticity Index (PI) were determined as 39.5, 28.8 and 10.7 respectively. The optimum moisture content (OMC) for British Standard Light (BSL), West African Standard (WAS) and British Standard Heavy (BSH) were 18.87, 17.18 and 15.78 respectively whereas the maximum dry content (MDD) was 1.63, 1.66 and 1.69Mg/m³ respectively. The unsoaked California Bearing Ratio (CBR) values for BSL, WAS and BSH were 4.45, 5.45 and 9.05% respectively whereas the soaked values were 4.75, 4.68 and 8.65% respectively. The unconfined compressive strength result for BSL WAS and BSH at 7 days curing were 182.7, 158.1 and 254.6kN/m² respectively. The values for 14, 21 and 28 days followed the same pattern. The sample was then vermi-remediated with earth worm species (*Eudrilus Eugeniae*) at 400 worms per 200kg of soil for a period of one month after which the TPH content in the soil was determined as 3300mg/kg. The sample was then stabilized with lime at 2%, 4%, 6% and 8% respectively and the following results were obtained. Atterberg test: LL, PL and PI at 0% lime stabilization were determined as 54.0, 32.3 and 21.7 respectively, at 2% were 46.5, 29.3 and 17.2 respectively, at 4% were 56, 30 and 26 respectively, at 6% were 44.5, 11 and 33.5 respectively, at 8% were 58.0, 13.0 and 45.0 respectively. The shrinkage limit for all samples was 11%. The specific gravity for lime stabilized samples was also determined as 2.4 except at 6% which was 2.3. The optimum moisture content (OMC's) for BSL, WAS and BSH at 2% lime admixture, were 20.38, 19.74 and 16.55 respectively the values for 4, 6 and 8% followed same pattern. The MDD's at 2%, were 1.61, 1.79 and 1.8 respectively and the same increasing pattern was observed for 4, 6 and 8%. The unsoaked CBR values for BSL, at 2%, 4%, 6% and 8% lime admixture were 4.45, 21.47, 41.09 and 39.50 respectively. whereas the soaked values were 4.14, 19.27, 37.34 and 52.82 respectively. the same pattern of increment in strength with admixture was observed for WAS and BSH. The unconfined compressive strength result for BSL at 7 days curing

ARTICLE INFO

Article History

Received: December, 2025

Received in revised form: January, 2026

Accepted: February, 2026

Published online: March, 2026

KEYWORDS

Crude Oil, Lime, Vermin (*Eudrilus Eugeniae*), Contamination And Remediation

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at 2%, 4%, 6% and 8% lime admixture were 127.1, 234.1, 101.8 and 90.7 kN/m². The same pattern was observed for 14- and 28-days curing period. The results show that lime is quite effective in stabilizing vermi-remediated crude oil contaminated soils at 8% admixture.

INTRODUCTION

This research is aimed at stabilizing vermin remediated crude oil contaminated soil with lime for use as a road base material. The modern world's interconnectedness, economic expansion, and social advancement depend heavily on the construction and maintenance of road networks. However, these processes often come at a high cost to the environment, particularly when contaminated material needs to be removed in order to develop and maintain roads. Hydrocarbons, heavy metals, pesticides, and diseases are among the hazardous substances that might be discovered in contaminated soil.

One method used by nature to clean up damaged environments is bioremediation. Bioremediation is defined as a process that uses living organisms, primarily microorganisms, green plants, and their enzymes, to remove, degrade, mineralize, transform, and detoxify the hazardous components of environmental waste and environmental pollutants into harmless or less toxic forms (Tyagi, 2021). Cometabolism, biotransformation kinetics, biotreatment, and biogeochemical modeling are among the fundamental research areas in the field of bioremediation. Field application research areas include biogeochemical assessment techniques, environmental attenuation, fate modeling, and cometabolic techniques (Tyagi, 2021).

Vermi-remediation is a type of earthworm-based bioremediation technology that gathers and extracts, transforms, or breaks down contaminants in the soil environment by utilizing the earthworms' life cycle (e.g., feeding, burrowing, metabolism, secretion) or their interactions with other abiotic and biotic factors (Shi, 2020). The environmental behavior of organic pollutants in the soil earthworm system has been the focus of several studies on vermi-accumulation in recent decades (Shi, 2020).

