Stabilization of Lateritic Soil Sample from Ijoko with Cement Kiln Dust and Lime

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***Abstract*:** *When building roads and paved surfaces, a strong foundation is always essential. A durable material that can withstand years of traffic while staying trustworthy must be used to build the foundation. A frequent problem in the construction of roads and pavements is the lack of high-quality, long-lasting materials for the pavement structure (base, subbase, and subgrade). Hence, this study examined stabilization of lateritic soil sample from Ijoko with cement kiln dust and lime. The study adopted the experimental design. Laboratory test were conducted on classification, swelling potential, compaction, California bearing ratio (CBR), unconfined compressive tests, among others were conducted on the laterite sample treated with cement kiln dust (CKD) and lime in incremental order of 2% up to 10% of dry weight soft soil sample. The results of the test showed that the studied soil can be classified as an A-7-6 and CL soil using American Association of State Highway and transport officials (AASHTO) and unified soil classification system (USCS) respectively. The plasticity (PI) of the studied soil reduced from 30.5% to 29.9% at the application of CKD. The maximum dry density on the application of CKD reduced from 1.97 mg/m^3 to 1.86mg/m^3 and lime application yielded a reduction from 1.97mg/m^3 to 1.88mg/m^3. The swell potential on CKD application was reduced from 0.05 to 0.039%. The study concluded that soil stabilizations are effective and economic way of improving road pavement for engineering benefit. The degree of effectiveness of stabilization in pavement construction was found to depend on the type of soil to be stabilized. The study therefore recommended that stabilized soil mixtures should be used to subbase material for flexible pavement since is a suitable.*

Keywords : *cement; lateritic soils; road pavement; sand; stabilization*

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INTRODUCTION

Laterite oxides, such as silicon oxide, ferric oxide, and aluminum oxide, are found in lateritic soils made from coastal plain sand harvested from Ijoko in South Western Nigeria (SiO2, Fe2O and Al2O3). Aggregation of fine particles to coarse particles is the outcome of ferric oxide/sesquioxide action. As a result, the soil develops granular structures that are unsustainable in water (Jha, et al., 2022). The granular nature causes lateritic soils to be assessed incorrectly. In that the soil loses cohesiveness, which is expected to alter the permeability and relate to the soil's property, the road pavement or other construction on the problematic laterite soil would eventually and prematurely collapse (Abdelhalim, et al., 2021).

Nigerian cement manufacture is notably very expensive. Additionally, its usage as a stabilizing agent is not commercially viable. Numerous studies on the stabilization of fine-grained soils with cement carried out over the world met quality standards. Kazar et al., (2022) affirmed that after 19 years of construction, the performance of the base is still good. This is because cement was used to stabilize a soft plastic Marl, a calcareous material that is present in Northern Belize as the base for road pavement. Lei et al., (2022) stated that addition of 1.5% and 3% cement enhanced the engineering qualities of recycled concrete and limestone aggregate that had some smectite, a clay mineral that has a detrimental effect on the materials.

The financial involvement alongside the environmental challenges on the choices of these chemical additives necessitate the comparative use of Cement Kiln Dust (CKD) – the by-product generated from cement production and the hydrated lime which has close chemical composition Ghavami et al., (2021). The production of cement kiln dust in Nigeria from the cement factories is high and, in most cases, constitutes an environmental problem as they are largely stockpiled. Large quantities of cement kiln dust are produced during the manufacture of cement clinker by dry process. With modern manufacturing techniques, it is technically possible to introduce most CKD back into the clinker-making cycle. However, it is not done due to the restrictions on the alkali and chloride contents in the cement Etim et al., (2021). When cement is blended with the other two ingredients, it increases the soil's characteristics, providing the finished material with the durability to handle traffic loading. This is all dependent on the kind of soil used, the amount of cement applied, the amount of moisture present, and the compaction of the mixture (Aksu & Eskisar, 2022). The use of a cement stabilized foundation to reinforce the base section directly beneath rigid or flexible pavements is very common in highway construction. Roads, parking lots, airports, residential streets, and other structures can all benefit from the soil-cement pavement. It is a low-cost pavement base that's recognized for its strength and longevity (Zhang et al., 2021). The California Bearing Ratio (CBR) is a measurement of a road's or other paved area's subgrade strength, as well as the materials used in its construction (Okonkwo et al., 2022). It is simply the most popular in pavement design. The CBR test should be performed on soil with equilibrium determined moisture content. CBR values of 80%, 30%, and 10% are recommended for base course, sub-base, and subgrade materials, respectively, according to the Nigerian General Specifications for road pavement design.

The UK cement industry has estimated that over 200,000 tons a year of landfill space could be saved if the surplus CKD could be recycled into the clinker-making process or if alternative uses could be found (Maslehuddin, et al., 2008). Approximately 6% of the total CKD generated is utilized off-site. The most common beneficial use of cement kiln dust is its use as a stabilizing agent for waste, where its absorptive capacity and alkaline properties can reduce the moisture. Lime, is a well-known chemical additive selected alongside with the CKD for meaningful comparison. The construction of standard roads and highways is essential to enhance stability and to reduce enormous waste in Nigeria economy. However, the actual nature or quality of the soil is problematic. This gives rise to the suggested improvement required to make the soil adequate for the intended purpose. Therefore, the inadequacy of the soil for engineering purposes particularly highway will be improved upon by the use of relatively better quality of chemical addictive of CKD and lime.

