Potentials of Cement Kiln Dust and Rice Husk Ash Blend on Strength of Tropical Soil for Sustainable Road Construction Material

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Abstract. The growing problem of containing wastes in developing countries has led to endless research on the chances of converting these wastes to materials for sustainable engineering construction. This study through experimental assessment explores the potentials of cement kiln dust (CKD) and rice husk ash (RHA), in circumventing the inadequacies often encountered in deficient tropical soil thereby ensuring profitable engineering construction. Specimens were prepared by blending dosages of 0, 2, 4, 6 and 8 % CKD as well as 0, 3, 6, 9, 12 and 15 % RHA by requisite weight of soil. The investigated outcomes revealed increasing cation exchange capacity (CEC) with corresponding increase in pH for the various increased CKD-RHA composition. The Atterberg limits indicated a reduction trend with increasing CKD-RHA blend, signifying a drastic improvement in the plasticity tendency of the soil. While the maximum dry density (MDD) decreased with up shoot in optimum moisture content (OMC) at varying combined dosages of CKD and RHA, the CBR (soaked condition) increased steadily from 5 % (natural) to peak of 35 % at 8 % CKD/15 % RHA blend. The highest CBR value in this study was not below the criterion of 20 – 30 % for sub-base as well as 10 – 15 % for subgrade road material. The regression analysis and analysis of variance from laboratory results validated the experimental outcome of using CKD-RHA blend to expressively enhance deficient lateritic soil. The outcome of this study has shown that CKD-RHA is recommended in improvement of strength of weak soil for either sub-base or more fittingly, subgrade of flexible pavement. Hence, using these waste materials will solve the twofold objective of proper waste management and good engineering materials for sustainability in construction of subgrade of flexible pavement.

Keywords: Lateritic soil, CEC, Atterberg’s limit, Compaction properties, admixtures, Subgrade.

1. Introduction
In Nigeria, during the construction of civil engineering infrastructures such as roads, structures, embankments etc. lateritic soil is frequently exploited as conventional fill material. This is because it is the locally predominant construction material found in abundance across the length and breadth of the tropical domain. However, when this soil material with poor engineering characteristics (such as high clay content) is exposed to interaction with moisture, it reacts in a detrimental pattern overtime. The detrimental behaviour of this soil in most cases makes the material fall below relevant standards based
on classified usage and as such, it calls for treatment to enhance its workability and geoengineering behaviour.

Treatment of this deficient soil material so as to meet required strength is achievable by incorporating some additives such as lime, cement, calcium chloride, fly ash, rice husk ash, cement kiln dust, oyster shell ash, periwinkle shell ash, metakaolin etc. which have been explored by some investigators [1-8]. However, there is increasing concern in the application of these waste materials (industrial, agricultural) which has attracted a lot of attention by researchers due to pozzolanic behaviour and reducing cost of infrastructure construction. Interestingly, due to the high demand for sustainable construction materials, the quest for new materials have been grown. Rice husk ash is a typical example of agricultural waste resulting from the process of rice milling, its major constituent is silica and it is greatly affected by the burning method [9]. Interestingly, there is a large volume of published studies describing the trend of outcomes using either rice husk ash (RHA) or cement kiln dust (CKD) as single stabilizers in improving deficient soils. However, the study of [10] concluded that utilization of RHA in clay soil enhances slight increase in strength of soil. Similarly, the addition of RHA to clayey soil improves the index property and as well makes the soil material fit for usage as subgrade material [11]. In contrast to other investigators, [12] documented that RHA is not fit for usage as a single stabilization agent in soil improvement. Hence, improvement of weak soil using RHA admixed with other additive such as cement, lime and calcium chloride was reported by [13-14]. Cement kiln dust is an industrial waste substance discharged during the manufacturing process of Portland cement. The engineering property of soil materials has been rejuvenated to meet up with construction standards via the utilization of stabilization agents such as cement kiln dust (CKD) [15]. In summary, the application of this waste has led to technical, economic and environmental benefits [16] as well as reduction in thickness of pavement and increase in strength indices [17].

Recently, researchers have shown an increased interest in the need of using two additives during soil stabilization with the aim of reducing high consumption of cement, construction cost and other environmental issues. Therefore, there is a great need to put in use cement kiln dust-rice husk ash blend for the enhancement of lateritic soil with poor geotechnical properties in a cost-effective manner for satisfactory usage as road material. Hence, this study aims at assessing the effect of cement kiln dust-rice husk ash blend on Atterberg limit, compaction characteristics and strength indices of the treated soil.

