Nigerian Journal of Technology (NIJOTECH)
Vol. 32, No. 1, March, 2013, pp. 109–116.
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University of Nigeria. ISSN 1115-8443

POTENTIALS OF CEMENT KILN DUST IN SUB-GRADE IMPROVEMENT

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Abstract

The ever increasing cost of construction materials in Nigeria and other developing countries has created the need for research into locally and readily available materials and also on how to convert materials considered to be waste by-product such as cement kiln dust (CKD) for use in construction and soil improvement. To achieve this, soil samples collected from Sankwalla – Busiri road, Obanliku, Cross River State classified as an A-2-7 soil on AASHTO classification were stabilized with 2-24% cement kiln dust (CKD) by weight of the dry soil. The investigation includes evaluation of properties such as compaction, consistency limits and strength of the soil. The results obtained show that the increase in CKD content increases the Optimum moisture content (OMC) with a reduction in plasticity. There was also improvement in the California Bearing Ratio (CBR) and Unconfined Compressive strength (UCS) with increase in the CKD content. A predictive model was developed and found to reasonably predict the relationship between properties of soil and the proportion of CKD used. The coefficients of correlation were high showing a strong relationship between the measured and predicted values. The study concluded that CKD can be used to improve the properties of soil for construction purposes and 24% CKD content was observed to yield maximum improvement for CBR and UCS.

Keywords: cement kiln dust (CKD), compaction, consistency, California bearing ratio, unconfined compressive strength, subgrade

1. Introduction

In road construction, a firm subgrade and base layers are essential components of a pavement structure. The geotechnical properties such as strength and volume stability of the subgrade have significant influence on the overall performance and durability of the pavement. Most of the subgrade soils encountered during construction of road are unable to respond effectively to the imposed stresses, which has become a dominant factor responsible for the failure of pavement especially in Nigeria [1]. Okechukwu et al [2] identified inadequacy of construction material and poor quality of construction as other factors responsible for road failure in south eastern Nigeria. Improving the properties of these soils by the addition of chemicals and cementitious additives becomes not only necessary but very important. These chemical additives range from waste products to manufactured materials and include lime, Class C fly ash, Portland cement and proprietary chemical stabilizers [3].

Cement and lime are the two main materials used for stabilizing soils. These materials have increased in price due to the sharp increase in cost of energy since 1970 [4]. Miller and Zaman [5] recognized the importance of recycling industrial waste with regards to natural resource conservation and efficient landfill utilization. They added that this has led to research on alternative uses of waste materials in different geotechnical application including soil improvement. CKD a waste product from the manufacture of cement; have proven to have potentials to be useful in the stabilization of soil [6]. Other materials that have also proven to be useful in soil stabilization are Rice Husk Ash [7] and Alginic acid and Polygal [8]. For instances, Chukweze [8] investigated the potentials of Alginic Acid and Polygal for soil stabilization and found that by using alginic acid and polygal obtained from organic wastes, the cost of stabilization using these additives can be greatly reduced.

Large quantities of CKD are generated from cement plant in most cities of the world during the production of cement. For instance, in Nigeria the total cement consumption in 2011 was 17 million metric tons and cement productive capacity of the country rose to 18.5 million metric tons in January 2012. Currently the total installed cement production capacity of the country stood at 22.5 million metric tons annually [9]. One metric ton of cement can produce between 0.6–0.70 tones of CKD. The resulting bye products (CKD) from cement production according to NCASI [10] have desirable properties that make them suitable for variety of beneficial application including stabilization. However, significant portion of cement kiln dust continues to be used as landfill as solid waste. Although disposal of CKD as landfill pose little threat to the environment, disposal at land fill might be viewed as the discarding of a useful commodity (material) and this has led to the consumption of available land where it is being dumped that would have been use for other purpose. This flouts the current global cry for sustainable development in term of economic resource utilization.

