International Journal of Engineering Trends and Technology
ISSN: 2231 – 5381 / https://doi.org/10.14445/22315381/IJETT-V71I2P219

Volume 71 Issue 2, 157-164, February 2023

Original Article

Engineering Properties of Laterite soil Stabilized with Heavy Fuel Oil for Use as a Road Sub-base Material

Benewende Thomas Arnaud Tamalgo[1], Timothy Nyomboi[2], Christopher Kanali[3]

[1]*Pan African University Institute for Basic Sciences, Technology and Innovation hosted at Jomo Kenyatta University of Agriculture and Technology, Kenya.*
[2]*Kenya Urban Roads Authority, Nairobi Kenya.*
[3]*Department of Agricultural and Biosystems Engineering, Jomo Kenyatta University of Agriculture and Technology, Kenya.*

[1]*Corresponding Author : thomas.benewende@students.jkuat.ac.ke*

Received: 26 October 2022 Revised: 31 January 2023 Accepted: 14 February 2023 Published: 25 February 2023

Abstract *- The present study investigates the engineering properties of laterite soil stabilized with heavy fuel oil for use as a road sub-base material. The laterite soil is thoroughly mixed with heavy fuel oil in varying amounts, with the concentration of heavy fuel oil varying from 0 to 10% of the total weight of the soil sample. To determine the best soil-heavy fuel oil combination, each soil sample undergoes tests for Unconfined Compressive Strength (UCS) permeability and Californian Bearing Ratio (CBR). UCS and CBR values increase as heavy fuel oil concentrations increase from 0 to 4% and decrease from 6 to 10%. At 7 days of curing, a 4% heavy fuel oil content results in a peak CBR of 40.8% and a UCS value of 1.21 MPa. The peak value of the CBR met the specifications (>30% recommended by Kenya's road design manual) and also 30% by the Federal Ministry of Works' General Specification on Nigerian Roads for use in the construction of road sub-base. The research discovers that the permeability values of the soil decrease from* 8.03×10^{-5} *to* 1.31×10^{-5} *cm/s as the amount of heavy fuel oil increases, with the lowest permeability values observed at a concentration of 6% fuel oil. Beyond this content, the permeability starts increasing. Therefore, based on the guidelines set by the Nigerian General Specification and Kenya Road Design Manual, which recommend a minimum CBR value of 30% for road sub-base, the utilization of 4% heavy fuel oil in the stabilization of laterite soil for use as a sub-base in road construction is recommended.*

Keywords *- Heavy fuel oil, Californian bearing ratio, Laterite, Unconfined compressive strength, Permeability.*

1. Introduction

The worldwide need to protect the environment and the good management of natural resources requires the creation of new laws, techniques, and new concepts. Waste recycling and natural material valorisation are effective ways to address recent economic and environmental constraints. Laterite soils have been the most commonly utilised for road construction in Africa for decades. Some of these soils are employed in pavement bodies (base layers and sub-base layers) [1] according to country-specific criteria. They are utilized in accordance with normal compaction rules. Laterites are more abundant depending on the area, and their widespread use as road construction materials makes them rare in some African countries. Laterite materials are most commonly found near road alignments. However, not all laterite borrowings, such as clay-rich laterites, are suitable for road construction.

The solution to this material's inadequacy is to use appropriate economic and innovative methods to improve or treat existing poor quality laterite material on site by mechanical, chemical or use of better quality borrowed material. Soil stabilization involves mixing one or several materials with the existing soil and compacting the mixture to enhance its strength, UCS, and other performance characteristics. This process aims to improve the soil's characteristics through treatment. Many techniques of stabilization have been developed to solve the weakness of laterite materials like lime [2], cement [3], fly ash [4], bitumen [5], crude oil [6], waste engine oil [7], [8] and so forth. Cement stabilization is, so far, the most popular method for stabilization. However, cement production is very energy-intensive and intensively emits many greenhouse gases, which have become very expensive. According to [9], producing one ton of cement results in the release of 0.8 tons of carbon dioxide into the environment. As a result, there is an effective need to find appropriate materials for stabilisation. Using heavy fuel oil as a soil admixture will minimise the quantity of cement employed in the soil stabilization method and reduce environmental pollution.

The main purpose of this study is to explore the feasibility of utilizing heavy fuel oil, a by-product of the petroleum industry, to reinforce laterite soils for road sub-base construction. The problem related to variant results of using petroleum products which are not clear, and the limited or non-existing investigation using HFOs. It is also important to note that bitumen and heavy fuel oil are different. The methods of manufacture are different. To simplify, bitumen is generally obtained by direct distillation of a selected crude oil, whereas heavy fuel oil is formulated by blending petroleum cuts selected on other criteria. The heavy fuel oil is used to mix with laterite soil during the laterite soil stabilization process.

Oil is very crucial in meeting the growing energy needs of the world's economy, particularly in the industrial and transportation industries. It is a crucial energy source that drives the global economy's development. Heavy fuel oil is composed of the remaining materials after the extraction of higher-quality hydrocarbons from petroleum feedstocks. These materials mainly consist of residue from vacuum distillation, catalytic, and thermal cracking processes. They are characterized as substances with undefined or varying compositions, products of complex reactions, or biological materials [10].