Soil stabilization is the concept or procedure of improving the mechanical structure of a specific soil to qualify it for civil engineering construction works. "Soil stabilization from an extensive perspective fuses the different techniques used for changing soil properties to improve its engineering qualities and performance. Further reasons for soil stabilization are conservation of energy, dust control, soil waterproofing and improved durability". (Bamitale et. al 2022). Lime stabilization is particularly useful for subgrade and base course improvements in road construction projects.

Lime stabilization is a method of soil improvement in which lime is added to the soil to ameliorate its properties. The types of lime used for soil include high calcium hydrated lime, monohydrated dolomite lime, calcite quick lime, and dolomite lime. The quantity of lime applied in most soil stabilization is about 5% to 10%. Lime modification describes an increase in strength brought by cation exchange capacity rather than cementing effect brought by pozzolanic reaction. IJPREMS, (2025). As clay particles flocculate, in soil modification, the naturally occurring plate-like clay particles transform into needle-like interlocking metal line structures. Clay soils become drier and less susceptible to changes in water content. Lime stabilization may refer to pozzolanic reaction, where the pozzolana materials react with IJTRD lime in the presence of water to produce cementitious compounds. The potential above could be caused either by quicklime, or hydrated lime. IJPREMS, (2025).

MATERIALS AND METHODS

Material

Lateritic soil: The lateritic soil was obtained from a borrowed pit at Shikka, Zaria with the coordinate 11.1708324, 7.6149292 N.E. and transported to the laboratory in air-tight sacks.

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Crude oil: The crude oil was obtained from Port Harcourt; rivers state Nigeria and the samples were properly mixed.

Lime: The lime used was purchased from an open market at Bayajidda street in Central Market Kaduna and transported to NDA in an air-tight sack.

Earthworms (*Eudrilus Eugeniae*): The earthworms were obtained from river Kaduna axis around Kabala Doki area.

Methods

The soil sample from the borrow site was air dried and hand sorted to remove the pebbles and vegetative matter if any. The soil was further air dried, pulverized and sieved through BS NO 4 Sieve (4.76mm aperture) to remove gravel fraction. The air dried and sieved soil was then stored in airtight bags and ready to use for mixing with the crude oil.

The laterite soil was then contaminated with crude oil at a rate of 75cl of crude content per 10kg of the soil sample and 1000 ml of water. The contaminated sample was then fully covered and kept for a period of one month for full contamination. After a period of one month, the crude oil contaminated soil was then remediated with vermin (earthworms) at a rate of 40, 50, 60, 70 and 80/40kg of contaminated soil sample, making a total of 300 worms per 200kg of soil sample. The sample was then placed in a large perforated tank in an aerated open place for a month for remediation to take place while adding water to the remediation tank on a daily basis and making proper observations.

Laboratory Test Index properties

Laboratory tests were conducted to determine the index properties of the natural soil (Contaminated soil) and soil – vermi-remediated soil-lime mixtures in accordance with British Standards BS 1377 (1990) and BS 1924 (1990) respectively as presented in table 1 for the crude oil contaminated lateritic soil (COCS) and Table 2 for the crude oil contaminated soil

Compaction characteristics

Compaction of the samples was conducted for both the natural soil (Contaminated soil) and vermi-remediated soils treated with varying percentages of admixtures following the procedures outlined by BS 1377 (1990) Part 4, Nigerian General Specifications (NGS, 1997), and BS 1924 (1990).

Unconfined compressive strength (UCS)

The unconfined compressive strength (UCS) test was performed on the soil samples in accordance with BS 1377 (1990) Part 7, using British Standard Light (BSL), West African Standard (WAS), and British Standard Heavy (BSH) compactive efforts. Both natural and treated soil samples were compacted in 1000 cm³ moulds at their respective optimum moisture content (OMC).

California Bearing Ratio (CBR)

The California bearing ratio (CBR) test were conducted in accordance with BS 1377(1990) for the natural and treated soils.