There have been significant research on the material characterization of cement kiln dust (CKD) stabilized subgrade soil and its utilization for engineering purpose [11]. One of the recorded investigations of CKD for soil improvement was done by McCoy and Kriner [12]. They employed CKD with different free lime contents and soils of different plasticity and found that the results favourably compared to those obtained with hydrated lime and Portland cement. They concluded that the use of CKD with appropriate composition at adequate additional levels was promising for stabilizing soils. Soil stabilization using CKD may be considered a cheaper alternative compared to lime, when encountering problematic soils that are collapsible, expansive and frost-susceptible [13]. Study by Solanki and Zaman [14] showed that the Modulus of resilient, Modulus of elasticity and unconfined compressive strength for CKD- stabilized specimen increased with CKD content.

An experimental study to investigate the effectiveness of CKD for stabilizing kaolinite clay was performed by Peethamparan et al [15] employing two CKDs having free lime content of 13.85 and 5.32% and LOI of 14.22 and 29.65% respectively. The percentages of CKD varied from 8 to 25% by dry weight of soil. They reported that the strength of CKD treated kaolinite clay is proportional to the CKD content and also the free lime content. A considerable improvement in strength of kaolinite was also observed. Also the CKD with higher free lime content (13.85) gave a compressive strength twice that of a CKD with lower free lime content (5.32%). Al-Refeai and Al-Karni [16] conducted an experimental study on the utilization of cement kiln dust for ground modification, by adding different percentages of CKD on the engineering properties of three different problematic soils in the central region of Saudi Arabia. The result shows significant improvement in their engineering properties. Okafor and Ewa [17] investigated the effect of CKD on the compressive strength of Obudu Earth block and found that the compressive strength of CKD-stabilized block generally increased with increase in CKD content.

The possibility of using CKD in stabilizing sandy soils for pavement subgrade application was investigated by Napeirara [18]. The results from the study show that an addition of 15% CKD having 5.9% free CaO and MgO and 0.97% total alkalis ($K_2O + Na_2O$) ensured a compressive strength of 0.25 Mpa, which is standard practice in Poland for the subgrade within 14 days of the treatment. Bhatty et al [19] conducted a study on the use of CKD in stabilizing soil. They reported that CKD with high free lime (26.6%) and moderate alkalies ($\approx$ 4.6% expressed as Na_2O equivalent) produced mixtures with compressive strengths comparable to those obtained with cements and lime. It has been shown that the addition of 8% CKD resulted in a reduction of the plasticity index from 513% to 326% for highly plastic bentonite clay [20]. This reduction in PI was found to increase with subsequent increase in CKD content. CKD was utilized in the stabilization of dune sand-asphalt mixes used for pavement bases in a study by Fatani and Khan [21] and reported an improvement in mix stability with 11% CKD content. Studies by other researchers [22 - 24] testify to the potential of using CKD for soil stabilization, though at dosages (8-30%) substantially greater than those used for other admixtures.

The aim of this paper is to explore the potentials of utilizing CKD in improving the properties of soil for use as base course material in pavement construction. The paper examined the fill material used for the construction of Sankwala- Busi Road in Obanliku, Cross River State, Nigeria, with a view of stabilizing it to obtain a subbase and base course material.

2. Materials and Methods

The soil sample used for this study was collected by method of disturbed sampling at average depths of 1.0–1.2 m, from deposits along Sankwalla – Busiri road, Obanliku, Cross River State. The area lies between Latitude 06°33N and Longitude 09°14E. The soil collected was air dried in open air before being used. The cement kiln dust used was obtained from United Cement Company of Nigeria (Unicem), located in Nfamoseng in Akamkpa Local Government Area of Cross River State. The kiln dust was obtained in bags and stored in air tight containers. The CKD was sieved through 75 m sieve before used. The preliminary tests for identification of the natural soil and the geotechnical properties of the soil treated with CKD were carried out in accordance with BS 1377

