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*Original Article*

# Investigation on the Suitability of High Clay Lateritic Soils Stabilized with Cement and Rice Husk Ash for Use in Road Base Construction: A Case Study of Juja Town

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***Abstract*** *- The problem being addressed in this study is the lack of suitable material for road base applications in areas with high clay lateritic soil. The study aims to investigate if a mixture of Ordinary Portland Cement (OPC) and Rice Husk Ash (RHA) can be used to improve the mechanical properties of this type of soil, making it suitable for road base construction. The natural soil is first characterized through tests such as Atterberg limits, compaction test, Californian Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS). After that, the soil sample is mixed with cement at a gradually varying content of 4–10 % of the dry weight of the soil sample at 2 % intervals, and the optimum cement content necessary to achieve the targeted strength properties (UCS) with regard to standards is selected. The optimum cement proportion is 8%, and the treated soil's UCS and soaked CBR values are 1.83 MPa and 142%, respectively. Following that, the soil is treated with a cement-RHA mixture, with RHA gradually replacing cement content from the optimum proportion selected to full replacement at 1% intervals. Atterberg limits, compaction, CBR, and UCS testing are performed on all treated samples. The mechanical performances of the treated specimens with a cement-RHA combination containing no more than 3% RHA meet the requirements for the desired use. All specimens with RHA content greater than 3% have lower and insufficient strength values. In conclusion, an optimal mixture of 5% cement+3% RHA is chosen, with soaked CBR and UCS values of 115 and 1.72, respectively.*

***Keywords*** *- Cement, Rice husk ash, Stabilization, High lay lateritic soil, Road base.*

## 1. Introduction

Transportation is a key sector in the global economy [1,2]. As a result, there is an urgent need to decarbonize and develop sustainable transportation systems to sustain the green economy. The transportation sector has been identified as the second-largest source of CO2 emissions in developed countries [3] and the fastest-growing source of CO2 emissions worldwide [4]. Transportation accounts for nearly 27% of all man-made greenhouse gas emissions worldwide [3]. This means that transportation is one of the greatest contributors to climate change, one of the most pressing challenges facing humanity today.

The heavy traffic resulting from population growth and the expansion in the use of vehicles has caused a rise in the engineering requirements of road construction materials. The life span of a road varies depending on its construction materials and the quality and maintenance it receives [5]. When particular attention is not paid to the quality of materials used, roads can deteriorate rapidly due to wear and tear from heavy traffic or from natural factors such as rain, snow or heat.

Materials in their natural state are sometimes not strong enough for the demands of modern-day road infrastructure. In civil engineering, for projects such as roads, building foundations, and dams among others, soil stabilization is absolutely essential since, in their natural state, most lateritic soils typically have low bearing capacity and low strength due to high-strength clay content [6]. By using approaches like preloading, soil replacement, using recycled construction materials, and using stabilizing agents for soils, the soil used for road construction can be improved [7]. Cement and lime, referred to as traditional stabilizers, have been used over the years to stabilize soil [8-12]. Cement is used in road construction as the main stabilizing agent in many countries, but it is expensive [2,7,9,16,36] and pollutes nature [7,9,13-16,36]. These factors have encouraged researchers to investigate and recommend adopting materials that may be obtained locally for less cost [6,8] and are more environmentally friendly [7,11]. Researchers have recently set their sights on agricultural waste to developing alternatives to traditional binding and stabilizing materials. Many investigations have reported the successful use of ash produced from agriculture waste such as bamboo leaf ash [9], palm bunch ash [17], saw dust ash [18], sugarcane bagasse ash [19], cow dung ash [19], rice husk ash [49] to stabilize soil for road purposes.

Rice husk ash is obtained from burning at a high-temperature rice husk after harvesting. The combustion consumes the organic compounds and water of the raw material (rice husk), and about 20% remains as RHA [20,22, 25,26]. According to [7], the nature and form of resulting ash from the burning process are influenced by various factors such as the physical and chemical properties of the material being burned, the composition of the material (stems, leaves, and bark), the presence of other fuel sources during combustion (such as coal), and the conditions under which the combustion takes place. RHA contains around 90% of silica (SiO2) [23], and this is the highest revealed concentration of all plant residue [28]. Silica is the most important compound that confers to rice husk ash or any other ash pozzolanic properties. When large concentrations of reactive CaO, Al2O3, and SiO2 are combined in the presence of water, pozzolanic reactions occur. Generally, CaO is supplied by cement or lime, while Al2O3 and SiO2 can be present in the ash and soil [8]. The pozzolanic reactions refer to the combination of Si and Al with Ca to form Calcium Silicate Hydrates (CSH) and Calcium Aluminate Hydrates (CAH), which are cementitious compounds [29, 30]. Many pieces of research in the literature [21-24] have shown that RHA significantly improves soil properties when added to the soil. This study consequently aims at investigating the suitability of cement-RHA-modified high clay laterites due to pozzolanic reactions for road base applications.

## 2. Materials and Methods

### *2.1. Materials*

Rice husk ash, laterite soil, and Ordinary Portland Cement with a nominal strength of 42.5 MPa (CEMI) are the materials used in this research.

The laterite soil sample was obtained along Thika Road Highway (Juja). The laterite soil was sampled from different points to have a sample that represents the area's soil very well. It was then taken in the civil engineering laboratory of Jomo Kenyatta University of Agriculture and Technology (Kenya) and sun-dried before use.

The RHA was purchased from a local company that industrially produces RHA. It was then sieved through a BS sieve 0.105mm before being used. The cement was purchased from a cement store in Thika town (Kenya).