Table 1: Physical properties of the crude oil contaminated lateritic soil (COCS) used for the study

Property	Quantity
Percentage passing BS sieve No. 200 (%)	64.00
Natural moisture content (%)	16.70
Liquid limit (LL) (%)	47.00
Plastic limit (PL) (%)	27.30
Plasticity index (PI) (%)	19.70
Linear shrinkage (LS) (%)	11.43
Specific gravity	2.66
AASHTO classification	A-7-6
USCS	CL

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Property	Quantity
Group index (GI)	12
pH	7.65
CEC (m/100meq)	0.56
Maximum dry density (MDD) (mg/m ³)	-
British standard light (BSL)	1.68
West African standard (WAS)	1.76
British standard heavy (BSH)	1.87
Optimum moisture content (OMC) (%)	-
British standard light (BSL)	20.20
West African standard (WAS)	15.90
British standard heavy (BSH)	14.20
Unconfined Compressive Strength (kN/m ²)	-
British standard light (BSL)	335.25
West African standard (WAS)	409.00
British standard heavy (BSH)	537.00
California Bearing Ratio (Unsoaked) (%)	-
British standard light (BSL)	12.68
West African standard (WAS)	19.56
British standard heavy (BSH)	24.15
California Bearing Ratio (24 hours soaking) (%)	-
British standard light (BSL)	5.76
West African standard (WAS)	15.17
British standard heavy (BSH)	22.87
Color	Light Brown
Dominant clay mineral	Kaolinite

Table 2: Physical properties of the vermi-remediated crude oil contaminated soil used

Property	Quantity
Percentage passing BS sieve No. 200 (%)	72.42
Natural moisture content (%)	—
Liquid limit (LL) (%)	51.8
Plastic limit (PL) (%)	32.26
Plasticity index (PI) (%)	19.5
Linear shrinkage (LS) (%)	11.0
Specific gravity	2.4
AASHTO classification	A-7-6
USCS	CL
Group index (GI)	12
Maximum dry density (MDD) (mg/m ³)	-
British standard light (BSL)	1.62
West African standard (WAS)	1.63

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Property	Quantity
British standard heavy (BSH)	1.86
Optimum moisture content (OMC) (%)	-
British standard light (BSL)	19.79
West African standard (WAS)	18.85
British standard heavy (BSH)	16.87
Unconfined Compressive Strength (kN/m ²)	-
British standard light (BSL)	604.3
West African standard (WAS)	631.3
British standard heavy (BSH)	695.5
California Bearing Ratio (Unsoaked) (%)	-
British standard light (BSL)	41.9
West African standard (WAS)	68.1
British standard heavy (BSH)	96.6
California Bearing Ratio (24 hours soaking) (%)	-
British standard light (BSL)	52.80
West African standard (WAS)	99.40
British standard heavy (BSH)	64.78
Color	Dark Brown
Dominant clay mineral	Kaolinite

Efficiency of Crude Oil Contaminant Removal

The total petroleum hydrocarbon for the contaminated and the remediated soils were analyzed by gravimetric method. This is done to establish the hydrocarbon content before and after the remediation. The total petroleum hydrocarbon for crude oil contaminated soil was determined as 4500mg/kg while the total petroleum hydrocarbon after vermi-remediation took place was determined as 3300 mg/kg. The remediation efficiency is therefore determined as 27.00%.

Effect of Lime stabilization on vermi-remediated crude oil contaminated soil

Specific gravity

The specific gravity of the soil generally remained the same as 2.4 for 0% to 4% lime stabilized soil, it then reduced to 3.6 at 6% only to finally increase again to 2.4 at 8% lime stabilization. (See Figure 1) The consistency in specific gravity of the samples before and after lime stabilization could be due to the closeness in

densities of the soil and lime. (Mahdi and Mahmoud, 2015).