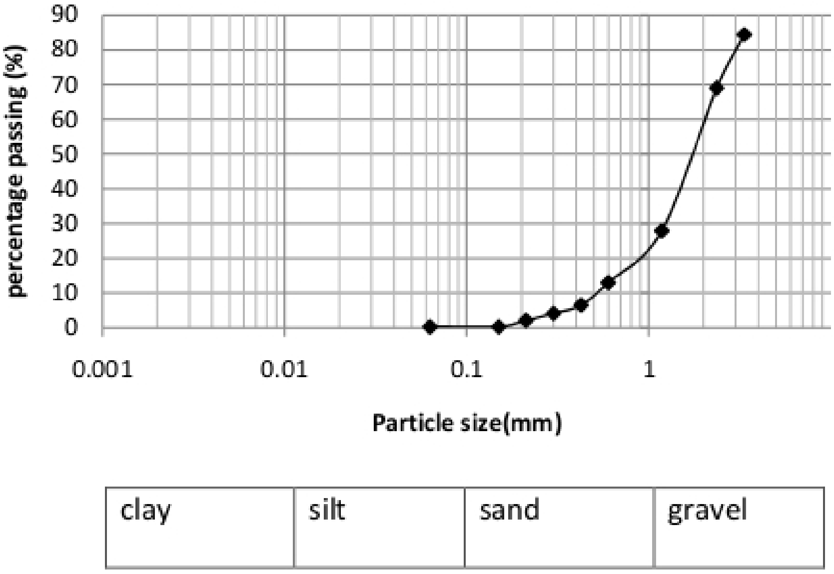

Figure 1: Particle size distribution.

[25]. The standard Proctor energy level was used for compaction test which was also used to determine the moisture content for the CBR and UCS specimens. The CKD was thoroughly mixed with pulverized soil and then with distilled water.

3. Results and Discussion

3.1. Identification of soil and CKD

The index properties of the natural soil before addition of stabilizer (CKD) are shown in Table 1. The particle size distribution is shown in Figure 1. The geotechnical properties of the natural soil showed that it has a liquid limit and plasticity index of 42% and 14.7% respectively and classified as well graded sandy gravel using the Casagrande classification chart. It is classified as A-2-7(1) in the AASHTO [26] classification system. In its natural state, the soil is suitable for use as fill material, but requires some level of improvement for it to be used as base course material based on NGS [27] for road and bridges.

The oxide composition of the CKD used was assessed through X-ray florescent test (XRF) the result is shown in Table 2. The composition of calcium oxide (CaO) alone is 55.06%. This is responsible for the ion exchange between soil and the CKD resulting in the formation of more granular material and strength development. The loss on ignition (LOI) for the cement kiln dust was 4.38 while the specific gravity was 2.60. The loss on ignition is the loss in mass associated with heating to ~ 950℃, usually contributed by chemically bound water and noncarbonated carbon. Soil treated with low LOI and high free lime CKD provided promising results in terms of strength [12].

Table 1: Index properties of natural soil sample.

DESCRIPTION	RESULTS
Liquid Limit (%)	42
Plastic Limit (%)	27.3
Plasticity Index (%)	14.7
Percentage Passing BS Sieve 200 (%)	2.10
AASHTO Classification	A-2-7(1)
USCS Classification	SW
Maximum Dry Density (kg/m^3)	1830
Optimum Moisture Content (%)	12.18
Unconfined Compressive Strength (KN/m^2)	395
California Bearing Ratio (after 24 hrs soaking) %	2.2
Unsoaked California Bearing Ratio (%)	22
Specific Gravity	2.54
Colour	Reddish Brown

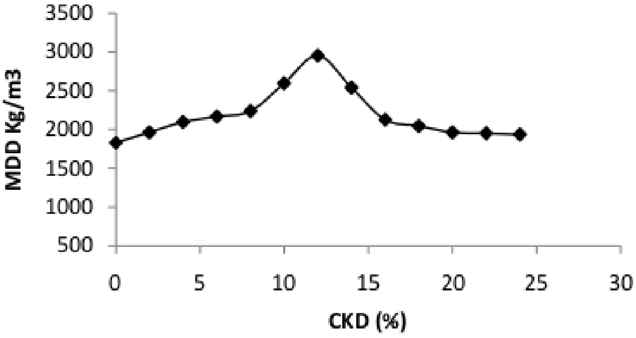

Figure 2: Variation of MDD with cement kiln dust.

