

Impact of Chelating Agents on Electrokinetic Remediated Crude Oil Contaminated Soil for Use in Road Construction

A. K. Abdulrahman, K. Adebayo*, J. E. Sani, I. I. Hassan, A. M. Anwar, G. Moses
Department of Civil Engineering,
Nigerian Defence Academy, Kaduna, Nigeria

ABSTRACT

A lot of work has shown that electrokinetic remediation (EKR) technology can be enhanced by a number of strategies for more effective performance. The suitability of EKR soils for use in road construction have also not been well researched. This work presents the impact of chelants enhanced EKR crude oil contaminated soil (COCS) for use in road construction by comparing the performance of ethylenediaminetetraacetic acid (EDTA), citric acid and traditional (unenhanced) EKR. COCS collected at a depth of 1 m from the Nigerian Pipeline and Storage Company, Kaduna in Kaduna State was remediated by using graphite electrodes to pass 1 V DC/cm across EKR setups enhanced by using 0.2 M EDTA, 0.2 M citric acid and distilled water separately as anode purging solutions. The total petroleum hydrocarbon results showed that the crude oil content of 78,600 mg/kg present in the COCS exceeds permissible limits for soils. Average removal efficiencies of 36.74%, 21.37% and 80.61% obtained from EDTA, citric acid and distilled water enhancements respectively showed that distilled water, with highest removal efficiency, is a good anode purging solution for COCS than EDTA and citric acid chelants. The results of the geotechnical properties of the COCS showed slight improvement with the chelants enhanced EKR with best performance with distilled water EKR. The CBR and durability properties of the COCS and remediated soils do not meet the requirements for road construction uses. As such, EDTA, citric acid or distilled water enhanced EKR soils should not be used for road construction without stabilization.

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INTRODUCTION

Exposure of contaminants such as heavy metals and organic compounds to soils are chief contributors to soil contamination (Arao et al., 2010; Haruna et al., 2023). These contaminants seep through soils into the groundwater and contaminate it. In the case of crude oil, they may remain in the soil pores, accumulate beyond 1000-2000 mg/kg limit for soils and make its behaviour unfit for structural uses like road constructions (Meshari, 2021). As a result, man is faced with proffering solutions to these problems of soil contamination. Many technologies have been investigated as remediation measures to these contaminants with a lot of deficiencies especially against crude oil (Virkytute et al., 2002; Haruna et al., 2023).

Crude oil like many other contaminants in soils has been shown to have negative effects on the index and engineering properties of soils. Decrease in the specific gravity, hydraulic conductivity, void ratio and water content, and non-predictable behaviour in the Atterberg limits have been reported. Likewise, decrease in the maximum dry density (MDD) and increase in optimum moisture content (OMC), lowering of the unconfined compressive strength (UCS) and California bearing ratio (CBR) of oil contaminated soils have been reported (Mohammad & Taghi, 2012; Akinwumi et al., 2014; Swaroop & Rani, 2015; Al-Qaisee et al., 2020; Suleiman et al., 2020; Oyediran & Enya, 2021; Salimnezhad et al., 2021). Many technologies have shown limited remediation efficiencies against oil

Corresponding author: K. Adebayo

✉ bavo997@gmail.com

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contaminants in soils. Choi et al. (2020) recommended elevated temperature of about 400°C for achieving about 100% remediation of oil contaminated soils from landfills and gas sites containing total petroleum hydrocarbons (TPH), polyaromatic hydrocarbons (PAHs), unresolved complex mixtures (UCM), and alkylated PAHs (Alk-PAHs) by thermal desorption in about 15 minutes. Cho et al. (2020) also obtained 91.1% removal of TPH from coarse grained soils by microwave heating, although 71.2% removal efficiency was recorded for fine grained soil after a relatively longer time. These show that even if there are different remediation methods for contaminated sites, they fail to deliver consistent results when the contaminated area is located at a considerable depth and the soil type is clay due to its low permeability. Moreover, pollutants, such as petroleum hydrocarbons, have a high adsorption rate compared to soil particles, making their removal or destruction more difficult (Streche et al., 2018).