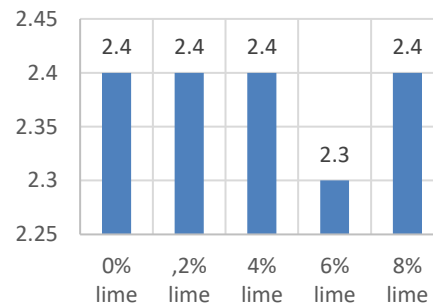


Figure 1: Specific gravity for lime remediated crude oil contaminated soil

Particle Size Distribution: The particle size distribution curves of the lime stabilized vermi-remediated crude oil contaminated laterite soil using Optimum moisture content (OMC) from BSL compaction are shown in figure 2-4. A trend of reduction in the percentage of fines with increasing lime contents was noticed. The reduction in the amount of clay sized particles was



as a result of hydration of lime concentration which acted as a nucleus to which soil particles adhered. With increase in lime content concentration, the quantity of free silt and clay progressively reduced and coarser materials were formed. This is in agreement with the findings reported by Amadi (2010). The increase in the quantity of coarser particles could be attributed to the moisture availability for pozzolanic reaction and hydration of free lime and silica in the soil matrix. The high moulding moisture content associated with BSL compaction energy level facilitated the agglomeration of the soil particles to form macro structural particles. The stabilized soil became more flocculated and agglomerated, resulting in coarser particles composed of pseudo silt to sand sizes (Alkaragooly, 2012; Portelinha *et al*, 2012).

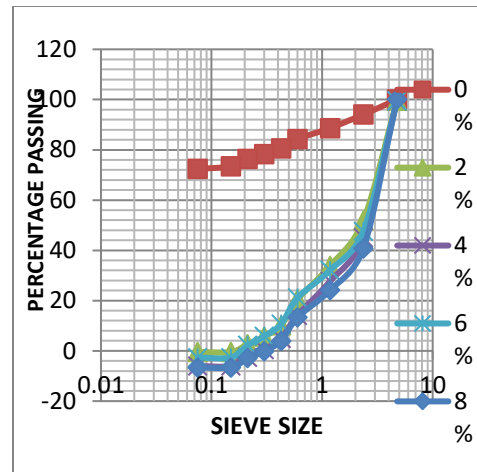


Figure 4: Particle size distribution of lime remediated crude oil contaminated soil (WAS)

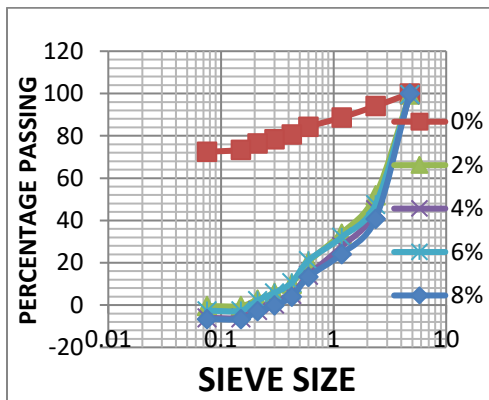


Figure 2: Particle size distribution of lime remediated crude oil contaminated soil (BSL)

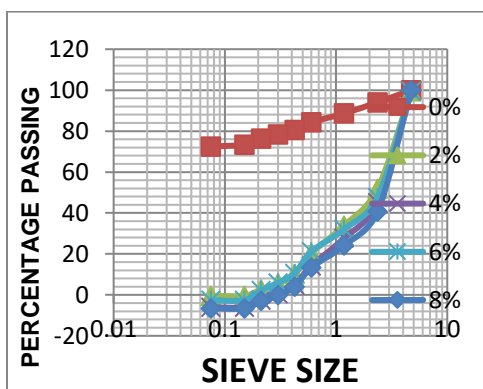


Figure 3: Particle size distribution of lime remediated crude oil contaminated soil (BSH)

Atterberg Limits

Liquid limit, plastic limit and plasticity index

The variation of liquid limit of laterite-lime mixtures is shown in figure.5. The liquid limit, Plastic limit and plasticity index for crude oil contaminated soil sample are 39.5, 28.8 and 10.7 respectively. The linear shrinkage is 11% these results fail to meet Nigerian general specification and federal ministry of works standard of LL not more than 30% whereas the liquid limit, plastic limit and plasticity index for the vermi-remediated sample were 54.0, 32.3 and 21.7 respectively.

