Stabilization of Expansive Subgrade Soil with Cow Dung Ash and Lime

Jacqueline Nikuze[1]*, Gershome Abaho G.[1], Adewole Kazeem K.[2] and Fidele Mbaraga[3]

[1,2,3] Department of Civil, Environmental, and Geomatics Engineering. School of Engineering, College of Science and Technology, University of Rwanda

*Corresponding Author: Jacqueline Nikuze, E-mail: jackynik97@gmail.com

Abstract

This paper presents the investigation made on cow dung ash (CDA) alone and a combination of CDA and lime for stabilizing expansive black clay soil with high plasticity used as a subgrade for road pavement. The study was mainly conducted to assess the performance of expansive black clay soil when stabilized with CDA and lime, and its suitability to solve the issue of structural damage identified on the road. The chemical compositions of lime, CDA, and natural unstabilized subgrade soil (control) were determined using X-ray fluorescence. The plastic limit (PL), plasticity index (PI), liquid limit (LL), linear shrinkage (LS), maximum dry density (MDD), optimum moisture content (OMC), free swell index (FSI), California bearing ratio (CBR) and unconfined compressive strength (UCS) of the control soil, the control soil mixed with varying quantities (0%, 6%, 10%, 14%, 20%, and 25% by dry weight of the soil) of CDA, and the control soil mixed with varying CDA-lime combinations consisting of mixtures of 5% lime with 10%,15% and 20% of CDA were determined experimentally. The experimental outcomes showed that the soil stabilized with the CDA-lime combination is synergistic, improves the CBR and UCS and lowers the PI, and swelling potential of the soil more than the soil stabilization with CDA alone.

Keywords: Stabilization, Expansive soil, Lime, Cow Dung Ash

1. INTRODUCTION

Clay-rich soils of smectite groups are expansive. The expansive nature of those clay-rich soils is problematic to supported structures because of the changes in the strength and the volume change clay-rich soils undergo due to fluctuations in their moisture contents with seasons. changes in the strength and volume of clay-rich soils cause structures to experience damage leading to the cracking and or failure of the structures. Damage to structures constructed on clay-rich soils due to clay mineralogy and environmental conditions has been observed in all continents except the polar continents (Steinberg, 1998). The UK reported an estimated cost of losses associated with expansive soil in the last ten years as £3 billion, while in the United States, the estimates exceed $15 billion each year (Jones & Jefferson, 2014).

The damages of structures constructed on problematic clay-rich soils were first identified in 1938 (Chen, 1975). Researchers have developed various treatment methods, such as the removal and replacement, surcharge loading, prewetting, remolding and compaction, chemical stabilization, and the use of horizontal and vertical barriers to control changes in moisture of the clay-rich soil to prevent or reduce the changes in volume and to increase the strength of expansive soils, thereby reducing or preventing damages to structures constructed on them (Al-

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Rawas & Goosen, 2006; Alazigha et al., 2016; Chindris et al., 2017; Karatai et al., 2017; Raviteja et al., 2018).

Cement, lime, or lime combined with industrial wastes such as fly ash, rice husk ash, pond ash, tyre rubber powder, waste of granite and quarry, cement kiln dust, silica fume, sugarcane bagasse ash, natural volcanic ash, and cow dung ash have been employed for the stabilization of expansive soils. A combination of lime and fly ash has been confirmed to efficiently and effectively lower the plasticity and swelling potential, and increase the strength of expansive soil (Magdi M. E. Zumrawi, 2014; Malhotra & Naval, 2013; Zhang & Cao, 2002). Karatai et al., (2017); Satish et al., (2018); and Seco et al., (2011) outcomes confirmed that a combination of rice husk ash (RHA) and lime improves the strength and engineering properties of expansive soil effectively. The use of cement kiln dust has been found to improve the CBR value of poor subgrade soil (Mosa et al., 2017) while its mixture with tyre rubber powder increased the strength characteristics and reduced the plasticity of expansive soils (Naseem et al., 2019), and an optimum amount of 5% TRP and 10% CKD were recommended. In their review, Thirumalai et al., (2017) noticed that the addition of industrial wastes, such as granite and quarry waste, cement kiln dust, silica fume, and rice husk, ameliorates the geotechnical properties like compaction properties, index properties, California bearing ratio (CBR), unconfined compressive strength (UCS), and swelling of problematic soil. Kumar Yadav et al., (2017) described a maximum increment in CBR by 134 %, 79.81 %, and 48.92 %, and UCS by 45.94 %, 27 %, and 38.51 %, together with volume stability when rural roads with a subgrade of alluvial soil were treated with RHA, sugarcane bagasse ash, and CDA respectively.

Cow dung ash (CDA) has been used effectively as a pozzolan in the partial replacement of Portland cement in concrete mix (Ramachandran et al., 2015; Rayaprolu & Raju, 2012; Samson & Moses, 2014; Venkatasubramanian et al., 2017). CDA has also been used as a soil stabilizer by (Kumar Yadav et al., 2017). However, the use of cow dung ash and lime combination for expansive soil stabilization has not been either considered or published yet. In this work, the use of cow dung ash alone and cow dung ash and lime combination for expansive soil stabilization are investigated for road construction.

2. MATERIALS AND METHODS

2.1. Materials

The investigation of the effectiveness of using CDA alone and a combination of CDA and lime as stabilizers was conducted on expansive clay soil samples excavated at a depth of 1.4m from the ground level near the segment of the road from the intersection of KK 3 Rd and KK 15 Ave to the intersection of KK 3 Rd and KK 17 Ave of the national road 4 (NR4) at the Gasabo district of Rwanda. Cow dung samples were obtained from a farm at Gisenyi village in Muyumbu sector, Rwamagana district of Rwanda. The sample of the lime used in this study was locally purchased from COCOCHAUMA (Cooperative de Commerce et Production de la Chaux de Mashyuza).

