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Original Article

Mechanical Performance of Laterite Soil Stabilized with Cement and Grewia Bicolour Bark Juice for Road Base Construction

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Abstract *- This paper aims to investigate the potential of the Grewia bicolour bush as a natural stabiliser for road construction. This study evaluates the feasibility of using Grewia Bicolour Bark Juice (GBBJ) as a partial replacement for cement in the stabilization of laterite soil. The soil is mixed with Ordinary Portland Cement (OPC) at different proportions of dry soil weight, ranging from 0 to 8%, with an interval of 2%. Californian Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) tests are performed on the soil-cement mixture to determine the optimum cement content. The UCS value of 6% cement content, with a strength of 2.1 MPa after 7 days of curing, meets the standards set by the Kenya Roads Design Manual Part III. Therefore, 6% cement content is chosen as the optimum. The soil is then treated with a cement-GBBJ mixture by partially replacing the optimum 6% cement content with GBBJ at increasing steps of 1%. The results show that, regarding the standards and the targeted strength, the optimum mix proportion is 4% cement plus 2% GBBJ. The corresponding CBR and UCS values are 130.7% and 1.98 MPa, respectively. The results of the tests provide promising prospects for an economical and sustainable way of soil strengthening.*

Keywords *- Cement, Grewia bicolour bark juice, Stabilization, Laterite soil, Road base.*

1. Introduction

Transport infrastructure is a key point in long-term economic development. As a developing country, Benin faces challenges related to the fragile transportation system, which does not facilitate transportation in the country and to the neighbouring countries. Due to the growing trade exchange of the country, the increase in the number of cars, and the concentration of administrative services in the Southern part (Cotonou and Porto-Novo), there is an increasingly faster deterioration of roads; therefore, there is need for road construction materials with superior mechanical properties.

The locally available materials cannot meet such requirements. This leads to increased construction costs, the premature degradation of roads resulting in the frequent need for maintenance (due to poor materials quality), and traffic accidents. It is, therefore, important to enhance the engineering capacity of soil supporting the road [1]. To improve the engineering properties of soil, especially for road construction, there is a need to stabilise it. Using common stabilisers such as cement and lime for road construction and maintenance has become very expensive [2]. These stabilisers also have a negative impact on the environment. Specifically, for 1kg of cement produced, there is 0.9kg of CO_2 emissions, which is equivalent to 3.24 billion tons of CO_2/year for 3.6 billion tons of cement produced annually [3].

Due to these reasons, and in alignment with Global Goals 11 and 13 [4], engineers have recently been interested in investigating alternative stabilizing agents compared to the traditional ones.

The biological approach offers an environmentally and long-term suitable way of soil stabilization. A study by [5] proved that Xanthan gum and Guar gum are effective in mine tailings stabilization by improving their moisture-retaining capacity and dust resistance.

Xanthan gum has been proven to enhance soil strength, as reported by [6]. There was an important increase in the compressive strength (440 to 2540 kPa) and elastic modulus (25 to 125 kPa) of clayey soil treated with Xanthan gum. The most efficient concentration of Xanthan gum for soil treatment was found to be in the range of 1-1.5%. The effect of Gum Arabic as a binding agent on the durability of compressed laterite blocks was investigated by [7]. The results showed that the abrasion resistance of the blocks increased with an increase in the amount of Gum Arabic used. When compared to blocks stabilized with cement only, the blocks stabilized with a combination of cement and Gum Arabic experienced a reduced abrasion rate, up to 95.18%.

The foregoing studies show that using biopolymers for soil stabilization is cost-effective. However, such natural elements are not available everywhere. That means they are not in a sufficient amounts or even available in some parts of the world for their use in construction. Grewia bicolour is a widely distributed plant species that grows in the drier regions of tropical Africa, including the Sudano-Sahel zone that extends from Senegal to Somalia and covers Kenya, Ethiopia, and Eritrea. It can also be found in eastern Africa, reaching as far south as Namibia, Botswana, South Africa, and Swaziland.

Additionally, it grows in coastal Togo and Benin and can be found in India, Yemen, and Saudi Arabia [8]. This large distribution in the continent is a great advantage compared to previously naturally studied materials for stabilization. Indigenous Beninese use Grewia bicolour bark for plastering their houses. This bark is mixed with laterite soil instead of using cement. Inspired by this local experience, this study investigates the possibility of using Grewia Bicolour bark juice to improve laterite soil properties for road base construction.