Table 2: Oxide composition of cement kiln dust.

Oxides	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO3	K_2O	Na_2O	F.CaO	LOI
Percentage (%)	14.79	4.51	2.64	55.06	2.66	1.48	1.26	0.18	4.04	4.38

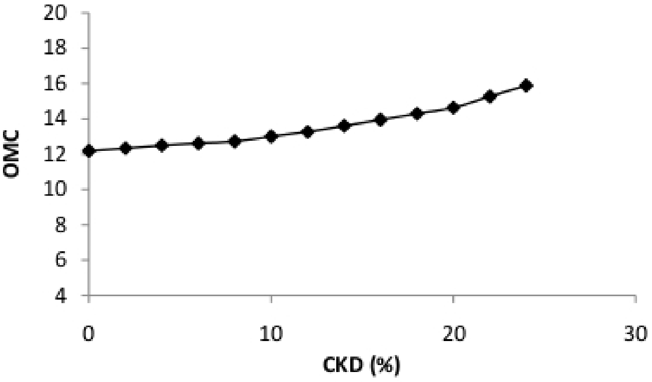

Figure 3: Variation of OMC with cement kiln dust.

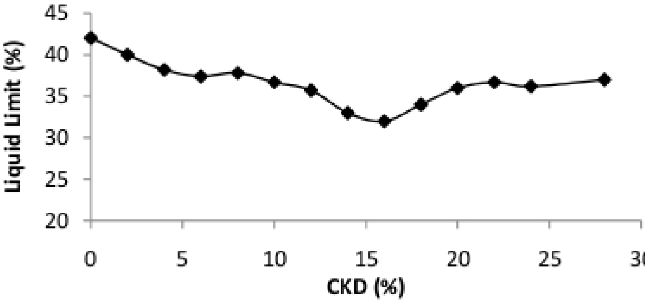

Figure 4: Variation of liquid limit with cement kiln dust.

3.2. Compaction characteristics

The relationship between MDD and CKD content is shown in figure 2. The results indicate that between 0% and 12% CKD content, the MDD increase from 1.83Mg/m^3 to 2.60Mg/m^3 respectively. This was as a result of CKD occupying the void within the soil matrix. It may also be due to the relatively higher specific gravity of CKD (2.60) to that of the soil (2.54) [28, 29]. While the decrease in MDD after 12% optimum CKD content could be attributed to the brittle nature of soil with higher CKD and this is one of the drawbacks identified by [30] in the use of CKD for soil stabilization.

Figure 3 shows the variation of OMC with CKD content. The result shows that the OMC increased with increase in CKD content. This result agrees with previous research by Zaman et al [22] and Miller and Zaman [13]. The increase in OMC is due to the additional water needed to coat the surface area and to lubricate the entire matrix for hydration process [31].

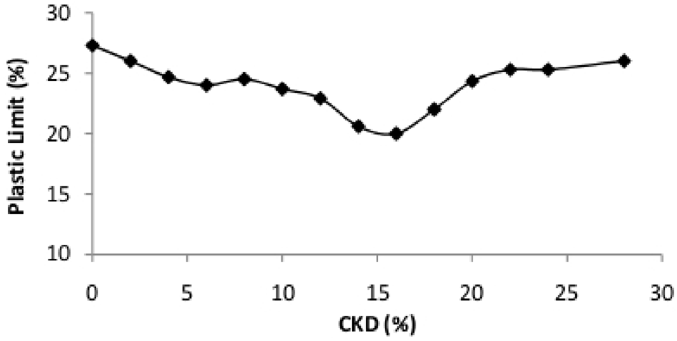

Figure 5: Variation of plastic limit with cement kiln dust.