The past stabilizations of soils were achieved with cement, lime, and other local stabilizer. These were not magical and were noted to be expensive. Therefore, to reduce economic waste by continually stabilizing lateritic soils with manufacturing product, not excluding lime, is financially challenging. The generating waste from cement – CKD will be adjudged to silent the economic waste to more than 50% of the previous stabilization methods. In view of this, this research is aimed at improving the lost standard in Nigeria roads and highways by evaluating a comparative analysis of utilizing chemical stabilizer, between the manufactured lime and the generating waste (CKD) of the Portland cement, so as to ensure a rideable and smooth delivery of goods and services. Among other benefits from the study are reductions in accident cost, saving maintenance cost, vehicle operating cost value of travel cost, value of savings in accidents etc.

METHODOLOGY

Research Design and Methodology

The study adopted the experimental design. The field work consists of collection of samples for this study and their physical properties were noted. The collected samples of lateritic soil from Ijoko, Ogun state, fresh cement kiln dust from Lafarge, sagamu plant in Ogun state and lime were taken to the laboratory for investigation.

Engineering Laboratory Tests

Routine laboratory test required and classify the soil (Barnes,200; Liv and Jack, 2004) and the test required to determine relevant soil parameters to assess the soil as subgrade and pavement material (eg Singh and Singh,2004; O'Flalierty, 2002a; Emesiobi, 1986) were carried out on soil samples, equipment and apparatus were carried out according to BS 1377(1990). The test to which the soil sample and the stabilized soil samples were subjected to are the Atterberg, limit (using Casagrande equipment) gradation test (sieve analysis and hydro meter tests) specific gravity, West African Compaction test, CBR test, Variable head permeability test.

Experimental Procedure

The testing program conducted on the lateritic soil samples include determination of the physical and chemical properties of the soil in its natural state. On the other hand, the testing program conducted on the lateritic soil samples mixed with different percentages of CKD and lime, included Visual Observation/ Examination, Moisture Content, Atterberg limits, specific gravity, compressibility, unconfined compression test.

Visual Observation/Examination Methods

Moisture Content Test

All moisture content determination was done by the oven drying method as specified by the BS 1377 (1990) code. For the determination of natural moisture content, samples were collected in polythene bag and immediately taken to the laboratory for the test. The water content is calculated from equation below:

$$W = \frac{m_2 - m_3}{m_3 - m_1} \times 100$$

Where m_1 = mass of container (g)
m_2 = mass of container and wet soil (g)
m_3 = mass of container and dry soil (g)

Atterberg Limit Test (LL, PL, SL, PI)

The Atterberg limits are basic measure of the nature of a fine-grained soil. Depending on the water content of the soil, it may appear in four states: solid, semi-solid, plastic and liquid. In each state, the consistency and behavior of a soil is different and thus so are its engineering properties. Thus, the boundary between each state can be defined based on a change in the soil's behavior. The Atterberg limits can be used to distinguish between silt and clay, and it can distinguish between different types of silts and clays. These limits were created by Albert Atterberg, and later refined by Arthur Casagrande.

Liquid Limit

The liquid limit test was performed using a Casagrande liquid limit apparatus in accordance with the guidelines provided in ASTM D 4318-00 on samples passing a 0.425 mm (No. 40) screen, including lateritic soils and soil mixed with (0, 2, 4, 6 8, and 10%) CKD and lime. The process for determining a soil's liquid limit test is described in BS 1377 (1990). To achieve homogeneity, 200g of the air-dried BC soil that passed through a 425-m sieve size was taken, combined with water, and kneaded. Five to ten minutes were designated for mixing. The liquid limit cup was filled with the soil paste, which was then leveled with the aid of a spatula. With the aid of a grooving tool, a clear and precise groove was created in the center. The number of blows necessary to force the two parts of the dirt pat that were separated by the groove to come together over a length of about 12 mm was counted as the crank was spun at about 2 revolutions per second. On the basis of a small sample of the soil paste, the water content was calculated.

A couple more times were performed with various consistencies or moisture concentrations. The soil samples were prepared with such consistency that between 10 and 25 shocks or blows would be needed to close the groove. On semi-logarithmic graph paper, the link between the number of blows and related moisture contents was plotted, with the logarithm of the blows on the x-axis and the moisture contents on the y-axis. The resulting "Flow-graph" or "Flow curve" graph, or the best-fit straight line. The liquid limit of the soil was determined to be the moisture level that corresponds to 25 blows from the flow curve.

Plastic Limit

According to the requirements outlined in ASTM D 4318-00, the plastic limit test was performed on samples passing a 0.425 mm (No. 40) sieve, lateritic soil, and soil mixed with (0, 2, 4, 6, 8, and 10%) CKD and lime. The water concentration at which soil begins to behave plastically is known as the plastic limit (PL). The same method that was used to determine the liquid limit (LL), the proportion of the material passing through a sieve with a 425 m aperture was also used to determine the plastic limit. The two hands' palms were used to mould a sample of the moist dirt. The sample was rolled, split into two subsamples, and then split again into parts.

The earth was rolled once again after being kneaded into a homogenous mass. This cycle of alternate rolling and kneading was carried out until the soil could no longer be wrapped into a thread and the thread broke under the pressure needed for rolling. The soil thread fragment was collected, and the moisture content was assessed in order to establish the plastic limit. The samples' plastic limit was discovered.

Plasticity Index

The plasticity index (PI) is computed as the difference between the liquid limit (LL) and the plastic limit (PL) as follows:

$$PI \text{ (or } I_p) = (LL - PL)$$

The Plasticity Index for the soil samples is obtained.

Sieve Analysis Test

After being washed and oven-dried, a representative sample of the lateritic soil weighing around 500g was utilized for the test. Automatic shakers and a set of sieves were used for the mechanical way of sieving. Finding out how the stabilized soil sample's particle size distribution is distributed is the goal of this.