2. Materials and Methods

2.1. Materials

The different materials used in this study include laterite soil, Ordinary Portland Cement, Grewia Bicolour Bark Juice, and water. The laterite soil was sourced from near Jomo Kenyatta University for Agriculture and Technology and underwent air-drying before being used. The OPC had a nominal strength of 42.5 MPa (CEMI) and was purchased from hardware in Thika town (Kenya). Finally, the Grewia bicolour bark was sourced from Narok (Kenya). It was soaked in water until saturation, 100g of GBB in 1 litre of water for 1 hour.

2.2. Methods

The chemical composition of laterite soil, OPC and GBBJ was determined using the X-Ray Fluorescence technique.

The engineering characteristics of laterite soil (i.e., OPC and GBBJ) were determined accordingly to the BS1377 standard [9]. Next, the soil was processed in two ways: the first treatment was with cement only by adding 0, 4, 6, and 8% by weight of dry soil. Many researchers have adopted the same procedure for soil stabilization in road construction [10], [26]. The different tests carried out to determine the optimum cement content were Atterberg limits, Compaction test, CBR, and UCS tests, all accordingly to BS1924 [12]. In the second treatment, the optimum cement content was partially replaced by GBBJ in increasing proportion of 1% interval by weight of dry soil—the tests performed in the first treatment aligned with BS1924 [12].

3. Results and Discussion

3.1. Characterization of Laterite Soil, cement and GBBJ

The results of X-Ray Fluorescence on laterite soil, GBBJ, and OPC are shown in Table 1. The major oxides found in laterite soil were ferrous oxide (Fe_2O_3) at 38.43%, followed by silica oxide (SiO_2) at 32.91% and aluminium oxide (Al_2O_3) at 16.37%. The main oxide in GBBJ was found to be calcium oxide (CaO) at 60.27%, followed by potassium oxide (K2O) at 21.45% and magnesium oxide (MgO) at 10.92%. Silica oxide (SiO_2) at 53.64% and Calcium oxide (CaO) at 28.8% were the dominant oxides found in OPC. The ratio of silica to sesquioxide SiO_2/(Al2O3+Fe_2O_3) was 1.27, which is less than 1.33, proving that the soil is lateritic [13].

Table 1. Chemical composition of OPC, GBBJ, and soil

Oxides	Oxides contained (%) Oxides contained in RHA (%) Oxides contained in soil (%)		
	OPC	GBBJ	Soil
Magnesium (MgO)	3.57	10.92	0
Aluminum (Al2O3)	5.51	0.34	16.37
Silica (SiO2)	53.64	-	32.91
Phosphorus (P2O5)	0.41	2.82	-
Sulphur (S)	1.1	1.79	0.20
Chlorine (Cl)	0.08	0.55	-
Potassium (K2O)	2.72	21.45	0.98
Calcium (CaO)	28.8	60.27	1.13
Titanium (Ti)	0.24	0.22	1.27
Manganese (Mn)	0.1	0.07	-
Ferrous (Fe2O3)	3.58	1.309	43.55
Copper (Cu)	0.01	0.07	-
Zinc (Zn)	0.01	0.01	0.02
Strontium (Sr)	0.08	0.058	-
Zirconium (Zr)	0.05	-	0.17