The water utilized in this study was taken from a borehole and was drawn from the laboratory's running taps. In order to produce data that would accurately reflect in-situ conditions, distilled water was not used for all the tests apart from the specific gravity test.

### *2.2. Methods*

The laterite soil sample, cement, and rice husk ash were subjected to X-Ray Fluorescence (XRF) test to determine their chemical composition. The test was conducted at the Ministry of Mining and Petroleum in Kenya.

To determine the physical and mechanical properties of the natural soil sample, several characterization tests were conducted. Those tests included particle size distribution, specific gravity, Atterberg limits, compaction test, soaked California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) for comparison.

To improve the soil's properties, the natural soil sample was treated with varying amounts of cement at 4%, 6%, 8%, and 10% of the dry weight of the soil sample. The optimum amount of cement necessary to meet the targeted specifications was then selected.

The soil was further treated using RHA blended with cement; RHA gradually replaced the cement content in 1% steps, starting from the optimum cement content to full replacement. The treated soil samples were then subjected to Atterberg limits, compaction, and CBR testing, in accordance with British Standard 1377 [31] for natural soil samples and British Standard 1924 [32] for stabilized samples.

## 3. Results and Discussion

### *3.1. Characterization of Laterite Soil, Cement and Rice Husk Ash*

Figure 1 displays the particle size distribution of the natural laterite soil sample, and Table 1 shows its other engineering properties. The soil sample was classified A-6 in the American Association of State Highway Transportation Officials (AASHTO) classification system based on its properties. Soil that falls under this class is labelled fair soil and hence not good to be used in road base construction unless treated [33, 34].

Table 2 presents the chemical compounds found in the soil, cement and rice husk ash. Iron oxides, silica oxides, and aluminium oxides are the main oxides that compose the soil and account for 43.13%, 39.71% and 11.73%, respectively.

The silica sesquioxide ratio ($SiO_2/(Al_2O_3+Fe_2O_3)$) is equal to 1.76, which is more than 1.33 but less than 2, revealing that the soil is lateritic soil [35]. Considering the percentage of fine particles, the soil sample used was identified as high clay lateritic soil. The RHA containing silica, which accounts for 93.63% more than 70% of the total, was classified as pozzolana [50].

**Table 1. Engineering properties of the soil**

| Properties | Proportion/Value |
|---|---|
| **Natural moisture content** | 10.19±0.10% |
| **Specific gravity** | 2.43±0.01 |
| **%Passing through BS Sieve 75μ** | 37.48 |
| **Liquid limit (LL)** | 39.5% |
| **Plastic limit (PL)** | 20.79% |
| **Plasticity Index (PI)** | 18.7% |
| **Classification (AASHTO)** | A-6 |
| **Soaked CBR (4 days)** | 16.9% |
| **UCS** | 0.32 MPa |

**Table 2. Chemical composition of the OPC, RHA, and soil**

| Oxides | Oxides contained (%) | | |
|---|---|---|---|
| | OPC | RHA | Soil |
| **MgO** | 1.57 | 1.19 | 4.81 |
| **Aluminum (Al2O3)** | 1.51 | 0.18 | 11.73 |
| **Silica (SiO2)** | 6.64 | 93.63 | 39.71 |
| **Phosphorus (P2O5)** | 1.41 | 0.86 | 0.06 |
| **Sulphur (S)** | 3.1 | 0.12 | 0.1 |
| **Chlorine (Cl)** | 0.08 | 0.18 | 0.03 |
| **Potassium (K2O)** | 2.72 | 1.88 | 1.35 |
| **Calcium (CaO)** | 81.8 | 1.12 | 2.63 |
| **Titanium (Ti)** | 0.24 | 0.07 | 0.82 |
| **Manganese (Mn)** | 0.1 | 0.14 | 1.17 |
| **Fe2O3** | 2.58 | 0.48 | 43.13 |
| **Zinc (Zn)** | 0.01 | 0.01 | 0.02 |
| **Strontium (Sr)** | 0.08 | - | - |
| **Zirconium (Zr)** | 0.05 | - | 0.12 |

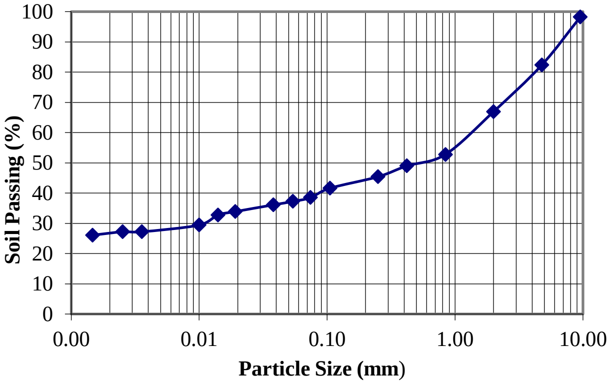

**Fig. 1 Grain size distribution curve of the soil**

### 3.2. Stabilization of the Lateritic Soil with Cement

From figure 2, it is observed that both the liquid limit and plasticity limit increased. This is the result of the hydration reaction of cement, which causes flocculation and agglomeration of soil particles [37]. Liquid limit decreased with further increase in cement content due to a higher amount of cementitious materials in the soil. The primary causes of soil's plasticity characteristics are the clay grains' plate shape and the lubricating bonding action of water adsorption surrounding the clay particles [38]. Consequently, the PI decreased. A similar trend was reported by other researchers [39, 40]. Soil that has a lower plasticity index is less clayey [41].

