Potentials of Cement Kiln Dust-Periwinkle Shell Ash Blends on Plasticity Properties of Two Selected Tropical Soils for use as Sustainable Construction Materials

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Abstract: This paper investigated the effect of cement kiln dust (CKD) and periwinkle shell ash (PSA) on the plasticity characteristics of two lateritic soil. Two Soils (termed soil A and B) were collected from two selected locations within Osun State, Nigeria. Air-dried soil was treated with CKD and PSA blend in order of 0, 5, 10, 15, and 20% for CKD and 0, 2, 4, 6, 8 and 10% for PSA by dry weight of soil. The specific gravity of both soils increased with increase in CKD and PSA fillings. The Index properties such as Atterberg’s limit (liquid limit, LL, plastic limit, PL, and plasticity index, PI), percentage fines content of the soils was determined. The index properties results showed that the two soils are clayey soil of low plasticity. There was a general decrease in the Atterberg’s limits (liquid limit, LL and plastic limit, PL). The scan electron microscopy (SEM) and electron diffraction spectroscopy of treated soil revealed the formation of crystalline products of calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH) which was responsible for strength gain. Based on preliminary investigations, the study concluded that the combination of CKD-PSA blends is a viable stabiliser for the two tropical soils under consideration to be used as sub-base construction.

Keywords: Lateritic soil, Periwinkle shell ash, Cement kiln dust, Atterberg’s limits, and Scanning electron microscope.

1. Introduction
The increase in urbanization has led to the development of more facilities like roads, railways, underground tunnels etc. Generally, in developing and advanced countries, laterite and lateritic soils form the components of roads which in turn are composed of sub-base and subgrade materials. Due to the poor engineering behaviour inherent in most of these soils (such as high shrinkage and swell potential, low plasticity and a reduced bearing capacity), these renders the soil unsuitable for construction, hence stabilization becomes an alternative. In road stabilization, recycling those materials considered as waste (agricultural and industrial wastes) has gradually become more attractive rather than discarding them off. This has prompted researchers into harnessing the possibilities of reusing and recycling those wastes instead of disposing them off. Several researchers have utilized the combination of both agricultural and industrial wastes for instance rice husk ash [13]; bagasse ash [24, 25]; steel slag [4]; sludge ash [20, 9]; cement kiln dust [21, 32]; periwinkle shell ash [15, 27] to improve soils with poor engineering properties. Results showed that a great improvement was recorded in the properties of these soils.

The by-products left during the production of cement is called cement kiln dust (CKD). They are usually obtained in the kiln during the production of cement clinker. Approximately 30 million tons of CKD worldwide is generated every year [13], out of which 4 million tons per year are produced in the US. CKD has found applications in various fields ranging from masonry and concrete blocks; soil stabilization; waste stabilization; agricultural amendments etc. [31, 32, 19, 18, 39].

Periwinkles on the other hand are marine shells predominantly dominant in the coastal regions. Their shells are usually deposited in open spaces which poses an environmental risk and as such, managing it
have become a challenge. Ekop et al. [14] reported that researchers have recently employed periwinkle shells for construction purposes. Several studies have employed periwinkle shells in replacing coarse aggregates in lightweight concrete [3,11]. Periwinkle shell ash (PSA) is a waste that comes from the calcination of periwinkle shells. Recent researches have shown that the geotechnical properties of soils have been improved on upon the addition of PSA and as such, it is considered a potential soil stabilizer [15, 27].

Studies conducted by Umoh and Olusola [37], Attah et al. [8] shows that PSA is rich in Calcium oxide (CaO) similar to CKD [38, 32]. The richness of these two additives in calcium has the potential of reducing diffuse double layer (DDL) through cation exchange reaction, flocculation and agglomeration, reduction of adsorbed water and formation of cementitious compounds which has the potential of improving the properties of soil significantly. However, there are no open literatures that has explored the possibilities of combining both additives to serve as an alternative to the traditional soil stabilizers in order to render it fit as a paving layer material. Hence, authoritative data on the combination of the blends is clearly needed. The specific objective of this study is to evaluate the effect of CKD and PSA on the Atterberg’s limits and microstructure of two selected tropical lateritic soils. On the basis of this, it is presumed that the combination of these blends will serve as an alternative to cement, lime and bitumen; so that both soil improvement and safe disposal will be realized.

2. Materials and Methods

2.1 Materials

2.1.1. Laterite soil

The two soils were sourced from an existing borrow pit at Ilesha West LGA and along Ibadan-Ile-Ife expressway, both in Osun State, South West Nigeria. The first soil was designated as Soil A (Latitude 7° 37’ 1652.25”N and Longitude 4° 44’ 1782.08”N) while the other soil was designated as Soil B (Latitude 7°30’ 1813.27” and Longitude 4° 27’ 1667.09”N).