Soil stabilization utilizing a bitumen emulsion and cement mixture as an admixture was investigated [11]. The study assessed the effect of using bitumen emulsion and cement to stabilize lateritic soil. Three additive percentages were considered: 4%, 6%, and 8%. Five additives were created by mixing bitumen emulsion and cement in the following proportions: 100% bitumen and 0% cement, 75% bitumen and 25% cement, 50% bitumen and 50% cement, 25% bitumen and 75% cement, and 0% bitumen and 100% cement. The geotechnical characteristics of stabilized and controlled soils were ascertained using tests such as the UCS and the CBR tests. UCS and CBR tests were carried out on soil samples A and B. The outcomes showed that soil sample A had a UCS value of 0.46 MPa and a CBR of 19.6%, while soil sample B had a UCS value of 0.95 MPa and a CBR of 22.6%. At 4% additives of mix proportions, the CBR of soil A improved from 49.1% to 218.5%. The UCS values for soil B increased from 0.64 to 1.33 MPa. With the addition of 8% stabilizing agents, the CBR for soil B improved dramatically from 78.4% to 288.1%, and the UCS also rose significantly from 0.48 to 2.45 MPa. The mixture of bitumen emulsion and soil was enhanced by the addition of cement, which resulted in an improvement of both the UCS and CBR values for soil samples A and B. It was discovered that blending bitumen emulsion with cement enhanced the strength of the laterite soil by stabilizing it.

An investigation was conducted by [12] to examine the impact of crude oil contamination on the index properties, strength, and permeability of lateritic clay soil. Different proportions of crude oil, varying from 0% to 10% in 2% increments, were added to the soil to create the mixture. Both control and blended soil samples underwent tests to determine their Atterberg limits, specific gravity, compaction, CBR, and permeability. The findings indicated that as the quantity of crude oil in the soil increased, there was a corresponding increase in the soil's liquid limit, plastic limit, and plasticity index. In addition, the presence of crude oil in the soil resulted in decreased permeability.

The study conducted by [13] evaluated the strength characteristics of lateritic soil with bituminous additives as a pavement material in the construction industry. Tests for specific gravity, moisture content, Atterberg limits, compaction, and CBR were carried out with bitumen concentrations of 3%, 6%, 9%, and 12%. At 0% additive content, the CBR values are 9.87%, 4.35%, and 7.28%, respectively, while at 12% additive content, the maximum CBR values for samples A and B are 41.21% and 40.04%, respectively. The author concludes that bitumen is a suitable admixture for improving the characteristics of lateritic soil as a material for paving.

A study in [14] examined the geotechnical characteristics of laterites contaminated with waste engine oil. The soil samples contaminated with waste engine oil were produced by combining dry soil and waste engine oil in weight ratios of 3%, 6%, 9%, and 12%. The findings indicated a reduction in OMC, liquid limits, and permeability for all samples; however, three of the samples also demonstrated a rise in shear strength, MDD, and CBR. The author concluded that waste engine oil has the potential for use in road construction due to the observed increase in CBR.

Research conducted by [37] assessed the strength of laterite soil used as a sub-base material for construction when combined with reclaimed asphalt pavement (RAP) and treated with sugarcane bagasse ash (SCBA). The laterite soil and RAP were blended in a 60/40 ratio, and the SCBA was added in increasing amounts from 0 to 10% by weight. The samples were tested for particle size analysis, compaction UCS, and CBR. The findings indicate that adding RAP into the soil-RAP mix reduces the OMC and raises the MDD compared to the untreated soil. Incorporating up to 4% of bagasse ash results in a rise in MDD. However, incorporating a higher amount of SCBA leads to a reduction in MDD and a rise in the OMC. The UCS and CBR both improved as the amount of sugarcane bagasse ash (SCBA) treatment increased, and the curing duration was prolonged. However, exposing the CBR sample to soaking for 24 hours decreased its CBR value. Based on these findings and strength requirements for soil-lime in the research, the author concluded that the soil-RAP-SCBA mixture is fit for use as a sub-base layer for low traffic with 6 to 8% SCBA treatments and for heavy traffic with 10% treatments.

Considering the previous studies on the potential use of petroleum by-products, including oil, as alternative stabilizers, it is evident that these by-products can be effectively used to stabilize laterite and lateritic soils [15,16]. Therefore, this research focuses on investigating the potential utilization of heavy fuel oil in soil stabilization.

2. Materials and Methods

2.1. Materials acquisition and Preparation

Laterite soil, Heavy Fuel Oil (HFO), and water were used in this study. The laterite soil utilized in this research project was collected near the Jomo Kenyatta University of Agriculture and Technology (JKUAT) in Kenya. The laterite was collected through various locations in a laterite pile, implying that it had previously been disturbed. Prior to testing, the laterite was transferred to JKUAT's civil engineering laboratory and air-dried. The moisture content of the laterite soil sample was also assessed by drying it in an oven set to 105 °C for 24 hours. HFO was also purchased from a local fuel station.

2.2. Data Collection Procedure

To commence, the laterite soil and HFO engineering properties were determined using the BS1377[17]. After that, the laterite soil was treated with HFO in various proportions that varied from 0 to 10% in 2% increments by the soil's weight. The same soil stabilization proportions were utilized by recent research [12], [37] potential application in the field of road construction. Several experiments on soil-HFO specimens were carried out to determine the optimal HFO concentration for application as a road sub-base construction material. The following parameters have been tested: Atterberg Limits, Compaction, UCS, durability, CBR, and permeability. These procedures were performed in line with BS1924[18].

The compaction test was conducted using a modified energy level method. This test establishes a link between MDD and OMC. Once the dried soil sample was rehydrated to reach the OMC by adding water, each laterite soil sample was mixed properly with a trowel. The soil sample was compacted into five layers using a Proctor mould with a 100 mm internal diameter and 115 mm height. The compaction hammer struck each layer 27 times.

The CBR test was performed on soil-HFO samples. The Proctor compaction test was done on soil samples compacted at their (OMCs). After being compacted, the samples were cured in a curing machine for 7 days and then soaked in water for 4 days per the guidelines set by Overseas Road Note 31 TRL [19].

On the other hand, the UCS tests were performed using samples compacted in the standard Proctor mould at their OMCs. Under controlled conditions, samples were cured for 7 and 14 days. Afterwards, the samples underwent a uniaxial compression test utilising a compression testing machine with a speed of 0.2 m/s. The highest force and compressive strength were measured at the point of failure. The UCS value was calculated. Due to the fact that the samples' length-to-diameter ratio was less than 2, correction factors specified in ASTM C39/C39M [20] were applied to obtain accurate UCS values for the samples. These correction factors are widely recognized as appropriate for cases where the length-to-diameter ratio is less than 2.

The soil-HFO samples were also tested for durability. The durability of the samples was determined by assessing their resistance to strength loss. The durability of the samples was calculated by comparing the UCS values of two groups of stabilized samples. One set of samples underwent a 7-day curing process followed by an additional 7 days of immersion in water. The other group underwent a 14-day curing process in a controlled environment in accordance with the guidelines outlined in BS1924 [18]. The durability was calculated by dividing the UCS value of the first group of samples by the UCS value of the second group. The above method of testing was chosen over the ASTM standard wet-dry and freeze-thaw tests as it truly reflects practice area parameters in the research region.

Two previous studies employed an identical type of test to assess the durability of stabilized lateritic soil for construction purposes. In [21], the test was employed to determine the durability of cement-stabilized laterite soil as a flexible pavement material, while in [28,35], the test was utilised to evaluate the durability of eggshell-stabilized lateritic soil. These studies used an identical method to determine the durability of the stabilized soils. The specific gravity, UCS, and durability tests used three samples, whereas the CBR test only required two. Each of the other tests used a single sample (i.e., sieve analysis, Atterberg limits, and chemical analysis).

Finally, the permeability of the soil-HFO samples was tested. The study employed the ASTM D5084 [23] falling head permeability test to measure the water flow through a soil specimen. This test involved connecting the soil sample to a standpipe that provided a water head and recording the volume of water that passed through the sample. The flow quantification process was initiated once the soil sample was completely saturated and the standpipes were filled with de-aired water to the predetermined level. The procedure began by letting water flow through the sample until the water level in the standpipes reached the designated lower limit. The duration for the water to fall from the upper to the lower level in the standpipe was recorded.

3. Results and Discussions

3.1. Characterization of Laterite Soil and Heavy Fuel Oil

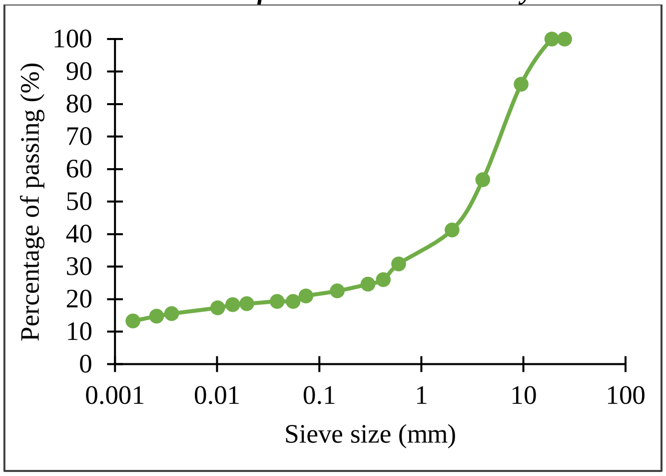

Fig. 1 Soil grain size distribution curve

Table 1. Laterite soil-HFO treatment mix design

Proportions of mix design (%)	
Laterite soil	HFO
100	0
98	2
96	4
94	6
92	8
90	10

Table 2. Chemical constituents of the laterite soil

Constituents	**Formulas**	**%**
Silica	SiO2	57.909
Iron	Fe	18.549
Aluminium	Al2O3	16.372
Manganese	Mn	2.771
Titanium	Ti	1.265
Calcium	CaO	1.134
Barium	Ba	0.397
Potassium	K2O	0.981
Sulphur	S	0.198
Zirconium	Zr	0.165

Table 3. Chemical and physical composition of heavy fuel oil

Properties	**Unit**	**Value**
Density @ 15°C	kg/m3	949
Specific gravity @ 15°C	kg/m3	0.951
Kinematic viscosity @ 50°C	10- 6 m 2 /s	604.5
Carbon (C)	wt %	88.8
Hydrogen (H)	wt %	10.82
Nitrogen (N)	wt %	0.1
Sulfur (S)	wt %	1
Oxygen (O)	wt %	0.62
Water content (H2O)	wt %	0.52
Sodium (Na)	mg/kg	8.2
Zinc (Zn)	mg/kg	530
Vanadium (V)	mg/kg	-
Nickel (Ni)	mg/kg	-
Potassium (K)	mg/kg	-

Table 2 shows the characteristics of laterite soil before the introduction of the stabilizer, whereas Figure 1 depicts the distribution of grain sizes curve of the soil. The global engineering features of the soil were classified as A-2-7 by the American Association of State Highway Transportation Officials (AASHTO) system of classification. This classification indicates that the soil is unsatisfactory for application as a road sub-base construction material and that stabilization is required [24], [25].

The chemical constituents of laterite soil and HFO are shown in Table 3 and Table 4. Silica oxides, iron oxides, and aluminium oxides comprised the most abundant oxides in laterite soil, accounting for 57.91%, 18.55%, and 16.37%, respectively. According to [26], for soil to be classified as laterite, $SiO_2/(Al2O_3+Fe)$ must be between 1.33% & 2%, which is 1.66%. The definition of heavy fuel oil in [27] is based on its density being above 900 kg/m3 at 15°C. In this study, the density of heavy fuel oil has a value of 949 kg/m3 at 15°C.

3.2. Stabilization of Laterite Soil with Heavy Fuel Oil

When the Atterberg limits were tested, it was found that adding heavy fuel oil reduced the liquid limit and rose in the plasticity limit. Consequently, the plasticity index decreased.

Table 4. Engineering properties of the laterite soil

Properties	**Proportion/value**
Natural moisture content	10.43±0.10%
Specific gravity	2.3±0.11
%Passing through BS Sieve 75µ	20.92
Liquid limit	43.58%
Plastic limit	18.84%
Plasticity Index	24.72%
AASHTO classification	A-2-7
Californian Bearing Ratio (4 days soak)	17.60%
Unconfined Compressive Strength	0.25Mpa
Permeability value of K (cm/s)	8.03E-05

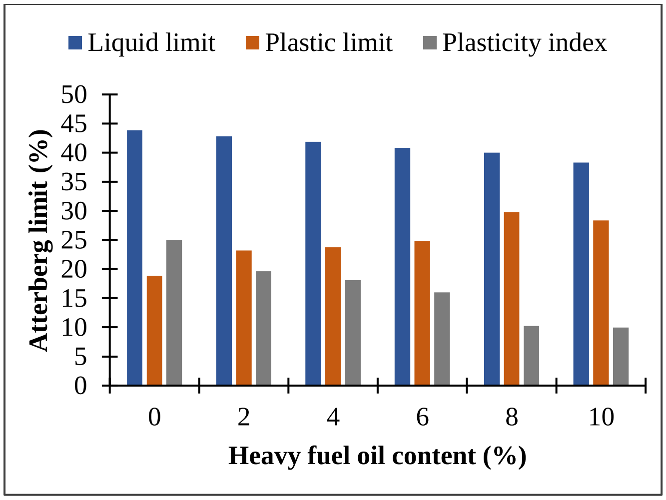

Fig. 2 Atterberg limits at varying heavy fuel oil content

Table 5. Atterberg limits at varying heavy fuel oil content

Mix design (%)		Liquid limit (%)	Plastic limit (%)	Plasticity index (%)
Laterite soil	Heavy fuel oil			
100	0	43.84	18.84	25.00
98	2	42.83	23.21	19.62
96	4	41.86	23.77	18.09
94	6	40.83	24.84	15.99
92	8	40.02	29.80	10.22
90	10	38.31	28.36	9.95

The illustration can be seen in Table 5 and Figure 2. The reduction in the liquid limit is attributed to the flocculation and clumping of minerals in the soil caused by the isomorphous replacement of cations at the soil particle surfaces, which is consistent with previous research findings [8], [36]. On the other hand, the plastic limit showed an increase due to the addition of heavy fuel oil, which could be due to the impact of cations between the soil particles and the HFO, causing a change in particle thickness. It also reveals that the soil plasticity index decreases as HFO increases, indicating that soil plasticity has improved. The clayeyness of the soil is proportional to its plasticity index [29].

The compaction experiment was carried out with a modified energy level, and the results presented in Table 6 and Figure 3 demonstrate that there was no substantial difference in the MDD and OMC as the concentration of heavy fuel oil was rise. The addition of HFO into the soil led to a transformation in its microstructure. It could be due to interlayer expansion within the clay minerals. The content of heavy fuel oil increased, and the soil's requirement for water to attain its maximum unit weight may have decreased [12].

Table 6. MDD and OMC with various heavy fuel oil content

Mix design (%)	MDD (g/cm 3)	OMC (%)
0	1.76	16
2	1.77	14,6
4	1.82	14,5
6	1.78	14,2
8	1.76	14
10	1.76	12

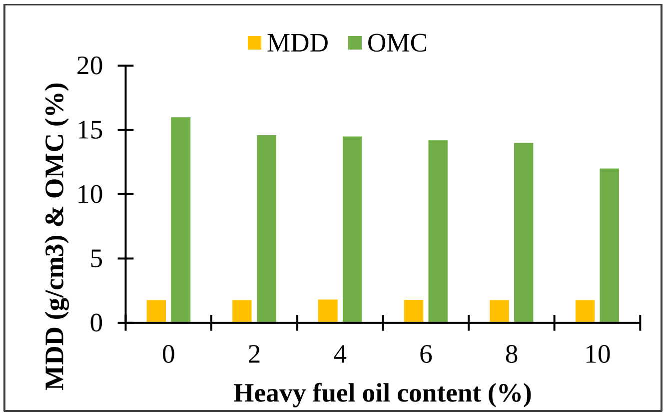

Fig. 3 MDD and OMC at varying heavy fuel oil content

Table 7. CBR at varying heavy fuel oil content

Mix design (%)	Soaked CBR (%)
0	18.0
2	29.2
4	40.8
6	31.3
8	27.0
10	22.5

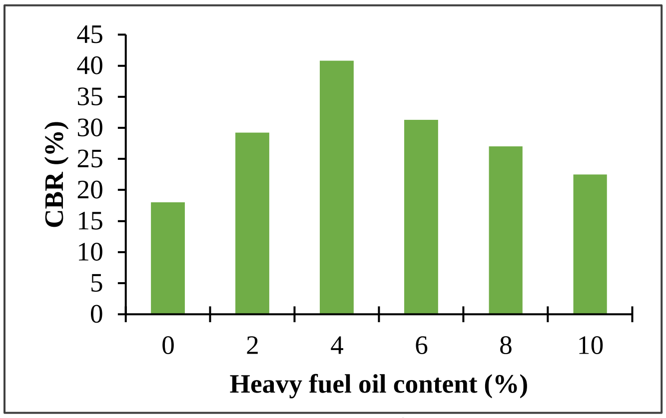

Fig. 4 CBR at varying heavy fuel oil content

The results also show that at 4% heavy fuel oil content, soaked CBR enhanced to a maximum value of 40.8% and then decreased (Table 7 and Figure 4). As a result, heavy fuel oil improves the CBR value significantly when properly mixed. Similar results were reported by [30], [31]. The enhancement in CBR could be due to the interaction between the stabilizers and the soil facilitated by compaction. This chemical reaction is what causes the increase in CBR. CBR values acquired for soil with 4-6% heavy fuel oil content were found to conform to the standards set by the Federal Ministry of Works and Housing in Nigeria and Kenya's road design manual [24] and [25] for the construction of road sub-bases. These standards require a minimum CBR value of 30%. An increase in the CBR at a particular combination of soil and HFO implies a rise in MDD. This is attributed to the lubricating effect of the oil on the soil particles, resulting in greater compaction [14].

The UCS test is a critical methodology for assessing the effectiveness of stabilized soil materials. According to specification [24], the base layer is required to have a UCS within a range of 1.5 MPa to 3.0 MPa after 7 days of testing at 100% modified AASHTO density and a UCS value of 1.0 MPa to 1.5 MPa when tested at 97% AASHTO density. The UCS for the sub-base layer is expected to be in the range of 0.75 MPa to 1.5 MPa when tested at 100% modified AASHTO density and 0.5 MPa to 0.75 MPa when tested at 97% AASHTO density. As per [32], the 7-day UCS for cement-stabilized soils must be at least 4.5 MPa for the base and 0.75 MPa to 1.5 MPa for the sub-base. The findings in table 8 and figure 5 demonstrate that the content of HFO increases from 0 to 4%, and the UCS values increase from 0.34 to 1.12 MPa for 7-day curing and from 0.41 to 1.21 MPa for 14-day curing. However, when the HFO content is increased further, the UCS values decrease from 1.12 to 0.23 MPa for 7-day curing and from 1.21 to 0.26 MPa for 14-day curing. UCS values at 7 days of curing with 2-4% HFO content are within the range of 0.75-1.5 MPa stipulated in Overseas Road Note 31 [19], [24], and [32].

Table 8. UCS at varying heavy fuel oil content

Mix design (%)	7-days UCS (MPa)	14-days UCS (MPa)
0	0.34	0.41
2	0.77	0.82
4	1.12	1.21
6	0.69	0.74
8	0.39	0.47
10	0.23	0.26

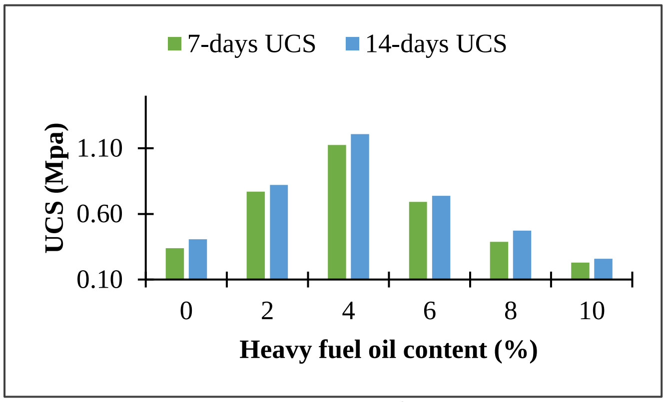

Fig. 5 UCS at varying heavy fuel oil content

Table 9. Durability at varying heavy fuel oil content

Mix design (%)	Durability (%)
0	0.00
2	43.27
4	46.06
6	39.79
8	37.35
10	35.58

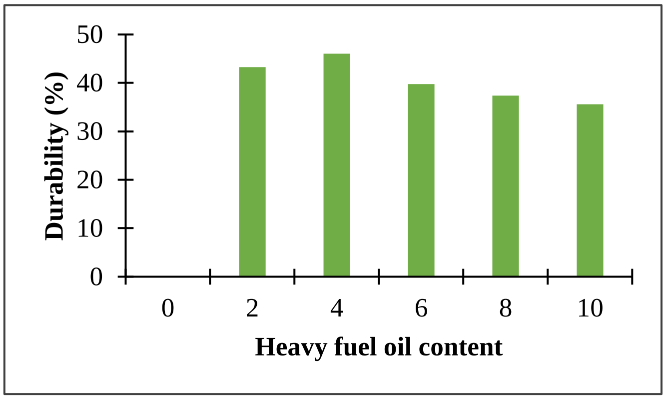

Fig. 6 Durability at varying heavy fuel oil content

Table 10. Permeability at varying heavy fuel oil content

Mix design (%)	Coefficient of permeability K (cm/s)
0	8.03E-05
2	4.97E-05
4	2.29E-05
6	1.31E-05
8	2.66E-05
10	6.08E-05

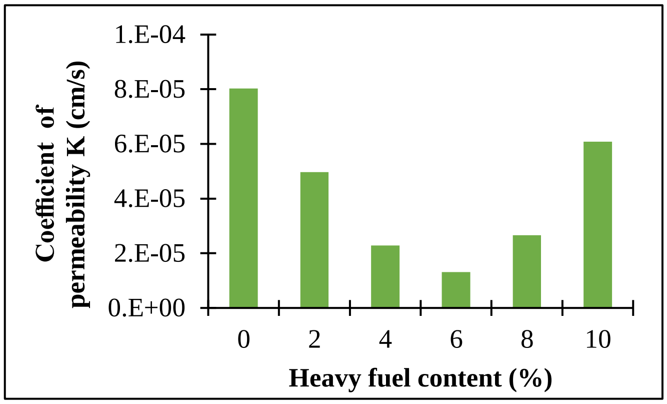

Fig. 7 Durability at varying heavy fuel oil content

The durability of the optimal soil-HFO mixtures under simulated tropical conditions was assessed by measuring their resistance to strength loss. Table 9 and Figure 6 show the results. The neat soil could not withstand the strength loss. The maximum durability value of laterite soil-heavy fuel oil content was 46.06% at 4% HFO content and dropped significantly to 35.58% at 10% HFO content, coming up short of the recommended minimum of 80% [33].

Table 10 and Figure 7 shows that as the amount of heavy fuel oil in the soil increased from 0% to 6%, the soil-HFO permeability decreased from $8.03\text{x}10^{-5}$ to $1.31\text{x}10^{-5}$ cm/s. Beyond this content, the permeability starts increasing. It is believed that incorporating HFO into the soil helps to fill some of the voids and thereby impedes water movement through the soil, as noted in references [12] and [34]. Heavy fuel oil reduces the thickness of the water film surrounding soil particles, increasing permeability from 6% to 10%.

4. Conclusion

This study shows that using heavy fuel oil significantly improves the engineering properties of the laterite soil if proper mixing is done. The decrease in Atterberg limits in laterite soil with increasing heavy fuel oil is a result of the impact of non-polar and viscous fluids on the structure of clay minerals and the water content in the soil. The MDD and the OMC of the soil decrease as the amount of heavy fuel oil in the soil increases. After four days of soaking, the best CBR value was observed when the soil was mixed with 4% heavy fuel oil by weight. The corresponding CBR value is 40.8%. At the same heavy fuel oil content, the UCS value has increased from 1.12 MPA to 1.21 MPA after 7 and 14 days of curing, respectively. From these results mentioned above, about Nigerian General Specification and Kenya Road Design Manual, 4% heavy fuel oil is recommended to stabilize laterite soil for road sub-base construction. The impact of the selected soil characteristics over time (aging) needs to be studied and evaluated against current test results. Future studies should also examine the potential interaction between the different groups present in soil and heavy fuel oil.

Acknowledgments

The authors express their appreciation to the Pan African University Institute for Basic Sciences, Technology, and Innovation and Jomo Kenyatta University of Agriculture and Technology for providing access to equipment and laboratory support during their research. They also extend their thanks to the African Union for its financial assistance and support.

References

[1] Mahamadou Souley Issiakou et al., “Study of Lateritic Materials Used in Road Construction in Niger: Improvement Method,” *Civil Engineering University Meetings*, Bayonne, France, 2015.

[2] G. Vorobieff, *AustStab Construction Tip 1F*, 2008.

[3] A. Pandey, and A. Rabbani, “Soil Stabilisation using Cement Effect of Temperature on Swelling Pressure and Compressibility Characteristics of Soil View Project Soil Contamination Remediation Technology View Project Soil Stabilisation,” *International Journal of Civil Engineering and Technology*, vol. 8, no. 6, 2017.

[4] Afaf Ghais Abadi Ahmed, “Fly Ash Utilization in Soil Stabilization,” *International Conference on Civil, Biological and Environmental Engineering*, Turkey, Istanbul, 2014.

[5] N. Vijay Kumar et al., “Study on Strength of Laterite Soil Using Bitumen Emulsion and ESP, CSA,” *International Journal of Current Engineering and Scientific Research*, vol. 4, no. 7, 2017.

[6] Z. N. Rasheed, F. R. Ahmed, and H. M. Jassim, “Effect of Crude Oil Products on the Geotechnical Properties of Soil,” *WIT Transactions on Ecology and the Environment,* vol. 186, pp. 353–362, 2015. *Crossref*, https://doi.org/10.2495/ESUS140301

[7] M C Jayaprakash et al., “Experimental Study on Lateritic Soil Stabilization with Waste Engine Oil and Lime,” *Turkish Journal of Computer and Mathematics Education*, vol. 12, no. 10, 2021. *Crossref*, https://doi.org/10.17762/turcomat.v12i10.4054

[8] Kamran Iqbal et al., “Effect of Used Motor Oil and Bitumen as Additive on the Permeability and Mechanical Properties of Low Plastic Soil,” *Advances in Materials Science and Engineering*, 2020. *Crossref*, https://doi.org/10.1155/2020/1360197

[9] Abdullah Ekinci, Mohammad Hanafi, and Ertug Aydin, “Strength, Stiffness, and Microstructure of Wood-Ash Stabilized Marine Clay,” *Minerals*, vol. 10, no. 9, p. 796, 2020. *Crossref*, https://doi.org/10.3390/min10090796

[10] Richard H McKee et al., “The Toxicological Effects of Heavy Fuel Oil Category Substances,” *International Journal of Toxicology,* vol. 33, pp. 95S-109S, 2014. *Crossref*, https://doi.org/10.1177/1091581813504230

[11] Ayininuola Gbenga Matthew, and Abidoye Shola Paul, “Soil Stabilization Using Bitumen Emulsion and Cement Combination as Additive,” *Journal of Earth Science and Engineering,* vol. 8, pp. 66–74, 2018. *Crossref*, https://doi.org/10.17265/2159-581X/2018.02.000

[12] I. I. Akinwumi, D Diwa, and N Obianigwe, “Effects of Crude Oil Contamination on the Index Properties, Strength and Permeability of Lateritic Clay,” *Journal of Applied Sciences and Engineering Research,* vol. 3, no. 4, 2014. *Crossref*, https://doi.org/10.6088/ijaser.030400007

[13] Bamitale Dorcas Oluyemi-Ayibiowu, Igibah Christopher Ehizemhen, and Lucia Omolayo Agashua, “Appraisal of Strength Characteristics of Bituminous Additive Lateritic Soil as Pavement Material in Construction Industry,” *International Journal of Research Publication and Reviews*, vol. 3, no. 4, pp. 1780-1788, 2022.

[14] I. N Obeta, and O. J Eze-Uzomaka, “Geotechnical Properties of Waste Engine Oil Contaminated Laterites,” *Nigerian Journal of Technology,* vol. 32, no. 2, 2013.

[15] Ismaël Dabakuyo, Raphael N. Mutuku, and Richard O. Onchiri, "Effect of Sugarcane Molasses on the Physical Properties of Metakaolin Based Geopolymer Stabilized Laterite Soil," *SSRG International Journal of Civil Engineering,* vol. 8, no. 12, pp. 1-12, 2021. *Crossref*, https://doi.org/10.14445/23488352/IJCE-V8I12P101

[16] Hans F. Winterkorn, and E. C. Chandrasekharan, *Laterite Soils and Their Stabilization*, 1949.

[17] B. S. 1377, Soils for Civil Engineering Purposes, 1990.

[18] BS. 1924, Stabilized Materials for Civil Engineering Purposes, 1990.