The optimum moisture content slightly increased with an increase in cement content. An illustration is shown in figure 3. This increase results from cement being finer than the lateritic soil; the more cement the mixture contains, the finer the mixture is, and more water is needed to achieve optimum compaction [42]. On the other hand, figure 4 shows a decrease in maximum dry density as cement content increased in the mixture. This can be attributed to the test being performed right after the addition before reactions took place. A higher amount of water was necessary to achieve optimum compaction resulting in lower dry density. This is in agreement with previous works [39, 40].

Analysis of Figure 4 and Figure 5 shows that the mechanical characteristics of the soil improved in proportion to the increase in cement content after 7 days of curing. This is principally due to the pozzolanic reaction between soil particles and cement, which over time, results in the formation of calcium silicate hydrate and calcium aluminate hydrate. These newly formed compounds have the capacity to cement the soil particles together and increase the strength parameters of the soil [42]. For cement-treated soil, the UCS value after 7 days of curing is the principal strength parameter to consider to qualify the suitability of the soil for road purposes [43]. On this basis, with regard to the specification (1.5-3MPa for UCS value after 7 days curing) of the Oversea Road Note 31 [44] for soil material to be used for road bases, 8% cement content by dry weight of the lateritic soil was established as the optimum cement content. The soaked CBR and UCS values of the modified lateritic soil at the optimum cement content are respectively 142% and 1.83. Although the soaked CBR value does not satisfy the specification for cement-based stabilized materials for road base constructions (Min CBR 160%, Min UCS 1,8) of Kenya Road Manual for Pavement Design [33], the UCS value, which is the most important parameter, in this case, falls within the range.

### 3.3. Stabilization of the lateritic soil with cement and RHA

This treatment used RHA to replace optimum cement content to achieve targeted strength parameter values in steps of 1% decrement.