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(a) (b) (c) (d)

Figure 1: (a) Wet cow dang, (b) Dry cow dang, (c) Cow dung ash, (d) Lime

2.2. Methods

The physical properties, particle size distribution, PI, and natural soil classification were obtained experimentally using the relevant reference standards shown in **Error! Reference source not found.**. The Cow dung was sundried, burned at a temperature of 500^{o}C in an incinerator, cooled, and pulverized to powder. The pH and specific gravity of the soil, CDA, and lime were determined using $^{GTM-24}$ and ASTM D 854 as the reference standard. The chemical composition of natural unstabilized (control) soil, CDA, and lime was obtained using X-ray fluorescence as shown in **Error! Reference source not found.**, **Error! Reference source not found.**, and **Error! Reference source not found.**.

Sieve analysis, Atterberg limits, proctor compaction, UCS, FSI, bar linear shrinkage, and CBR tests were carried out on the soil samples (control), soil samples stabilized with varying proportions of CDA alone, and varying proportions of a CDA and lime combination. The aforementioned tests were conducted following the procedures in ASTM D 4609, ASTM D 5102, IS 2720 (Part 40), and BS 1377: Part 4 standards and test methods.

Dry control soil samples mixed with CDA alone and with a combination of CDA and lime were kept for one hour before the tests for the determination of the MDD and OMC. The dry soil samples used for the UCS and CBR tests were mixed thoroughly with water corresponding to its OMC and sealed in an airtight and moisture-proof bag for 24 hours to allow good chemical reactivity and material change before compaction. The specimens used for the UCS tests were compacted in proctor mould at the MDD and OMC and trimmed to obtain cylindrical UCS specimens of 38 mm in diameter and a length between 79 to 90 mm. The compacted specimens for the UCS test were wrapped in a plastic, moisture-proof bag and cured for seven days in a desiccator. The soil samples used to determine the FSI consisted of two sets of well-dried samples of ten grams, and a size of less than 425μm sieve put in two different graduated glass cylinders of 100 ml; one filled with kerosene and another filled with distilled water. The FSI was calculated after 24 hours as follows:

$\boldsymbol{FSI} = \frac{V_d - V_k}{V_k} \times 100$,   Where;

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FSI is the free swell index
V_d is The volume of soil sample obtained from the cylinder comprising distilled water
V_k is the volume of soil sample obtained from the cylinder comprising kerosene (IS 2720 part 40, 1977).
With the help of the Eads-Grim test, the minimal time required to stabilize the soil was 9% obtained at a maximum pH value of 12.04.

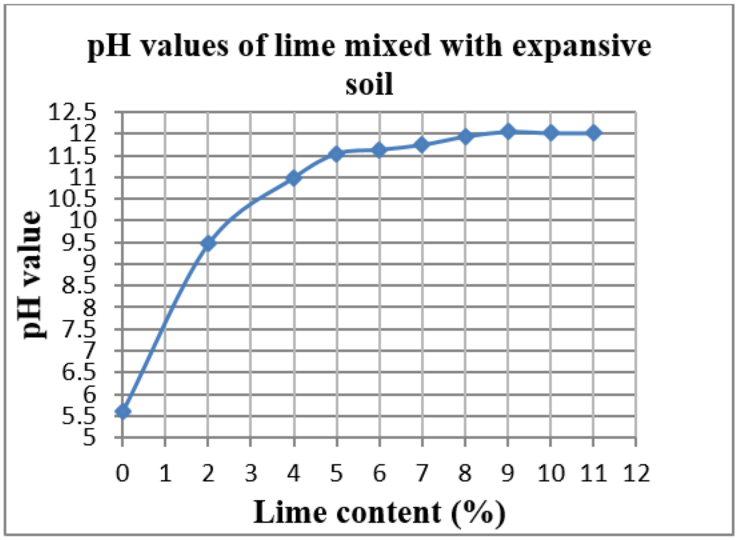

Figure 2: pH value and lime content

With the above correlation of pH value and lime content, the study maintained 5% of lime content correlating to 11.5 pH to evaluate the effect of CDA and lime. This is because it was intended to evaluate the capacity of CDA to stabilize the soil with a minimum content of lime.

3. RESULTS

The specific gravity, pH, particle size distribution, Atterberg limits, linear shrinkage, soil classification, MDD, OMC, FSI, CBR, and UCS of the control soil sample are presented in Table 1. While for stabilizers (CDA and lime) their pH and specific gravity are presented in Table 2. The chemical compositions of the CDA and lime in percentage (%) by weight are presented in Tables 4 and 5 respectively. The sieve analysis of soil, lime, and CDA, the variation of the Atterberg limits (LL, PL, PI) and linear shrinkage, MDD, OMC, CBR, UCS, strain at failure, and FSI of the soil treated with the varying percentages of CDA alone, and with the varying percentages of the combinations of the CDA and lime are shown from Figure 2 to Figure 12.

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Table 1: Properties and classification of the natural unstabilized soil sample (control)

Soil properties	Standard	Value	Studied Properties of soil	Standard	Value
Specific gravity	ASTM D854	2.61	Linear shrinkage		12.6
pH	GTM-24	5.6	Soil classification		
Particle size distribution			Unified Soil Classification System (USCS)	ASTM D2487	CH
Sand (%)	ASTM D422	9.47	American Association of State Highway and Transportation Officials (AASHTO)	ASTM D3282	A-7-6
Silt (%)	ASTM D422	62.59	Compaction test characteristics		
Clay (%)	ASTM D422	27.92	MDD (Kg/m3)	ASTM D 1557	1736
Atterberg limits (%)			OMC (%)	ASTM D 1557	16
Liquid limit	ASTM D4318	57.5	Free swell index (%)	IS: 2720 (Part 40)	112.5
Plastic limit	ASTM D4318	20.7	4 days soaked CBR (%)	BS 1377: Part 4	2.6
Plasticity index	ASTM D4318	36.8	UCS (KPa)	ASTM D 2166	293.8

As shown in Table 1 above the result indicates that the soil belongs to CH which means that it is very poor soil with a low load-bearing capacity which could impact its ability to support road structures.