The linear shrinkage was also 11%. After lime stabilization at 2%, 4%, 6% and 8%, the results obtained for liquid limit were 46.5, 56, 44.5 and 58 respectively, the plastic limits were determined as 29.3, 30, 11 and 13 respectively, the plasticity index results were also determined as 17.2, 26, 33.5 and 45 respectively. All the values of LL and PI did not meet the standard as well. This could be as a result of the effect of vermin action in breaking down the soil.

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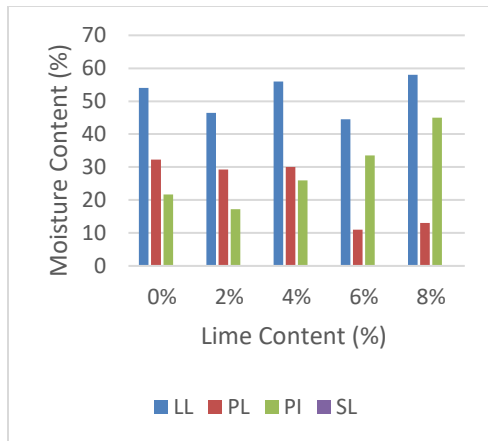


Figure 5: LL, PL, and PI of lime stabilized vermiremediated soil samples

Maximum dry density

The Maximum Dry Density (MDD) generally increased (see Figure 6) from 1.62 g/cm³ to 1.67 g/cm³ for remediated and treated soil at 8% admixture under BSL compactive effort. Similarly, under WAS compactive effort, the MDD increased from 1.73 g/cm³ to 1.77 g/cm³, while for BSH compactive effort, it increased from 1.80 g/cm³ to 1.85 g/cm³ for remediated and lime-treated soils at 8% lime content, respectively.

The observed increase in MDD with increasing stabilizer content is attributed to improved particle packing, void filling, and the formation of cementitious compounds arising from pozzolanic reactions between lime and silica/alumina present in the soil and admixtures (Adekanle, 2026; Almuaythir, 2024). These reactions enhance inter-particle bonding and lead to a denser soil matrix, thereby improving compaction characteristics.

Furthermore, similar trends have been reported in recent studies on stabilized lateritic and clay soils, where increases in MDD were observed at higher stabilizer contents (typically 6–8%), confirming improved densification and engineering performance (Olayiwola et al., 2025). This behaviour is also consistent with earlier findings by Osinubi and Umar (2003) and Osinubi and Alhassan (2008), which established that the addition of lime and other stabilizing agents leads

to increased MDD due to flocculation and agglomeration of soil particles.

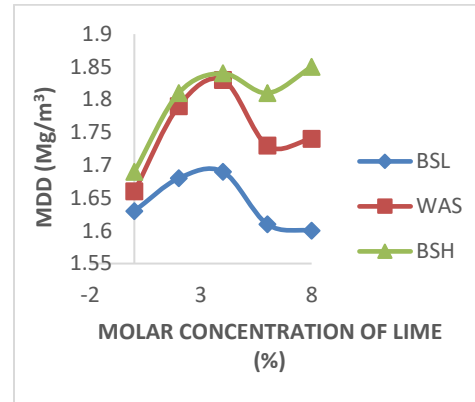


Figure 6: MDD of lime stabilized vermiremediated crude oil contaminated soil for BSL, WAS, BSH

Optimum moisture content

For BSL compactive effort, the Optimum Moisture Content (OMC) values recorded were 18.87%, 20.23%, 20.46%, 17.54%, and 19.58% for lime-stabilized vermi-remediated soil at 0%, 2%, 4%, 6%, and 8%, respectively (See Figure 7). This indicates that the OMC generally increased from 18.87% to 19.58% at 8% lime content.

Similarly, for WAS compactive effort, the OMC values obtained were 17.18%, 19.74%, 19.45%, 17.16%, and 18.88%, while for BSH compactive effort, the values were 15.78%, 16.55%, 17.94%, 14.59%, and 16.44% at corresponding admixture levels. Under BSH compaction, the OMC increased from 15.78% to 16.44% at 8% lime content.