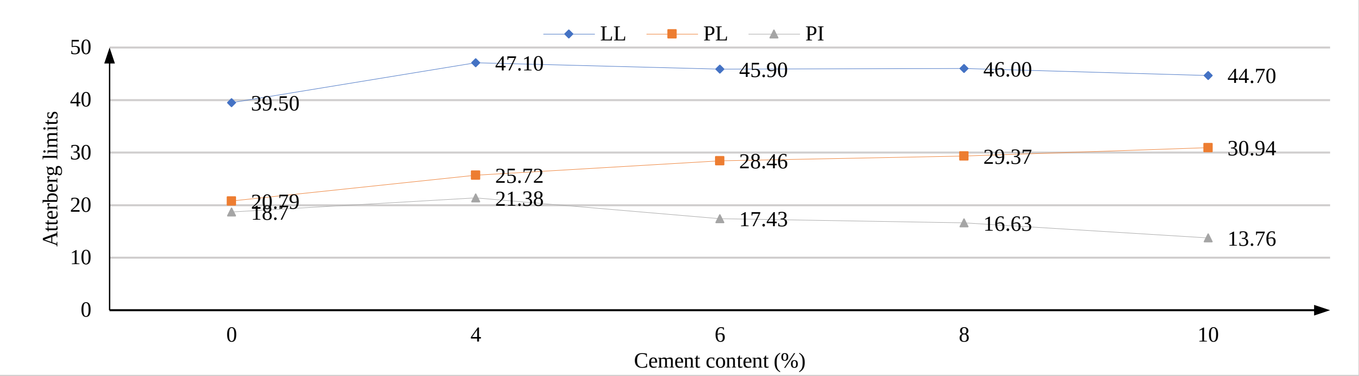

**Fig. 2 Effect of cement on Atterberg limits of the lateritic soil**

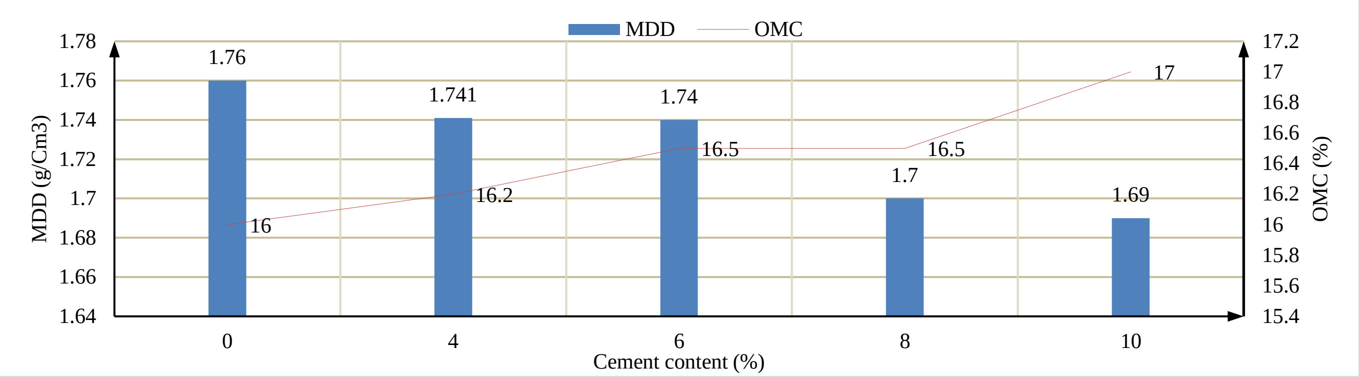

**Fig. 3 Effect of cement addition on MDD and OMC of the lateritic soil**

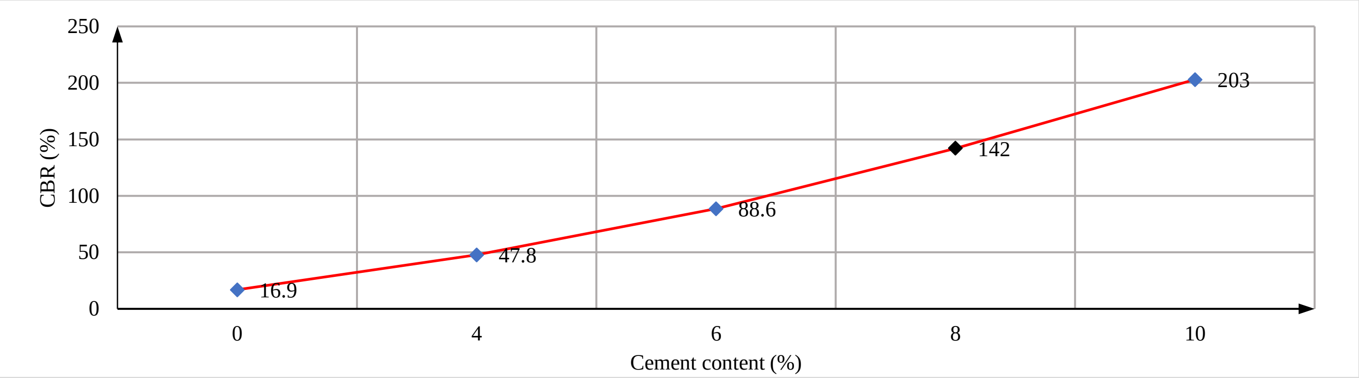

**Fig. 4 Effect of cement addition on CBR values of the lateritic soil**

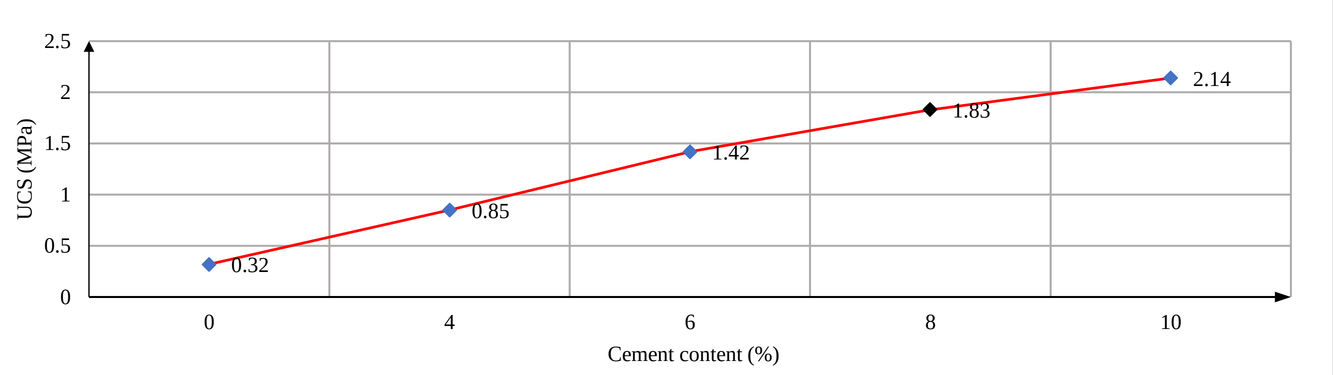

**Fig. 5 Effect of cement addition on UCS values of the lateritic soil**

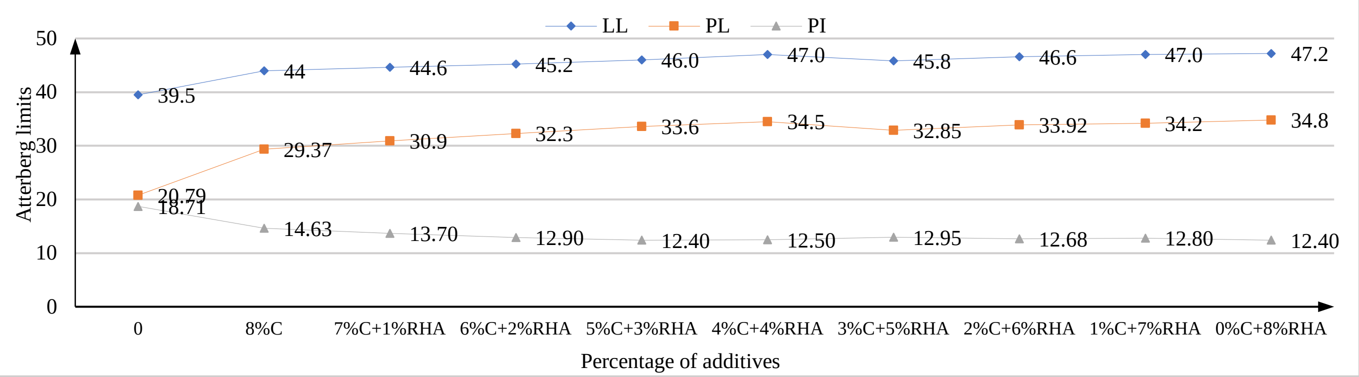

**Fig. 6 Effect of cement-RHA addition on CBR values of the lateritic soil**

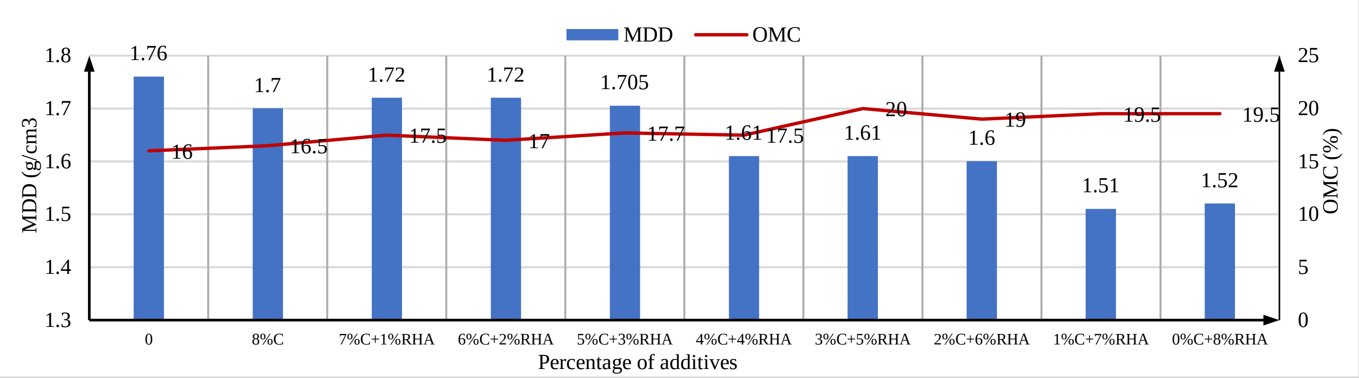

**Fig. 7 Effect of cement-RHA addition on MDD and OMC of the lateritic soil**

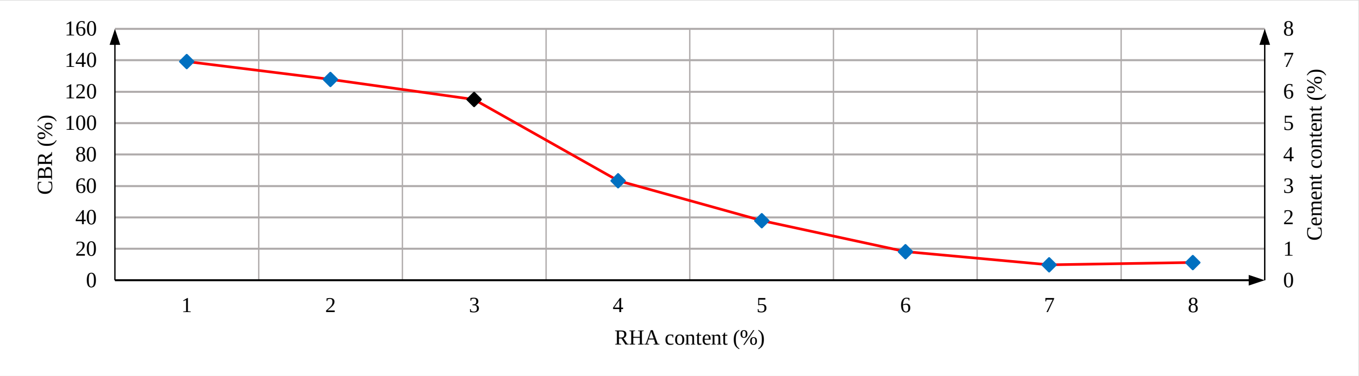