Table 2: The pH and the specific gravity of CDA and lime

Material	pH	Specific gravity
CDA	9.5	2.55
Lime	12.12	2.38

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Table 3: Chemical compositions of the control soil in % by weight

MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	ZrO_2	Mn_2O_3	Fe_2O_3	ZnO	SrO	ZrO_2
4.68	16.55	57.61	0.23	2.15	2.15	2.05	0.17	0.06	10.73	0.03	0.02	0.17

Table 4: Chemical compositions of the CDA in % by weight

SiO_2	CaO	K_2O	Fe_2O_3	MgO	Al_2O_3	P_2O_5	SO_3	TiO_2	Mn_2O_3	ZnO	SrO	ZrO_2
59.5	11.9	6.11	5.75	4.92	4.51	2.75	1.09	0.7	0.48	0.11	0.11	0.05

Table 5: Chemical compositions of the lime in % by weight

CaO	MgO	SiO_2	Al_2O_3	Fe_2O_3	SrO	TiO_2	P_2O_5	Ba O	Cr_2O_3	Mn_2O_3
79.6	4.8	3.1	2.71	0.39	0.35	0.21	0.2	0.11	0.05	0.03

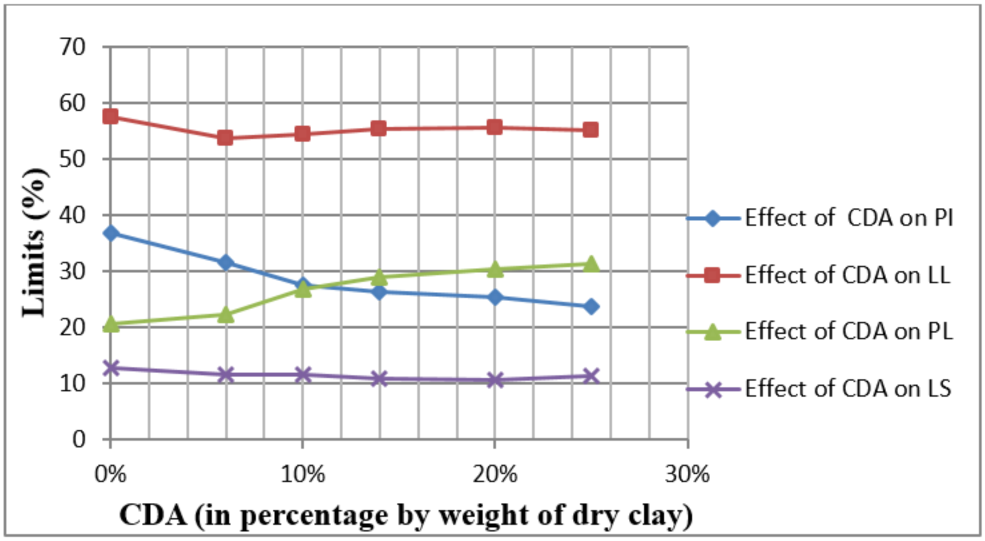

Figure 3: Effect of CDA on Atterberg limits and linear shrinkage

Figure 3 shows that the addition of 6%, 10%, 14%, 20%, and 25% CDA to the soil resulted in 7.6%, 7.7%, 14.2%, 15.3%, and 9.8% reductions in the linear shrinkage; and 14.4%, 25%, 28.5%, 31%, and 35.3% reductions in the plasticity index.

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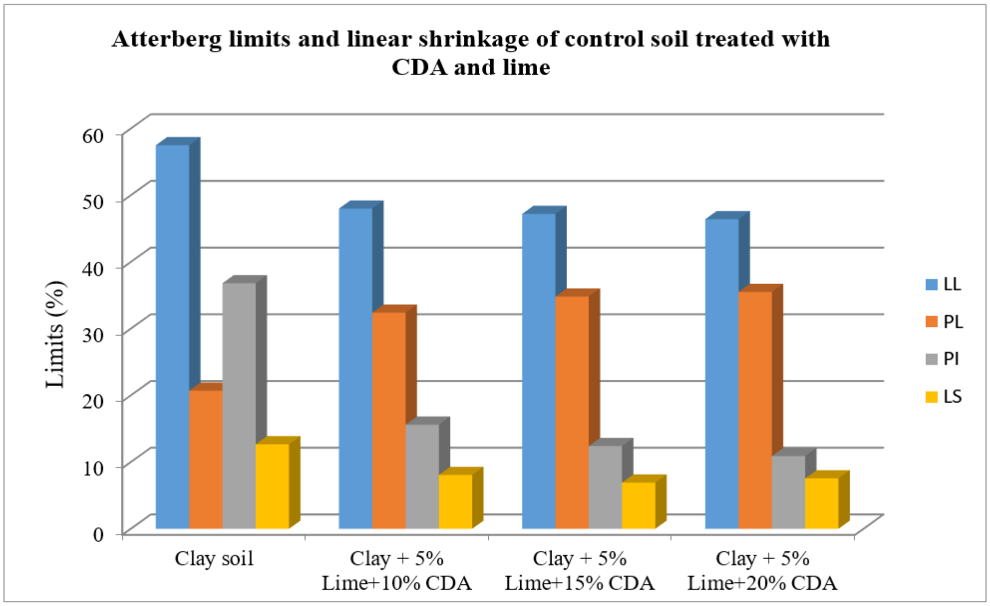

Figure 4: Atterberg limits and linear shrinkage of soil with varying CDA-lime combination contents

Figure 4 shows that the addition of the combinations of 5% Lime and 10% CDA, 5% Lime and 15% CDA, and 5% Lime and 20% CDA, reduced the liquid limit by 16.5%, 17.9%, and 19.3%; the linear shrinkage by 36.2%, 45.3%, 40.3%, and reduced the plasticity index by 57.6%, 66.3%, and 70.4% respectively.

