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Investigating the Use of Kiln Dusts in Stabilization of Expansive Clay Soils for Use as a Subgrade Material in Road Construction

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Abstract

The general objective was to investigate the use of kiln dusts in the stabilization of expansive clay soils for use as a subgrade material in road construction. This study focused on stabilizing *in situ* expansive clay soils found in three different road construction projects in Nyandarua County using cement and lime kiln dusts. The preparations involved the acquisition of soil materials from the road projects and CKD and LKD materials from Machakos (Athi River) and Nakuru (Salgaa). The tests carried out were chemical tests on CKD and LKD, and mechanical tests on NEAT expansive clay soils and kiln-dust-stabilized expansive clay soils. The study established that stabilization with cement kiln dust (CKD), lime kiln dust (LKD), and their 50:50 blend significantly improved the soil's engineering properties. Plasticity index reduced to 6.8%, 6.3%, and 5.5% for CKD, LKD, and CKD-LKD, respectively, while swell potential decreased by up to 97%. Compaction characteristics improved with reduced optimum moisture content and increased maximum dry density. Strength performance also improved, with the soaked CBR increasing from 4.8% in untreated soil to 7.5% with CKD, 6.5% with LKD, and 45% with the CKD-LKD blend. The study recommends that road agencies and contractors consider incorporating the kiln dusts in subgrade designs and promote the use of locally available kiln dusts as a sustainable stabilization material for subgrades.

Keywords

Expansive Clay Soils, Soil Stabilization, Cement Kiln Dust, Lime Kiln Dust

1. Introduction

Expansive clay soils pose a great deal of difficulty because of their sensitivity to volumetric changes with different moisture levels. These challenges are compounded by the widespread occurrence of swelling clay, which can seriously harm infrastructure, especially in arid or semi-arid areas. The geotechnical qualities of these soils have been improved through the use of various additives and techniques, resolving this problem and making the soils suitable for construction [1]. Expansive soils are found in many parts of the world, especially in arid and semi-arid regions, when rainy conditions follow protracted periods of drought. The application of industrial wastes to soil in civil engineering construction has recently been receiving attention in several countries, including the United States of America, the United Kingdom, the European Region, and India. The idea of utilizing industrial wastes in productive construction is a sustainable strategy and is being promoted under the Green Development Initiative (GDI) to conserve the environment from their negative impacts. The main stabilizers used globally are: kiln dust, foundry sand, marble dust, and quarry dust. Other wastes from agricultural-based activities are rice-husk ash, corn-husk ash, or bagasse ash [2].

Expansive clay soils are a major problem in all road construction works all over the world [3]. This material is classified as an S1 subgrade (CBR between 2% - 5%) since it has very low structural strength (recommended CBR for subgrade > 14%); it also has a very high plasticity index of more than 35% (recommended P.I for subgrade < 18%). Also, the swell due to saturation is more than 2% (recommended swell for subgrade <1%), making it very unsuitable for any road works layers. Soil stabilization is a method of enhancing the engineering characteristics of soft clay by mixing stabilizers with the soil. The purpose of this technique is to improve soil compressibility, compressive strength, plasticity, durability, and soil permeability.

Silty and clay soils that are encountered in Michigan, USA, often pose design and constructability challenges in road construction projects. The solution to weak soils has been to remove and replace them with suitable material. The earthwork volume involved in undercutting is very large, given the large extent of the road network that spans over weak soils that the Department of Transportation is required to maintain, especially in the more populated areas. The use of cement kiln dust (CKD) or lime kiln dust (LKD) as a subgrade stabilizer has been proven as a cost-effective solution to stabilize expansive soils [4]. In Jiangsu Province, China, expansive soils underlie a range of important slope engineering projects, where repeated slope instabilities pose severe risks to transportation corridors, embankments, and other critical structures. Historically, civil engineers have relied on cement and lime as primary stabilizing agents to mitigate these deleterious volume-change effects. While undeniably effective in controlling soil swelling and improving load-bearing capacity, these conventional stabilizers pose critical challenges in the modern era due to their carbon-intensive production processes. Consequently, identifying low-carbon alternatives that retain or exceed the efficacy of traditional methods has emerged as a central focus in soil improvement science, reflecting the broader movement toward climate-responsive infrastructure development [5].

In Algeria, several methods have been proposed to improve the physical and mechanical properties of poor soils. Chemical stabilization is a technique mainly used to improve workability, bearing capacity, swelling/shrinkage potential, and permeability of problematic soils. Portland cement and quicklime are the two substances that are most frequently employed in soil stabilization. Adding CKD and CKD-LKD blend decreases the maximum dry density and improves the moisture content [6]. The expansive clay soils, which cover most of the new urbanized areas in Egypt, create major damage in most of the engineering structures and infrastructures, such as buildings, roads, bridges, and pipelines. These geotechnical challenges and their treatment solutions consume most of the urbanized project budget and delay the development plan. The high plasticity and soft to firm clay soils were stabilized using various dosages of fresh cement kiln dust (CKD) as an economical alternative to the other expensive stabilizing agents (stabilizers or binders) such as lime, cement, and other chemical stabilizers [7]. The construction of rural roads in Nigeria has been a great challenge over the years, with the situation giving serious concerns to the stakeholders. Many factors have been adduced to poor soil materials and construction methodology. Stabilization of soils for road pavement construction has been a major technique employed in improving the engineering properties of soil that fail to meet the acceptable criteria of plasticity index, shrinkage, density, and strength. The method has been used on many soil terrains during the construction of major roads in different parts of the country [8]. Utilization of CKD as a soil stabilizer in Uganda not only provides an alternative method of disposing of CKD but also reduces energy consumption, greenhouse gas emissions, and landfilling, as well as ongoing environmental challenges. Adding Cement Kiln Dust (CKD) significantly improved soil properties, reducing liquid limit and plasticity index. CKD also enhanced compaction characteristics, unconfined compressive strength (UCS), and California Bearing Ratio (CBR), attributed to pozzolanic reactions and cementitious compound formation. Cement Kiln Dust stabilized and improved the engineering properties of weak subgrade soils with adequate reactive CaO_2 and Al_2O_3 [9].

Large areas of Kenya are covered with expansive clay soils, commonly known as black cotton soils. These soils exhibit significant volume changes when wet or dry. Typical damage to roads on expansive clay soils includes longitudinal unevenness and bumpiness, differential movement near culverts, and longitudinal cracking. Expansive clay soils generally owe their expansive characteristics to their constituent clay minerals, especially montmorillonite, and to their natural and imposed environments. It is believed that the primary source of residual expansive clay soils is the in-situ weathering of basic igneous, metamorphic, and pyroclastic rocks, which occur in abundance in Kenya [10].

2. Research Methodology

2.1. Research Design

This study adopted a laboratory-based experimental research design aimed at evaluating the effectiveness of Cement Kiln Dust (CKD) and Lime Kiln Dust (LKD) as stabilizing agents for expansive clay soils used as subgrade material in road construction. The design involved systematic characterization of raw materials, controlled stabilization experiments at varying dosages, and comprehensive geotechnical testing to assess improvements in engineering properties. This experimental approach enabled direct comparison between untreated (neat) and treated (stabilized) soils under standardized laboratory conditions, following relevant ASTM and British Standard (BS) procedures. The methodology was structured to ensure reproducibility, reliability, and scientific rigor.

2.2. Materials

The primary materials used in this study were expansive clay soils, Cement Kiln Dust (CKD), and Lime Kiln Dust (LKD). Expansive clay soils, representing problematic subgrade materials common in Kenya's highland regions, were collected from selected road alignment sites in Nyandarua County. CKD and LKD were sourced from major cement and lime manufacturing plants due to their pozzolanic and calcium-rich properties, making them suitable alternatives. All materials were collected, handled, and stored in accordance with ASTM and BS standards to preserve their chemical and physical integrity before testing.

2.3. Sampling of Expansive Clay Soils

Thirty samples of the expansive soils were collected from three different road projects along their alignments (10 samples per project spaced at 500 M apart - 5 KM section) in Nyandarua County: RWC 567 (Ndaragwa Constituency), RWC 589 (Ol Kalou Constituency), and RWC 596 (Kinangop Constituency). A stratified random sampling technique, guided by NTCP 103.1 standards, was employed. Stratification was based on subgrade depth, moisture exposure zones, and observable in-situ soil conditions. Sampling points were randomly selected within each stratum to minimize bias and ensure representative coverage. A minimum separation distance of 50 km was maintained between project sites to capture spatial variability in clay mineralogy, swelling potential, and moisture regimes. Samples were sealed in airtight polythene bags and labeled with location coordinates, depth, moisture condition, and project ID.

2.4. Sampling of Stabilizers (CKD and LKD) Materials

CKD samples were obtained from three major cement manufacturing plants in Athi River, Machakos County: Bamburi Cement, Simba Cement, and East African Portland Cement (EAPC). LKD samples were collected from lime production facilities in the same region. Three 50 kg samples of each stabilizer were collected from each plant. The plants were purposively selected because they utilize locally produced clinker, ensuring comparable chemical reactivity and pozzolanic potential. Samples were packed in sealed cement bags and transported under controlled conditions to prevent moisture contamination and maintain homogeneity.

2.5. Material Characterization

Comprehensive characterization was performed on both the expansive clay soils and the stabilizers (CKD and LKD) to establish baseline engineering properties.

For Expansive Clay Soils:

- Natural Moisture Content (BS 1377: Part 2).
- Atterberg Limits (Liquid Limit, Plastic Limit, and Plasticity Index) using cone penetrometer and rolling methods (BS 1377).
- Linear Shrinkage (BS 1377).
- Particle size distribution (BS 1377).
- Standard and Modified Proctor Compact Tests (AASHTO T99 and T180).
- California Bearing Ratio (CBR)- unsoaked and soaked (AASHTO T193).

2.6. For CKD and LKD

- Chemical composition (ASTM C114).
- Fineness, specific gravity, and moisture content (ASTM C311).
- All tests followed standardized procedures outlined in BS 1377 and AASHTO specifications. Samples were prepared in accordance with BS 1377 Part 1 (drying, pulverizing, quartering, and sieving) before testing.

2.7. Stabilization Experiments

Stabilization trials were conducted by combining predetermined percentages of CKD, LKD, and CKD-LKD blends with the expansive clay soils. Mixture preparation followed BS 1924 guidelines for cementitious and lime-based soil stabilization. The stabilizers were first blended with dry soil to ensure uniform distribution. Tested and approved water was then added to achieve the Optimum Moisture Content determined from compaction tests. The mixtures were thoroughly mixed, sealed in airtight containers, and allowed to cure before testing. Performance was assessed by comparing untreated and stabilized samples across varying stabilizer dosages.

2.8. Laboratory Testing of Stabilized Samples

Stabilized samples underwent the same geotechnical tests as natural soils, including Atterberg Limits, Linear shrinkage, Compaction characteristics, and California Bearing Ratio (CBR)—unsoaked and soaked. These tests quantified improvements in plasticity, volumetric stability, compaction behaviour, and load-bearing capacity resulting from kiln dust stabilization.

2.9. Data Analysis

Laboratory data were analyzed using descriptive statistics to evaluate the effectiveness of kiln dusts and their blends in stabilizing expansive clay soils. Descriptive statistics were computed to quantify improvements in key geotechnical properties, including Atterberg limits (Liquid Limit, Plastic Limit, and Plasticity Index), Linear Shrinkage, compaction characteristics (Optimum Moisture Content and

Maximum Dry Density), and strength properties (California Bearing Ratio—unsoaked and soaked). Comparative analysis was performed to evaluate the relative performance of CKD, LKD, and CKD-LKD blends at different dosages (i.e., 5%, 10%, 15%, and 20%). Trends were visualized using line graphs and bar charts to illustrate the relationship between stabilizer dosage and key engineering properties. This systematic approach ensured objective evaluation of stabilization effectiveness, identification of optimum stabilizer type and dosage, and reliable interpretation of results for practical application in road subgrade improvement.

3. Results

3.1. Atterberg Limits

This study evaluated the relationship between the increase of Cement Kiln Dust (CKD), Lime Kiln Dust (LKD), and 50 percent (50:50) CKD and LKD on the Atterberg limits of the expansive clay soil. Liquid limit (LL), Plastic limit (PL), Plasticity Index (PI), and Linear Shrinkage (LS) were evaluated because they are the primary indicators for determining plasticity of a soil and swelling potential.

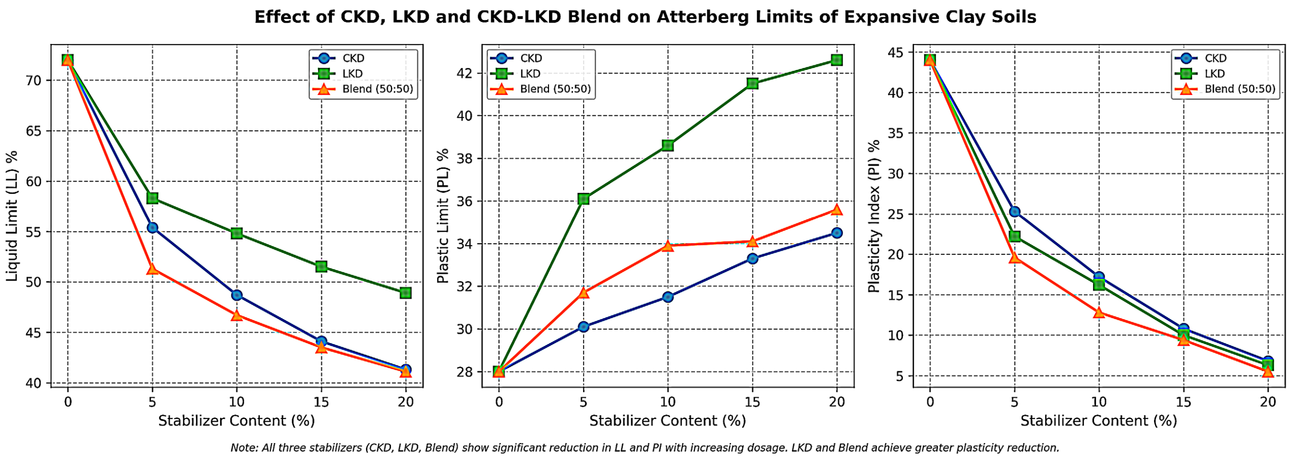

Figure 1. Effect of stabilizers on Atterberg limits on expansive clay soils.

Results in **Figure 1** show a consistent decrease in LL for all three materials (CKD, LKD, CKD-LKD blend) with increasing stabilizer content. The LL decreased for CKD-treated soil from 72.0 percent at 0 percent to 41.3% at 20%. The LL of soil treated with LKD was similarly decreased to 48.9% at 20%, while the blended CKD-LKD was decreased to 41.1% at the same stabilizer content. The reduction of the LL indicates that the ability of the soil to retain water has decreased. An engineer would consider using soils with lower liquid limits. The Plastic Limit (PL) shows consistent upward movement with increased stabilizer quantity. For example, PL increases from 28%, no stabilizer (untreated soil), to 34.5% (20% CKD), 42.6% (20% LKD), and 35.6% (50:50 CKD: LKD blended) stabilizers. Moreover, as the amount of stabilizer added increases, the Plasticity Index (PI) decreases significantly from a PI of 44.0% for untreated to 6.8%, 6.3%, and 5.5% for each of the three stabilizer additions (CKD, LKD, 50%: 50% mixture, respectively) for a combined reduction of PI of approximately 38.5% to 39.5%. The substantial reduction in PI indicates to civil engineers that the amount of plasticity and associated degree of swelling of expansive clay has been reduced significantly. This is important because high plasticity soil can undergo volume changes over wetting and drying; this can cause pavement failure due to cracking and/or upheaving.