**Fig. 8 Effect of cement-RHA addition on CBR values of the lateritic soil**

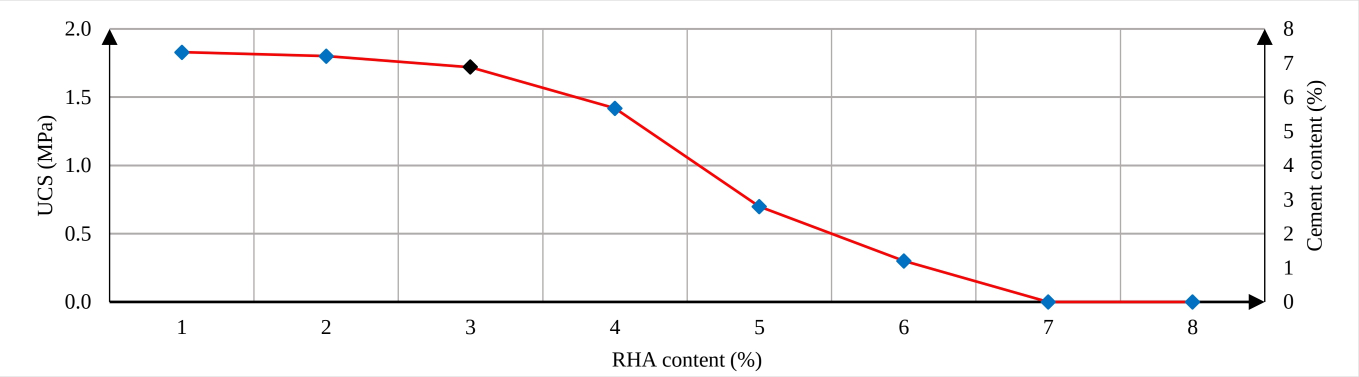

**Fig. 9 Effect of cement-RHA addition on UCS values of the lateritic soil**

As shown in figure 6, the replacement of cement content by RHA caused an increase in the liquid limit as well as the plastic limit. The change in plastic limit was observed to be faster and greater than that of liquid limit at the earlier stage of cement replacement. Consequently, the plasticity index decreased when a small amount of cement was replaced by RHA (up to 4%). Beyond this value, the PI started increasing before becoming stagnant. The same results were observed in previous works for cement-RHA-treated soil [39].