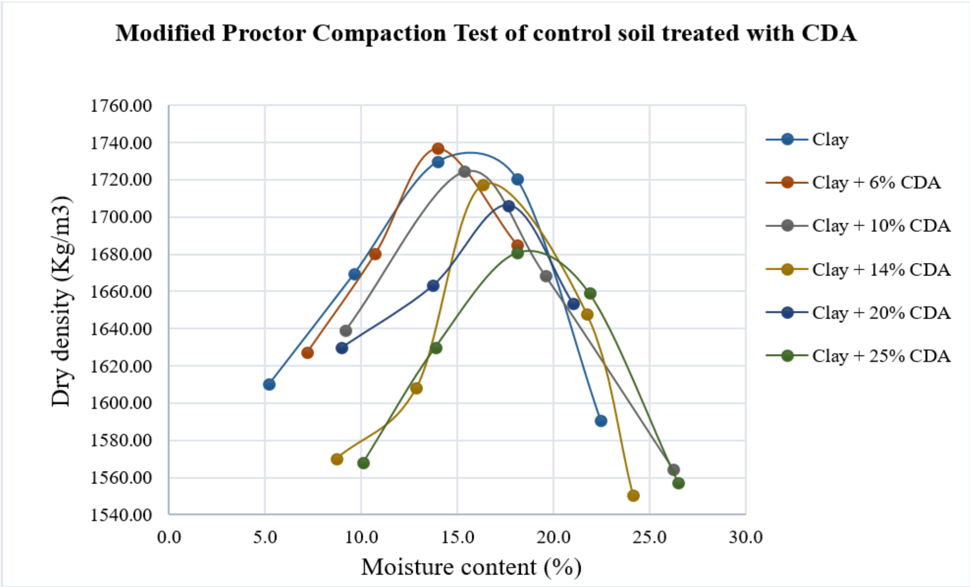

Figure 5: Compaction curves of soil with varying CDA contents

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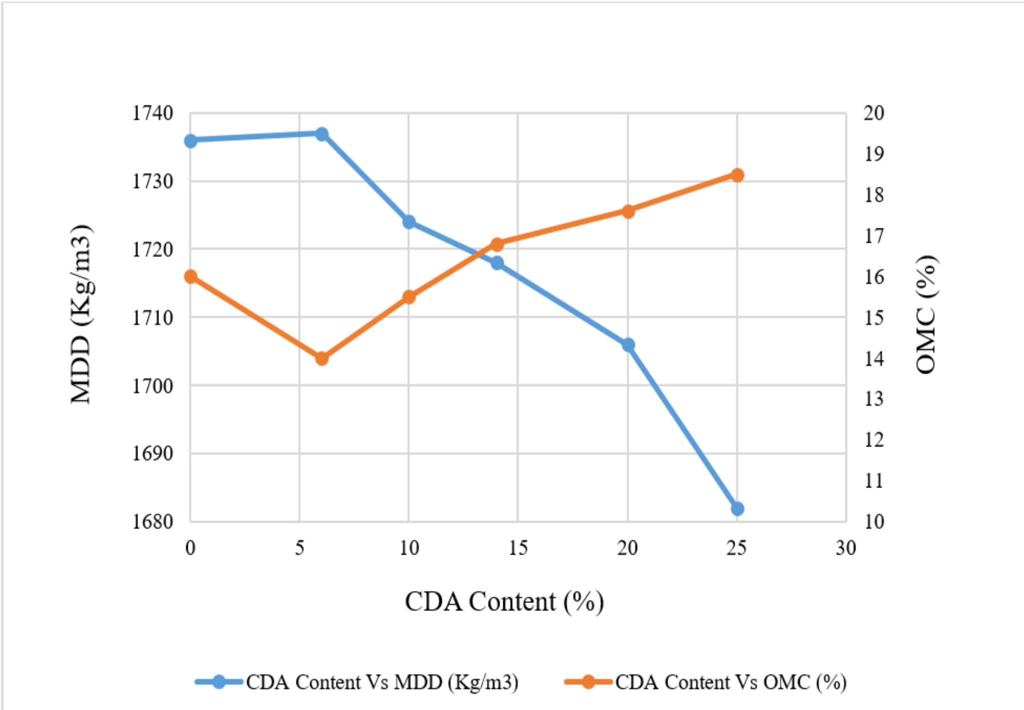

Figure 6: Variation of MDD and OMC with CDA

Figures 5 and 6 show that the MDD decreases, and the OMC increases with the increase of CDA content.

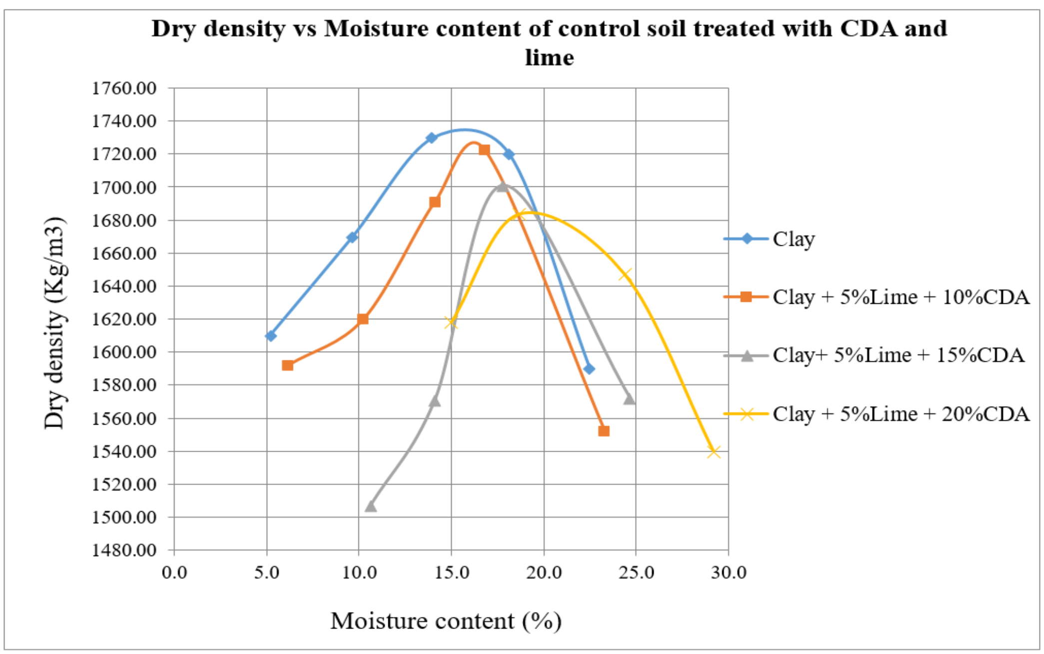

Figure 7: Compaction curves of soil with varying CDA-lime combination contents

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Figure 7 shows that the OMC of the soil samples treated with lime and CDA at different ash and lime content were greater than that of control soil, whereas the MDD of all trials went on the decrease with lime-ash content compared to MDD of natural untreated clay soil.