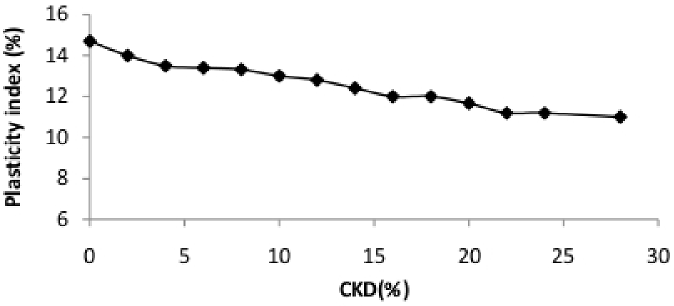

Figure 6: Variation of plasticity index With cement kiln dust.

3.3. Consistency limits

The variation of liquid limit with CKD is shown in figure 4. The liquid limit decrease with the addition of CKD up to 12% and then increase slightly with further increase in the addition of CKD. The initial reduction in the liquid limit may be attributed to the cementitious properties of CKD due to high content of calcium oxide (CaO) which aid flocculation and aggregation of the soil particles [16]. The increase in liquid limit beyond 12% CKD content is attributed to the extra water required to turn the soil-CDK mix to fluid.

Figure 5 shows the relationship between plastic limits and CKD content. The trend is similar to that of the liquid limit. The reasons for the variation of the liquid limit with CKD content are also similar to that of the variation of plastic limit with CKD content.

Plasticity Index and CKD content relationship is shown in figure 6. The plasticity index decrease from 14.7% to 11.2% with increase in CKD content from 0% to 24%. This trend may be attributed to the replacement of the finer soil particles by CKD with consequent reduction in plasticity index [32]. This trend

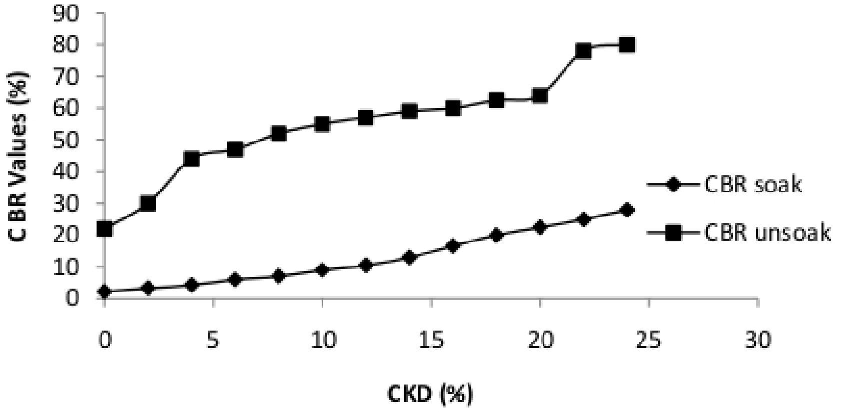

Figure 7: Variation of CBR of soil with cement kiln dust for both soaked and unsoaked sample.

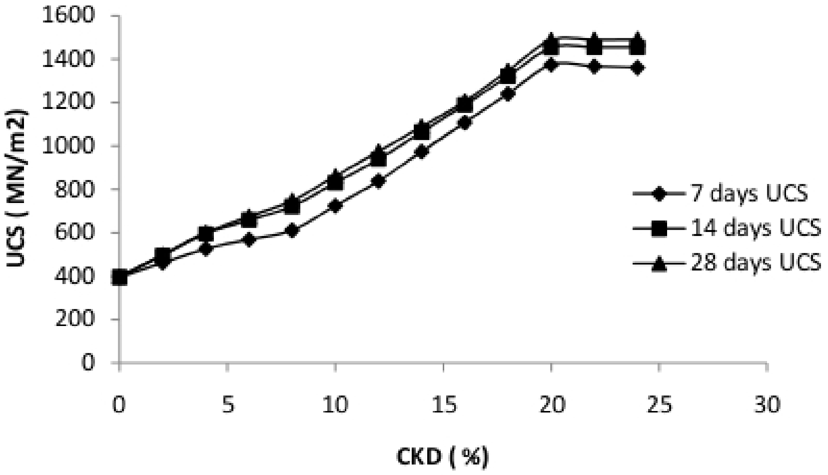

Figure 8: Variation of UCS of soil with cement kiln dust.

