



STRENGTH CHARACTERISTICS OF FILTER MEDIA THICKNESS ON ELECTROKINETICALLY REMEDIATED LEAD- CONTAMINATED SOIL

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ABSTRACT

The reuse of contaminated soils for geotechnical applications presents both environmental and engineering challenges. This study evaluates the influence of filter media thickness on the mechanical properties of electrokinetic remediated lead contaminated clay soil intended for road sub-base construction. Electrokinetic remediation (EKR) was carried out using filter media thicknesses of 0.5cm, 1.0cm, 1.5cm, and 2.0cm. Treated soils were subsequently compacted using West African Standard (WAS) and British Standard Heavy (BSH) methods to assess the effect of the compaction energy on soil densification and strength. The highest maximum dry (MDD) of 1.95g/cm³ and least optimum moisture content (OMC) of 11% for WAS, was obtained at 1.5cm filter media thickness while MDD of 2.03g/cm³ and OMC of 9.50% for BSH was also at 1.5cm filter media thickness. California Bearing Ratio (CBR) test for soaked and unsoaked were conducted to evaluate sub-base suitability, the best result for the soaked CBR at WAS and BSH compactive efforts were 6.95% and 10.60% at 1.5cm filter media thickness respectively, while for the unsoaked CBR for WAS at 2.0cm is 23.51% and for the BSH is 88.15%. Results indicated that filter media thickness and compaction energy significantly affect the MDD and CBR of the remediated soil. BSH compaction generally produced higher dry densities and bearing ratios than WAS, though optimal performance was achieved at moderate filter thicknesses. The findings demonstrate that appropriately designed EKR treatment coupled with suitable compaction standards can enhance engineering performance of contaminated soils for sustainable road construction in West Africa.

1. INTRODUCTION

Soil contamination by heavy metals such as lead has become a pressing environmental issue, particularly in industrial, mining and urban areas where improper waste disposal, mining activities and vehicular emissions are prevalent (Alloway, 2013; Ogundiran and Osibanjo,

2008). Such soils often exhibit poor geotechnical and mechanical properties, limiting their use in civil engineering works (Akinwumi et al., 2017). Electrokinetic remediation (EKR) has emerged as an effective in-situ and ex-situ technique for the removal of heavy metals from fine-grained soils through the application of a low-intensity electric potential (Reddy and Cameslle, 2009). Beyond contaminant removal, EKR can also modify soil fabric, improve particle arrangement, and influence compaction behavior, all of which are critical for road sub-base performance (Alshawabkeh, 2019).

In west Africa, the West African Standard (WAS) of compaction is widely adopted for pavement material evaluation, while the British Standard Heavy (BSH) method is commonly referenced in international practice (FMWH, 1997; BS 1377, 1990). Both methods differ in the energy imparted during compaction, which directly affects the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC), key indicators of soil strength and stiffness (Osinubi and Nwaiwu, 2005). Comparative studies between these two standards remain limited, especially when applied to electro-kinetically treated soils (Eze and Ijimdiya, 2020).

This research investigates how variations in filter media thickness influence the engineering suitability of lead-contaminated lateritic soil subjected to EKR treatment and subsequently compacted under WAS and BSH standards. The study aims to determine the optimal filter media thickness that maximizes density and bearing capacity while maintaining environmental safety for use as road sub-base material.

2. MATERIALS AND METHODS

2.1 Materials

2.1.1 Lead Contaminated Soil (LCS)

The lead contaminated soil (LCS) was collected at a depth of 1m from Awai mine site in Nassarawa state Nigeria, with the following coordinates N8.41'36"86'765" and E8.32'36"82'982", having a lead content of 142.3mg/kg which exceeds the allowable limits set by the WHO of 85mg/kg, and 60mg/kg by the US environmental protection agency. This necessitated the remediation of the LCS to improve its properties. The use of activated charcoal as a filter media at different thicknesses gave remarkable results. Representative samples were air-dried, pulverized, and sieved through a 4.75mm aperture size.