Compaction Test

The ASTM D 1557-compliant standard compaction tests were completed. The specimens had a height of 116 mm and a diameter of 102 mm. The air-dried soil samples that were combined with the aforementioned amounts of cassava peel ash and 6% water underwent compaction testing. For each of the mixtures, the maximum dry density and ideal moisture contents were established.

Numerous engineering characteristics of soil, including CBR value, compressibility, stiffness, compressive strength, permeability, shrinkage potential, and swell ability, are influenced by the degree of compaction. In order to meet the essential soil properties, it is crucial to obtain the desired level of relative compaction.

California Bearing Ratio Test (Soaked and Unsoaked Specimen)

A mixture of air-dried soil, cassava peel ash, and roughly 6% water was added. Three layers of this were placed in the C.B.R. mould, and each layer was compressed with 27 blows from a 4.5 kg hammer. When the mould and the compacted soil mixture were placed beneath the C.B.R. machine, a seating load of roughly 4.5kg was applied. At penetrations of 0.5, 1.0, 2.0, 2.5, 3.5, 5.0, and 6.5mm, loads were observed. The soil's moisture content after compaction was measured. The same process was done for CKD and lime additions of 2%, 4%, 6%, 8%, and 10%.

Unsoaked California Bearing Ratio Test

The procedure involved weighing about 5.5 Kg of the oven dried soil to the nearest gram and placing it in a mixing tray it's then broken up and mixed. Sufficient water is then added from a measuring cylinder to bring the moisture of the soil to the desired value (optimum moisture content) and the soil and water are thoroughly mixed. The CBR mould was weighed to the nearest gram. The amount of soil gives the required density (maximum dry density) was weighed out and poured into CBR mould in three layers. Each evenly spread compacted by 55 blows using the rammer. After compaction of the top layers, the collar was removed and the soil trimmed level with the straight edge. The mould and the soil were weighed to check the bulk and dry density of the soil.

Weight of soil = $R_d V = (1 + M)$

Where R_d= maximum dry density
V= volume of CBR mould
M= optimum moisture content (compaction test)

Soaked California Bearing Ratio Test.

For the soaked California bearing ratio test, the procedure involved taking a specimen of the soil in a CBR mould was prepared with a perforated base. After the compaction of the specimen was completed and the specimen trimmed, a perforated plate was placed on the surface of the compacted soil and 2 No 2.27Kg surcharge weights placed on top. The whole assembly was immersed in water to allow; free access of water of both the top and bottom. The stem of the perforated plate is adjusted in height so that it will be in contact with the gauge. The bridge was placed and the gauge was set at zero. Measurements of the swelling of the specimen were obtained at 24 hours. At the end of 1day, the sample was removed from the water and allowed to drain for 15 minutes. The test procedure described above for the unsoaked specimen was then carried out. The procedure was repeated for samples already mixed with CKD and lime in proportion of 2-10%.

Specific Gravity Test

The specific gravity test was conducted on the soil in accordance with ASTM D 854- 02. The specific gravity of the soil sample was determined using the density bottle method. The sieved sample was grouped into approximately four equal parts. Each part was placed into dried 50cm^3 density bottle of known mass (M_1) to the nearest 0.01g. The mass of each bottle with sample inside was measured (M_2) to the nearest 0.01g. Each bottle was then filled with water and mixed thoroughly removing all air bubbles. The bottle was weighed to a mass (M_3). Finally, each bottle was washed and dried. Water was introduced and the mass of the bottle with water full taken (M_4). The specific gravity is expressed as

$$G_s = \frac{M_2 - M_1}{(M_4 - M_1) - (M_3 - M_2)}$$

The average of the values was taken for various samples. The variation of specific gravity with pulverized cow bone ash contents was tabulated.

Unconfined Compressive Strength

The test is carried out to determine the unconfined compressive strength (q_u) of the soil. It is a quick test to obtain the shear strength parameters of cohesive (fine grained) soils either in undisturbed or remolded state. The test is not applicable to cohesionless or coarse-grained soils. The test is strain controlled and when the soil sample is loaded rapidly, the pore pressures (water within the soil) undergo changes that do not have enough time to dissipate. Hence the test is representative of soils in construction sites where the rate of construction is very fast and the pore waters do not have enough time to dissipate.

The equipment and materials used include unconfined compression testing machine (Triaxial Machine), Specimen preparation equipment, Sample extruder and Balance. The test procedure involved remolded specimens are prepared in the laboratory depending on the proctor's data at the required molding water content. If testing undisturbed specimens retrieved from the ground by various sampling techniques, trim the samples into regular triaxial specimen dimensions (2.8" x 5.6"). The diameter and length of the specimen is measured. The triaxial cell is placed above the sample and no confinement is applied. The rate of strain is maintained at 1.2700 mm/min as per ASTM specifications. The data acquisition system collects real time data and the test is stopped when there is a drop observed in the strain versus load plot.

The parameters Axial strain and Stress are obtained using the following formula:

Axial Strain =

$$\varepsilon_a = \left(\frac{\Delta H}{H_0}\right) \times 100$$

$$\sigma = \frac{F}{A_c}$$

where

$$A_c = \frac{A_i}{1-\varepsilon}$$

A_i is the initial area of the specimen (πr_i^2)

PRESENTATION OF RESULTS, ANALYSIS AND DISCUSSION

The result of visual observation of the collected lateritic soil sample and the chemical addictives, stabilizers, the cement kiln dust (CKD) and the lime as well as their engineering properties tests with required chemical analysis were described in this chapter.

Result of visual observation and description of samples

A reddish brown colouration was noticed on the lateritic soil samples below the surface of the borrow pit. The reddish coloration may be attributed to the presence of ferric oxide. The CKD is physically brown and has no distinct difference from the ordinary Portland cement. The lime has a white colouration and is as fine as white cement.