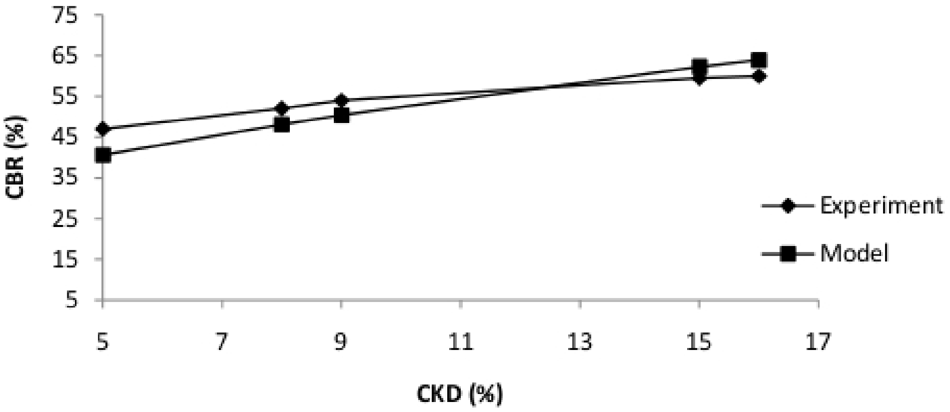

Figure 9: Plot of California bearing ratio (unsoaked) against percentage CKD.

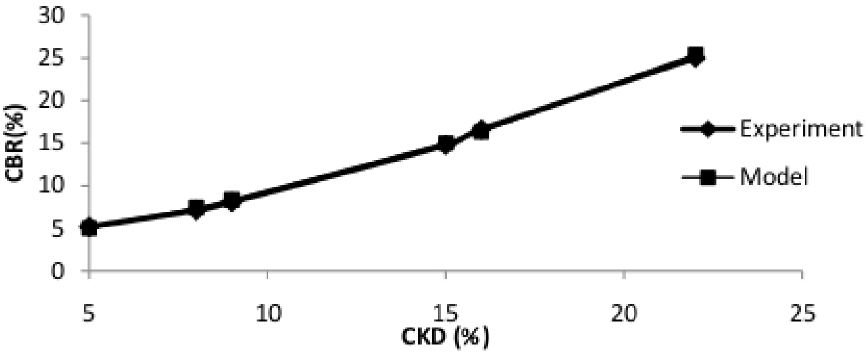

Figure 10: Plot of California bearing ratio (soaked) against percentage CKD.

was also observed by several researchers [22, 23].

3.4. California bearing ratio

Figure 7 shows the relationship between the CBR and CKD content at optimum moisture content (OMC). The result shows that the CBR for unsoaked sample increase from 22% to 80% with increase in CKD content from 0% to 24% respectively. The reason for the increment in CBR may be because of the gradual formation of cementitious compound in the soil by reaction between the CKD and some amount of CaOH present in soil [33]. The trend of the soaked CBR was similar to the Unsoaked though with lower values. The CBR is a measure of the strength of subgrade.

3.5. Unconfined compressive strength

Unconfined compressive strength (UCS) is the most common and adaptive method of evaluating the strength of stabilized soil. It is the main test recommended for the determination of the amount of additive required to be used in stabilization of soil [34]. Results of variation of UCS with increase in CKD for 7days, 14days and 28days are shown in fig 8. The UCS values increases as the percentage of CKD increases from 0% to 24%. The peak UCS value for the 7, 14 and 28 days are 1360kN/m^2, 1454kN/m^2 and 1490kN/m^2 respectively at 24% CKD. The 7 days peak value of 1360kN/m^2 at 24% fell short of 1710kN/m^2 specified by TRRL [35] as criterion for adequate stabilization using OPC. The increase in the UCS is attributed to the formation of cementitious compound between CaOH present in the soil and the CKD. The optimum CKD was found to be 24%.