2.1.2 Electrokinetic Remediation (EKR) Set-up

The electrokinetic remediation setup that was used in this research is based on the model adopted by Yu et al., (2019). The system comprised an acrylic cell containing soil specimen, with graphite electrodes placed at the anode and cathode ends. A constant DC potential gradient with 30v until no effluent was collected at the cathode. The filter medium was installed adjacent to the electrodes at four thickness levels: 0.5cm, 1.0cm, 1.5cm, and 2.0cm. Distilled water combined with nitric and oxalic acid were used as electrolytes, and voltage, current, effluent and pH, variations were monitored throughout the process. Solar power setup was used to ensure continuous power supply to the setup.

2.1.3 Activated Charcoal

The activated charcoal used as filter media in this study was obtained at a chemical and science laboratory equipment shop located along Kano road, Kaduna.

2.2 Methods

In accordance with BS 1377 (1990) "Methods of Tests for Soil used for Civil Engineering Purposes," as advised in the Nigerian General Specifications (1997) Clause 1050 ".

2.2.1 Compaction test

Following remediation, the treated soils were subjected to West African Standard (WAS) and British Standard Heavy (BSH) compaction test to determine MDD and OMC in accordance with BS 1377: 1990 and FMWH (1997) procedures.

2.2.2 California Bearing Ratio (CBR)

CBR tests were performed on the compacted samples to evaluate the load-bearing potential of each soil type under both standards. The test followed FMWH (1997) specifications for sub-base materials. CBR values were compared with standard sub-base requirements (CBR \geq 30%).

3. RESULTS AND DISCUSSION

The samples were air-dried and remediated at different filter media thicknesses of 0.5cm, 1.0cm, 1.5cm, and 2.0cm. According to AASHTO (1986) soil classification system, the soil falls under A-7-6 and falls into the CH group according to the Unified Soil Classification System (ASTM, 1992). It has a liquid limit of 42%, a plastic limit of 21.64%, a plasticity index of 20.36%, a specific gravity of 2.56, and of high swell potential according to NBRRI (1983) classification. These values show that the soil is highly plastic, with approximately 76.5% of the soil particles passing the BS. No 200 sieve. The strength characteristics are also very low, making the soil unsuitable for geotechnical engineering use. However, after remediation the soil fell into the A-5 and CL groups according to AASHTO and USCS soil classification systems respectively. The soil is considered to have low to medium compressible clays and is poor as a sub-grade material. The tables and figures shown and discussed below provides the results for the effects of compactive efforts at West African Standard (WAS) and British Standard Heavy (BSH).

4.COMPACTION

4.1 Maximum Dry Density

The variations in Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) of the electrokinetically remediated soils under different filter media thicknesses and compaction standards are presented in the Figures 1 and 2 below.