Electrokinetic remediation technology has also been shown to be a good remediation technology for these types of soils (Liu et al., 2017). Improved results have been obtained when this technology was enhanced by some forms of strategies like the use of cosolvents, complexing agents, chelants, filter membranes, etc. (Muhsina & Chandrakaran, 2015; Haruna et al., 2023). However, research has established that EKR can only make the pollutants in the soil move to the designated region, but cannot easily eliminate the pollutants. As such, it is often combined with other technologies to achieve the effect of migrating and removing pollutant in the soil (Yunfeng et al., 2022). Otherwise, reversal of Electroosmotic (EO) flow would occur thereby prolonging the duration of the remediation (Genc et al., 2009; Zanjani et al., 2012).

The technology combining EKR and with chelants is one of the limited techniques that can improve the removal efficiency of pollutants and the performance of EKR. This works by accelerating the transport and removal of pollutants, thus reducing manpower and material inputs. Efficient application of this technology relies on the proper choice of the chelating agent, which depends mainly on the type of contaminant that must be treated (Yeung et al., 2011). The use of chelants like EDTA and

citric acids have been experimented against heavy metals with huge results and no report have been made against crude oil contaminated soils (Yeung et al., 2011).

Health and environment safety is not the only requirements for remediated soils especially by civil engineers. Focus is also on the improvements in the geotechnical properties of these soils. Geotechnical properties of soils that qualify them for structural use are good specific gravity, moisture content, consistency limits, compaction parameters, strength properties, permeability properties, shrinkage property and compressibility properties. Materials for compacted sub-base course and base course, specified by Clause 6200 of the Nigerian General Specifications for Roads and Bridges (2016), are to be tested for Atterberg limits, gradation, compaction and CBR tests and it requires that:

Normally the minimum strength of such base course material shall not be less than 80% C.B.R. value being determined at maximum dry density and optimum moisture content un-soaked with either West African or Modified AASHTO (American Association for State and Highway Transportation Officials) compaction. However, where the Engineer's Representative considers it necessary on account of perched water-table or any other reasons, he may specify that a C.B.R. value of 80% be obtained after at least 24 hours soaking (The Nigerian General Specifications for Roads and Bridges, 2016, clause 6201).

Such sub-base material classified as, Type 1 is made from pit-run laterite, sand, or screening, and soil of other similar binding or filler material. The percent by weight passing the 75 µm sieve shall be less than but not greater than 35%. The material passing the 425 µm sieve shall have a liquid limit of not more than 35% and a plasticity index of not more than 12%. A minimum CBR of 30% after at least 24 hours soaking is also required as determined by British Standard. Type 2 requires that the CBR assessed by West African Compaction test shall not be less than 20% after at least 24 hours of soaking, for light traffic, a liquid limit greater than 35%, and a plasticity index greater than 12 may be disallowed for use as subbase course or base course in this class. Type 3 consists of materials designated as sub-standard but may be used for sub-base or base.

Corresponding author: K. Adebayo

✉ bavo997@gmail.com

Department of Civil Engineering, Nigeria Defence Academy, Kaduna, Nigeria

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These properties of soil do not remain the same throughout the design life of roads. They can change due to many reasons like capillarity action, flooding, seismic loads, frost action, and exposure to various contaminants (Akinwumi et al., 2014). One of these contaminants which have led to the abandonment of projects, change in projects scope or great increase in projects cost is oil in the form of hydrocarbon, which can be crude oil or any of its fractions (Rahman et al., 2010). A de-contaminated soil which is safe to human health and environment and can provide the basic geotechnical qualities required for the use of the soil either as construction materials or as materials to support constructions is the ultimate aim of remediation by engineers.

The foregoing has shown that crude oil content in soils can exceed permissible limits thereby posing dangers to human and environments, these contaminated soils can be remediated by electrokinetic technology. However, previous research work (Akinwumi et al., 2014; Karthigeyan & Ramachandran, 2020; Suleiman et al., 2020) have indicated a gap that no thorough investigation of the impacts of chelants enhanced electrokinetic remediation on the index and engineering properties of crude oil contaminated soils as they relate to road materials for subgrades, sub-bases and road bases has been carried out. This research would look into investigating the impact of chelating agents on electrokinetic remediated crude oil contaminated soil for use in road construction.

MATERIALS AND METHODS

This research work involved the usage of many materials and equipment, all of which were used in many laboratory experiments to determine chemical, index and engineering properties of samples with the ultimate aim of determining the impact of chelating agents on electrokinetic remediated crude oil contaminated soil for use as road construction materials.