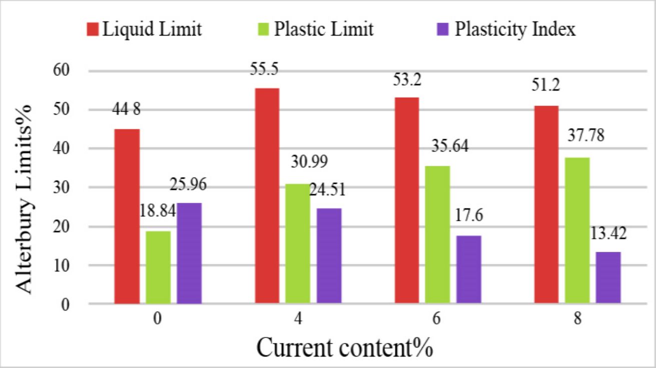

Fig. 1 Effect of varying cement content in laterite soil on Atterberg limits

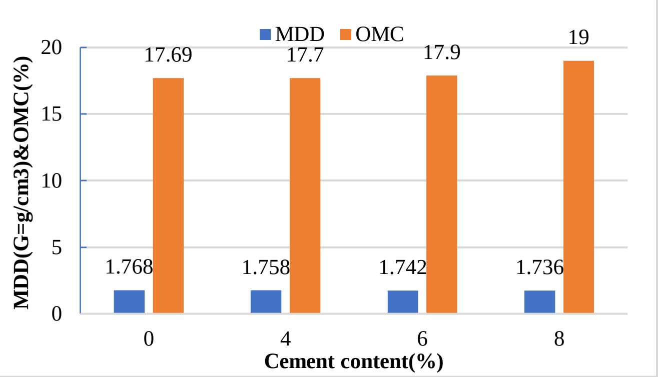

Fig. 2 Effect of varying cement content in laterite soil on MDD and OMC

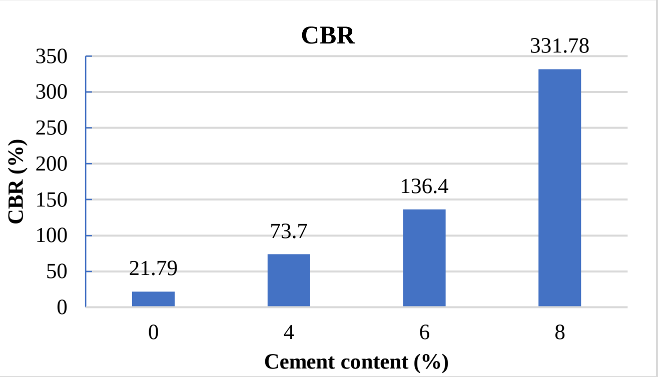

Fig. 3 Effect of varying cement content in laterite soil on CBR values

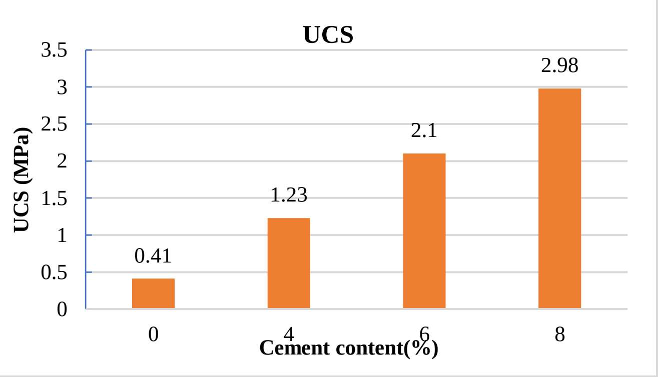

Fig. 4 Effect of Effect of varying cement content in laterite soil on UCS values

Table 2. Engineering properties of laterite soil

Properties	Proportion/Value
Natural moisture content	10.44±0.10%
Specific gravity	2.25±0.01
%Passing through BS Sieve 75µ	31.56
Liquid limit	26.40%
Plastic limit	14.84%
Plasticity Index	11.56%
AASHTO classification	A-2-7
Soaked CBR (4 days)	21.79%
UCS	0.41 MPa

Table 2 summarizes the engineering properties of the neat laterite soil. The soil can be classified as A-2-7 according to the American Association of State Highway Transportation Officials (AASTHO) classification system [14]. This confirms that the soil is weak and needs stabilising for road base construction purposes [15].

3.2. Stabilization of the Laterite Soil with Cement

Fig. 1 shows the effect of varying cement content in the laterite soil on Atterberg limits. As the cement content increased from 0 to 8%, the plasticity index decreased from 25.96 to 13.42%, meaning there was an improvement in soil plasticity [16]. Fig. 2 presents the effect of varying cement content in laterite soil on MDD and OMC. The results show that there was hardly any change in MDD and OMC.

According to [17], this could be explained by the fact that only a small amount of cement was added and the slow pace of the hydration process. A similar outcome was reported by [27]. Furthermore, it is observed from Fig. 3 and 4 that the CBR and UCS values increased proportionally with the increase in cement content.

According to [11,19], it could be explained by a combination of factors, including compaction, hydration of the cement, and a chemical reaction between the cement and soil particles that results in the formation of calcium aluminate hydrate and calcium silicate hydrate. These substances play a crucial role in binding soil particles together over time.