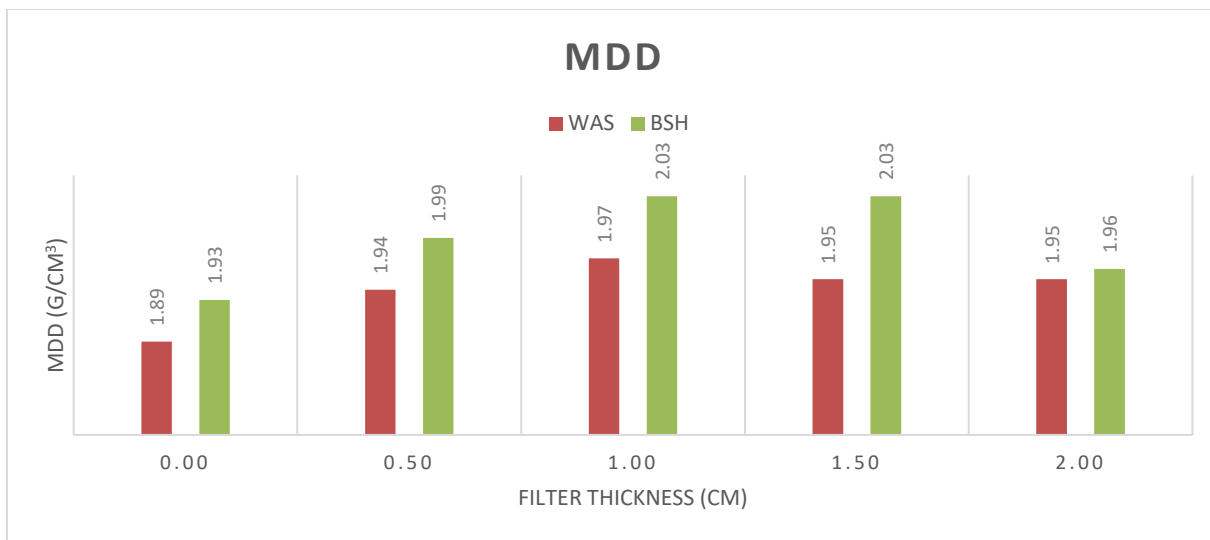


Figure 1. Variation of MDD with filter media thickness under WAS and BSH

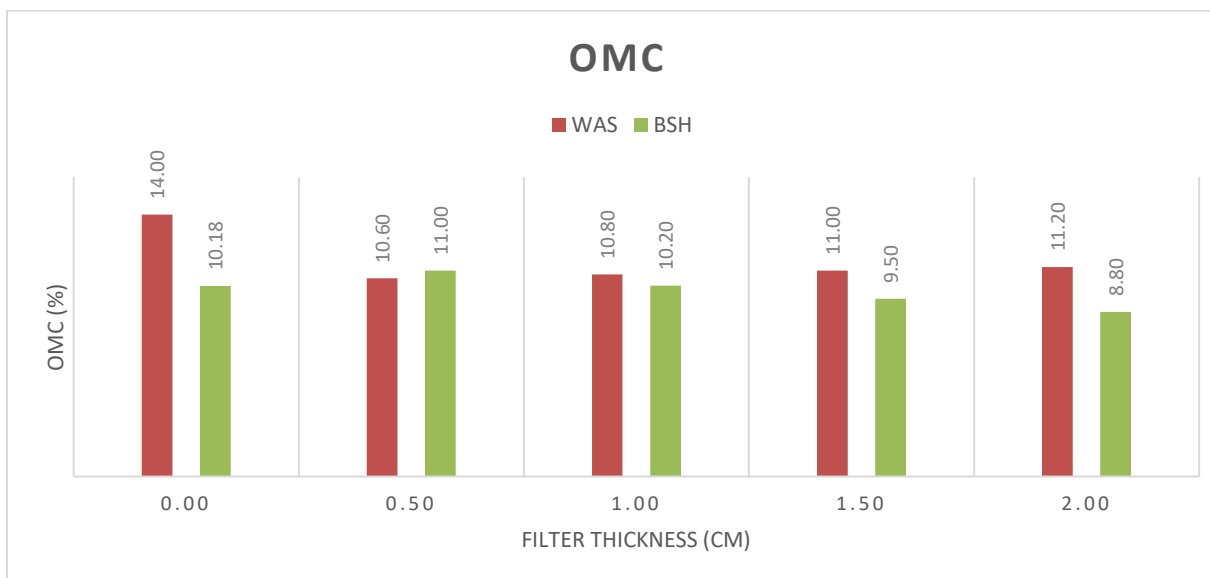


Figure 2. Variation of OMC with filter media thickness under WAS and BSH

A general trend was observed in which the MDD (1.95g/cm^3 and 2.03g/cm^3 at WAS and BSH efforts) increased with increasing filter media thickness up to 1.5cm thickness, beyond which it slightly decreased to 1.95g/cm^3 and 1.96g/cm^3 at WAS and BSH respectively. This indicates that the thickness of the filter media affects the degree of electroosmotic consolidation and subsequent particle rearrangement within the soil. Under both compaction standards, BSH yielded higher MDD values than WAS due to the greater compactive effort, which enhanced particle interlock and reduced air voids. These findings align with those reported by Muntohar and Liao (2010) which showed that increasing filter media thickness improves the soil MDD and reduces the OMC. It is also supported by Salahudeen et al. (2014) on the properties of lead contaminated soils in Nigeria and the effect of remediation using various methods.