The observed variation shows that OMC sometimes decreases at intermediate admixture levels but generally increases with increasing stabilizer content. This trend is attributed to the higher water demand required for hydration and pozzolanic reactions between lime and the silica/alumina components of the soil and admixtures (Adekanle, 2026; Almuaythir, 2024). Additionally, the increase in OMC is linked to cation exchange and flocculation processes, which alter soil structure and increase water absorption capacity.

Recent studies on stabilized soils have similarly reported that OMC tends to increase with lime or waste ash addition due to increased surface area and chemical reactions requiring additional moisture for proper compaction (Olayiwola et al., 2025). However, slight decreases at certain percentages may occur due to improved gradation and particle rearrangement, which temporarily reduce water demand. These findings are consistent with earlier studies by Osinubi and Umar (2003) and Osinubi and Alhassan (2008), which established that OMC generally increases with stabilizer content, although fluctuations may occur depending on soil type, compactive effort, and admixture proportion..

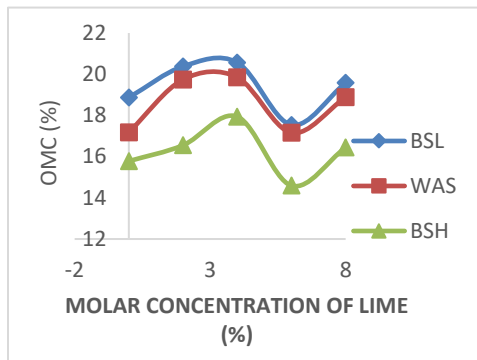


Figure 7: (OMC) of lime stabilized vermiremediated crude oil contaminated soil for BSL, WAS, BSH

Strength Characteristics

Unconfined Compressive Strength

7 days curing period

The 7 days UCS results of lime stabilized vermiremediated crude oil contaminated lateritic soil sample at 0%, 2%, 4%, 6% and 8% for BSL, WAS and BSH compactive efforts are presented thus. The figure 8 shows sharp decrease from vermiremediated soil and lime stabilized soil sample at 8% at BSL and BSH except for WAS. For BSL the highest UCS value obtained was 426.8kN/m² at 8% lime admixture. For WAS the highest UCS value obtained was 461.5kN/m² at 8% lime. For BSH, the highest value obtained was 462.3kN/m², at 8% lime stabilized vermiremediated contaminated soil.

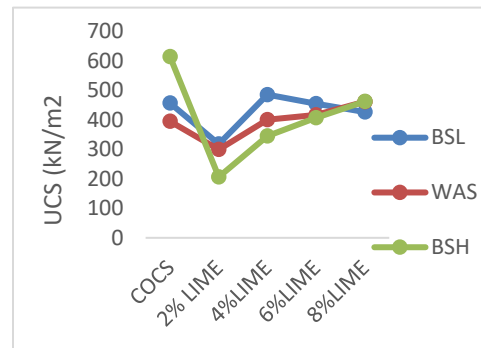


Figure 8: (UCS) of lime stabilized vermiremediated crude oil contaminated lateritic soil at 7 days BSL, WAS and BSH.

14 days curing

The figure 9 shown below indicates the 14 days UCS results of lime stabilized vermiremediated crude oil contaminated lateritic soil sample at 0%, 2%, 4%, 6% and 8%. For BSL the highest UCS value was 808kN/m² at 0% lime whereas the highest value after lime stabilization was 454.3kN/m² at 8%. For WAS, highest UCS value was 481.3kN/m² at 4% lime stabilization which is quite lesser than that of the unstabilized soil which was 702.1kN/m². For BSH the highest UCS values were 543.3kN/m² and 475.5kN/m² for unstabilized and 8% lime stabilized soils respectively. The values obtained are not in line with the specifications by Inghes and Metcalf (1972) who presented a benchmark range of 687-1373kN/m².