Materials

The materials for this research work include;

- i. Contaminated Soil: Crude oil contaminated soil (COCS) obtained at a depth of 1 m from the Nigerian Pipeline

and Storage Company, Kaduna located around latitude 10°24'6" and longitude 7°29'32" was used for this work.

- ii. Distilled Water: Distilled water obtained from the Department of Fashion Design and Clothing Technology; Kaduna Polytechnic was used.
- iii. Water: Tap water from the borehole provided near the Civil Engineering laboratory of the Nigerian Defence Academy, Kaduna was used.
- iv. Electrodes: Graphite electrodes rods, 8 mm diameter by 300 mm long, obtained from Parsity laboratory equipment store at Lagos Street in Kaduna State was used.
- v. EKR Cell: Electrokinetic remediation cell made from clear plexiglass plate of overall dimension, 400 mm by 200 mm by 300 mm, with middle internal partition, 300 mm by 200 mm by 300 mm and two outer partitions, 50 mm by 200 mm by 300 mm adjoining the middle was used.
- vi. Connecting Wires and Clips: Flexible connecting wires and battery clips obtained from Parsity laboratory store at Lagos Street in Kaduna State were used.
- vii. Ethylenediaminetetraacetic Acid (EDTA): 0.2 M EDTA prepared by dissolving 74.45 g of EDTA disodium salt in 1 litre of distilled water was used.
- viii. Citric Acid: 0.2 M citric acid prepared by dissolving 38.4 g of citric acid salt in 1 litre of distilled water was used.
- ix. Sodium Hydroxide (NaOH): 0.01 NaOH solution prepared by dissolving 4 g of its salt in 1 litre of distilled water was used.

Methods

For the purpose of classification, checking compliance and determining the degree of improvement obtained in the engineering properties of the enhanced EKR crude oil contaminated soil, the following laboratory tests were carried out on both the COCS and the EK remediated soils in accordance with BS 1377 (1990) "Methods of Tests for Soil for Civil Engineering Purposes" as recommended in the Nigerian General Specifications for Roads and Bridges (2016) Clause 1050 "Tests to be Carried Out":

- i. Specific gravity test
- ii. Moisture content test

Corresponding author: K. Adebayo

✉ bayo997@gmail.com

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- iii. Particle size distribution (sieve analysis) test
- iv. Consistency limits (liquid limit, plastic limit and plastic index)
- v. Compaction test
- vi. California Bearing Ratio (CBR) test
- vii. Unconfined Compressive Strength (UCS) test.

Total Petroleum Hydrocarbon (TPH) Test

The TPH contents of the COCS, EDTA and citric acid chelants enhanced EK soil, and the unenhanced EK soils in this research were conducted by gravimetric method (the cold extraction method) at the department of Civil Engineering, Nigerian Defence Academy, Kaduna state Nigeria. The TPH was computed as:

$$TPH \text{ (mg/kg)} = \frac{(W_0 - W_1)(\text{in mg})}{W_0 \text{ (in kg)}} \quad (1)$$

Where;

W_0 = initial weight of sample

W_1 = weight of sample after solvent extraction.

Electrokinetic Remediation (EKR)

The electrokinetic remediation setup used in this research consists of direct current (DC) supply, electrokinetic cell, electrodes, connecting cables and clips, chelating agents, electrolytes, solar power supply means and reservoir tanks. The DC supply is used to supply constant 30 V and maximum of 5 A through graphite electrodes to the contaminated soil in the setup to achieve 1 V DC/cm across the setup. The Solar powered electrokinetic unit, shown in Figure 1 and described in Table , collects the contaminated soil to be remediated in its middle partition, has chelants (anode

purging solution) in one of the adjacent partitions, and 0.01 M NaOH (cathode purging solution) in the other attached to the middle partition by a well perforated plexiglass divider which ensures electroosmotic flow between the anode and cathode purging solutions through the soil. Two graphite electrodes each 8 mm diameter, and 30 cm long were placed vertically with a face-to-face configuration at the anolyte and catholyte compartment for passing direct current from the DC supply using connecting cables attached to clips through the setup.

The middle partition of the setup was filled with the contaminated soil at optimum moisture content, three set-ups with the introduction of 0.2 M EDTA, 0.2 M citric acid and distilled water separately as purging solutions into the outer anode partition and 0.1 M NaOH as purging solution in the outer cathode partition as shown in Table 1. The setup was connected as shown in Figure 1 with provisions for continuous supply and recycling of purging solution using reservoirs at the anode end. Power supply was switched on and the remediation was carried out while daily pH, electrical conductivity and current variations were determined across the soil length throughout the duration of the process. Effluents from the cathode valve were collected and its volume measured and recorded. The process was left on until no more effluent was produced at the cathode. At the end of the process, the remediated soil was sliced into five equal parts and air dried. The TPH at each slice was determined to ascertain the level and variation in the remediation of the contamination carried out with the chelating agents.



Figure 1: Chelant Enhanced EK Remediation of Crude-oil Contaminated Soil

Corresponding author: K. Adebayo

bavo997@gmail.com

Department of Civil Engineering, Nigeria Defence Academy, Kaduna, Nigeria

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Table 1: Summary of Electrokinetic Remediation Setup

Details	Experiment 1	Experiment 2	Experiment 3
Contaminant	Crude Oil	Crude Oil	Crude Oil
Length of Soil (cm)	30.0	30.0	30.0
Width of Soil (cm)	20.0	20.0	20.0
Depth of Soil (cm)	30.0	30.0	30.0
Electrical potential (V)	30.0	30.0	30.0
Anode Purging Solution	0.2 M EDTA	0.2 M Citric Acid	Distilled Water
Cathode Purging Solution	0.01 M NaOH	0.01 M NaOH	0.01 M NaOH

RESULTS AND DISCUSSION

The results of all the laboratory experiments carried out on the COCS, chelants

enhanced EKR soils and unenhanced EKR soils are reported and discussed accordingly.

Contaminant Level, Remediation Process and Removal Efficiency

Table 2: Summary of Chelants Enhanced EKR of COCS

Details	EDTA	Citric Acid	Unenhanced
Initial TPH (mg/kg)	78,600	78,600	78,600
Duration (days)	14	11	47
Average Remediation Efficiency (%)	36.74	21.37	80.61

Table 2 shows the initial TPH of the COCS to be 78,600 mg/kg, this value far exceeds the permissible limits for soils and thus needed to be remediated before its engineering usage (Meshari, 2021).

The incorporation of EDTA and citric acid chelants separately to enhance the EKR technology adopted for the COCS did not give remarkable results like the unenhanced EKR. The use of EDTA in enhancing EKR of the COCS took 14 days. This when compared to the 18 days reported in Muhsina and Chandrakaran (2015) showed 22.22% time efficiency. With citric acid as chelent, the set up took 11 days. This translates to 21.43% duration advantage when compared to that involving EDTA as chelants. When the EKR of the COCS was carried out without chelant enhancement, the

set up took 47 days to complete the remediation process. This shows that EKR of COCS with EDTA and citric acid as chelants enhancements provide 70.2% and 76.6% duration advantages respectively over the unenhanced EKR.

The average crude oil removal efficiencies for the EDTA chelant enhanced, citric acid chelant enhanced and the unenhanced EKR set ups were 36.74%, 21.37% and 80.61% respectively. This shows that the chelants enhancement for the removal of crude oil from the soil did not yield significant result as when not incorporated. The unenhanced EKR of COCS, though with a longer duration, with an average removal efficiency of 80.61% exceeds the 71.2% reported by Cho et al. (2020) with diesel contaminated soil.

Effects of Chelants on the Geotechnical Properties of EK Remediated COCS

Table 3: Moisture Content and Specific Gravity of COCS and EKR Soils

Soil Type	Moisture Content (%)	Specific Gravity
COCS	11.8	2.28
EDTA Enhanced EKR	20.5	2.33
Citric Acid Enhanced EKR	18.8	2.26
Unenhanced EKR	25.9	2.44

Corresponding author: K. Adebayo

✉ bayo997@gmail.com

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Natural Moisture Content

From Table 3, the natural moisture content of the crude oil contaminated soil is 11.8%. This value is seen to increase by 73.7% to 20.5% for EDTA chelant enhanced electrokinetic remediated COCS. For the citric acid chelant enhanced electrokinetic remediated COCS, a 59.3% increase is observed in the 18.8% moisture content when compared to that of the COCS. This also represents an 8.3% decrease to the moisture content of the EDTA chelant enhanced electrokinetic remediated COCS. The unenhanced EKR of COCS have a moisture content of 25.9%. This was observed to be generally higher than those of the contaminated and chelants enhanced EKR soils.

The lower water content from the chelants enhanced EKR soils could be due to their lower crude oil removal with higher coating effects and granulating properties of the crude oil on the soil, creating a thick adsorbed water layer on the soil thereby preventing the penetration of water into the soil grains (Al-Qaisee et al., 2020; Suleiman et al., 2020).

Specific Gravity

The specific gravity of the COCS is presented in Table 3 as 2.28. This value is seen to increase by 2.2% to 2.33 for the EDTA chelant enhanced electrokinetic remediated COCS. For the citric acid chelant enhanced electrokinetic remediated COCS, the specific gravity was obtained as 2.26. This represents 0.9% and 3% reduction when compared to those of the COCS and EDTA chelant enhanced soils respectively.

For the unenhanced electrokinetic remediated COCS, the specific gravity was obtained as 2.44. This shows to the higher when compared to that obtained with chelants enhanced soils. This could mean a reduction in the granulating effects of the soil and increase the particle to particle contact of the soil grains when remediated without any enhancement. The high specific gravity with unenhanced electrokinetic remediated COCS could indicate higher strength and material quality of the resulting soil when compared to those with chelants enhanced EKR soils as hinted in Oyediran and Enya (2021).

Particle Size Distribution

Table 4: Gradations of COCS and Chelants Enhanced EKR Soils

Soil Type	Fraction	Percentage (%)
COCS	Sand	68.94
	Silt	10.25
	Clay	20.81
EDTA EKR	Sand	65.76
	Silt	9.69
	Clay	24.55
Citric Acid EKR	Sand	56.70
	Silt	10.08
	Clay	32.50
Unenhanced EKR	Sand	64.18
	Silt	34.16
	Clay	1.66

From Table 4 above, the gradations of the COCS shows it consists of 68.94% sand, 10.25% silt and 20.81% clay. However, the clay content of the COCS is high (above 12%) as the

soil classifies as clayey sand with silt. For the EDTA chelant enhanced electrokinetic remediated soil, its gradation shows it consists of 65.76% sand, 9.69% silt and 24.55% clay.

Corresponding author: K. Adebayo

✉ bayo997@gmail.com

Department of Civil Engineering, Nigeria Defence Academy, Kaduna, Nigeria

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This also classifies as clayey sand with silt. The gradation of the citric acid enhanced EKR soil from Table 4 shows that it consists of 56.70% sand, 10.8% silt and 32.50% clay. This also classifies as clayey sand with silt. The high clay content of the COCS and the chelants enhanced EKR soils can clog the pores of the sand and silt thereby reducing the hydraulic conductivity of the soils.

When the EKR of the COCS was not enhanced, the gradation was obtained as 64.18% sand, 34.16% silt and 1.66% clay. This classifies as silty sand with little clay. The pore clogging effect prominent in the COCS and the chelants enhanced EKR soils is expected to be absent in the unenhanced EKR soil as the clay

responsible for this property is virtually absent here.

The high quantity of clay for the chelants enhanced EKR soils could be due to their lower crude oil removal efficiencies. However, the citric acid chelant enhanced EKR crude oil contaminated soil with 43.3% fines is a poorer soil compared to the EDTA chelant enhanced EKR crude oil contaminated soil with 31.24% fines. The above 35% of the percentage passing sieve 75 μm for the citric acid enhanced and the unenhanced EKR crude oil contaminated soils generally makes them unsuitable for use as subgrade, sub-base or base materials for road construction by the Nigerian General Specifications for Road and Bridges (2016).

Atterberg Limits

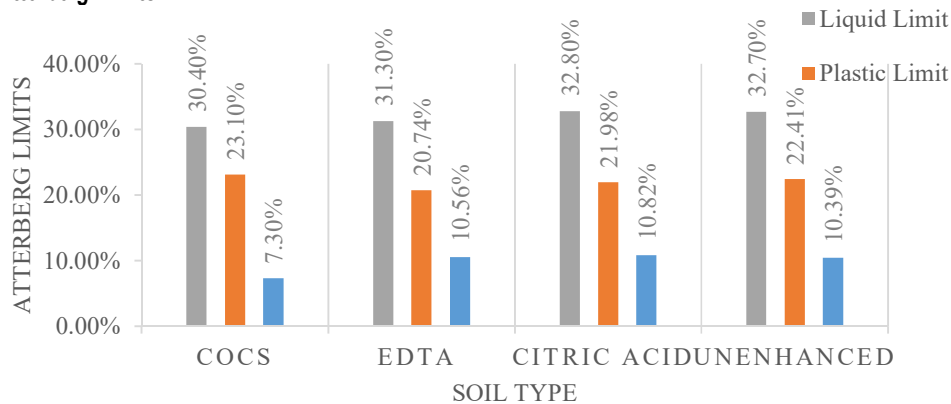


Figure 2: Atterberg Limits of COCS and Chelants Enhanced EKR Soils

From Figure 2 above, the liquid limit, plastic limit and plasticity index of the COCS are 30.40%, 23.10% and 7.30% respectively. For the EDTA chelant enhanced EK remediated soil, the liquid limit, plastic limit and plasticity index are 31.30%, 20.74% and 10.56% respectively. These values show an increase of 2.96%, decrease of 10.22% and an increase of 44.66% for the liquid limit, plastic limit and plasticity index respectively when compared to those of COCS. For the citric acid chelant enhanced EK remediated soil, the liquid limit, plastic limit and plasticity index are 32.80%, 21.98% and 10.82% respectively. These values show an increase of 7.89%, decrease of 4.85% and an increase of 48.22% for the liquid limit, plastic limit and plasticity index respectively

when compared to those of COCS. When compared with those of the EDTA chelants enhanced EK remediated soil, a 4.79% increase in the liquid limit, 5.98% increase in the plastic limit and 2.46% increase in the plasticity index are observed. For the unenhanced EK remediated crude oil contaminated soil, the liquid limit, plastic limit and plasticity index are 32.70%, 22.41% and 10.39% respectively. By the Nigerian General Specifications for Road and Bridges (2016); the liquid limit of not more than 35%, and plasticity index of below 12% obtained from all the soils qualify them as Type 1 material for use as sub-base and base courses (Karthigeyan & Ramachandran, 2012; Akinwumi et al., 2014; Swaroop & Rani, 2015).

Corresponding author: K. Adebayo

bayo997@gmail.com

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Classifying the soils from their gradations and Atterberg limits by AASHTO (1986), the COCS is classified as an A-2-4 soil which is a silty or clayey sand and described as a good soil for road construction. The EDTA chelant enhanced EKR soil is classified as an A-2-6 soil which is also a silty or clayey soil and

described as a good soil for road construction. The citric acid chelant enhanced EKR soil is also classified as an A-6 soil which is a clayey soil and described as a poor for road construction. The unenhanced EK remediated crude oil contaminated soil is classified as A-4 soil which is fair for road construction.

COMPACTION PARAMETERS

West African Standard (WAS) Compaction

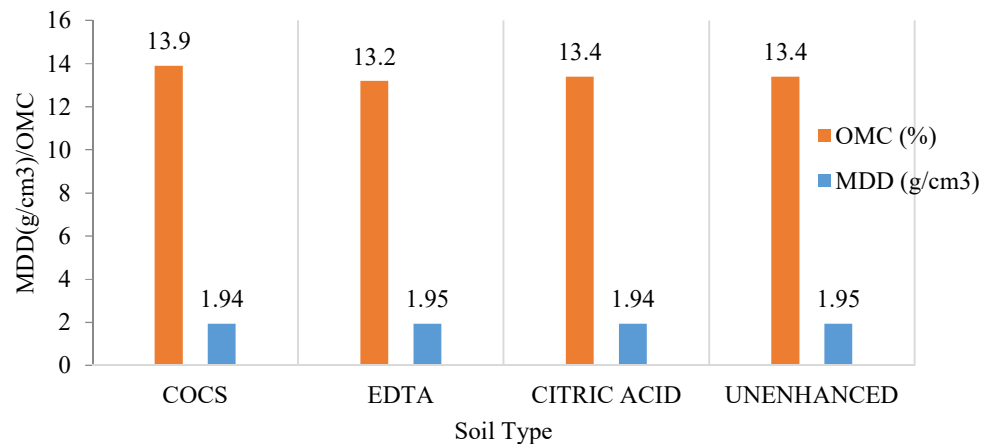


Figure 3: WAS Compaction Parameters of COCS and Chelants Enhanced EKR Soils

The compaction parameters, maximum dry density (MDD) and optimum moisture content (OMC) of the COCS at West African Standard (WAS) compaction energy are obtained as 1.94 g/cm³ and 13.9% respectively as shown in Figure 3 above. This MDD is seen to increase to 1.96 g/cm³ and OMC decrease to 13.2% when the contaminated soil was remediated using EDTA chelant enhanced EKR technology. These parameters with EDTA chelant enhanced EKR show an increase of 0.52% in the MDD and a decrease of 5.04% in the OMC to those for COCS. When further compared to 1.94 g/cm³ MDD and 13.4% OMC obtained with citric acid chelant enhanced EKR, the MDD for the COCS shows no difference and the OMC decreases by 3.60%. For the unenhanced EKR crude oil contaminated soil, MDD and OMC of 1.95 g/cm³ and 13.4% respectively were obtained. The compaction

parameters of the EDTA chelants enhanced EKR soil were seen to be best.

The OMC for the COCS is seen to be the highest. This could be due to thick adsorbed water on the contaminated soil particles which is covered by the crude oil, this makes the particle-to-particle contact required in compaction difficult. The addition of water, at first, breaks the separation layer between the adsorbed water and the free water before the lubrication of the particles for compaction starts. The lower OMC for the EKR soils can be attributed to the reduced crude oil content of the soils which reduces the thickness of the adsorbed water and relatively increases the particle to particle contact of the soil grains, the addition of water ensures the lubrication of the particles and closer packing of the soil grains (Mohammad & Taghi, 2012; Akinwumi et al., 2014; Suleiman et al., 2020; Salimnezhad et al., 2021).

California Bearing Ratio (C.B.R.)

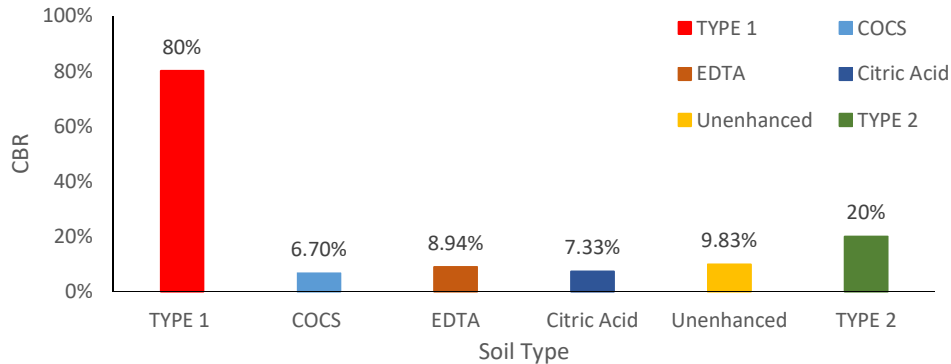


Figure 4: C.B.R. Values of COCS and Chelants Enhanced EKR Soils

The CBR values of the COCS and chelants enhanced EKR soils obtained by West African Standard Compaction after 24 hours of soaking are shown in Figure 4.5 above. The CBR value of the COCS is 6.70%. The value increases to 8.94% for EDTA chelant enhanced EKR soil. This 8.94% represents 33.43% improvement to the value for COCS. This shows that the use of EDTA as chelant in enhancing EKR of COCS can slightly improve its CBR value. The CBR value with citric acid chelant enhanced EKR soil is 7.33%. This represents 9.4% improvement to the value for COCS and 18.01% decline to the value for the EDTA chelant enhanced EKR soil. For the

unenhanced EKR soil, the CBR value is 9.83%. This represents 46.72%, 9.56%, and 34.11 % improvements to the CBR values for the COCS, EDTA and citric acid chelants enhanced EKR soils respectively.

The CBR value generally decreases with increase in crude oil content (Akinwumi et al., 2014; Suleiman et al., 2020). From Figure 4 above, none of the CBR values obtained meet the 80% minimum requirements for Type 1 base or sub-base materials for Nigerian roads. Neither do they also meet the 20% minimum requirements for Type 2 sub-base materials for light trafficked roads by the Nigerian General Specifications for Road and Bridges (2016).

Durability Analysis

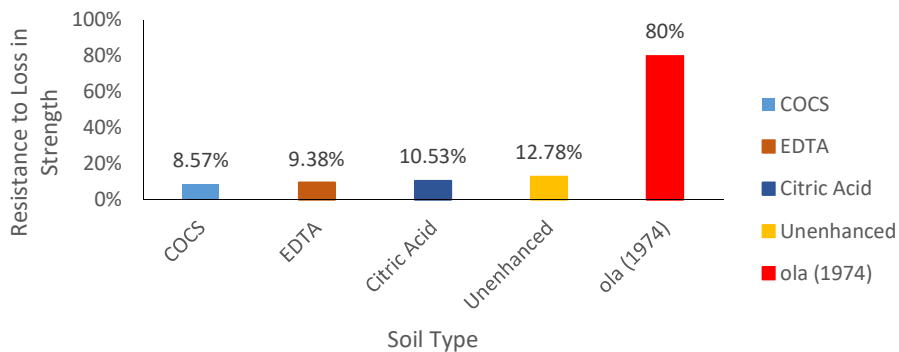


Figure 5: Resistance to Loss in UCS of COCS and Chelants Enhanced EKR Soils

The durability of the COCS and EKR soil enhanced by the use of chelants are presented in Figure 5 above. The unenhanced

EKR soil has the highest durability with resistance of 12.78% to loss in strength (UCS) when subjected to alternate drying and wetting

Corresponding author: K. Adebayo

bayo997@gmail.com

Department of Civil Engineering, Nigeria Defence Academy, Kaduna, Nigeria

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conditions. This, when compared to the resistance to strength loss of 8.57% in the COCS, has 49.12% durability advantages. With 9.38% resistance to strength loss with the EDTA enhanced EKR soil, the unenhanced EKR soil has 36.25% durability advantages when used over it as a road material in an area subjected to alternate drying and wetting conditions. When the unenhanced EKR is finally compared to the citric acid chelant enhanced EKR soil, with 10.53% resistance to strength loss, it has 21.37% durability advantages. Although, the COCS and the EKR soils are not stabilized soils. The very low resistance to loss in strength could be due to the residual oil content of the COCS and the EK remediated soils. None of the samples meet the 80% resistance to strength loss required for a durable road soil material recommended by Ola (1974).

The higher resistance to strength loss with citric acid chelant enhanced EK remediated soil (10.53%) when compared to that of the EDTA chelants enhanced EK remediated soil (9.38%) shows that citric acid is a better chelant for enhancing EKR than EDTA.

CONCLUSION

Effects of EDTA and citric acid as chelants on EKR COCS for use in road construction have been investigated and the results have been presented, analysed and discussed. From the study, the following conclusions are drawn:

- i. The total petroleum hydrocarbon (TPH) content of a COCS can be as high as 78,600 mg/kg. The use of chelants in enhancing EKR of COCS is not a viable technology. Compared to the performance of unenhanced EKR technology, EDTA and citric acids are not good chelants for enhancing EKR of COCS.
- ii. The incorporation of EDTA and citric acid as chelants into EKR technology for COCS cannot significantly improve the geotechnical properties of the resulting remediated soil.
- iii. Decontaminated soils obtained from EDTA and citric acid chelants enhanced EKR technology have very low resistance to loss in shear strength. Also, the bearing capacity properties of the EDTA and citric acid chelants enhanced EKR COCS with CBR assessed by WAS Compaction after

24 hours soaking are not adequate for their use as sub-base materials in the construction of light trafficked roads in Nigeria.

It is recommended that where no alternative soil is available, chelants enhanced EKR COCS should be stabilized before use in road construction.

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Corresponding author: K. Adebayo

✉ bayo997@gmail.com

Department of Civil Engineering, Nigeria Defence Academy, Kaduna, Nigeria

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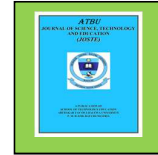
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Corresponding author: K. Adebayo

✉ bavo997@gmail.com

Department of Civil Engineering, Nigeria Defence Academy, Kaduna, Nigeria

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Corresponding author: K. Adebayo

✉ bayo997@gmail.com

Department of Civil Engineering, Nigeria Defence Academy, Kaduna, Nigeria

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