2.1.2. Periwinkle shell ash

The shells of the periwinkle were sourced from a dumpsite in Nwaniba road, Uyo, Akwa Ibom State, Nigeria. It was further calcined and allowed to cool inside the kiln. The calcined ash was brought out of the kiln and further pulverized to powdered form. The ash was then sieved through 75µm and thereafter stored in a sealed polythene bag before it was mixed with requisite percentages by dry weight of the soil.

2.1.3. Cement Kiln Dust. The CKD was sourced from a local cement industry which was herein after sealed in tight sacks in order to prevent moisture from coming in contact with it which might result in hardening and loss of properties before being transported to the laboratory.

2.1.4. Physicochemical analysis of soil samples, CKD and PSA

The pH of the soil samples, CKD and PSA in its natural states was determined using standardized pH meter while the oxide composition of the specimens (soils, PSA and CKD) were investigated by X-ray Fluorescence (XRF) technique using the Thermo Fisher Model ARL 9990.

2.2 Methods

2.2.1. Index tests

The liquid limit, LL and plastic limit, PL otherwise referred to as the Atterberg’s limits was done on soil specimen passing through sieve No. 425µm, the particle size distribution (PSD) were both investigated according to ASTM D 4318 and ASTM D 422. The plasticity index, PI of the samples, was also determined. The soil samples were classified according to [1] based on Atterberg’s limits and PSD.
2.2.2. Microanalysis
The structural and morphology properties of the treated and typically treated soil was determined using the scanning electron microscope (SEM). The PHENOM WORLD scanning electron microscope together with the energy dispersive X-ray spectrometers (EDS) operated at 5kv and 15kv at a resolution of 50µm, 80µm, and 100µm was employed for micro analysis. The morphology and structural orientation of the soil structure is predicted with a high degree of accuracy and precision using the SEM.

3. Results and Discussion

3.1. Index Properties
Presented in Table 1 are the summary of the properties of the untreated soils in their natural states. The results show a higher natural moisture content for soil A in comparison with soil B. The shows that both soil samples contain some appreciable amount of moisture. The pH shows that both soils is acidic probably as a result of intensive weathering caused by high temperature and rainfall which eventually results into the leaching of alkaline and alkaline earth basic metals from the soil [16, 40]. The two soils (A and B) according to AASHTO [1], are classified as A-7-5(3) and A-7-6 (7), respectively. The USCS [41] classified the two soils as CL, which implies a low plasticity clay. The chemical composition of both soils, CKD and PSA are shown in Table 2, in the form of their oxide composition.

Table 1. Properties of the natural soils used in this study

| Property                      | Soil A | Soil B |
|-------------------------------|--------|--------|
| Natural Moisture Content (%)  | 19.4   | 11.6   |
| Specific Gravity (Gs)         | 2.55   | 2.51   |
| Colour                        | Reddish brown | Yellowish brown |
| pH                            | 6.2    | 6.5    |
| LL (%)                        | 45.0   | 43.5   |
| PL (%)                        | 28.5   | 22.5   |
| PI (%)                        | 16.5   | 21.0   |
| Percentage passing sieve No. 200 | 45.46 | 40.94 |
| Percentage passing sieve No. 40 | 81.34 | 57.36 |
| AASHTO classification         | A-7-5 (3) | A-7-6 (7) |
| USCS                          | CL     | CL     |
| Maximum Dry Density, MDD (Mg/m³) | 1.600 | 1.770 |
| Optimum Moisture Content, OMC (%) | 20.50 | 17.00 |
| Group Index                   | 3      | 7      |