4. Modeling of Strength Indices and Model Verification

Scheffe's Predictive mixture models [36] were formulated for CBR (soaked and unsoaked) and 7-days UCS. The correlation between the experimented and the model results were computed for $r = \pm$ and the t-test was used to verify the significance of r at 5% level. This was done to facilitate the application of laboratory results and serve as a guide in predicting relationship between variables and also reduce the rigorous laboratory work by facilitating prediction of results.

Figures 9-11 shows the plots of the experimental and predicting models from equations (1-3) developed. The models were those for CBR soaked and unsoaked and 7-days UCS.

$$\text{CBR}_{(unsoaked)} = -1.257x_1 + 0.2639x_2 + 4.60 \times 10^{-2}x_1x_2 \qquad r = 0.9247 \tag{1}$$

$$\text{CBR}_{(soaked)} = 3.347x_1 + 0.0224x_2 + 2.9 \times 10^{-2}x_1x_2 \qquad r = 0.9940 \tag{2}$$

$$\text{UCS}_{(7\,days)} = 68.19x_1 + 3.62x_2 + 0.2647x_1x_2 \qquad r = 0.99 \tag{3}$$

Where x_1 = % cement kiln dust and x_2 = % soil sample.

5. Conclusions

The following conclusions may be drawn from the study:

1. The soil used for the study was obtained from Sankwala–Busi road in Obanliku, Cross River State and classified as A-2-7 (1) based on AASHT0 (1986) classification system, (sandy gravel). In its natural state the soil is suitable as filled material.
2. The geotechnical properties of soil such as CBR, UCS were greatly improved by the addition of CKD to the soil. 24% of CKD addition was observed to yield maximum improvement. The soil after improvement could be used as sub base and base course material based on the specification contained in NGS for road and bridges.

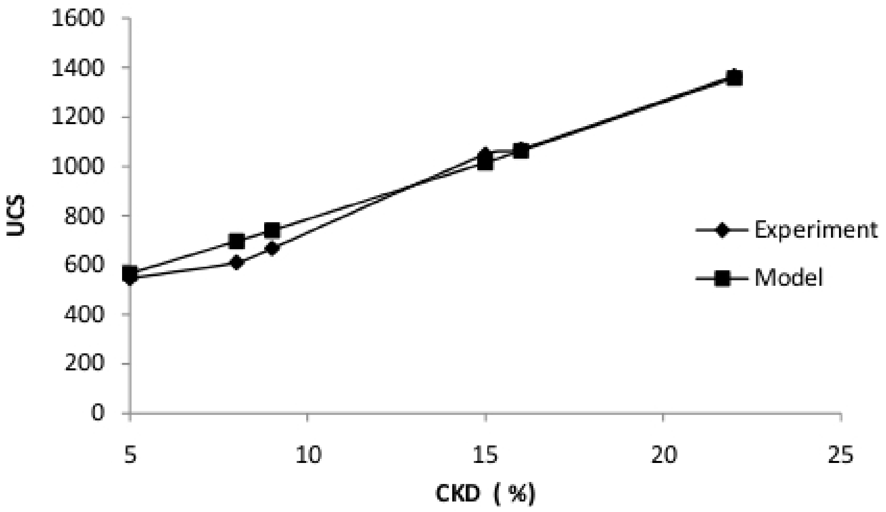

Figure 11: Plot of unconfined compressive strength (7 days) against percentage CKD.

3. The addition of CKD brings about alteration in plasticity properties of the soil. CKD was very effective in reducing the plasticity of the soil.
4. At specified CKD content (0-12%) treatment of the soil it showed an increased in MDD from 1.083Mg/m^3 to 2.6Mg/m^3 after which there was a slight reduction in MDD. The OMC generally increased with increase in CKD content.
5. The CKD used has LOI and free lime content of 4.3 and 4.04% respectively. Both content were low. The LOI of the CKD relates to its performance in terms of strength. The low content of LOI and free lime content also contributed to the increased in strength of the soil after stabilization.
6. Models developed correspond well with experimental results. The model can be successfully be used to predict the soil-CKD properties in the absence of experimental data for soil.

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