3.3. Stabilization of Laterite Soil with Cement and GBBJ

The laterite soil was further stabilized with cement and GBBJ by replacement of the optimum cement content with GBBJ from 6 to 0% in steps of 1%. Fig. 5 shows that the plasticity index decreased from 17.56-15.8% with an increase in GBBJ content from 0-4%; however, it slightly increased from 16 to 16.1% with the addition of 5-6% GBBJ. The decrease in the plasticity index means that the cement-GBBJ mixture improves the soil properties. According to [14], the decrease in plasticity index characterizes a decrease in the compressibility and swelling of the laterite soil.

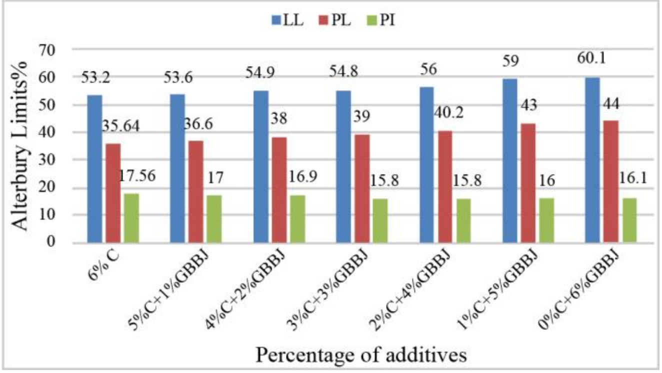

Fig. 5 Effect of varying cement-GBBJ content in laterite soil on Atterberg limits