OMC values were slightly lower under BSH, at 1.5cm the OMC was 11% and 9.5% for WAS and BSH respectively, reflecting the soil's reduced water demand for achieving maximum density. This observation aligns with findings by Ola (1983) and Osinubi et al. (2015), who reported that higher compactive effort results in reduced OMC and increased MDD for lateritic soils. The OMC experiences a slight increase at 2.0cm filter thickness this may be as a result

of thick filters reducing electroosmotic efficiency due to increased current path length and lower voltage gradients, leading to marginally lower MDD and OMC values.

The influence of EKR treatment is evident at optimal filter thickness (typically around 1.5-2.0cm), the migration of ions and water led to improved particle bonding, thus facilitating higher densities during compaction.

4.2 California Bearing Ratio (CBR)

The LCS recorded 4.0% and 21.16% for both the soaked and un-soaked respectively. The highest CBR value was recorded at 1.5cm filter media thickness with 88.15% and 10.60% for both the un-soaked and soaked with higher compaction energy (BSH) aligns with the standard requirement for adequate compaction to achieve necessary strength and stability. Thicker filter media enhances CBR values, indicating better load distribution and stability, which is a criterion for performance. The un-soaked CBR values obtained at the British standard Heavy (BSH) energy compaction at 1.0cm, 1.5cm and 2.0cm activated charcoal filter media thickness of 75.59%, 87.92%, and 88.15% meets the 80% minimum requirement for a Type 1 base or sub-base materials while the values obtained at the West African Standard compaction energy for the un-soaked for filter media thickness at 0.5cm, 1.5cm and 2.0cm which are 28.58%, 22.76% and 23.51% meets the minimum requirement for Type 2 sub-base material for light trafficked roads. According to the Nigerian General Specifications (1997) for Roads and Bridges, the minimum California Bearing Ratio (CBR) value for subgrade materials for highways and major roads, the minimum requirement for subgrade material is 10% when tested un-soaked condition while for minor roads or less trafficked roads, the minimum CBR is generally 5-7%. The soaked CBR value (10.60) peaked at 1.5cm filter media thickness and at BSH energy, this value met the minimum of 10% requirement for a subgrade material for a minor road. The impact of higher energy levels did not impact any significant improvement on the un-soaked CBR value of the EKR lead contaminated soil, this is consistent with what was reported by Moses (2007). The reduction in CBR values when soaked underscores the need to consider moisture content and drainage, as stipulated by standards. The values for each condition are presented in figure 3 and 4 below.

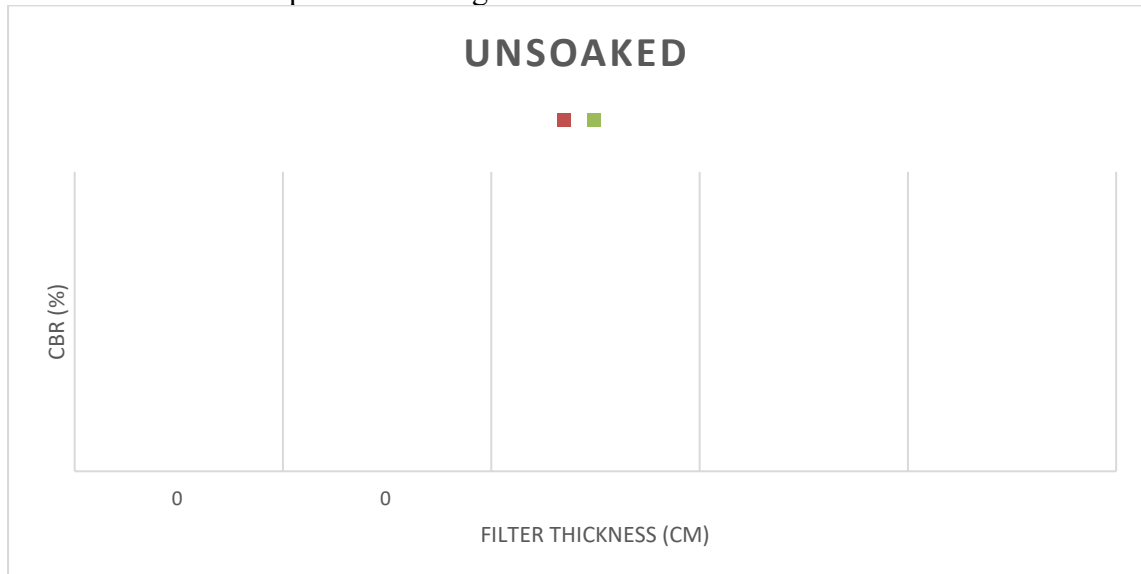


Figure 3. Variation of CBR values with filter media thickness under WAS and BSH (un-soaked)

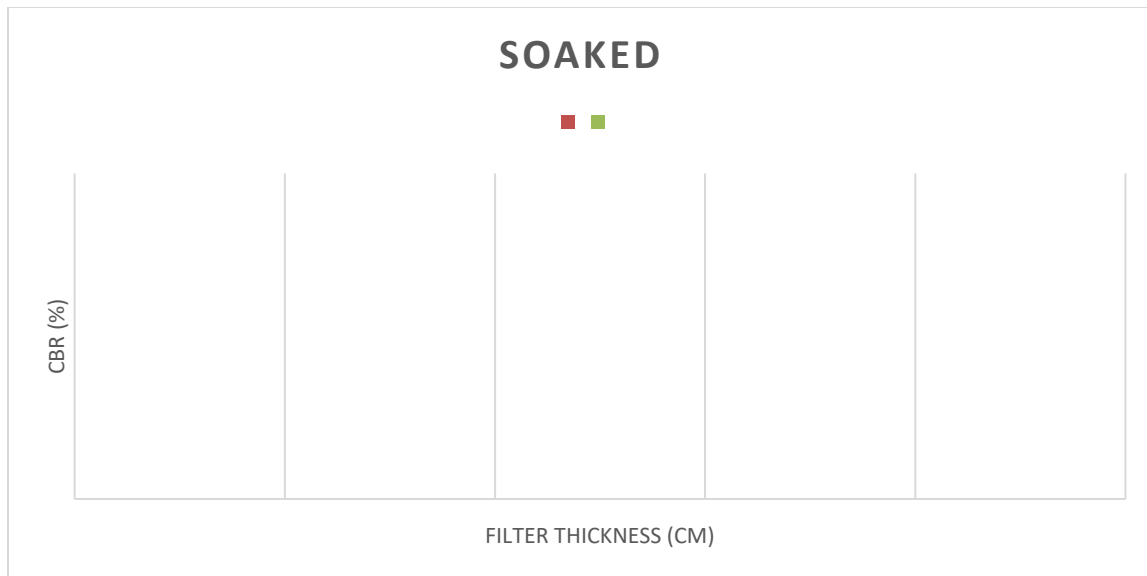


Figure 3. Variation of CBR values with filter media thickness under WAS and BSH (soaked)

Notably, all treated soils compacted BSH energy met or exceeded the minimum CBR requirement of 30% (un-soaked) specified by FMWH (1997) for sub-base materials. In contrast, WAS-compacted samples did not achieve satisfactory performance across all the filter media thicknesses, suggesting the use of higher compactive energy ensures better engineering reliability.

5. RECOMMENDATION

For field applications, the filter media thickness of 1.5cm at BSH energy is recommended as optimal, balancing treatment efficiency, energy consumption, and mechanical performance. Further research should explore the use of EKR and the effects of activated charcoal and its efficiency in removing other heavy metals from lateritic soils.

6. CONCLUSION

The comparative analysis between the West African and British Heavy compaction standards demonstrates that the choice of compaction method significantly affects the engineering behavior of the electrokinetically remediated soils. Although BSH compaction achieved superior densification and CBR values, the WAS method still produced some acceptable results, implying that locally adopted compaction standards remain viable for subgrade construction if EKR process is optimized. Electrokinetic remediation significantly improved the compaction characteristics and bearing strength of lead-contaminated clay soil. Integrating EKR treatment with suitable compaction procedures offers a cost-effective and sustainable approach.

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Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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