2. Materials and Methods

2.1. Materials

A reddish brown soil material was gotten from Ikot Ekong (Latitude 4° 38’ 23"N and Longitude 7° 49’ 19”E), Mkpat Enin Local Government Area, Akwa Ibom State, Nigeria by disturbed sampling technique at an average 1.5 m depth. The sample was transported to the laboratory in airtight bags, air-dried for some days and pulverised using pestle inside the tray. CKD was source from Lafarge Cement Company, Mfamosing in Calabar, Cross River State, Nigeria. The rice husks used for the production of rice husk ash was source from a local rice-milling factory and it was burnt in an open space until it turned into an ash. The ash was transported to the laboratory and sieved with 75 μm aperture size before usage. The oxide composition of cement kiln dust and rice husk ash was known with the aid of X-ray fluorescence analysis.

2.2. Methods

The soil gradation was determined based on [18]. The various tests specimens were prepared by blending 0, 2, 4, 6 and 8 % CKD and 0, 3, 6, 9, 12 and 15 % RHA by weight of soil. The experimental programme of Atterberg limits (consistency test), compaction and CBR (strength test) was performed based on the guidelines defined in [19-20] for natural and CKD-RHA stabilized soils, respectively. Cation exchange capacity (CEC) and pH of natural and stabilised soil were determined in line with method of [21].
3. Results and Discussion

3.1. General characterization and classification of test material

A series of laboratory investigations on the reddish brown soil in its natural state is shown in Table 1. The particle gradation is shown in Figure 1. Similarly, the oxide composition of soil, CKD and RHA materials used is displayed in Table 2. The properties of the soil revealed that it is an A-7-6(10) soil based on AASHTO [22] and CL according to USCS [23].

Table 1. Properties of the natural soil sample used in the study

| Property           | Quantity          |
|--------------------|-------------------|
| NMC, %             | 19.80             |
| Passed BS No 200 sieve | 52.40           |
| LL, %              | 43.80             |
| PL, %              | 24.83             |
| PI, %              | 18.97             |
| Gs                 | 2.60              |
| AASHTO             | A-7-6(10)         |
| USCS               | CL                |
| MDD, Mg/m³         | 1.83              |
| OMC, %             | 12.95             |
| CBR (48 h soaking), % | 5               |
| Colour             | Reddish Brown     |

Figure 1. Plot of particle gradation for the unmodified soil

Table 2. Composition of materials

| Oxide  | *Soil | **RHA | CKD   |
|--------|-------|-------|-------|
| CaO    | 0.30  | 2.95  | 45.75 |
| SiO₂   | 36.35 | 75.30 | 7.95  |
| Fe₂O₃  | 27.41 | 1.98  | 5.10  |
| Al₂O₃  | 29.19 | 1.40  | 1.98  |
| MnO    | 0.028 | 2.10  | 0.11  |
| Na₂O   | -     | 0.98  | -     |
| TiO₂   | 0.431 | -     | 0.54  |
| SO₃    | 0.69  | -     | -     |
| ZnO    | 0.004 | -     | -     |
| K₂O    | -     | 5.55  | -     |
| LOI    | 4.8   | 5.61  | 37.25 |

*[24], **[25]
3.2 Cation exchange capacity and pH
The cation exchange increased with increasing RHA and CKD content (see Figure 2a). This behaviour is associated with the increase in alkaline nature of the mixture due to higher RHA and CKD content, which is been seen by a corresponding increase in pH (Figure 2b). One of the mechanisms that govern soil stabilisation is the cation exchange. The quantity of negative charge held by a clay is a function of the total sum of exchangeable cations. In a mixture of soil and stabilizer blend, cation exchange is the primary reaction required first, before the flocculation and agglomeration process. Therefore, improvement of fine grain soil that has some amount of clay content is associated with reaction induced by cation exchange [26-28]. The results in this study has shown that increased in CKD and RHA will results to corresponding increase in both pH and cation exchange capacity and the combine effect of CKD and RHA will be more potent in improving the geoengineering properties of the soil.