Table 2. Oxides composition of natural lateritic soils, CKD and PSA

| Chemical (% Oxide Concentration) | Soil A | Soil B | CKD | PSA |
|----------------------------------|--------|--------|-----|-----|
| Silica (SiO₂)                    | 57.02  | 56.42  | 9.87| 33.85|
| Alumina (Al₂O₃)                  | 21.32  | 19.17  | 3.80| 9.24 |
| Iron oxide (Fe₂O₃)               | 6.01   | 10.49  | 2.41| 7.20 |
| Lime (CaO)                       | 0.46   | 0.13   | 45.08| 53.87|
| Magnesium oxide (MgO)            | 0.21   | 0.15   | 1.08| 0.06 |
| Sulphur oxide (SO₃)              | 0.00   | 0.00   | 0.22| 0.16 |
| Potassium oxide (K₂O)            | 2.29   | 1.46   | 0.17| 0.06 |
| Dinitrogen pentoxide (N₂O₅)      | 0.11   | 0.13   | 0.07| 1.40 |
| Phosphorous pentoxide (P₂O₅)     | 0.09   | 0.12   | 0.60| 0.37 |
| Tin oxide (TiO₂)                 | 0.76   | 1.53   | 0.24| 0.09 |
| Loss on Ignition                 | 9.73   | 8.45   | 35.66| 38.68|
3.2. Specific Gravity
Specific gravity is a vital index which is used in determining the void ratio and particle size of any soil particle. The variation of specific gravity of soil-CKD and PSA contents are presented in Fig.1. The specific gravity of both soils increases with an increase in CKD and PSA contents as shown in the results. The specific gravity of soil A shows a general increase of about 9.41% while that of soil B shows an increment of about 9.96%. Peak value of 2.79 was obtained at 20% CKD/10% PSA for soil A while 2.76 was obtained at 20% CKD/8% PSA for soil B. The general increasing trends in specific gravity for both soils may be attributed to the higher specific gravity of the additives (CKD, 2.93 and PSA, 2.63) replacing the soils A and B with specific gravity of 2.55 and 2.51 respectively. A similar trend of increase in specific gravity was reported by Etim [43] and Yohanna [44].

![Figure 1](image1.png) Variation of specific gravity of CKD and PSA treated soils for; (a) soil A and (b) soil B

3.3. Atterberg’s Limits
3.3.1. Liquid limit
The variation of liquid limit, LL of soil-CKD with PSA for both soils are presented in Figs.2. The LL values of both soils decreases with an increase in CKD and PSA contents as presented in the results. The LL of soil A shows a reduction from 45% to a minimum value of 32.2 % at 15% CKD/6% PSA while soil B reduced to a minimum value of 31.7% at 20% CKD/10% PSA. Both soils show a general decrease with as high as 28% decrement. The formation of flocs coupled with the clay particles clustering together due to exchange of cations might have attributed to the overall reduction in LL of both soils as well as reduction in diffuse double layer (DDL) of clay minerals. Sharma and Lewis [35], Abood et al. [2], Al-Zoubi [6], Ramesh et al. [30], Ayodele et al. [42] reported similar trends of decrease in liquid limit.

![Figure 2](image2.png)
Figure 2. Variation of liquid limits of CKD and PSA treated soils for; (a) soil A and (b) soil B

3.3.2. Plastic limit
The effects of CKD and PSA on plastic limit, PL of soil-CKD-PSA for both soils are shown in Figs. 3. A general decreasing trend with increase in CKD and PSA admixtures was observed for soil A while the reverse was the case for soil B. The decrement in soil A was about 19.3% decrease and an increment of about 13.7% increase for soil B. An increase or decrease in PL is inconsequential as long as the PI decreases which actually typifies an improvement in the properties of the soil. The presence of divalent cations in the admixtures such as Ca$^{2+}$ might have replaced those weakly bonded monovalent cations of Na$^+$ and K$^+$ in the clay structures; thus, resulting in the formation of flocs and escape of water that has been bonded at the outer layers. The reduction in the trend is similar to the findings of Osinubi [28], Amadi [7], Ramesh et al. [30], and Ayodele et al. [42]. Furthermore, it could also be attributed to the presence of silica (SiO$_2$) and alumina (Al$_2$O$_3$) offered by the PSA that further facilitated the exchange of cations between clay particles of the soil and Ca$^{2+}$ from the PSA.

Figure 3. Variation of plastic limits of CKD and PSA treated soil for; (a) soil A and (b) soil B

3.3.3. Plasticity index
The general decrease in LL and increase in PL resulted to a decrease in PI of the soil. The graph of PI of soil-CKD mixture with PSA for both soils is shown in Figs. 4. The PI values decreases generally with increase in CKD and PSA contents. The PI of untreated soil A at 16.5% reduced to a minimum value of 8.1% at 15% CKD/6% PSA. A minimum value of 10.6% was obtained for soil B at 10% CKD/8% PSA. The general decrement in PI of both soils is a pointer that the natural soil has actually improved. The CKD which is rich in lime (CaO) undergoes cation exchange reaction with water in the stabilized; further dissociation might be accountable for the decrease in PI of the soil on addition of
different percentages of PSA blends. The PSA with a divalent electron replaces the monovalent electrons in the soil thereby leading to a reduction in DDL i.e. diffuse double layer so that the soil becomes more workable with field equipment. Peter [29] and Abood et al [2] reported similar studies of decrease in plasticity index.

![Variation of plasticity index of CKD and PSA treated soils for; (a) soil A and (b) soil B](image)

**Figure 4.** