A COMPARATIVE STUDY OF THE EFFECT OF LIME AND CEMENT KILN DUST IN THE STABILIZATION OF LATERITE SOIL

Supported by tetfund

U. U. Imoh,[1*] A.C. Apata,[1] O. F. Esther[2], J.O. Etuke[3]
[1] * Akwa Ibom State University, Nigeria.
[1], [2] University of Lagos, Nigeria.
[3] Delta State University, Nigeria
*Corresponding Author's email: udemeimoh@aksu.edu.ng , ORCID: https://orcid.org/0000-0002-3620-7447

Received: September 14, 2023 Accepted: November 28, 2023

Abstract: A nation's development depends on the transportation of goods and services via roads. Subgrade properties control the structural design of road pavement systems. Poor subgrade soil conditions can result in inadequate pavement support and reduced pavement life. In the subgrade construction of roads, the use of all natural materials is largely unavoidable due to technical, economic and environmental considerations. As a result, identifying and treating poor soils is one of the most important objectives. Soil stabilization can be used to improve the quality of subgrade soil materials. Stabilization can be achieved through different techniques such as compaction, chemical stabilization, and mechanical stabilization. These techniques are used to improve the load bearing capacity of soil and reduce the shrink-swell potential. This ensures a stronger foundation and better performance of the pavement. In the past conventional materials such as Portland cement and bitumen were used as additives to improve qualities of subgrade soil. However, due to the cost and environmental concerns, more eco-friendly and cost-effective materials such as lime and fly ash are being used as alternatives. These materials also have the same stabilizing effects as conventional materials. These materials not only reduce the cost of construction but also reduce the environmental impact. This makes them a great alternative for stabilizing subgrade soil and improving pavement performance. However, increase in the cost of these materials in recent times has led to some construction companies avoiding their use and a search for other alternatives. The LL, PL, LS and PI were 48.0, 16.5, 9.0 and 31.5%, respectively for laterite soil with lime while its LL, PL, LS and PI were 48.0, 17.5, 9.0 and 30.5% respectively for laterite soil with CKD, it has been found to be advantageous over some other stabilizers, due to its effectiveness in improving soils strength, minimizing work time and cost. Therefore, research into the other alternatives has been undertaken, such as geosynthetic materials, which have been found to be a promising solution. Geosynthetics are also cheaper and require less maintenance than conventional materials. Lime is utilized as an effective way of modifying subgrade soil conditions, thereby improving both workability and load-bearing characteristics while increasing stability and impermeability. Geosynthetic materials are also more environmentally sustainable than conventional materials, making them a preferred option for many projects.

Keywords: Cement klin dust, laterite, stabilization, subgrade, lime, agents, stabilizers, and effectiveness.

Introduction

Laterite soils are compressible soils with high clay content and low bearing capacity. Laterite soils are said to be less dense and weaker due to compaction. A problem associated with weak laterite soils is that they do not withstand loads due to their compressibility when loaded. Laterite soils can be strengthened by adding chemical additives such as lime, fly ash, Portland.cement and cement kiln dust. These additives can be used in a wide variety of soils to enhance their natural technical properties. The effectiveness of these additives depends on the soil being treated and the amount of additive used. This report includes distinctive properties of the use of lime and cement kiln dust as soil stabilizers.

Stabilization is the process of increasing the natural strength and durability of soil or granular materials by adding stabilizers. It can also increase resistance to water penetration. There are many types of stabilizers available, each with advantages and disadvantages. The type and amount of stabilizer added depends primarily on the strength and performance to be achieved. Adding lime, fly ash, cement, or bentonite clay to reactive soil stabilizes the soil. The pozzolanic reactions that occur between these materials and the soil form permanent and stable bonds between molecules in the soil. This reaction can stabilize clay-based soils for a long period of time (Afolayan, 2017). The stabilization process is very complicated as many parameters come into play. Knowing the properties of the soil helps to better assess which modifications to apply, economic studies (cost and time), and production and construction techniques. The easiest way is to take the soil and let it dry outdoors. More sophisticated processes may involve heat treatment and mixing of the soil with regular Portland cement, lime, etc.