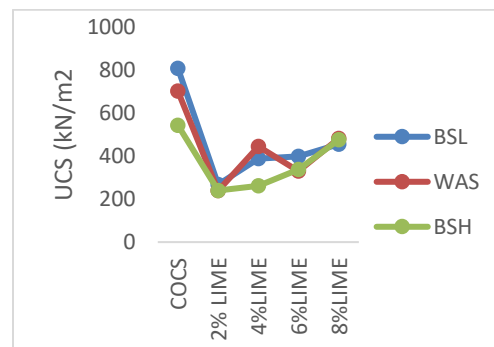


Figure 9: (UCS) of lime stabilized vermiremediated crude oil contaminated lateritic soil at 14 days BSL, WAS and BSH.

28 days curing

The figure 10 shown below indicates the 28 days UCS results of lime stabilized vermi-remediated crude oil contaminated soil (VRCOCS) sample at 0%, 2%, 4%, 6% and 8% for BSL, WAS and BSH compactive efforts. For BSL the highest UCS values were 1110.6kN/m² and 604.3kN/m² for unstabilized and 8% lime stabilized soils respectively. For WAS, the highest UCS values were 1135.4kN/m² and 631.3kN/m² for unstabilized and 8% lime stabilized soils respectively. For BSH the highest UCS values were 945.2kN/m² and 695.5kN/m² for unstabilized VRCOCS and 8% lime stabilized VRCOCS soils respectively. The values obtained for 28 strength gain are in line with the specifications by Inghes and Metcalf (1972) who presented a benchmark range of 687-1373kN/m² for stabilized sub base material.

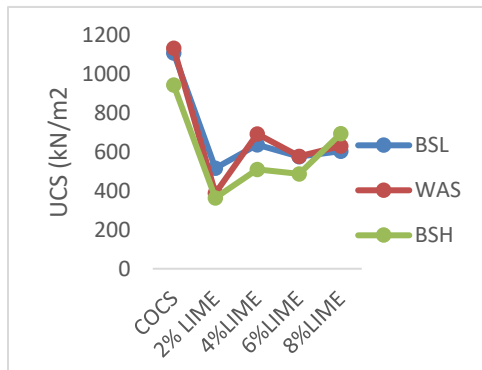


Figure 10: (UCS) of lime stabilized vermi-remediated crude oil contaminated lateritic soil at 28 days BSL, WAS and BSH.

Strength Development

From the chart presented in figure 11, it can be observed that the unconfined compressive strength, was optimum at 8% Lime admixture and the strength development shows that there was gradual gain in strength from 7days to 28days and the greatest strength was observed at 28days curing Period. The UCS strength value for BSL at 7 days was 426.8kN/m². The UCS strength increased to 454.3kN/m² at 14 days only to finally increase to its greatest strength of 604.3kN/m² at

28 days. The same pattern was observed for WAS and BSH.

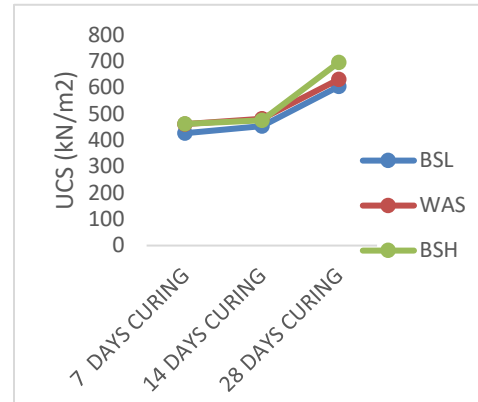


Figure 11: strength development of 8% Lime stabilized vermi-remediated crude oil contaminated lateritic soil for BSL, WAS and BSH

California Bearing Ratio

Unsoaked condition

The CBR values increased with the increases in admixture (See Figure 12), the highest CBR value obtained was 41.9% and the admixture level of 6% for BSL compactive effort. For WAS, the highest CBR value was 68.1% at the same admixture level of 6%. For BSH the highest CBR values was 96.6% at the same admixture level of 6%. The value for BSH was above 80% and suitable for base material as specified by The Nigerian General Specifications for Roads and Bridges, 2016, clause 6201.