For Linear Shrinkage (LS), a similar decreasing trend occurred with increased amounts of stabilizer added to the soil. The LS decreased from around 21% in untreated soil to approximately 3% at 20% stabilizer content across various types of stabilizers. This decrease in LS illustrates that there is a considerable reduction in shrink-swell potential, a major concern when working with expansive clays when constructing roads. In terms of engineering, the reduction in plasticity and shrinkage characteristics of the stabilized soil suggests improved construction workability due to reduced swelling potential and increased long-term stability as a subgrade material. Of the stabilizers tested, CKD-LKD showed slightly higher reductions in plasticity than either material individually, indicating an increased combined stabilizing effect. Overall, the testing showed that greater amounts of kiln dust help to improve the consistency limits and volumetric stability of expansive clays, thus improving their ability to be used as subgrade materials in roadways.

3.2. Effect of Stabilizers on OMC and MDD

The study evaluated the compaction characteristics of the expansive clay soil by determining the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) at different percentages of kiln dust. These metrics are essential in pavement engineering since they determine the moisture conditions needed to achieve maximum soil density and stability during field compaction.

The compaction results in Figure 2 indicate that increasing the content of

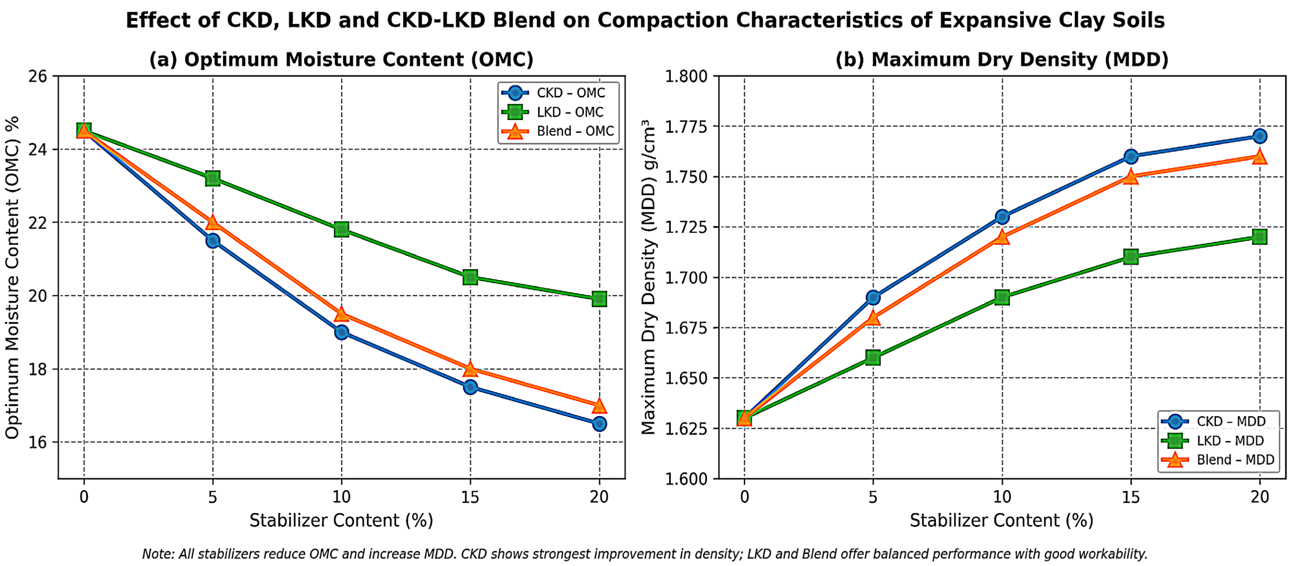

Figure 2. Effect of stabilizers on OMC and MDD.

Cement Kiln Dust (CKD), Lime Kiln Dust (LKD), and the 50:50 CKD-LKD progressively improved the compaction characteristics of the expansive slay soil. For all stabilizers, the Optimum Moisture Content (OMC) decreased while the average maximum dry density (MDD) increased with increasing stabilizer content. The untreated soil recorded and OMC of 24.5% and an MDD of 1.63 g/cm^3. At 20% stabilizer content, CKD reduced the OMC to 16.5% and the MDD increased to 1.77 g/cm^3. Similarly, the CKD-LKD blend reduced the OMC to 17.0% and increased the MDD to 1.76 g/cm^3 whereas LKD achieved an OMC of 19.9% and an MDD of 1.72 g/cm^3.

The LKD-only treated soil also showed similar improvements, but the overall decreases in the OMC and increases in the MDD were not as significant as with CKD and/or blended stabilizers. The additional drying density (MDD) shows that adding kiln dust makes the treated soil denser than it was before. This change occurs because larger soil aggregates have formed, and free spaces in the soil have been filled with the small kiln ash particles. Among the stabilizers tested, CKD showed superior compaction characteristics and produced the highest MDD and the lowest OMC at high stabilizer concentrations. The CKD-LKD blend performed comparably, indicating the potential for using these 2-material combinations as a stabilizing agent. LKD improved compaction; however, the effects of LKD on compaction were not nearly as pronounced as with CKD. The improvements in compaction characteristics that occurred suggest a benefit of kiln dust stabilization to the structural integrity and stability of the expansive clay soil based on engineering principles. The result is a subgrade layer that provides a stronger and more durable foundation to support pavement loadings due to a higher dry density and lower moisture requirements.

3.3. Effect of Kiln Dust on Compaction Characteristics

The California Bearing Ratio (CBR) test was conducted to examine the improvement in the load-bearing ability of the expansive clay soil when stabilized with kiln dust. CBR is among the most essential metrics used in pavement design since it indicates the subgrade soil's ability to support traffic loads.

The California Bearing Ratio (CBR) results in **Figure 3** show that kiln dust stabilization notably improved the load-bearing capacity of the expansive clay soil especially under soaked conditions. The untreated soil exhibited unsoaked and soaked California Bearing Ratio (CBR) values of 4.8% and 2.7%, respectively, confirming its poor suitability as a pavement subgrade. Increasing stabilizer content improved CBR values even though the extent of improvement differed among the stabilizers. Lime Kiln Dust (LKD) produced the least improvement while unsoaked CBR remained almost the same (4.8% - 4.9%) and CBR increased progressively to 13.5% at 20% of stabilizer. On the contrary, CKD increased the unsoaked CBR to 7.5% and the soaked CBR to 19.8%, while the 50:50 CKD-LKD blend achieved the highest soaked CBR of 20.8% and an unsoaked CBR of 6.8% at the same stabilizer content. Among the stabilizers evaluated, CKD showed the

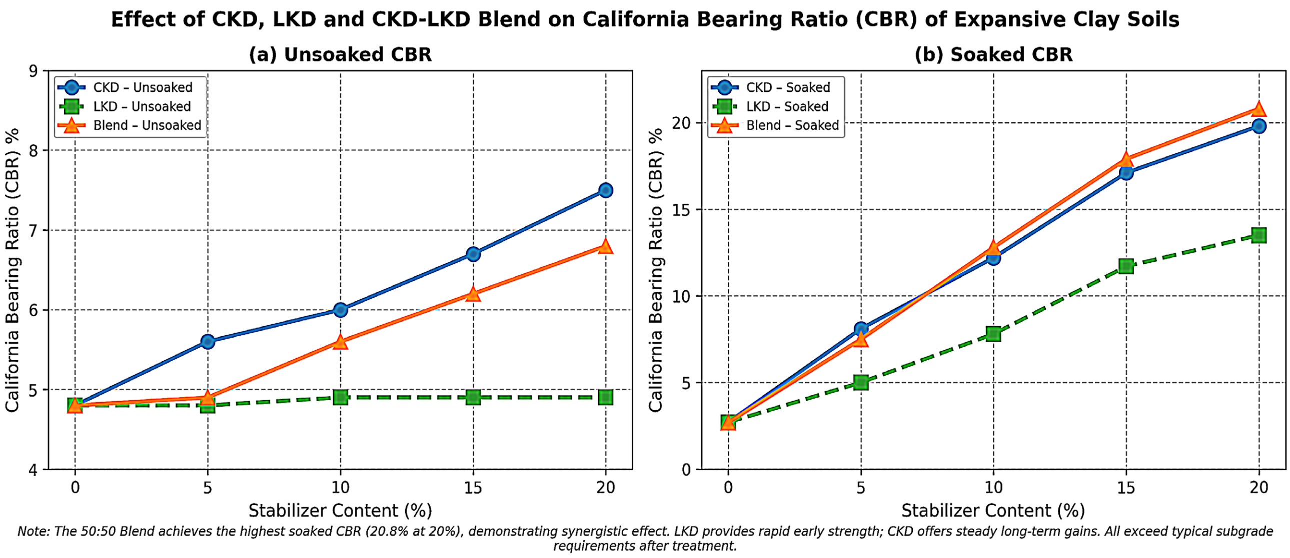

Figure 3. Effect of kiln dust on California bearing ratio (CBR).

greatest improvement in unsoaked CBR, whereas the CKD-LKD blend produced the highest soaked CBR. This finding indicates that CKD-LKD blend provides complementary stabilization benefits under saturated conditions. The increase in soaked CBR from 2.7% for the untreated soil to 20.8% for the blended stabilizer represents a very high improvement in load-bearing capacity, demonstrating the effectiveness of kiln dust stabilization in improving subgrade performance.

The notable increase in CBR may be due to cation exchange, flocculation-agglomeration, and pozzolanic reactions initiated by the calcium-rich kiln dusts. These cementitious products bind the soil and give it greater stiffness and resistance to penetration when loaded. Clay particle flocculation and agglomeration also reduce plasticity of the soil and enhance its internal structure. The increase in soaked CBR value is of major importance for engineers, as subgrade clay may be exposed to moisture throughout its lifetime. Thus, the increased soaked CBR value means that the stabilized clay will have sufficient strength to resist deformation and failure due to moisture. Ultimately, using kiln dust to stabilize expansive clay will allow engineers to convert weak expansive clay into acceptable subgrade materials for building roads, resulting in greater durability and performance of the road.

4. Conclusion and Recommendations

4.1. Conclusion

Stabilization of expansive soils with CKD, LKD, or CKD-LKD blends notably enhanced the soil's engineering properties for subgrade use. LKD was the most effective stabilizer, achieving the greatest reductions in plasticity index (from 44% to 6.3%) and swell potential (up to 97%), and the highest gains in unsoaked and soaked CBR (65% and 13.5%, respectively) and compaction density (MDD = 1.72 g/cm^3 at 20% dosage). The CKD-LKD blend showed a synergistic effect, combining the rapid early reaction of LKD with long-term pozzolanic contribution of CKD, resulting in balanced improvements in strength, compaction, and dimensional stability. CKD alone produced moderate improvements in plasticity, CBR, and density, but it is still suitable for low-to-medium traffic subgrade layers. Kiln dust stabilization effectively changed weak, expansive soils into a denser, stronger, and dimensionally stable material suitable for road subgrade material, showing technical effectiveness and practical application in road construction.