The optimum moisture content kept increasing as cement content was gradually replaced by rice husk ash. An illustration is shown in figure 7. This is attributed to finer particles in the mixt matrix due to the fact that more volume of RHA is needed to replace the same weight of cement because it has lower specific gravity. Note that the specific gravity of cement and RHA was reported to be respectively 3.16 and 1.8. The finer the material, the more water is needed to achieve maximum compaction. The same trend was found by other researchers [23, 45, 46].

Figures 8 and 9 show that both soaked CBR and UCS decreased continually with cement content replacement by RHA after 7 days of curing. When only a small percentage of cement is replaced, there is a very small loss in these strength parameter values; nevertheless, this decline increases as cement replacement increases by over 3%. The loss in soaked CBR and UCS is attributed to excess RHA amount not involved in the pozzolanic reaction that occurred within the first seven days of curing. Due to its low specific gravity relative to cement and soil, extra RHA replaces some of the soil in the mixture, lowering the mixture's mechanical performance [2, 39].

Pozzolanic processes are expected to continue after 7 days of curing, and specimens will exhibit higher mechanical properties [38]. However, the most crucial strength parameters for evaluating the suitability of cement-stabilized materials for road applications are the CBR and UCS values after 7 days of curing [43]. Considering the strength parameter specifications (1.5-3MPa for UCS value after 7 days curing) of the Oversea Road Note 31 [44] for soil material to be used for road bases, the optimum mix of the additives is cement 5%/3% RHA. The corresponding soaked CBR and UCS values are respectively 115% and 1.72.

Beyond 3% replacement, the mixture's mechanical performance no longer meets the requirements indicated in the above standard. Both values are slightly lower than the limits indicated in Kenyan Standards for cement-based stabilized materials for road base (Min CBR 160%, Min UCS 1,8) [33]. However, according to many other standards, such as Nigerian General Specification [47] and Indians [48], a material that exhibits the earlier performance can be used in road bases. We conclude that the stabilized material can be used in low volume road bases in the Kenyan context.

## 4. Conclusion

The natural soil used in this study was defined as a high clay lateritic soil categorized A-6 in the American Association of State Highway and Transportation Officials (AASHTO) classification system. According to chemical analysis, the cement utilized was Ordinary Portland Cement, and the rice husk ash was classed as pozzolanic material.

The optimum cement content necessary to be added to the natural soil to reach the mechanical performance measured by UCS and CBR was also established to be 8% by weight of the soil. The achieved values were respectively 1.83 MPa for UCS and 142% for CBR.

The optimum cement-RHA mix proportion for which the resulting modified soil satisfied the need was found to be 5%cement+3%RHA. The UCS and CBR value of the stabilized soil at these proportions were 1.72 MPa and 115%, respectively. Thereby, with regard to specifications of the Oversea Road Note 31, the studied high clay lateritic soil can be modified and becomes suitable for road base applications with an additional 5%cement + 3% RHA by the dry weight of the natural soil.

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## References

[1] C. Wang et al., "CO2 Emission in Transportation Sector Across 51 Countries Along the Belt and Road From 2000 to 2014," *Journal of Cleaner Production*, vol. 266, p. 122000, 2020. *Crossref*, https://doi.org/10.1016/j.jclepro.2020.122000

[2] Faiza Sana, and Fazal Haq, "Subgrade Stabilization Using Cement and Rice Husk Ash," *Global Scientific Journals*, vol. 8, no. 7, pp. 1231–1237, 2020.

[3] Y. Van Fan et al., "A Review on Air Emissions Assessment: Transportation," *Journal of Cleaner Production*, vol. 194, pp. 673-684, 2018. *Crossref*, https://doi.org/10.1016/j.jclepro.2018.05.151

[4] W. F. Lamb et al., "A Review of Trends and Drivers of Greenhouse Gas Emissions by Sector From 1990 to 2018," *Environmental Research Letters*, vol. 16, no. 7, 2021. *Crossref*, https://doi.org/10.1088/1748-9326/abee4e

[5] W. P. S. Dias, “Factors Influencing the Service Life of Buildings,” *Engineer: Journal of the Institution of Engineers*, vol. 46, no. 4, pp. 1-7, 2013. *Crossref*, https://doi.org/10.4038/engineer.v46i4.6801

[6] I. I. Obianyo, A. P. Onwualu, and A. B. O. Soboyejo, “Mechanical Behaviour of Lateritic Soil Stabilized with Bone Ash and Hydrated Lime for Sustainable Building Applications,” *Case Studies in Construction Materials*, vol. 12, p. e00331, 2020. *Crossref*, https://doi.org/10.1016/j.cscm.2020.e00331

[7] P. Maichin et al., “Stabilized High Clay Content Lateritic Soil Using Cement-Fgd Gypsum Mixtures for Road Subbase Applications,” *Materials*, vol. 14, no. 8, p. 1858, 2021. *Crossref*, https://doi.org/10.3390/ma14081858

[8] E. S. Nnochiri, O. M. Ogundipe, and S. A. Ola, “Geotechnical and Microstructural Properties of Cement-Treated Laterites Stabilized with Rice Husk Ash and Bamboo Leaf Ash,” *Acta Polytechnoca*, vol. 61, no. 6, pp. 722-732, 2021. *Crossref*, https://doi.org/10.14311/AP.2021.61.0722

[9] K. C. Onyelowe et al., “Swelling Potential of Clayey Soil Modified with Rice Husk Ash Activated by Calcination for Pavement Underlay by Plasticity Index Method (PIM),” *Advances in Materials Science and Engineering*, vol. 2021, 2021. *Crossref*, https://doi.org/10.1155/2021/6688519

[10] Deepak Gupta, Harpinder Singh, and Sanjeev Kumar Sharma, “Cement Stabilised and Fiber Reinforced Clay Mixed with Rice Husk Ash,” *International Journal of Engineering Sciences & Research Technology*, vol. 7, no. 2, pp. 441-462, 2018. *Crossref*, https://doi.org/10.5281/zenodo.1173584

[11] L. A. Taiwo et al., “Mechanical Behaviour of Composite Produced with Quarry Dust and Rice Husk Ash for Sustainable Building Applications,” *Case Studies in Construction Materials*, vol. 17, p. e01157, 2022. *Crossref*, https://doi.org/10.1016/j.cscm.2022.e01157

[12] N. Yoobanpot, and P. Jamsawang, “Effect of Cement Replacement by Rice Husk Ash on Soft Soil Stabilization,” *Kasetsart Journal-Natural Science*, vol. 48, no. 2, pp. 323-332, 2014.

[13] P. Sukontasukkul, “Methodology for Calculating Carbon Dioxide Emission in the Production of Ready-Mixed Concrete,” *1st International Conference Computer Technoogy. Concrete Structure*, vol. CPN 137, no. 2009, pp. 1-9, 2009.

[14] A. Dubey, “Studies on the Air Pollution Around Cement and Lime Factories,” *Journal of Environment and Earth Science*, vol. Vol. 3, no. No.9, 2013.

[15] A. Imran, and T. Islam “Reduction of Energy Consumption, Co2 Emission & Construction Cost of a Model Building,” *A Review on the Recent Development in Concrete Technology*, 2014.

[16] K. Anjaneyulu, “Partial Replacement of Cement Concrete by Waste Materials,” *International Journal of Engineering Development and Research*, vol. 5, no. 2, pp. 1374-1383, 2017.

[17] I. I. Obianyo et al., “Performance of Lateritic Soil Stabilized with Combination of Bone and Palm Bunch Ash for Sustainable Building Applications,” *Cogent Engineering*, vol. 8, no. 1, 2021. *Crossref*, https://doi.org/10.1080/23311916.2021.1921673

[18] T. H. T. Ogunribido, “Geotechnical Properties of Saw Dust Ash Stabilized Southwestern Nigeria Lateritic Soils,” *Environmental Research, Engineering and Management*, vol. 60, no. 2, 2012. *Crossref*, https://doi.org/10.5755/j01.erem.60.2.986

[19] A. Kumar Yadav et al., “Stabilization of Alluvial Soil for Subgrade Using Rice Husk Ash, Sugarcane Bagasse Ash and Cow Dung Ash for Rural Roads,” *International Journal of Pavement Research and Technology*, vol. 10, no. 3, pp. 254-261, 2017. *Crossref*, https://doi.org/10.1016/j.ijprt.2017.02.001

[20] T. C. Vishnu et al., “Soil Stabilization using Rice Husk Ash, Lime and Jute,” *SSRG International Journal of Civil Engineering*, vol. 3, no. 2, pp. 19-28, 2016. *Crossref*, https://doi.org/10.14445/23488352/IJCE-V3I2P104

[21] A. K. Anupam, P. Kumar, and R. N. G. D. Ransinchung, “Effect of Fly Ash and Rice Husk Ash on Permanent Deformation Behaviour of Subgrade Soil under Cyclic Triaxial Loading,” *Transportation Research Procedia*, vol. 17, pp. 596-606, 2016. *Crossref*, https://doi.org/10.1016/j.trpro.2016.11.114

[22] E. A. Basha et al., “Stabilization of Residual Soil With Rice Husk Ash and Cement,” *Construction and Building Materials*, vol. 19, no. 6, pp. 448-453, 2005. *Crossref*, https://doi.org/10.1016/j.conbuildmat.2004.08.001

[23] L. Behak, and M. Musso, “Performance of Low-Volume Roads with Wearing Course of Silty Sand Modified with Rice Husk Ash and Lime,” *Transportation Research Procedia*, vol. 18. pp. 93-99, 2016. *Crossref*, https://doi.org/10.1016/j.trpro.2016.12.013

[24] D. Gupta, and A. Kumar, “Performance Evaluation of Cement-Stabilized Pond Ash-Rice Husk Ash-Clay Mixture as a Highway Construction Material,” *Journal of Rock Mechanics and Geotechnical Engineering*, vol. 9, no. 1, pp. 159-169, 2017. *Crossref*, https://doi.org/10.1016/j.jrmge.2016.05.010

[25] F. H. Ali, A. Adnan, and C. K. Choy, “Geotechnical Properties of a Chemically Stabilized Soil from Malaysia with Rice Husk Ash as an Additive,” *Geotechnical & Geological Engineering*, vol. 10, no. 2, pp. 117-134, 1992. *Crossref*, https://doi.org/10.1007/BF00881147

[26] L. Behak, “*Soil Stabilization with Rice Husk Ash*,” Rice-Technology and Production, 2017. *Crossref*, https://doi.org/10.5772/66311

[27] G. P. Scheepers, and B. Du Toit, “Potential Use of Wood Ash in South African Forestry: A Review,” *Southern Forests: A Journal of Forest Science*, vol. 78, no. 4, pp. 255-266, 2016. *Crossref*, https://doi.org/10.2989/20702620.2016.1230716