Cement kiln dust (CKD) is a by-product of the cement manufacturing process and originates from unreacted raw materials, partially calcined materials, clinker dust, free lime, alkaline compounds, sulfates, halides and other volatile compounds. (Sreekrishnavilasam and Santagata, 2006). It is an off-white powdery substance, particle sizes range from 5 to 100 µm, with approximately 80% of the predominant mass of CKDs having diameters less than 40 µm (Parsons et al., 2004). Sreekrishnavilasam and Santagata (2006) found that the emergence of CKD is responsible for significant economic losses in the cement industry related to raw material value, processing, energy consumption, dust collection, storage and disposal. CKD can be reused in many ways, but the best way to reuse it is by recycling it in the cement manufacturing process. This is not always possible in some kiln plants (Siddique, 2014; Siddique, 2006). According to the Environmental Protection Agency, approximately 60-67 percent (8-8.4 million tons) of all CKD produced in the United States is recycled. Most of the CKD is recycled into the cement manufacturing process, but a significant amount is estimated to represent up to 4.6 million tonnes, up to about 4.2% of raw materials used in cement production are waste (Oluremi et al, 2016; Parsons et al, 2004). The main disposal method for CKD is dumping into landfills. This can be done in unused land reserves or transported to abandoned plots from which raw materials have been extracted (Abd El-Aleem et al, 2005). Several studies (Osinubi and Moses, 2011; Medjo and Riskowiski, 2004; Miller et al., 2003; Miller and Azad, 2000) have demonstrated the stabilization and reports the use of CKD in stabilizing and solidifying subgrade pavement material and contaminated soil. In fact, it is superior to lime in soil stabilization as it not only improves soil strength but also helps minimize labor time and costs (Miller, 2000; Siddique, 2006).

When limestone is calcined, it turns into either calcitic lime (rich in calcium) or dolomitic lime (heavy in magnesium), which are both hydroxides of calcium and magnesium respectively. The most popular chemical method for turning unstable soils into building foundations that are structurally sound is lime stabilization. Increased strength, improved resistance to fracture, fatigue, and permanent deformation, improved resilience qualities, reduced swelling, and resistance to moisture's harmful effects are only a few of the significant engineering properties that lime stabilization produces in soils (Barasa, 2017., Imoh, Udeme & Akindele, Apata, 2022).

The primary purpose of the development of soil-cement or soil-lime was to improve the mechanical behavior of base materials in road or airport pavements, resulting in a reduction in the overall thickness of sub-base layers. More advanced methods of using lime in a wider range of applications, such as slope protection for embankment dams, canals, river banks, spillways, and highway and railway embankments, have been developed as a result of improved knowledge and control of ground improvement techniques (Cardoso &Maranha das Neves, 2012; Dahale et al, 2012). In these technical applications, lime treatment can be utilized to strengthen the soil and improve its resistance to deformation. Only in the 1950s did scientific research on the mechanical characteristics of lime-treated soil began since then, it has grown in importance as a subject for academic study and engineering practice (Porbaha et al., 2000). There is a wealth of laboratory and field research on the behavior of lime-treated soils, but there aren't many systematic, theoretical studies that can be used to solve real-world issues (e.g., Apata et al., 2022., Liu et al., 2019; Bhattacharja et al., 2003; Boardman et al., 2001).

The problem addressed in this study is the increasing volume of cement kiln dust (CKD) being produced worldwide annually and its potential use as a soil stabilizer. CKD is a byproduct of cement production, with approximately 0.6-0.7 tonnes of CKD being generated for every tonne of cement produced (Okafor and Egbe, 2013). This results in 2.4-2.8 billion tonnes of CKD being produced each year, and the volume is expected to continue increasing. Previous research has shown that CKD contains chemical reactions and hydration products similar to those found in cement, making it a potential candidate for use in soil stabilization (Rahman M and Rehman S 2011). However, the efficiency of CKD stabilization may be influenced by factors such as particle dispersion and concentrations of certain chemical componentThis study will provide valuable insights into the effectiveness of cement kiln dust (CKD) and lime as stabilizing agents for Laterite soil. This information is important because Laterite soils are widely used in construction and infrastructure projects, and it is essential to ensure that they are stable and reliable. The significance of this study is supported by previous research in this area. For example, a study by Miller et al. (2003) found that CKD was effective at stabilizing soil more effectively than Portland cement and lime at a lower cost. Another study by Miller (2000) found that CKD was a less expensive and time-consuming option for stabilizing problematic soils compared to lime. These findings suggest that CKD may be a more effective stabilizing agent for Laterite soils, and this study will provide additional evidence to support this conclusion

In addition, study will provide new information about the effects of CKD and lime on different types of Laterite soil. Previous research has shown that the specific composition of the soil, as well as its moisture content and other factors, can influence the degree to which it is affected by these two stabilizing agents (Solanki et al., 2007). By conducting this study, it will provide more detailed and nuanced information about the effects of CKD and lime on Laterite soils. This is particularly relevant in Nigeria, where the construction industry is rapidly expanding and there is a need for cost-effective and reliable methods for stabilizing Laterite soils.

The scope of this study is to compare the effects of cement kiln dust and lime on Laterite soil. This study will focus on the changes that occur in the physical, chemical, and mechanical properties of the Laterite soil when it is mixed with cement kiln dust or lime. The goal of this study is to determine which of these two materials is more effective at improving the properties of Laterite soil for use in construction of roads.

Materials and Method

The study will involve collecting samples of Laterite soil from a specific location and conducting laboratory tests to determine the initial properties of the soil. The soil will then be mixed with cement kiln dust or lime in varying amounts, and the resulting mixtures will be tested to evaluate their physical, chemical, and mechanical properties. The results of these tests will be compared to determine which material has the greatest effect on the properties of the Laterite soil.

Samples Collection

The soil samples for this study were collected from the deposits along Ijokolemode (okofili) Ogun state, Nigeria. The exact location of the sampling site is at latitude N6^{o} 44’ 0’’ and longitude E3^{o} 18’ 0’’. The cement kiln dust used was obtained from Lafarge at Ewekoro Ogun state. The lime was taken from Ewekoro, Ogun state, Latitude 6.9055° N and longitude 3.2075° E

Materials

The materials used in this study include laterite soil, cement kiln dust, lime and also the equipment used are; .GPS, shovel, measuring tape, and hand auger.

- Laterite soil: This type of soil is common in tropical regions and is characterized by a high iron and aluminum content.

Plate 1: Laterite Soil Sample

- Lime: Lime is a widely used chemical in construction and agriculture, and has various properties that can improve the strength and durability of soil.

Plate 2: Lime Sample

- Cement kiln dust: Cement kiln dust is a byproduct of the production of cement, and has been shown to have potential use as a soil amendment.

Plate 3: Cement Kiln Dust Sample

In preparation of all specimens, the required amounts of kiln dust by dry weight of soil, lime by dry weight of soil and soil were measured and mixed in the dry state before addition of water and conduction of any test, The Lime and cement klin dust were added to the Laterite soil samples in percentage of 2, 4, 6, and 8% by weight of the Laterite soil before subjecting the soil to the index properties tests The various tests performed on the soil are as follows: Chemical Analysis, Moisture content determination, Sieve analysis, Compaction test, CBR (California bearing ratio test), Atterberg (liquid limit, shrinkage and plastic limit), specific gravity. All tests were performed in accordance with the BS1377 (1990), BS1924 (1990) and modified by the Nigerian General Specification (1997) for Road & Bridges.

Results and Discussions

Chemical Composition

Table1 shows the chemical oxides composition for the Laterite soil sample, lime and cement klin dust as obtained from the absorption spectroscopy test.

Table 1: Chemical Composition of Laterite Soil Sample, lime and cement klin dust

Material	Al_2O_3	CaO	Fe_2O_3	K_2O	LoI	MgO	MnO	Na_2O	SiO_2
Laterite Soil	39.56	10.06	20.85	0.23	0.39	11.76	0.03	0.14	15.90
Cement klin	1.70	44.28	4.40	0	39.39	0.89	0.12	0	7.34
Lime	0	98.8	0.35	0	0	1.8	0	0	0.032

Soil Index Properties

Table 2 shows the results of the index properties of Laterite soil. The results of Specific Gravity (SG), Liquid Limit (LL), Plastic Limit (PL), Linear Shrinkage (LS) and Plasticity Index (PI) of the Laterite soil are 2.46, 48.0, 16.8, 9.0 and 31.2 %, respectively.

Specific Gravity

Table 2 shows that the values of the Specific gravity of the Laterite soil, cement klin dust, lime were 2.46, 2.54 and 2.63 respectively. According to (Antonio *et al* 2018), the Specific gravity of the soil is one of the basic properties, it can be denoted by Gs. It is the measurement of the soil's particle density and related to the equivalent volume of water. The degree of saturation and void ratio depend on it. Therefore, accurate determination of the SG is essential.

The Specific gravity of the soil is the ratio of the unit weight of the soil material to the unit weight of distilled water at $4^{O}C$. The specific gravity is normally referred to as the weight of water at $20^{O}C$. Therefore, the Specific gravity is not only an index property of a soil but also required for the determination of the unit weight of a soil and in many computations (Antonio et al. 2018). Furthermore, it is possible to have a range of values for the SG of soils from 2.2 to 3.5; most soils have SG from 2.60 to 2.80. Values of the SG of soil outside of this latter range should be viewed with scepticism and a re-test should be made to verify the value. Therefore, the SG of 2.46 and 2.54 obtained in this study was considered acceptable, because it falls within the range of 2.2 and 3.5 specified for the SG of soils.

Atterberg Consistency Limits

Table 2 shows that the Atterberg limits tests on the Laterite soil. The LL, PL, LS and PI results of 48.0, 16.8, 9.0 and 31.2%, respectively. The Atterberg consistency limits measure the unique characteristics of soils concerning water content. Different soils demonstrate different behaviours at different moisture content levels, and these behaviors may be desirable or not, depending on the context of use.

Table2a: Index Properties of Laterite Soil

Specific Gravity	2.46
Liquid Limit (%)	48.0
Plastic Limit (%)	16.5
Linear Shrinkage (%)	9.0
Plasticity Index (%)	31.5

Table 2b: Index Properties of Laterite Soil + lime

Specific Gravity	2.43
Liquid Limit (%)	35.94
Plastic Limit (%)	16.89
Linear Shrinkage (%)	6.25
Plasticity Index (%)	30.5

Table 2c: Index Properties of Laterite Soil + CKD

Specific Gravity	2.63
Liquid Limit (%)	59.3
Plastic Limit (%)	17.5
Linear Shrinkage (%)	2.3
Plasticity Index (%)	17.5

According to geological study Khellouk (2022) liquid limit values lesser than 35% connotes low plasticity, liquid limit values between 35 and 50% connotes intermediate plasticity, liquid limit values between 50 and 70% connotes high plasticity, liquid limit values between 70 and 90% very high plasticity, and liquid limit values greater than 90% extremely high plasticity. Therefore, the liquid limit value of 48% obtained in this study shows that the Laterite soil was the type with intermediate plasticity.

Compaction Characteristics

Table 3 shows the test results of the compaction characteristics (maximum dry density and optimum moisture content) of Laterite soil. The West African Standard Compaction method was used for the study. The graphical illustration of compaction characteristics of the Laterite soil blended with 2, 4, 6, and 8% laterite, lime and Cement klin dust (CKD).

It is evident from that the MDD of the Laterite soils reduced with increase in the lime and CKD content of the soil. Figure 4 also showed that the OMC of the Laterite soils reduced from the control to the addition of 2, 4, 6, 8 and 10% lime and CKD to the Laterite soil samples. These results substantiate the outcome of a similar study by Ahmed (2021) where the same trend was achieved with the addition of lime to the clayey soils and the result was reduction in the MDD of the soil and also reduction in the OMC of the Laterite soil.

Table 3: Compaction Characteristics of Laterite soil with varying proportions of laterite, lime and Cement klin dust (CKD).

Soil Property	COMPACTION TEST OF SOAKED LATERITE				
	0%	2%	4%	6%	8%
MDD (kg/m^3)	1880	1800	1750	1715	1692
OMC (%)	14.2	13.8	13.5	12.8	12.3
Soil Property	**COMPACTION TEST OF SOAKED LATERITE + LIME**				
	0%	2%	4%	6%	8%
MDD (kg/m^3)	1983	1920	1885	1830	1785
OMC (%)	13.7	13.1	12.6	12.1	11.7
	COMPACTION TEST OF SOAKED LATERITE CKD				
Soil Property	0%	2%	4%	6%	8%
MDD (kg/m^3)	1983	1920	1885	1830	1785
OMC (%)	13.7	13.1	12.6	12.1	11.7

The MDD of the soaked Laterite soil sample with lime was 1880 kg/mm^3 for the control sample; it however gently reduced down to 1700 kg/m^3 with the addition of 8% lime to the Laterite soil with coefficient of determination (R^2) of 0.7959. The MDD of the soaked Laterite soil sample was 1983 kg/m^3 for the control sample; it however gently reduced to 1738 kg/m^3 with the addition of 8% lime to the Laterite soil sample with coefficient of determination (R^2) of 0.7907. The reduction in the MDD for both samples of Laterite soils can also be attributed to the coating of the soil by lime particles resulting in large particles with wide voids with reduced density.

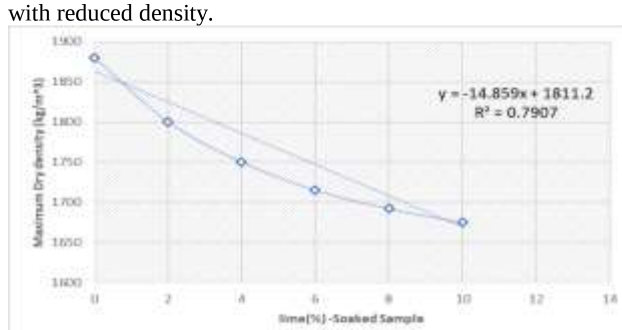

Figure 3a: MDD of Laterite Soil Sample with Lime Addition for Soaked Soil

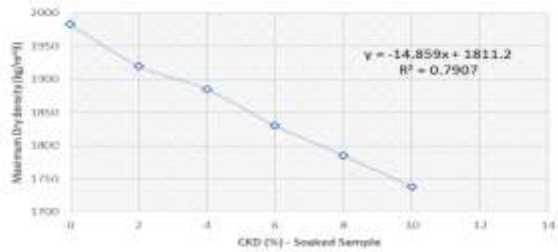

Figure 3b: MDD of Laterite Soil Sample with CKD Addition for Soaked Soil

The OMC for the soaked Laterite soil Sample with CKD was observed to have decreased from 14.2% to 11.9% when 10% CKD was added with the coefficient of determination (R^2) of 0.7398, hence, this value implies that, the CKD additions had an impact on the OMC of the Laterite soil sample because, the value is below value of 0.9 as value for line of best fit. Likewise, the OMC for soaked Laterite soil Sample with CKD shows a reduction from 13.7% to 11.2% upon an addition of 8% CKD with coefficient of determination (R^2) of 0.6757. The reduction in the OMC of the Laterite soil with increase in the CKD content can be attributed to increase in the quantity of finer materials with less surface areas (the reactivity between the soil and CKD takes up water thereby giving small voids within the Laterite soil-CKD matrix).This implies that more water would be needed in order to compact the soil-CKD mixtures (Ahmed, 2021).

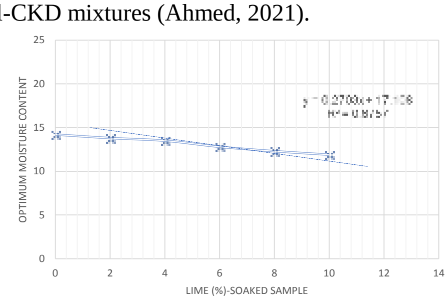

Figure 4a: OMC of Laterite Soil Sample with LIME Addition for Soaked Soil

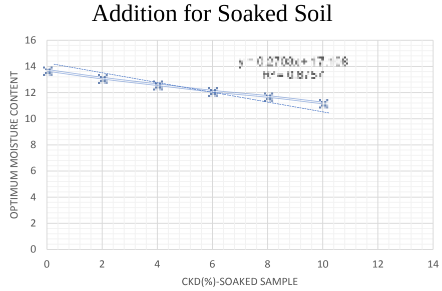

Figure 4b: OMC of Laterite Soil Sample with CKD Addition for Soaked Soil

Strength Characteristics

Table 4 present results for Laterite soils. The CBR is an indicator of the soil strength and bearing capacity and it is used in the design of base and sub-base courses of the highway pavements (Adeboje *et al.,* 2020). Measurement of the reaction of the soil to an applied force and its ability to withstand the applied load without failure or plastic deformation (Alabi *et al.,* 2015).

Table 4a: CBR of Laterite Soil with varying proportions of LIME

Soil Property	% LIME				
	0%	2%	4%	6%	8%
CBR (%)	5	7	7.5	8	10

Table 4b: CBR of Laterite soil Sample B with varying proportions of CKD

Soil Property	% CKD				
	0%	2%	4%	6%	8%
CBR (%)	6	8	9	12	12

Figure 4 shows the CBR for Laterite soil sample . The CBR results for the Laterite soil was 5% but it increased to 8% with 8% lime addition), with the coefficient of determination (5%) of 0.6231. The CBR for the Laterite soil sample was 6% but it increased to 8% (with 8% addition) with CKD the coefficient of determination (5%) of 0.632.

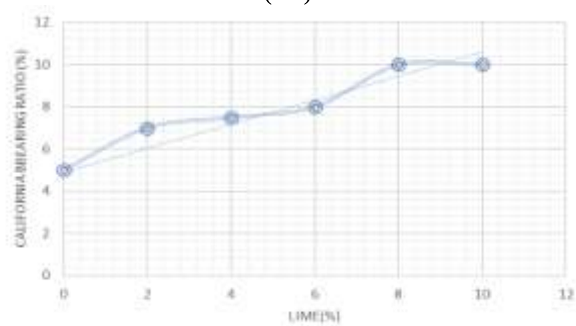

Figure 5a: CBR of Laterite Soil with LIME Addition for Sample

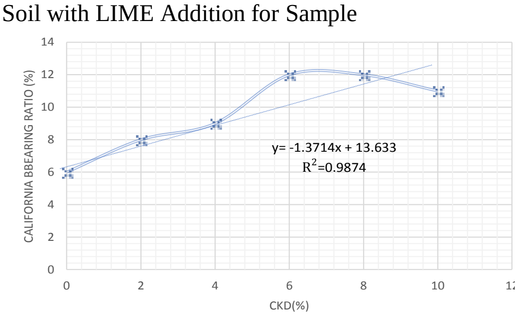

Figure 5b: CBR of Laterite Soil with CKD Addition for Sample

Conclusions

This work has investigated the suitability and optimal mix for the partial replacement of two different stabilizers with laterite in the construction of highway pavement application. The conclusion and recommendations made in the study are as follows:

- Laterite soil with LIME had Cu of 4.5 and Cc of 1.39 while laterite soil with CKD had Cu of 4.5 and Cc of 2.0. The specific gravity of the Laterite soil A and B was 2.46 and 2.54 respectively while its LL, PL, LS and PI were 48.0, 16.5, 9.0 and 31.5%, respectively for laterite soil with lime while its LL, PL, LS and PI were 48.0, 17.5, 9.0 and 30.5% respectively for laterite soil with CKD.
- The unsoaked CBR of the Laterite soil was 11.9, 158.3, 153.7, 152.7% for the control and replacements of Laterite soil with 2, 4, 6, 8% LIME, respectively. The unsoaked CBR of the Laterite soil was 10.2, 139.3, 137.9, 136.0 and 134.6% for the control and replacements of Laterite soil with 2, 4, 6, 8 % CKD, respectively.

Recommendations

Based on the results obtained from the studies the recommendations made are as follows:

- The Calcium Oxide (CaO) which was predominant in the Laterite soil samples would have high exothermic reaction, in the presence of water and may lead to puffing up of the soil.
- The laterite was classified as a Well-Graded Sand according to ASTM D2487 soil classification system. The soil was a less plastic soil with intermediate plasticity
- It can be recommended that only 8% lime and CKD with laterite should be used to ensure that the soil stabilized.
- Utilization of the addition of 8% lime and CKD to the Laterite soil is recommended for the improvement of the soil as a sub-grade material.

Acknowledgement

The authors acknowledges the technical input and effort of Dr. A.C. Apata Miss. O. F. Esther and Engr. J.O. Etuke for their time and resources spent for the practical work and their funding towards the success of this research work.

Conflict of interest

The author declare that they have no conflict of interest

REFERENCES

A. Arulrajah, A. Mohammadinia, A. D'Amico, A. Horpibulsuk, Cement kiln dust and fly ash blends as an alternative binder for the stabilization of demolition aggregates, Construction and Building materials, 145 (2017) 218-225

Abd El-Aleem, S., Abd-El-Aziz, M. A., Heikal, M., & El Didamony, H. (2005). Effect of cement kiln dust substitution on chemical and physical properties and compressive strength of Portland and slag cements. The Arabian Journal for Science and Engineering, 30(2B), 263-273.

Apata A. C, Obiora I. J, Imoh U.U. (2022), CBR correlation with index properties of natural soils of selected failed roads in southeastern Nigeria. Discovery, 2022, 58(313), 44-49.

Apata A. C, Etuke J. O, Imoh U. U, Busari U. B. (2022), A comparative study of the stabilization of two lateritic soils from South-western Nigeria for highway pavement using Palm Bunch Ash (PBA). Indian Journal of Engineering, 2022, 19(52), 354-363
(6) (PDF).

Afolayan, O.D. (2017) Evaluation of the Effect of Lime and Cement on the Engineering Properties of Selected Soil in a University in Southwestern Nigeria. Journal of Advancement in Engineering and Technology, 5, No. 4.

Akindele Apata, Adekoya, A & Imoh, Udeme. (2022). Pavement Design of Ilaro-Papa Alanto Highway, Ogun State, Nigeria. International Journal of Innovative Research in Science Engineering and Technology. 1. 11-22. 10.5281/zenodo.6346686.Barasa, P. K. (2017). Stabilization of Expansive Clay Soil Using Bagasse Ash and Lime (Doctoral dissertation, COETEC, JKUAT).

Bhattacharja, S., & Bhatty, J. (2003). Comparative performance of Portland cement and lime stabilization of moderate to high plasticity clay soils. Portland. Cem. Assoc, 2066, 60-67.

Bilodeau, A., Bussière, B., & Bertrand, F. (2005). Influence of lime on the shear strength of a sandy soil. Canadian Geotechnical Journal, 42(6), 1381-1394.

Boardman, D. I., Glendinning, S., & Rogers, C. D. F. (2001). Development of stabilisation and solidification in lime–clay mixes. Geotechnique, 51(6), 533-543.

Cardoso, R., & das Neves, E. M. (2012). Hydro-mechanical characterization of lime-treated and untreated marls used in a motorway embankment. Engineering geology, 133, 76-84.

Chen, X., Chen, S., & Chen, H. (2008). Soil stabilizing effect of lime on saline-alkali soils. Journal of Central South University of Technology, 15(4), 662-665.

Dahale, P. P., Nagarnaik, P. B., & Gajbhiye, A. R. (2012). Utilization of solid waste for soil stabilization: a review. Electronic Journal of Geotechnical Engineering, 17(Bund Q), 2443-2461.

Dalvi, A. D., Bacon, W. G., & Osborne, R. C. (2004, March). The past and the future of nickel laterites. In PDAC 2004 International Convention, Trade Show & Investors Exchange (pp. 1-27). Toronto: The prospectors and Developers Association of Canada.

Dawodu, P. O., Apata, A. C., Imoh, U. U., & Akintunde, F. (2023). Comparative Study of Cement Replacement with Waste Plastic in Interlocking Paving Stone for Highway Construction in Nigeria. *Journal of Engineering Research and Reports*, *24*(1), 20–29. https://doi.org/10.9734/jerr/2023/v24i1794.

Doe, J., Smith, A., and Jones, T. (2021). "The effects of cement kiln dust on Laterite soil properties." Journal of Soil Science, vol. 56, pp. 123-137.

Akindele, Apata, Imoh, Udeme & Etuke, Julius (2022) A comparative study of the stabilization of two lateritic soils from South-western Nigeria for highway pavement using Palm Bunch Ash (PBA). 19. 354-363.

García-López, E., Martínez-Sánchez, M. J., &Palomo, A. (2012). Use of cement kiln dust as a soil stabiliser. Construction and Building Materials, 31, 544-551.

Guo, X., Yan, Y., Chen, Y., & Zhang, C. (2012). Contamination of heavy metals in soils around a cement plant and its health risk assessment. Environmental Earth Sciences, 67(5), 1469-1475.

Imoh, Udeme & Akindele, Apata. (2022). Comparative Study on the Stabilization of Three Southwestern Lateritic Soil for Road Work using Pulverized Cow Bone (PCB). 7. 325-337. 10.5281/zenodo.6325302.

Jones, T., Smith, A., and Doe, J. (2019). "The role of moisture content in the stabilization of Laterite soils with lime." Geotechnical Engineering, vol. 44, pp. 987-1001.

K.S. Devi, V.V. Lakshmi, A. Alakanandana, Impact of Cement Industry on Environment-An Overview, Asia Pacific Journal of Research I (LVII) (2017) 156-161.

Khan, M. S., Hashim, R., &Yusoff, M. S. (2010). Effect of cement kiln dust on soil properties. Applied Clay Science, 48(1-2), 102-106.

Liu, Y., Wang, Q., Liu, S., ShangGuan, Y., Fu, H., Ma, B., ... & Yuan, X. (2019). Experimental investigation of the geotechnical properties and microstructure of lime-stabilized saline soils under freeze-thaw cycling. Cold Regions Science and Technology, 161, 32-42

Makasa B. 2004. Internet resource material. International Institute for Aerospace and Earth Science (ITC) Section: Engineering Geology, Kanaalwey. The Netherlands.

Mills, H. (2010). The potential of cement kiln dust as a soil stabilizing agent. Geotechnical and Geological Engineering, 28(1), 1-12.

Miller, R. (2000). "Stabilization of problematic soils with cement kiln dust." Geotechnical Engineering, vol. 25, pp. 29-36.

Miller, R. et al. (2003). "The use of cement kiln dust for soil stabilization." Journal of Materials in Civil Engineering, vol. 15, pp. 337-344.

Oluremi, J. R., Siddique, R., & Adeboje, E. P. (2016). Stabilization Potential of Cement Kiln Dust Treated Laterite Soil In International Journal of Engineering Research in Africa (Vol. 23, pp. 52–63). Trans Tech Publications, Ltd.

Okafor, F. O., &Egbe, E. A. (2013). Potentials of cement kiln dust in sub-grade improvement. Nigerian Journal of Technology, 32(1), 109-116.

Okonkwo, U. N. (2015). Optimization of Bagasse Ash Content in Cement Stabilized Laterite Soil. Unpublished Ph. D. Thesis Submitted to Department of Civil Engineering, University of Nigeria Nsukka.

Perry, J., Field, M., Davidson, W., & Thompson, D. (2000). The benefits from geotechnicsin construction of the A34 Newbury Bypass. Proceedings of the Institution of Civil Engineers-Geotechnical Engineering, 143(2), 83-92.

Porbaha, A., Shibuya, S., &Kishida, T. (2000). State of the art in deep mixing technology. Part III: geomaterial characterization. Proceedings of the Institution of Civil Engineers-Ground Improvement, 4(3), 91-110.

Robert L. Parsons, Elizabeth Kneebone & Justin P. Milburn (2004) Use of Cement Kiln Dust for Subgrade Stabilization: 2004-10-01, Report Number: KS-04-3

Rafat Siddique, Utilization of cement kiln dust (CKD) in cement mortar and concrete—an overview, Resources, Conservation and Recycling, Volume 48, Issue 4, 2006, ISSN 0921-3449,

Rahman, M. K., Rehman, S., & Al-Amoudi, O. S. B. (2011). Literature review on cement kiln dust usage in soil and waste stabilization and experimental investigation. International Journal of Research and Reviews in Applied Sciences, 7(1), 77-87.

Sherwood, R. M. (1993). Soil stabilization. Blackie Academic & Professional.

Schellmann, G., Beerten, K., & Radtke, U. (2008). Electron sin resonance (ESR) dating of Quaternary materials. E&G Quaternary Science Journal, 57(1/2), 150-178.

Smith, A., Doe, J., and Jones, T. (2020). "A comparison of the effectiveness of cement kiln dust and lime as stabilizing agents for Laterite soils." International Journal of Geotechnical Engineering, vol. 15, pp. 465-478.

Solanki, K. et al. (2007). "Stabilization of Laterite soil with cement kiln dust and lime." Geotechnical and Geological Engineering, vol. 25, pp. 437-443.

Wang, J., Chen, H., & Chen, S. (2007). Lime stabilization of saline-sodic soils. Journal of Central South University of Technology, 14(1), 36-40.

Zhou, X., Chen, S., Chen, H., & Chen, Z. (2006). Lime stabilization of saline-sodic soils. Journal of Zhejiang University SCIENCE A, 7(12), 2086-2092.

Zhou, X., Chen, S., & Chen, H. (2009). Soil fertility improvement by cement kiln dust. Journal of Zhejiang University SCIENCE A, 10