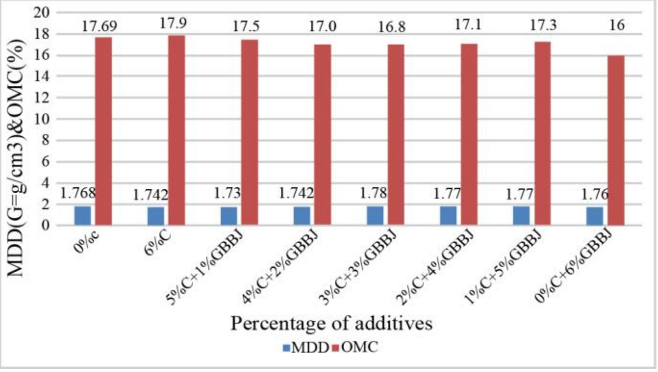

Fig. 6 Effect of varying cement-GBBJ content in laterite soil on MDD and OMC

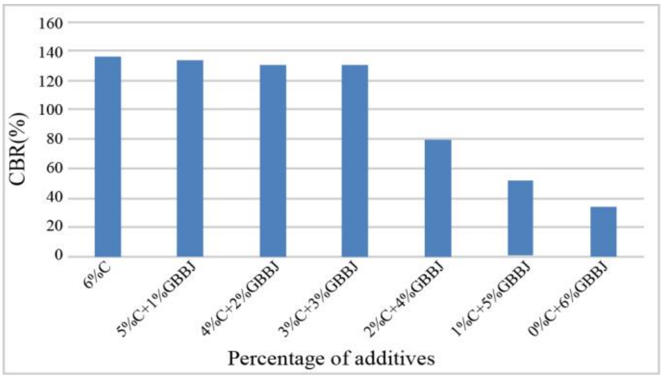

Fig. 7 Effect of varying cement-GBBJ content in laterite soil on

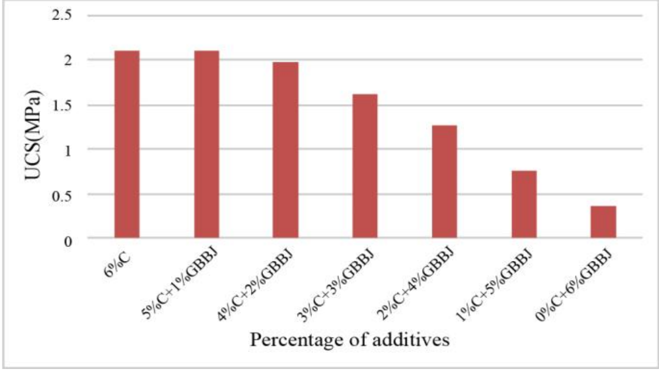

Fig. 8 Effect of varying cement-GBBJ content in laterite soil on UCS values

The results of the compaction test on the laterite-cement-GBBJ mixture are presented in Fig. 6. The MDD decreased from 1.74 to 1.73 g/cm^3 with the increase in GBBJ from 0 to 1%, but it increased from 1.74 to 1.77 g/cm^3 with the addition of 2 to 5% of GBBJ; it further slightly decreased from 1.77 to 1.76 g/cm^3 with the addition of 6% of GBBJ. The fact that the increase in GBBJ did not affect MDD that much may be justified by the liquid nature of GBBJ; it does not change the volume in the solid mixture. On the other hand, the OMC decreased from 17.9 to 16.8%, with the increase of GBBJ from 0 to 3%. However, it increased from 17.1 to 17.3% with an increase of GBBJ from 4 to 5%; it decreased from 17.3 to 16% with further addition of 6% of GBBJ. According to [21] and [22], the increase in OMC is due to the hydration of calcium oxide.

The results of the soaked CBR and UCS tests with laterite soil treated with various contents of the cement-GBBJ mixture are presented in Figures 7 and 8. The CBR value decreased from 136.4 to 33.7%, and the UCS value decreased from 2.1 to 0.37 MPa with an increase in GBBJ. Beyond 2% of GBBJ content, the decrease was drastic. However, there was an improvement in the soil strength with the GBBJ-cement mixture (4% cement +2% GBBJ) compared to the soil strength with only cement content (4%). This implies that GBBJ can improve the soil strengthening up to certain content. The reaction between the silica oxide and calcium oxide [23], which are predominant elements respectively in laterite soil and Grewia bicolour bark, could be the reason for such improvement as per Equation (1).

$$SiO_2 + CaO \rightarrow CaSiO_3 \qquad (1)$$

The newly formed compound $CaSiO_3$ in the mixture leads to a reaction called liming. This reaction makes $CaSiO_3$ behave as lime in the lateritic soil [24]. As a cementitious material, the metasilicate reinforces the bounding between the particles of lateritic soil. This reaction could have a cementitious effect on the lateritic soil and bind the soil particles together [25].

Analysing Fig. 7 and 8, the optimum mix of cement+GBBJ was 4% cement plus 2% GBBJ. The CBR value corresponding to the optimum mix is 130.47%, and the corresponding UCS is 1.98 MPa. The CBR value obtained does not satisfy the minimum specification of 160% stated in [17]. The UCS value is beyond the recommended one (1.8MPa). According to [20], the UCS after 7 days of curing is the most significant measure of strength when evaluating cement-stabilized materials used in road construction.

4. Conclusion

This study was performed to investigate the performance of GBBJ as a partial replacement of cement in the stabilisation of laterite soil stabilization. Many properties were evaluated, such as Atterberg limits, MDD, OMC, CBR, and UCS values.

The results showed that with 4%cement and 2%GBBJ by weight of dry soil, the UCS value, which is the main criterion to consider in road design, slightly decreased from 2.1 MPa to 1.9 MPa but still in the range recommended by the Kenya Roads Design Manual Part III. Furthermore, the performance achieved with 4% cement and 2% GBBJ (1.9 MPa) is greater than the one achieved with just 4% of cement (1.23 MPa). Beyond the 4%cement+2%GBBJ, the results obtained are below the required standards. It implies that GBBJ is a good material to partially replace cement in laterite soil for road base construction purposes.

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References

[1] M. S. Saleh, and A. B. Bala, “The Use of Gum Arabic as a Lateretic Soil Stabilizer,” *Journal of Sciences and Multidisciplinary Research*, vol. 2, 2010.

[2] B. Alabi and J. Fapohunda, “Effects of Increase in the Cost of Building Materials on the Delivery of Affordable Housing in South Africa,” *Sustainability*, vol. 13, no. 4, p. 1772, 2021. *Crossref*, https://doi.org/10.3390/su13041772

[3] G. U. Fayomi et al., “Perspectives on Environmental CO2 Emission and Energy Factor in Cement Industry,” *IOP Conference Series: Earth and Environmental Science*, vol. 331, no. 1, 2019. *Crossref*, https://doi.org/10.1088/1755-1315/331/1/012035

[4] “*The 2030 Agenda and the Sustainable Development Goals an opportunity for Latin America and the* Caribbean,” Goals, Targets and Global Indicators, United Nations Publication, 2018.