[28] A. A. Boateng, and D. A. Skeete, “Incineration of Rice Hull for Use as a Cementitious Material : The Guyana Experience,” *Cement and Concrete Research*, vol. 20, pp. 795-802, 1990. *Crossref*, https://doi.org/10.1016/0008-8846(90)90013-N

[29] D. Dermatas, and X. Meng, "Utilization of Fly Ash for Stabilization/Solidification of Heavy Metal Contaminated soils," *Engineering Geology*, vol. 70, no. 3-4, pp. 377-394, 2003. *Crossref*, https://doi.org/10.1016/S0013-7952(03)00105-4

[30] Z. Nalbantoğlu, "Effectiveness of Class C Fly Ash as an Expansive Soil Stabilizer," *Construction and Building Materials*, vol. 18, no. 6, pp. 377–381, 2004. *Crossref*, https://doi.org/10.1016/j.conbuildmat.2004.03.011

[31] British Standards Institute, BS 1377, Methods of Testing Soils for Civil Engineering Purposes, London, 1990.

[32] British Standards Institute, BS 1924, Methods of test for stabilized soils, London, 1990.

[33] "*Road Design Manual: Part III Materials & New Pavement Design*," Kenya Ministry of Roads and Public Works, pp. 1-263, 1987.

[34] F. Netterberg, "Review of Specification for the Use of Laterite in Road Pavements," vol. 60, pp. 1-60, 2014.

[35] F. Alayaki, A. Al-Tabbaa, and J. Ayotamuno "Defining Niger Delta Soils : Are They Laterites ?," *Civil and Environmental Research*, vol. 7, no. 5, pp. 21-27, 2015.

[36] J. Jonnalagadda, J. Jonnalagadda, and V. S. Sarikonda, "Triple Blending of Concrete by Partial Replacement of Cement with Perlite and Rice Husk Ash," SSRG International Journal of Civil Engineering, vol. 7, no. 6, pp. 80-87, 2020. *Crossref*, https://doi.org/10.14445/23488352/IJCE-V7I6P110

[37] W. Al-Jabban et al., "A Comparative Evaluation of Cement and By-Product Petrit T in Soil Stabilization," *Applied Sciences*, vol. 9, no. 23, 2019. *Crossref*, https://doi.org/10.3390/app9235238

[38] Z. Eliaslankaran et al., "Evaluation of the Effects of Cement and Lime with Rice Husk Ash as an Additive on Strength Behavior of Coastal Soil," *Materials*, vol. 14, no. 5, pp. 1-15, 2021. *Crossref*, https://doi.org/10.3390/ma14051140

[39] B. Dabou, C. Kanali, and Z. Abiero-Gariy, "Structural Performance of Laterite Soil Stabilised with Cement and Blue Gum (Eucalyptus Globulus) Wood Ash for use as a Road Base Material," *International Journal of Engineering Trends and Technology*, vol. 69, no. 9, pp. 257-264, 2021. *Crossref*, https://doi.org/10.14445/22315381/IJETT-V69I9P231

[40] M. Bayat, M. R. Asgari, and M. Mousivand, "Effects of Cement and Lime Treatment on Geotechnical Properties of a Low Plasticity Clay," *International Conference on Civil Engineering, Architecture & Urban Sustainable Development*, 2014.

[41] S. Roy, and S. Kumar Bhalla, "Role of Geotechnical Properties of Soil on Civil Engineering Structures," *Resources and Environment*, vol. 7, no. 4, pp. 103-109, 2017. *Crossref*, https://doi.org/10.5923/j.re.20170704.03

[42] S. Jaritngam, O. Somchainuek, and P. Taneerananon, "Feasibility of Laterite-Cement Mixture as Pavement Base Course Aggregate," *Iranian Journal of Science and Technology - Transactions of Civil Engineering*, vol. 38, no. C1, pp. 275-284, 2014.

[43] W. W. Bandara, W. K. Mampearachchi, and K. H. S. M. Sampath, "Cement Stabilized Soil as a Road Base Material for use in Sri Lankan Roads," *Engineer: Journal of the Institution of Engineers, Sri Lanka*, vol. 50, no. 1, p. 21, 2017. *Crossref*, https://doi.org/10.4038/engineer.v50i1.7241

[44] O. W. Road, and O. Development, "*A Guide to The Structural Design of Bitumen- Surfaced Roads in Tropical and Sub-Tropical Countries*," Overseas Road Note 31, 1993.

[45] Rathan Raj, R. S. Banupriya, and R. Dharani, "Stabilization of Soil Using Rice Husk Ash," *International Journal of Computational Engineering Research*, vol. 6, no. 2, pp. 43-50, 2016.

[46] Grytan Sarkar et al., "Interpretation of Rice Husk Ash on Geotechnical Properties of Cohesive Soil," *Global Journal of Researches in Engineering Civil and Structural Engineering*, vol. 12, no. 2, pp. 1-7, 2012.

[47] Federal Ministry of Works and Housing, "*Nigerian general specifications for roads and bridges*," Federal Highway Department, FMWH: Lagos, Nigeria, vol. 11, 1997.

[48] Ministry of Transport (Roads Wing) Department of Surface Transport, "*Ministry's Technical Circulars and Directives on National Highways and Centrally Sponsored Road and Bridge Projects*," vol. 1, 1986.

[49] V. K. S. Sandeep Chhokar, "Soil Stabilization of Clayey Soil," *International Journal of Creative Research Thoughts*, vol. 8, no. 11, pp. 901-903, 2020.

[50] ASTM C39/C 39M, Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens website, 2009. [Online]. Available: https://www.astm.org/astm-tpt-174.html