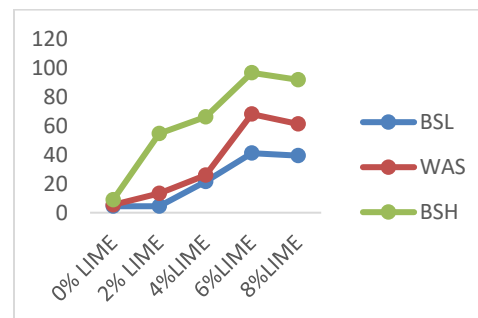


Fig. 12: The variation of unsoaked CBR of lime stabilized vermi-remediated crude oil contaminated lateritic soil for BSL, WAS and BSH compactive effort.

Soaked C.B.R

The figure 13, indicate the variations of CBR (soaked) of lime stabilized vermi-remediated soil at 0%, 2%, 4%, 6% and 8%. Generally, The CBR values increased with the increase in admixture, the highest CBR values obtained was 52.82% for BSL compactive effort at the admixture level of 8%. For WAS, the highest CBR values was 99.4% at the admixture level of 6%. For BSH the highest CBR values was 64.78% at the admixture level of 8%.

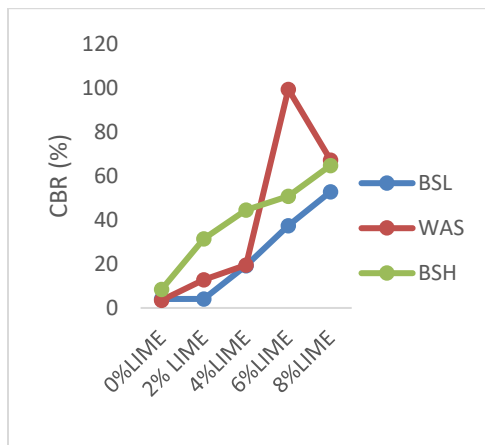


Fig. 13: The variation of soaked CBR of lime stabilized vermi-remediated crude oil contaminated lateritic soil for BSL, WAS and BSH compactive effort.

Durability

The resistance to loss in strength increased with the increase in admixture (See Figure 14), the highest resistance to loss in strength value recorded were 168.4%, 120.9% and 76.9% at 8% each for BSL, WAS and BSH compactive effort respectively. It is pertinent to note that the UCS values for soaked specimens are far too low compared to those obtained for 7-, 14- and 28-days curing periods; which is probably due the ingress of water that resulted in loss of strengths. (Ola, 1974; Osinubi 1998a; 1999). All the sample obtained were above 80% resistance to strength loss required for durable road soil material recommended by Ola (1974).

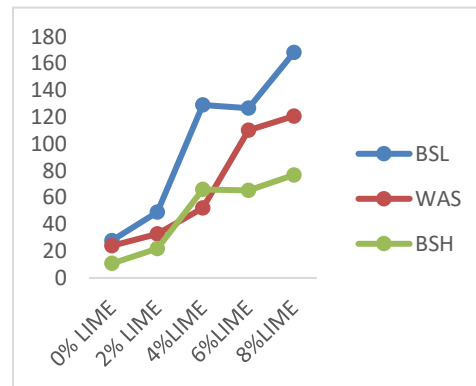


Figure 14: Loss in strength of lime stabilized vermi-remediated crude oil contaminated lateritic soil for BSL, WAS and BSH

CONCLUSION

In conclusion, it was observed that there was no significant decrease in the Atterberg limit test results between the crude oil contaminated soil sample and the lime stabilized VRCOCS as both samples did not meet standard of not greater than 30%. The specific gravities of lime stabilized soil samples were 2.4 and same as that of crude oil contaminated soil sample except at 6% which was 2.3.

The MDD and OMC after lime stabilization increased as compared to unstabilized vermi-remediated crude oil contaminated soil. UCS greatest value was 695KN/m² for BSH at 8% lime admixture. The result met the standard for stabilized sub base material as presented by Ingles and Metcalf.

The greatest value for CBR was 52.82% for BSL at 8%. For WAS, was 99.4% at 6%. For BSH was 64.78%. all values for CBR met the standard of 30% for sub base material but only WAS met the standard for base material as specified by Nigerian general specification.

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