[19] O. W. Road, and O. Development, “A Guide to The Structural Design of Bitumen- Surfaced Roads in tropical and Sub-Tropical, London, 1993. [Online]. Available: http://insitu-asphalt.com/wp-content/uploads/2009/07/A-Guide-To-The-Structural-Design-Of-Bitumen-Surfaced-Roads-In-Tropical-And-Sub-Tropical-Countries-ORN-31-TRL.pdf

[20] A.S.T.M. C39/C 39M, “Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens,” *American Society for Testing and Materials*, West Conshohocken, 2009.

[21] Manasseh Joel, and Isaac O. Agbede, “Mechanical-Cement Stabilization of Laterite for Use as Flexible Pavement Material,” *Journal of Materials in Civil Engineering,* pp. 146-152, 2011. *Crossref*, https://doi.org/10.1061/(ASCE)MT.1943-5533.0000148

[22] Majoie Ronelyam Mbakbaye, Erick Kiplangat Ronoh, and Isaac Fundi Sanewu, "Effects of Shea Nutshell Ash on Physical Properties of Lateritic Soil," *SSRG International Journal of Civil Engineering,* vol. 8, no. 11, pp. 1-6, 2021. *Crossref,* https://doi.org/10.14445/23488352/IJCE-V8I11P101

[23] ASTM D5084: Standard Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter.

[24] Federal Ministry of Works and Housing, Nigerian General Specifications for Roads and Bridges, Federal Highway Department, FMWH: Lagos, Nigeria, vol. 11, 1997.

[25] Kenya, Ministry of Roads and Public Works, Road Design Manual: Part III Materials & New Pavement Design, pp. 1263, 1987.

[26] Brice T Kamtchueng et al., "Geotechnical, Chemical and Mineralogical Evaluation of Lateritic Soils in Humid Tropical Area (Mfou, Central-Cameroon): Implications for Road Construction," *International Journal of Geo-Engineering,* vol. 6, no. 1, 2015. *Crossref,* https://doi.org/10.1186/s40703-014-0001-0

[27] MARPOL, International Convention for the Prevention of Pollution from Ships, 2011. [Online]. Available: https://media.voog.com/0000/0041/3078/files/MARPOL IMO.pdf

[28] J. D. Akshatha, Ramakrishna Hegde, and K. E. Prakash, "Experimental Study of Lateritic Soil Stabilized with Diospyros Malabarica," *SSRG International Journal of Civil Engineering*, vol. 9, no. 9, pp. 27-32, 2022. *Crossref,* https://doi.org/10.14445/23488352/IJCE-V9I9P105

[29] Surendra Roy, and Sanjeev Kumar Bhalla, Role of Geotechnical Properties of Soil on Civil Engineering Structures, *Resources and Environment*, vol. 7, no. 4, pp. 103-109, 2019. *Crossref*, https://doi.org/10.5923/j.re.20170704.03

[30] Oluwapelumi O. Ojuri, and Omotayo Ogundijo, "Modeling Used Engine Oil Impact on the Compaction and Strength Characteristics of a Lateritic Soil," *Electronic Journal of Geotechnical Engineering*, vol. 17, pp. 3491-3501, 2012.

[31] Magdi Zumrawi, and Mohamed Awad, "Effect of Bitumen and Fly Ash on Expansive Soil Properties," *Journal of Scientific and Engineering Research,* vol. 2017, no. 49, pp. 228–237, 2017.

[32] IRC 37-2012: Guidelines for the Design of Flexible Pavements, The Indian Roads Congress, New Delhi.

[33] Ziming He et al., "Effect of Wollastonite Microfibers as Cement Replacement on the Properties of Cementitious Composites: A Review," *Construction and Building Materials,* vol. 261, 2020. *Crossref,* https://doi.org/10.1016/j.conbuildmat.2020.119920

[34] Mashalah Khamehchiyan, Amir Hossein Charkhabi, and Majid Tajik, "Effects of Crude Oil Contamination on Geotechnical Properties of Clayey and Sandy Soils," *Engineering Geology,* vol. 89, no. 3-4, pp. 220–229, 2007. *Crossref*, https://doi.org/10.1016/j.enggeo.2006.10.009

[35] Opeyemi E. Oluwatuyi et al., "Case Studiesin Construction Materials Ameliorating Effect of Milled Eggshell on Cement Stabilized Lateritic Soil for Highway Construction," *Case Studies in Construction Materials*, vol. 9, p. e00191, 2018. *Crossref*, https://doi.org/10.1016/j.cscm.2018.e00191

[36] Solomon Idowu Adedokun, "Valorization of Spent Engine Oil Contaminated Lateritic Soil with High Calcium Waste Wood Ash," *Journal of Engineering Research*, vol. 7, no. 1, 2019.

[37] Joshua Ochepo, and A. B. Salahudeen, "Strength Evaluation of Laterite Soil Mixed with Reclaimed Asphalt Pavement and Bagasse Ash for Sub-Base Construction", *Nigeria Engineering Conference*, 2014.