4.2. Recommendations

The road authorities, such as KeNHA, KeRRA, and KURA, should encourage partnerships with cement manufacturers to secure locally produced CKD and LKD, ensuring consistent supply and quality of stabilizers. Lime Kiln Dust (LKD) should be the preferred stabilizer for expansive clay soils requiring rapid strength gain and high resistance to swelling, particularly in medium- to high-traffic road subgrades. CKD-LKD blends can be used where both cost efficiency and long-term pozzolanic stabilization are desired, providing a balance between early and later strength development. Cement Kiln Dust (CKD) is suitable for low-traffic road subgrades or for projects where industrial by-product utilization is a priority, though higher dosages may be required.

Contractors should apply strict moisture conditioning around the new OMC range and compaction at the achieved MDD benchmarks, supported by controlled CKD storage similar to cement handling, to avoid strength inconsistency due to premature hydration or moisture contamination before mixing. Kenya's road materials manuals and highway standards should be updated to formally classify CKD as an approved soil stabilization additive, with testing routine validation standardized in all pavement construction projects.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Devkota, B., Karim, M.R., Rahman, M.M. and Nguyen, H.B.K. (2022) Accounting for Expansive Soil Movement in Geotechnical Design—A State-of-the-Art Review. *Sustainability*, **14**, Article 15662. https://doi.org/10.3390/su142315662

[2] Mousa, E., Fouad, M., Abo El-Naga, I., El-Sekelly, E.A. and El-Ashwah, A.S. (2025) Utilising Cement Kiln Dust as a Sustainable Cementitious Alternative for Recycled Asphalt Pavement Materials: A Mechanical, Economic, and Environmental Study. *International Journal of Pavement Engineering*, **26**, Article 2544904. https://doi.org/10.1080/10298436.2025.2544904

[3] Bantayehu, U.U. (2017) Investigation on the Swelling Characteristics and Unsaturated Shear Strength of Expansive Soils from Arba Minch in Ethiopia. *Journal of Geotechnical and Transportation Engineering*, **2**, 16-23.

[4] Kenya Ministry of Transport, Infrastructure, Housing, Urban Development and Public Works (2017) Pavement Design Guidelines for Low Volume Sealed Roads (LVSR) Government Printer.

[5] Kenya Ministry of Transport and Communications (1986) Road Design Manual, Part III: Materials and Pavement Design for New Roads. Government Printer.

[6] Bandara, N., Hettiarachchi, H., Jensen, E., Binoy, T.H. and Perera, R. (2023) Using Kiln Dust to Improve Weak Subgrades for Pavement Construction: A Field Verification in Michigan, USA. *Geotechnics*, **3**, 179-192. https://doi.org/10.3390/geotechnics3020011

[7] Yan, Q., Peng, B., Li, W., Wang, B., Zuo, J., Lv, G., *et al.* (2025) Low-Carbon Stabilization of Expansive Soils Using Cement Kiln Dust and Calcium Carbide Slag: Mechanisms and Performance. *Frontiers in Earth Science*, **13**, Article 1554812. https://doi.org/10.3389/feart.2025.1554812

[8] Ogila, W.A.M. (2021) Effectiveness of Fresh Cement Kiln Dust as a Soil Stabilizer and Stabilization Mechanism of High Swelling Clays. *Environmental Earth Sciences*, **80**, Article No. 283. https://doi.org/10.1007/s12665-021-09589-4

[9] Ubani, O.U., Ngezahayo, E., Nwaiwu, C.M.O. and Nwakaire, C.M. (2025) Strength Development and Durability of Cement-Stabilized Tropical Clay-Quarry Dust Mixtures for Pavement Construction. *Sustainability*, **17**, Article 8825. https://doi.org/10.3390/su17198825

[10] Gilbert, A. (2025) Investigating the Effectiveness of Cement Kiln Dust as an Expansive Soil Stabilizer in Road Construction. *International Journal of Research and Innovation in Social Science*, **IX**, 1401-1412. https://doi.org/10.47772/ijriss.2025.9010117