![Figure 2. Effect of CKD-RHA on the; (a) cation exchange capacity and (b) pH of lateritic soil](image)

3.3 Atterberg’s limits characteristics
The behaviour of liquid limit of soil sample with various concentrations of CKD and RHA is depicted in Figure 3. The findings portrayed that liquid limit of soil mixtures diminishes with increase in both cement kiln dust and rice husk ash contents, respectively. The values diminished from 43.80 for natural soil to a minimum value of 35.30 % at 8 % CKD / 15 % RHA. The observed trend of results could be ascribed to the changes in soil structure as a result of incorporating pozzolanic materials to the soil matrix. It could be that the combined effect of CKD-RHA modifies the soil fabric and increased the pH of the mixture with corresponding increase in the mechanism of exchangeable cation. This reaction favours the introduction of divalent cations of Ca$^{2+}$ that consequently replaces / displaces monovalent cations. The resultant outcome diminished the expanded diffuse double layer and shearing resistance of the soil that is reflected in the reduction of moisture content (liquid limit). The outcomes in the current study were matching with the previous endings of [29-30] and [7].
Figure 3. Behaviour of liquid limit of lateritic soil-CKD-RHA mixtures

Figure 4 depicts the behaviour of plastic limit of soil sample with various concentrations of cement kiln dust and rice husk ash. Similar to liquid limit, the plastic limit diminished with increase in both cement kiln dust and rice husk ash contents, respectively. The observed trend could be due to possible cation exchange reaction liberating absorbed water from the clay composition, thereby enhancing the process of flocculation and aggregation of the soil mixtures [31] and reduction in expanded moisture layer [6]. The reduction could also be due to the non-plastic structure of RHA. The results in this study similar with the outcome of [32] who correlated decreased in plastic limit of expansive soil due to non-plastic structure of the one of the compositional admixtures (iron ore-tailing) in cement modification of fine grain soil.

Figure 4. Behaviour of plastic limit of lateritic soil-CKD-RHA mixtures

The behaviour of plasticity index of soil sample with various concentrations of cement kiln dust and rice husk ash is display in figure 5. The plasticity index of the soil mixtures presented in figure 5 ranged between 16.60 and 18.97 %. However, based on the data publicised in figures 3, 4 and 5, it can be undoubtedly confirm that both CKD and RHA have some level of effects on the Atterberg limits of the soil mixtures.
3.4 Compaction characteristics

Figure 6 depicts the variations of maximum dry density (MDD) of soil-CKD mixtures with RHA. The MDD of the soil mixtures ranged between 1.68 and 1.83 Mg/m$^3$. The compaction results documented reveals that the addition of varying proportion of RHA to each of the CKD treatments reduces the values of MDD. This tendency could be unconnected to the substitution of RHA and CKD for the soil in the soil-CKD-RHA mixtures. This reduction in the values of MDD may be accredited to RHA having a lower specific gravity of 2.10 substituting a higher specific gravity (2.60) of the soil [33]. Secondly, this trend may also be credited to flocculation and agglomeration of soil mixtures. However, the documented reduction in MDD with increased CKD is in line with the outcome of [34].

The behaviour of lateritic soil-CKD-RHA in terms of optimum moisture content (OMC) is displayed in figure 7. On the contrary, the OMC of the soil mixtures ranged between 12.95 to 15%. As per the data expressed in figure 7, it can unquestionably be said that OMC improves gradually with the addition of different dosage of RHA for each CKD treatments. Improvement in OMC could be accredited to the hollow (porous) nature of RHA particles, which will in turn require more water to perfect lubrication of soil mixtures. In a previous study carried out by [35] also produced a related result.
3.5 California bearing ratio (CBR)

Figure 8 shows the soaked CBR values for different dosages of cement kiln dust (CKD) mixed with different dosages of rice husk ash (RHA) in lateritic soil. It can be said without any uncertainty that the CBR values enhance gradually with the increase in quantity of stabilization materials (CKD and RHA) mixed with soil. This gradual enhancement could be adduced to the pozzolanic reaction taking place between the soil and pozzolanic material thereby developing a more cementitious compound which aids enhancement of strength in soil mixtures. The CBR value increased from a minimum of 5% at 0% CKD / 0% RHA to a maximum value of 35% at 8% CKD / 15% RHA content. The CBR value recorded at 8% CKD / 15% RHA content met the conditions by Nigerian General Specifications for highways for use as sub-base [36].

3.6 Comparison between laboratory and predicted results.

The entirety of soil major physical attributes establishes a simple technique where outcomes of representative samples could be simultaneously associated with one or more relevant properties of the soil. The association could be express in one of the following form: multi-linear, exponential or in the form of polynomial. Exploring these correlations may possibly contribute a very positive information, precisely in reducing significantly the magnitude of difficult test and/or exorbitant analysis, so long as a correlation between a basic engineering characteristic and some simple test results can be set up. A simple model is establish using multiple regression statistics for CBR being dependent variable as well as a function of CKD and RHA (independent variables) (see equation 1). Details of regression results are presented in appendix A. Basically, it was observed that the model is consistent with achieved laboratory outcome of increased strength with stepped increase in both CKD and RHA. This was possible because specimens were densified to the required MDD at the requisite OMC. The result is suggestive of the fact that controlling the amount of admixtures (CKD and RHA) for stabilisation during
Field compaction is important to achieve desirable result for sustainable strength in service. However, [32] and [37] reported a reduction in strength of stabilised soil due to excess admixture content (iron ore in cement or lime stabilization). The excess admixture contributed to excess of fine and silt content which did not take part in the stabilisation process.

\[
\text{CBR} = 0.948 + 1.908\text{CKD} + 1.025\text{RHA} \tag{1}
\]

\[R^2 = 93\%\]

The graph of projected CBR gotten from equation (1) against experimental value measured from laboratory (see Figure 9), indicated a good correlation in a second order polynomial function having R square correlation coefficient value of approximately 0.97. Similar analysis were reported by [38-39]. Furthermore, the analysis of variance (two-way) indicated that the various variations in CKD and RHA had tremendous effect on the properties of the soil at 95% probability certainty, p-value < 0.05 (see Table 3).

![Figure 9. Predicted CBR versus laboratory CBR](image)

**Table 3.** Analysis of variance of properties of lateritic soil-CKD mixtures with RHA

| Property | SOV | DOF | FCAL | P-value | F_CRIT | Remarks |
|----------|-----|-----|------|---------|--------|---------|
| LL       | RHA | 5   | 140.5329 | 7.2E-15 | 2.71089 | FCAL > F_CRIT, SS |
| PL       | RHA | 5   | 103.4294 | 1.38E-13 | 2.71089 | FCAL > F_CRIT, SS |
| PI       | RHA | 5   | 13.63198 | 1.61E-05 | 2.866081 | FCAL > F_CRIT, SS |
| OMC      | RHA | 5   | 52.7399 | 7.79E-11 | 2.71089 | FCAL > F_CRIT, SS |
| MDD      | RHA | 5   | 40.80618 | 8.03E-10 | 2.71089 | FCAL > F_CRIT, SS |
| CBR      | RHA | 5   | 33.50731 | 4.63E-09 | 2.71089 | FCAL > F_CRIT, SS |
|          | CKD | 4   | 33.50731 | 4.63E-09 | 2.71089 | FCAL > F_CRIT, SS |

4. Conclusion

They waste materials used in this study have shown some level of significance in terms of strength indices of the deficient lateritic soil. From the outcomes of the experimental investigations performed, the following conclusions are extracted and listed: The natural lateritic soil studied is an A-7-6 (10) and CL soil. The Atterberg limits of the soil specimens diminished with higher concentrations of CKD and RHA. In terms of compaction characteristics, an increase in CKD and RHA dosages caused a diminishment in MDD and enhancement in OMC. For the strength criterion, the maximum CBR (soaked condition) of 35% was documented at 8% CKD / 15% RHA blend which implied that CKD-RHA blend could be helpful in enhancing deficient soil required as an alternate hydraulically bound
material for sub grade in road construction. Although additional strength tests and micro level analysis are underway in further studies, the statistical measures and formulated model showed an excellent performance with R square of 0.97 and Adjusted R Square of 0.93 at $\alpha = 5\%$ level of significance.

### Appendix A

| Regression Statistics |
|-----------------------|
| Multiple R | 0.96626 |
| R Square | 0.933658 |
| Adjusted R Square | 0.928743 |
| Standard Error | 2.115788 |
| Observations | 30 |

| df | SS  | MS  | F    | Significance F |
|----|-----|-----|------|---------------|
| Regression | 2 | 1701 | 850.4998 | 189.9895 | 1.24E-16 |
| Residual   | 27 | 120.867 | 4.4765 |
| Total      | 29 | 1821.867 |

| Coefficients | Standard Error | t Stat | P-value | Lower 95% | Upper 95% | Lower 95.0% | Upper 95.0% |
|--------------|---------------|--------|---------|----------|-----------|-------------|-------------|
| Intercept    | 0.9476        | 0.8760 | 1.082   | 0.2889   | 2.7450    | -0.8498     | 2.7450      |
| CKD          | 1.9083        | 0.1366 | 13.97   | 7.07E-14 | 2.1886    | 1.6281      | 2.1886      |
| RHA          | 1.0247        | 0.0754 | 13.59   | 1.36E-13 | 1.1795    | 0.8701      | 1.1795      |

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