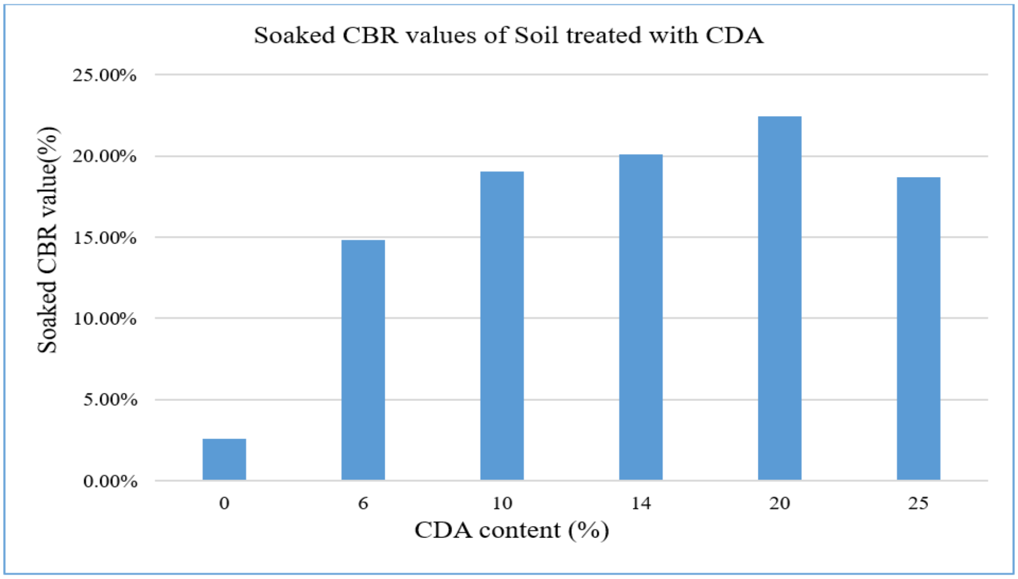

Figure 8: CBR value of soil treated with CDA

Figure 8 shows that the addition of 6%, 10%, 14%, and 20% CDA increases the CBR value of the control (unstabilized) clay soil from 2.6% to 14.8%, 19%, 20.1%, and 22.4% respectively.

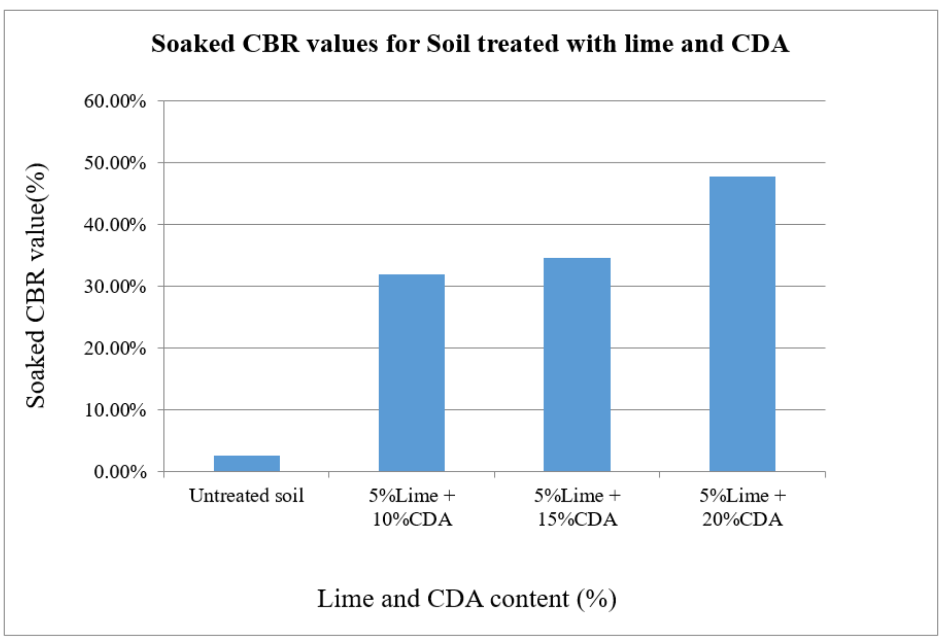

Figure 9: CBR value of soil treated with lime and CDA

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Figure 9 shows that the CBR values of the soil stabilized with the combinations of 5% lime with 10%, 15%, and 20% CDA are 31.94%, 34.59%, and 47.83% from the strength of the control soil sample respectively.

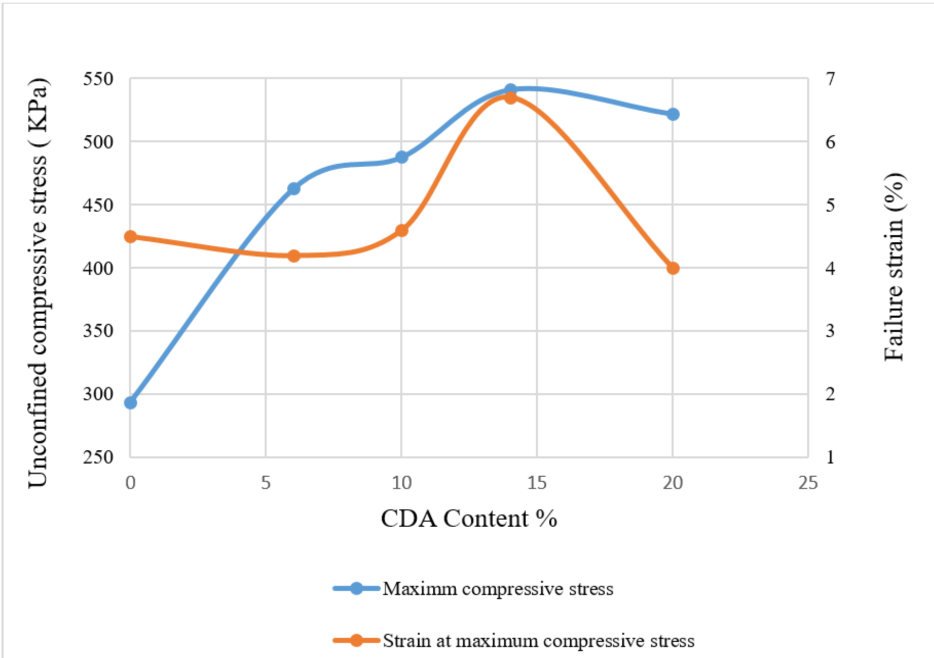

Figure 10: UCS and strain at failure of soil with varying CDA contents

Figure 10 shows that the addition of 6%, 10%, 14%, and 20% CDA increases the UCS of control (unstabilized) clay from 293.8KPa to 462.7KPa, 487.8KPa, 541.3KPa, and 521.9KPa, respectively while the strain at maximum compressive stress was between 4 and 6.7