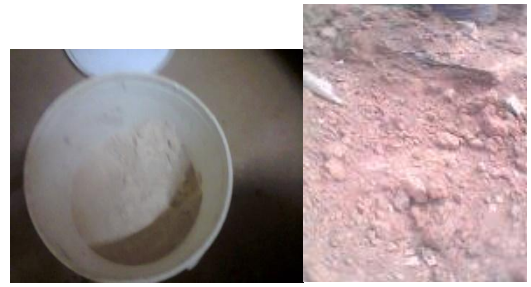

Figure 1. Visual of samples

Geotechnical Results

Specific gravity test on soil sample and stabilized soil sample.

	Laterite	CKD	Line
Weight of bottle (w_1)	27.6	29.4	32.1
Wt of bottle + soil	52.9	50.2	55.1
Weight of bottle + soil and water (w_3)	93.5	79.4	82.1
W_2-w_1	77.7	20.8	23
(w_4-w_1)-(w_3-w_2)	50.1-40.3	50-419	50.1-41.3
(specific gravity) G.S	2.66	2.57	2.64

The results of the specific gravity test conducted are shown in table as follow. Whereas the value of specific gravity of the studied soil was found to be 2.66 which agrees with the range of 2.6-3.2 given by charman (1988) for lateritic soils and with the values obtained by Ola (1983 a, b) for lateritic soils from Zaria, Nigeria that of the CKD and lime used are 2.57 and 2.64 respectively. This shows that CKD (2.57) with lower specific gravity has a reduced weight when compared with lime.

Atterberg Limits

The Atterberg limits tests were conducted or the soil sample and the stabilized soil with CKD and lime between 0 and 10%.

Liquid Limit

The CKD stabilized soil resulted in reduced liquid limit with increase in the percentage of the stabilizer from 0% to 10%. In the case of lime-stabilized soil, there was a slight increase in the liquid limit with percentage increase of the stabilizer.

Table 1. The liquid limit of CKD and lime

	C.K.D	**Lime**
0%	46.0	46
2%	46.0	46
4%	45.3	46.3
6%	45.2	46.4
8%	45.1	46.9
10%	45.0	47.0

This shows that CKD stabilized soil is more acceptable by engineering judgment. The results fall within the specification of ministry of road transport and highways (MORTH) which state that the maximum limit should be under 70%.

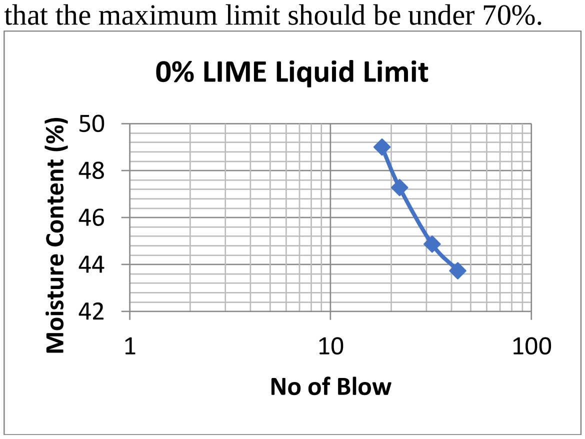

Figure 2. Liquid Limit on 0% Stabilizer

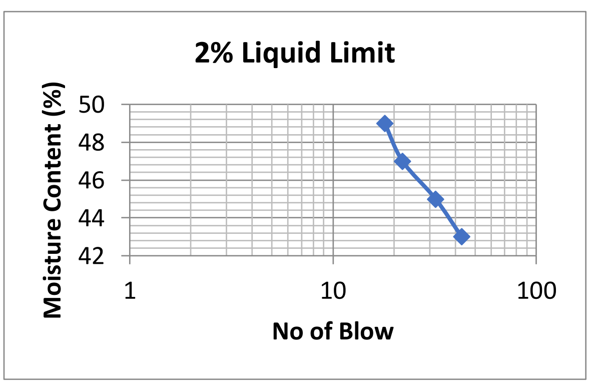

Figure 3. Liquid Limit on 2% Stabilizer

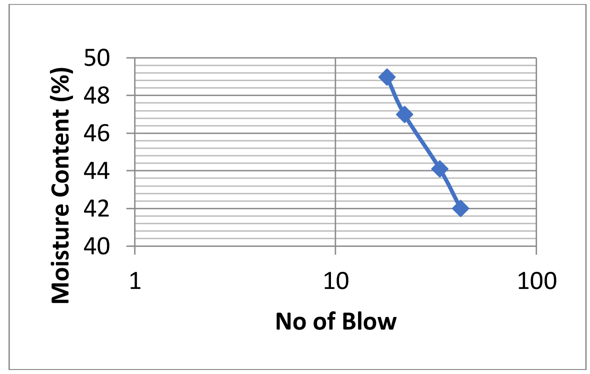

Figure 4. Liquid Limit on 4% Stabilizer

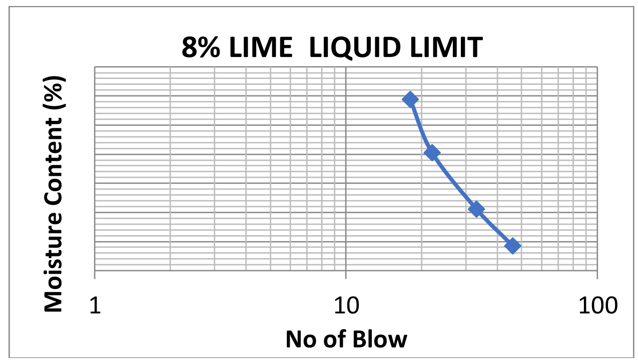

Figure 5. Liquid Limit on 8% Stabilizer

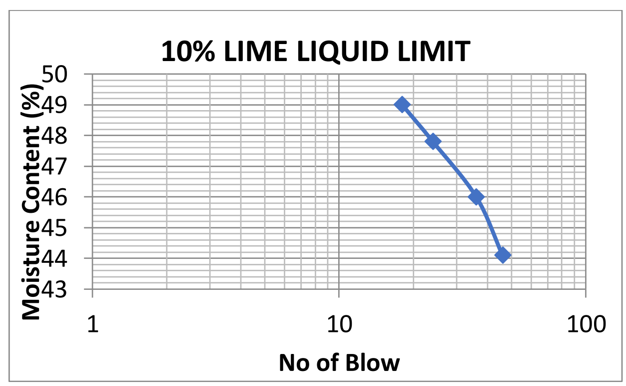

Figure 6. Liquid Limit on 10% Stabilizer

Plastic Limit

The table below shows the variations of treated soil with an increase in the plastic limit of lime stabilized and a decrease in CKD stabilized soil.

Table 2. The variations of treated soil with the plastic limit of lime sand CKD stabilized soil

	Lime	**C.K.D**
0%	15.5	15.5
2%	15.8	15.5
4%	15.8	15.3
6%	15.9	15.3
8%	15.9	15.2
10%	16.0	15.1

The reduction in the CKD stabilized soil sample is more suitable for construction of highway. The reduction in the plastic limit may be due to insufficient free lime content in the CKD. The reduction is from 15.5% to 15.1%. This percentage reduction is an indication of less soil to be flocculated which thereby presented a more stabilized road.

Plasticity Index

The variation of plasticity index of the treated and untreated soil sample with percentage increase in the stabilizer is the in the table below.

Table 3. The variation of plasticity index of the soil sample with percentage increase in the stabilizer

	C.K.D(%)	**Lime(%)**
0%	30.5	30.5
2%	30.5	30.5
4%	30.0	30.5
6%	29.9	30.5
8%	29.9	31.0
10%	29.9	31.0

The untreated soil sample has 30.5% value. This gives an idea of the clay content in the collected soil sample. A slightly decreased noticed in the CKD stabilized soil is more acceptable for engineering use. But an increase in the PI with lime could probably be due to deficiency of $Ca^{2}+$ which is required to replace the weekly bounded ions in the soil structure and hence flocculation did not occur as required. There was an increase in the fine fraction which absorbs more water and makes the soil to be more plastic. The figures the graphical explanation

Shrinkage Limit

Linear Shrinkage.

The result of the linear shrinkage limit is in table below.

Table 4. The linear shrinkage limit

	C.K.D (%)	**Lime (%)**
0%	7.8	7.8
2%	7.0	7.8
4%	7.0	7.8
6%	6.3	6.3
8%	6.3	5.3
10%	6.3	5.5

The stabilized lateritic soil sample with lime have a notable reduced volume more than that of the CKD treated soil sample. The CKD treated soil sample will be more suitable in for engineering use as this will in turn reduce the unwanted crack of the soil. below the shrinkage limit the soil does not remain saturated.

Sieve Analysis and soil classification

The result of the sieve analysis conducted on the lateritic soil sample from Ijoko is shown in the figure 7 represents the graphical behavior.

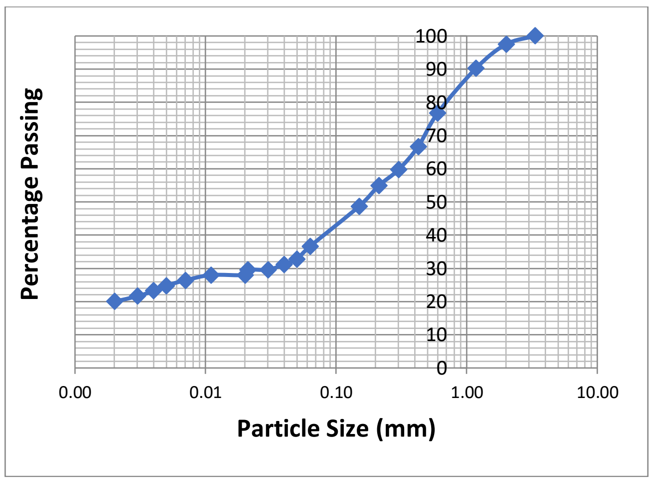

Figure 7. The sieve analysis

The soil classification was based on the results of the Atterberg and Sieve analysis using the AASHTO classification method. The soil was classified as A-7-6 soil. This means that the soil is problematic and has poor engineering qualities, particularly since it contains low clay and silt content as binder to the soil grains.

Swelling potential (%)

The swelling percentage result is shown in table 5.

Table 5. The swelling percentage

	C.K.D (%)	Lime (%)
0%	0.9	0.9
2%	0.05	0.9
4%	0.05	0.9
6%	0.04	10
8%	0.054	1.0
10%	0.039	1.1

The CKD swelling percentage led to decrease in the swelling percentage as against that of the lime.

Compaction Test Results

The summary of compaction test results is shown on figure 8-13.

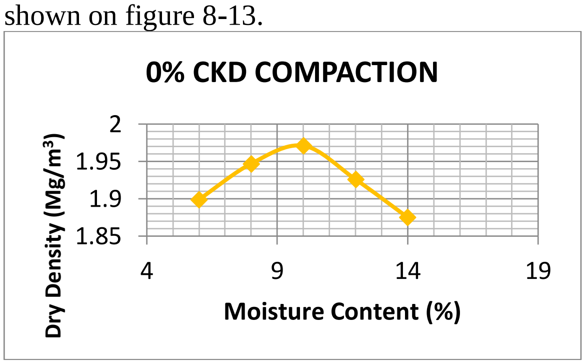

Figure 8. The compaction of soil with 0% CKD Stabilizer

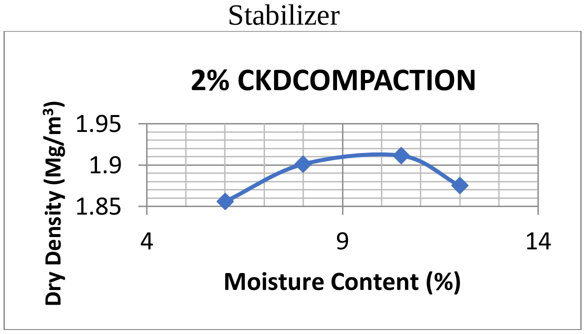

Figure 9. The compaction of soil with 2% CKD Stabilizer

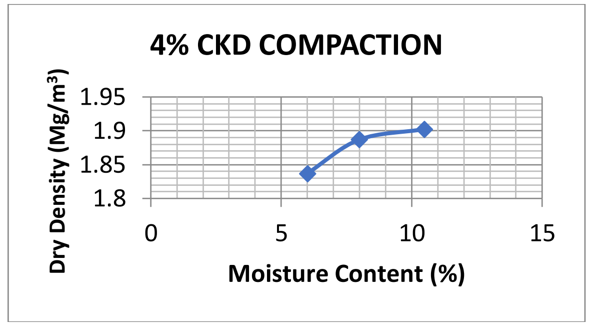

Figure 10. The compaction of soil with 4% CKD Stabilizer

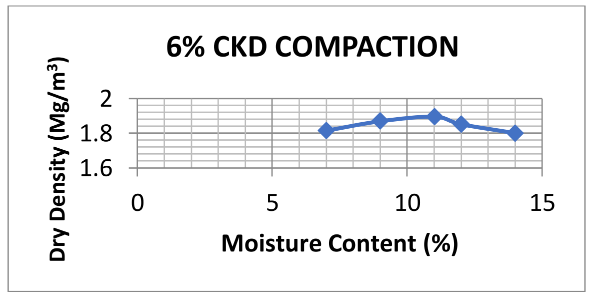

Figure 11. The compaction of soil with 6% CKD Stabilizer

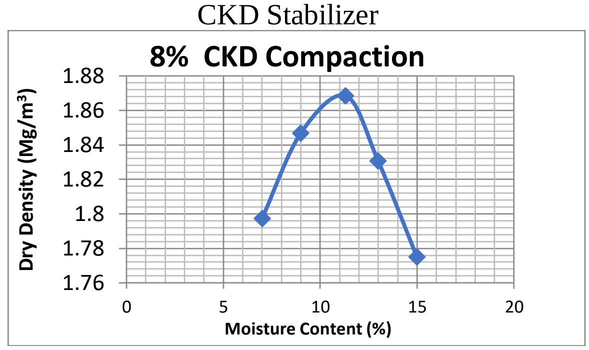

Figure 12. The compaction of soil with 8% CKD Stabilizer

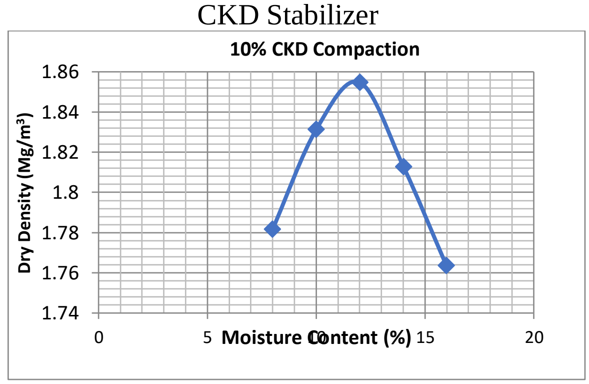

Figure 13. The compaction of soil with 10% CKD Stabilizer

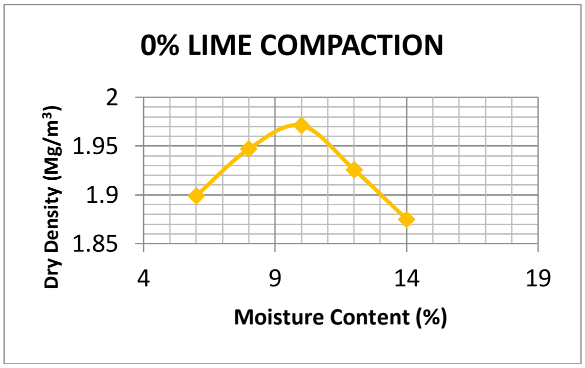

Figure 14. The compaction of 0% Lime Stabilizer

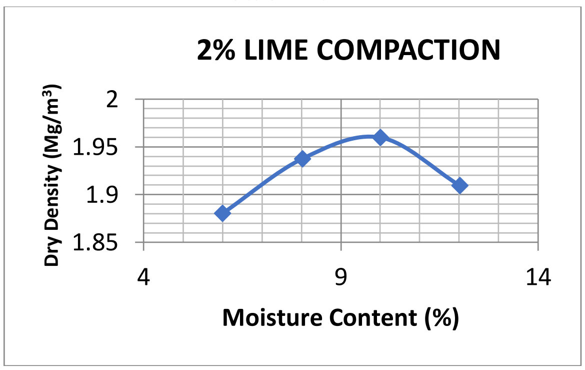

Figure 15. The compaction of 2% Lime Stabilizer

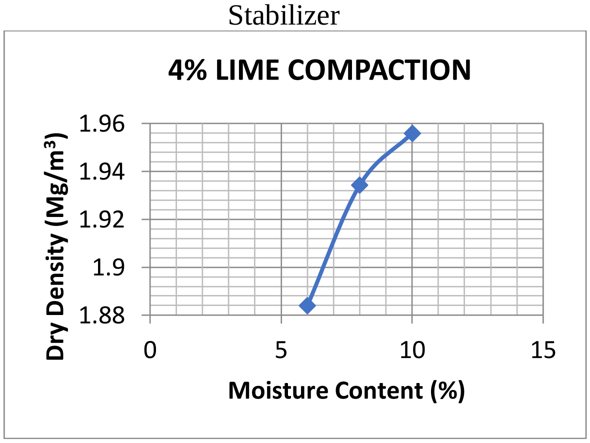

Figure 16. The compaction of 6% Lime Stabilizer

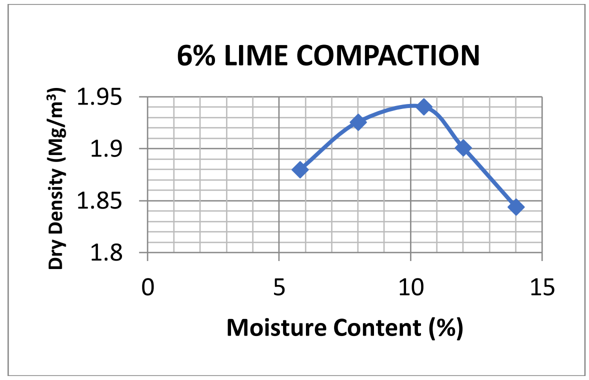

Figure 17. The compaction of 6% Lime Stabilizer

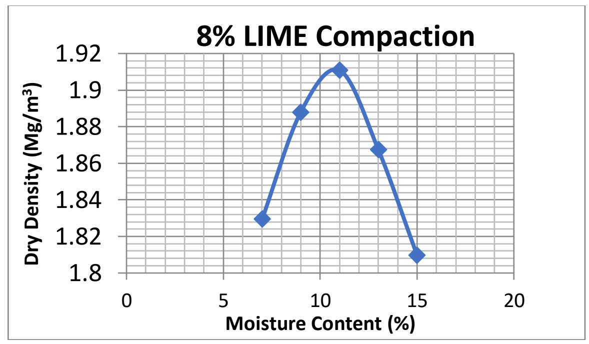

Figure 18. The compaction of 8% Lime Stabilizer

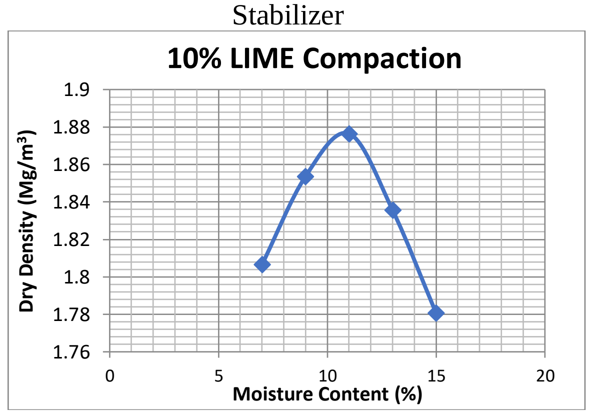

Figure 19. The compaction of 10% Lime Stabilizer

The results showed that the maximum dry density and the optimum water content of the studied lateritic soil sample were 1.97mg/m^3 and 10.0% respectively.

In general, the stabilizations with lime from 2% - 10% resulted in an increase in the optimum moisture content from 10% to 11.0% and a decrease in the maximum dry density from

1.97kg/cm^3 to 1.88g/cm^3. And the addition of CKD led to an increase in the optimum content from 10.0% to 12.0% and a decrease in the maximum dry density from 1.97 mg/m^3 to 1.86g/cm^3. The increase in lime was due to the addition of used stabilizers, which decreased the quantity of free silt and clay fraction and made the soil more granular in nature, which in turns decreased the specific gravity of the stabilized soil sample as a result of the coated soil.

Table 6. Summary of OMC with variation of CKD and lime

	OMC OF CKD STABILIZED SOIL	OMC OF LIME STABILIZED SOIL
0%	10	10
2%	10.2	10
4%	10.5	10.1
6%	10.8	10.5
8%	11.2	10.8
10%	12.0	11

Table 7. Summary of MDD with variation of CKD and lime

	MDD OF CKD STABILIZED SOIL	MDD OF LIME STABILIZED SOIL
0%	1.9707	1.9709
2%	1.9115	1.9602
4%	1.9022	1.9559
6%	1.8951	1.9402
8%	1.8691	1.9106
10%	1.855	1.8765

Unconfined compressive strength Test Results

Figure 10 showed the results of unconfined strength test of both studied soil sample and stabilized soil samples with both CKD and line in their respective percentages from 2% to 10%. The addition of lime stabilizer increased strength value from 111.22 to 140.28kn/m^2 after about four hours curing. On the other hand, the additions of CKD resulted in reduction from 99.6kN/m^2 to 42kN/m^2. The use of CKD produced no significant strength improvement with few hours of road construction. Within allowable setting time it yielded significant improvement though lower than that of lime (in it stockpiled state as discussed in past literature) but CKD in its freshness used for this research was noted to improve soil quality after longer setting time.

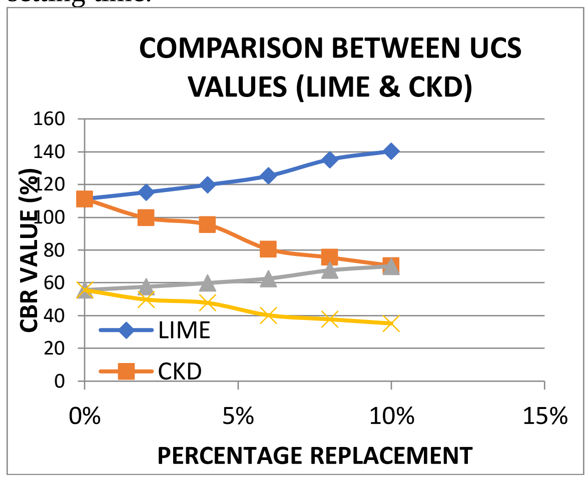

Figure 20. Unconfined strength test of both studied soil sample and stabilized soil samples

California bearing ratio test results

The variation of soaked and unsoaked California Bearing Ratio (CBR) for lateritic soils treated with CKD and lime were analyzed and the results are shown in figure 11 and 12.

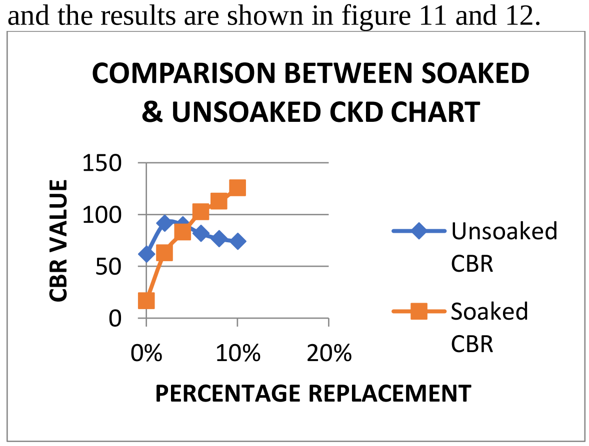

Figure 21. California Bearing Ratio (CBR) of soil with CKD stabilizer

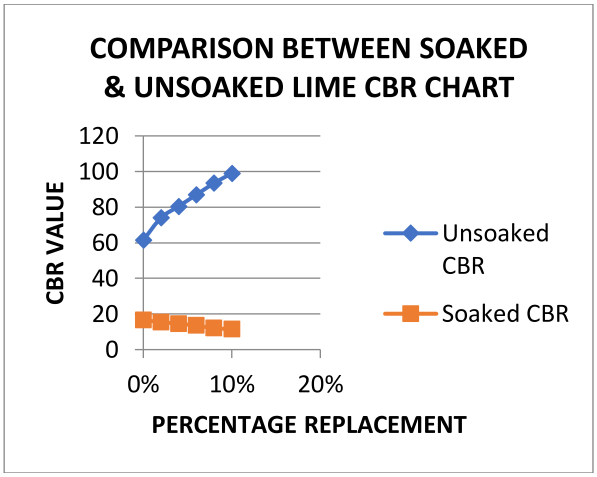

Figure 22. California Bearing Ratio (CBR) of soil with Lime stabilizer

The unsoaked CBR values of the laterite soil treated with lime increased from 61.5% to 99% with percentage variation from 0% to 10%. After 4 days soaking, the lime stabilized soil samples values were found to reduce from 16.5% to 11.5 of 0% to 10% variation. The unsoaked CKD stabilized soil sample showed reduction in values from 91.1% to 73.9% with percentage variation from 2% to 10% stabilization. But there was notable increment from 62.5% (2%) to 125.5 (10%). It is hereby noted that CKD – Stabilized laterite soil regained strength after being soaked for 4 days (4 days). This is compared with the past work on the use of CKD that vary from this recent result. Stockpiling effect of this material was probably responsible for this variation. As the CKD used was freshly obtained from the kiln.

Permeability Test Results

Table 8. Permeability test

Percentage variation	C.K.D stabilized Soil (cm^2/s) x 10^{-6}	Lime stabilized soil (cm^2/s) x 10^{-6}
0%	7.232	7.232
2%	6.640	7.200
4%	6.240	6.3
6%	6.00	5.640
8%	6.00	5.020
10%	5.340	4.560

The treated soil sample was of low permeability. This was seen to decrease down with percentage increase of the stabilization. The falling head permeability is adopted due to the low permeability of the studied soil samples.

Chemical Analysis of cement kilm dust (CKD) and lime.

The oxide composition of CKD and lime are given in table below the result of the freshly collected CKD sample was compared with stockpiled CKD samples derived from past work.

Table 9. The oxide composition of CKD and lime.

Parameter	Fresh CKD Sample	Stock piled	Hydrated Lime (L)
Al_20_3	4.55	3.24	0.6
siO_2	15.6	11.9	1.3
SO_3	6.2	2.40	-
K_2O	4.33	2.92	0.3
CaO	42.7	44.2	65
Fe_2O_3	2.0	1.9	1.4
MgO	1.55	1.73	1.7
Free lime	4.4	0.0	-
Loss of ignition	23.4	30.2	32

The oxides tested are Alumina (Al_2O_3), silica (SiO_2), Potassium oxide (K_2O), lime (CaO), iron oxide (Fe_2O_3), magnesium oxide the result from the fresh CKD was notably different from the stockpiled sample. The lime (CaO) content was notably high in both the fresh and stockpiled principle constituent of the chemical addictive. This is contrary to the content of the free lime in both samples of fresh CKD and the stockpiled. There is no free lime content in the stockpiled CKD that has been exposed to the environment for long period.

CONCLUSIONS AND RECOMMENDATIONS

The study concluded that soil stabilizations are effective and economic way of improving road pavement for engineering benefit. The degree of effectiveness of stabilization in pavement construction was found to depend the type of soil to be stabilized. The study therefore recommended that stabilized soil mixtures should be used to subbase material for flexible pavement since is a suitable.

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