[5] R. Chen, L. Zhang, and M. Budhu, “Biopolymer Stabilization of Mine Tailings,” *Journal of Geotechnical and Geoenvironmental Engineering*, vol. 139, no. 10, pp. 1802-1807, 2013. *Crossref*, https://doi.org/10.1061/ (ASCE) GT.1943-5606.0000902

[6] I. Chang et al., “Effects of Xanthan Gum Biopolymer on Soil Strengthening,” *Construction and Building Materials*, vol. 74, pp. 65-72, 2015. *Crossref*, https://doi.org/10.1016/j.conbuildmat.2014.10.026

[7] A. Rimbarngaye, J. N. Mwero, and E. K. Ronoh, “Effect of Gum Arabic as Partial Replacement of Cement on the Durability Properties of Compressed Laterite Blocks,” *Open Journal of Civil Engineering*, vol. 11, no. 4, pp. 398-410, 2021. *Crossref*, https://doi.org/10.4236/ojce.2021.114023

[8] website, 2015. [Online]. Available: https://www.feedipedia.org/node

[9] Portland Cement Association, Soil-Cement Laboratory Handbook website, 1992. [Online]. Available: http://secement.org/wpcontent/uploads/2017/04/EB052.07s.pdf

[10] H. M. Jafer et al., “Assessing The Potential of a Waste Material for Cement Replacement and the Effect of its Fineness in Soft Soil Stabilisation,” *International Journal of Environmental, Chemical, Ecological, Geological and Geophysical Engineering*, vol. 9, no. 8, pp. 794-800, 2015.

[11] 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

[12] BS 1924-2:1990 Stabilized materials for civil engineering purposes, Methods of test for cement-stabilized and lime-stabilized materials (Withdrawn), 1990.

[13] H. F. Winterkorn, and E. C. Chandrasekharan, “Laterite Soils and Their Stabilization,” *Highway Research Board Bulletin*, no. 44, pp. 10-29, 1951.

[14] AASHTO. 2001b, 21st Ed, Standard Specification for Transportation Materials and Methods of Sampling and Testing, Washington, DC: American Association of State Highway and Transportation Officials.

[15] Giora Rozmarin “*ROAD DESIGN MANUAL - Part III - Materials & Pavement Design*,” Republic of Kenya, 1987.

[16] G. M. Ayininuola, and S. P. Abidoye, “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

[17] A. A. Nur et al., “Effect of Cement Stabilized Kaolin Subgrade on Strength Properties,” *Journal of Applied Sciences*, vol. 14, no. 8, pp. 842-845, 2014. *Crossref*, https://doi.org/10.3923/jas.2014.842.845

[18] 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

[19] O. E. Oluwatuyi et al., “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

[20] 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*, vol. 50, no. 21, pp. 1-9, 2017. *Crossref*, https://doi.org/10.4038/engineer.v50i1.7241

[21] B. D. Oluyemi, and Ayibiowu, “Effect of Cement on Asphalt - Emulsion Stabilised Lateritic Soils,” *International Journal of Innovative Science and Research Technology*, vol. 3, no. 5, pp. 159-172, 2016.

[22] 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

[23] K. J. Osinubi, “Influence of Compactive Efforts on Lime- Slag Treated Tropical Black Clay,” *Journal of Materials in Civil Engineering*, vol. 18, no. 2, pp. 175-181, 2006. *Crossref*, https://doi.org/10.1061/(ASCE)0899-1561(2006)18:2(175)

[24] R. Ferreira De Souza et al., “Carbonate-Silicate Ratio for Soil Correction and Influence on Nutrition, Biomass Production and Quality of Palisade Grass,” *Animal Science and Pastures*, vol. 68, no. 5, 2011. *Crossref*, https://doi.org/10.1590/S0103-90162011000500003

[25] V. Mohanalakshmi et al., “Geotechnical Properties of Soil Stabilized with Wollastonite,” *International Journal of Engineering Research & Technology*, vol. 5, no. 3, 2016. *Crossref*, http://dx.doi.org/10.17577/IJERTV5IS031046

[26] O. Agashua, Lucia, and S. Ogbiye, “Influence of Cement, Bitumen, and Lime on Some Lateritic Soil Samples as Pavement Material,” *IOP Conference Series: Materials Science and Engineering*, vol. 413, 2018. *Crossref*, https://doi.org/10.1088/1757-899X/413/1/012012

[27] 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