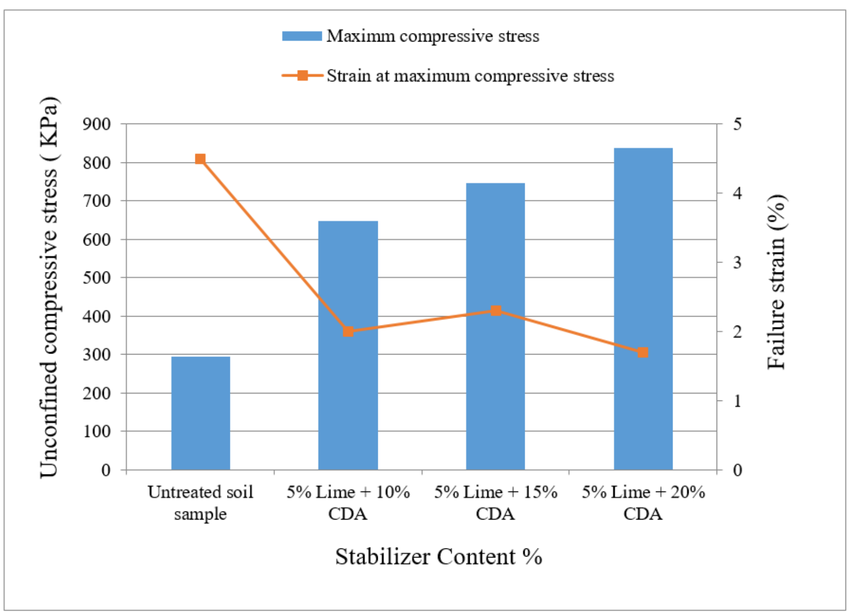

Figure 11: UCS and strain at failure of soil with varying lime-CDA combination contents

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Figure 11 shows that the UCS values of soil treated with the combinations of 5% lime with 10%, 15%, and 20% CDA are 648KPa, 747.1KPa, and 838.1KPa respectively. The strain values are 2%, 2.3%, and 1.7% for 5% lime + 10% CDA, 15% CDA, and 20% CDA respectively.

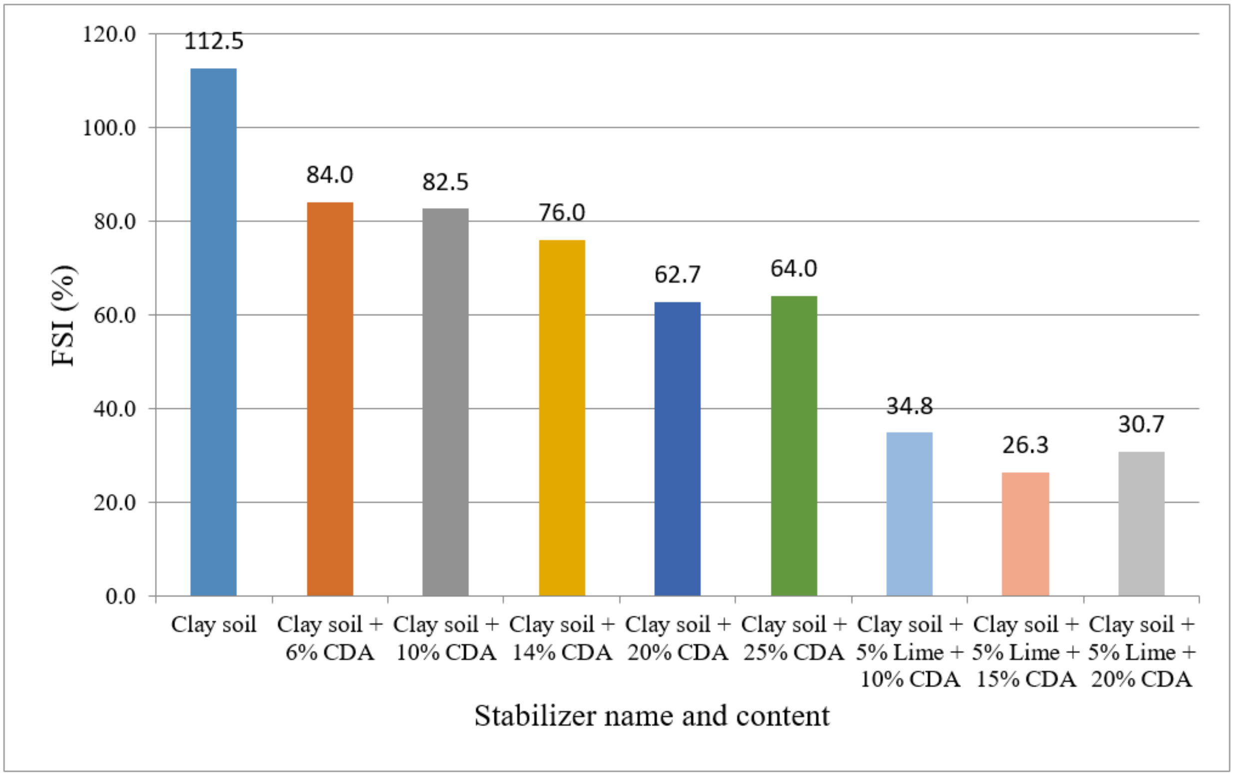

Figure 12: FSI of soil with varying CDA and CDA-lime combination contents

4. Discussions

4.1. Effect of CDA and CDA-lime combination on Atterberg Limits

As shown in Figure 3, The reduction in linear shrinkage shows that the soil stabilized with CDA is less likely to crack and deform during drying, this plays a crucial role in maintaining the integrity of structures built on such soil. while the reduction in plasticity index indicates that the soil is less prone to alterations in volume and moisture. These results agree with the results obtained by Yadav et al. (2017) for alluvial soil stabilized with CDA. These results demonstrate that the higher the CDA content, the higher the reductions in the linear shrinkage, plasticity index, and liquid limit, and the higher the increase in the plastic limit.

Figure 4 shows that the combination of lime and CDA resulted in more substantial reductions in both linear shrinkage and plasticity index compared to the use of CDA alone. This indicates that the combination of lime and CDA may have synergistic effects, leading to less susceptibility to changes in moisture, and less prone to swelling and instability.

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4.2. Effect of CDA and CDA-lime combination on the compaction behavior, MDD, and OMC

As shown in Figures 5, 6, and 7, the reduction in the MDD of the clay soil treated with the CDA alone, and lime-CDA combination might be due to the coarser particles' formation during the flocculation and agglomeration process due to cation exchange within the clay, CDA, and lime particles. The bigger particles formed during the flocculation, and agglomeration process occupy spaces of great size in the soil matrix and increase the volume of void, thereby reducing the dry density of soil stabilized with the lime-CDA combination.

4.3. Effect of CDA and CDA-lime combination on CBR

As shown in Figure 8, the addition of CDA improves the CBR values of the soil up to 20%, beyond which further addition leads to a decrease in CBR. This is because disproportionate CDA addition reduces the strength due to excessive cementitious gel formation. As shown in Figure 9, the combination of lime and CDA is synergistic and leads to a significant improvement in the control soil strength. Therefore, it can be a potent method for soil stabilization.

4.4. Effect of CDA and CDA-lime combination on UCS

As shown in Figure 10, the UCS and axial strain increase with increased CDA content up to 14%. A decrease in UCS and axial strain was observed beyond 14% CDA content. It seems that at 14% the clay soil stabilized with CDA alone exhibits higher deformability while maintaining a relatively high compressive strength. As shown in Figure 11, The combination of lime and CDA in expansive clay soil stabilization resulted in higher compressive strength and reduced strain compared to CDA alone. This reduction in strain indicates that lime has a great role in improving stability and reducing deformability.

4.5. Effect of CDA and CDA-lime combination on FSI

As shown in Figure 12, the FSI decreases from 112.5% to 84%, 82.5%, 76%, 62.7% and 64% with the additional 6%, 10%, 14%, 20%, and 25% of the CDA contents respectively. Also, it shows a high decrease in FSI to 34.8%, 26.3%, and 30.7% for the soil treated with the combinations of 5% lime with 10%, 15%, and 20% CDA respectively. Based on the IS 1498-1970 classification reaffirmed in 2007, the soil expansion potential changed from high level to medium level, while for the expansive soil sample stabilized with lime-CDA combinations, the expansion potential changed from high potential to low potential.

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5. Conclusions

The use of CDA alone and a CDA-lime combination to stabilize expansive subgrade clay soil with high plasticity is investigated. The chemical compositions of the lime, CDA, and natural unstabilized soil (control) soil were obtained using X-ray fluorescence. The Atterberg limits test, proctor compaction test, UCS test, free swell tests, and CBR test were conducted on the control soil, the soil stabilized with varying CDA quantities (0%, 6%, 10%, 14%, 20%, and 25% by dry weight of the control soil), and the soil treated with a varying CDA-lime combination consisting of a mixture of 5% lime with 10%,15% and 20% of CDA. The LS and FSI of the treated soil reduce as the CDA content in the soil samples increases up to the optimum CDA content of 20%. The LS and FSI of the treated soil reduce as the CDA of the lime-CDA combination content in the soil samples increases up to the optimum lime-CDA content of 5% lime and 15% CDA. The UCS of the treated soil increases as the CDA content in the soil samples rises to the optimum CDA content of 14% while the CBR of the treated soil increases as the CDA content in the soil samples rises to the optimum CDA content of 20%. The UCS and CBR of the treated soil increase as the CDA content of the lime-CDA combination content of the soil samples increases for all samples tested. The addition of lime and CDA combination reduces the PI, LS, and FSI, and increases the UCS and CBR better than CDA alone. Thus, CDA alone and lime-CDA combination can contribute to the improvement of the strength and swelling potential of the expansive clay soil. The lime-CDA combination is synergistic and leads to a significant improvement of the strength and the swelling potential of the black expansive clay soil more than CDA alone and thus can be a potent method for stabilization of the black expansive clay soil.

6. References

Al-Rawas, A. A., & Goosen, M. F. A. (Eds.). (2006). Expansive Soils: Recent advances in characterization and treatment. Taylor & Francis/Balkema P.O. Box 447, 2300 AK Leiden,The Netherlands.

Alazigha, D. P., Indraratna, B., Vinod, J. S., & Ezeajugh, L. E. (2016). The swelling behaviour of lignosulfonate-treated expansive soil. Proceedings of the Institution of Civil Engineers: *Ground Improvement*, 169(3), 182–193. https://doi.org/10.1680/jgrim.15.00002

ASTM D 1557-12. (2012). ASTM D 1557-12, Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort. *ASTM International, West Conshohocken*, PA 19428-2959, United States, 91(September 2000), 1–11. https://doi.org/10.1520/D1557-12.1

ASTM D 2166-06. (2007). ASTM D2166-06 Standard Test Method for Unconfined Compressive Strength of Cohesive Soil. *ASTM International,* West Conshohocken, PA 19428-2959, United States, January.

ASTM D 4609-01. (2002). ASTM D 4609-01. ASTM International, West Conshohocken, PA 19428-2959, United States, i, 1–5.

ASTM D 5102 -96. (1996). ASTM D 5102 - 96 Standard Test Method for Unconfined Compressive Strength of Compacted Soil-Lime Mixtures (Vol. 04).

https://dx.doi.org/10.4314/rjeste.v6i1.1

ASTM D 854-02. (2002). ASTM D 854 - 02 Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer. In *ASTM International*, *West Conshohocken*, PA 19428-2959, United States.

ASTM D422. (2007). Standard Test Method for Particle-Size Analysis of Soils. Astm, D422-63(Reapproved), 1–8. papers2://publication/uuid/32E2AE22-8555-4A27-B8B6-F7217202A1F2

ASTM D4318. (2005). Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils. Report, 04(March 2010), 1–14. http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Standard+Test+Methods+for+Liquid+Limit+,+Plastic+Limit+,+and+Plasticity+Index+of+Soils#1

Bureau of Indian Standards. (1977). IS 1977 Determination of Free Swell Index of Soils. Indian Standard Code, 1–6.

Chen, F. H. (1975). Foundations on expansive soils. ELSEVIER SCIENTIFIC PUBLISHING COMPANY. https://doi.org/10.1016/b978-0-444-99877-4.50001-x

Chindris, L., Stefanescuu, D. P., Radermacher, L., Radeanu, C., & Popa, C. (2017). Expansive soil stabilization - General considerations. International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM, 17(32), 247–256. https://doi.org/10.5593/sgem2017/32/S13.033

GTM-24. (2015). Test Method for the Determination of pH Value of Water or Soil by pH Meter. *Geotechnical Engineering Bureau*, August 7.

IS 1498-1970. (2016). Classification and identification of soils for general engineering purposes. BUREAU OF INDIAN STANDARDS, NEW DELHI, 1–24.

Jones, L. D., & Jefferson, I. (2014). Expansive soils. Institution of Civil Engineers Manuals Series, January 2012, 52–55. https://doi.org/10.1016/b978-1-4831-6762-6.50015-0

Karatai, T. R., Kaluli, J. W., Kabubo, C., & Thiong'o, G. (2017). Soil Stabilization Using Rice Husk Ash and Natural Lime as an Alternative to Cutting and Filling in Road Construction. *Journal of Construction Engineering and Management*, 143(5), 04016127. https://doi.org/10.1061/(ASCE)co.1943-7862.0001235

Kumar Yadav, A., Gaurav, K., Kishor, R., & Suman, S. K. (2017). 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*, 10(3), 254–261. https://doi.org/10.1016/j.ijprt.2017.02.001

Magdi M. E. Zumrawi, O. S. M. H. (2014). Improving the Characteristics of Expansive Subgrade Soils Using Lime and Fly Ash. *International Journal of Science and Research* (IJSR), 3(12), 1124–1129. https://www.ijsr.net/archive/v3i12/U1VCMTQ2MDg=.pdf

Malhotra, M., & Naval, S. (2013). Stabilization of Expansive Soils Using Low-Cost Materials. *International Journal of Engineering and Innovative Technology*, 2(11), 181–184.

Mosa, A. M., Taher, A. H., & Al-Jaberi, L. A. (2017). Improvement of poor subgrade soils using cement kiln dust. Case Studies in Construction Materials, 7(April), 138–143. https://doi.org/10.1016/j.cscm.2017.06.005

Naseem, A., Mumtaz, W., Fazal-e-Jalal, & De Backer, H. (2019). Stabilization of Expansive Soil Using Tire Rubber Powder and Cement Kiln Dust. *Soil Mechanics*

https://dx.doi.org/10.4314/rjeste.v6i1.1

and Foundation Engineering, 56(1), 54–58. https://doi.org/10.1007/s11204-019-09569-8

Ramachandran, D., Vishwakarma, V., Anbarasan, N., Viswanathan, K., George, R. P., Kumari, K., & Venkatachalapathy, V. (2015). Studies of Strength, Durability and Microstructural Properties of Cow Dung Ash Modified Concrete. 2nd RN Raikar Memorial Intl. Conference & Banthia-Basheer Intl. Symposium on ADVANCES IN SCIENCE & TECHNOLOGY OF CONCRETE, May 2016, 284–291.

Raviteja, K. V. N. S., Ramu, K., & Babu, R. D. (2018). Advances in Characterization and Analysis of Expansive Soils and Rocks (Vol. 1). https://doi.org/10.1007/978-3-319-61931-6

Rayaprolu, V. S. R. P. K., & Raju, P. P. (2012). Incorporation of Cow dung Ash into Mortar and Concrete. International Journal of Engineering Research and Applications, 2(3), 580–584.

Samson, D., & Moses, O. T. (2014). Investigating the Pozzolanic Potentials of Cowdung Ash in Cement Paste and Mortars. Iiste, 6(8), 110–117.

Satish, S., Koganti, S. P., Raja, K. H., & Sai, K. R. (2018). Stabilization of black cotton soil by using cement, lime and rice husk in flexible pavements. *International Journal of Engineering and Technology* (UAE), 7(2), 24–27. https://doi.org/10.14419/ijet.v7i2.1.9877

Seco, A., Ramírez, F., Miqueleiz, L., & García, B. (2011). Stabilization of expansive soils for use in construction. *Applied Clay Science*, 51(3), 348–352. https://doi.org/10.1016/j.clay.2010.12.027

Steinberg, M. L. (1998). Geomembranes and the control of expansive soils in construction (p. 222). https://trid.trb.org/view/655499

Thirumalai, R., Babu, S. S., Naveennayak, V., Nirmal, R., & Lokesh, G. (2017). A Review on Stabilization of Expansive Soil Using Industrial Solid Wastes. *Engineering*, 09(12), 1008–1017. https://doi.org/10.4236/eng.2017.912060

Venkatasubramanian, C., Muthu, D., Aswini, G., Nandhini, G., & Muhilini, K. (2017). Experimental studies on the effect of cow dung ash (pozzolanic binder) and coconut fibre on the strength properties of concrete. IOP Conference Series: *Earth and Environmental Science*, 80(1). https://doi.org/10.1088/1755-1315/80/1/012012

Zhang, J. R., & Cao, X. (2002). Stabilization of expansive soil by lime and fly ash. *Journal Wuhan University of Technology, Materials Science Edition*, 17(4), 73–77. https://doi.org/10.1007/bf02838423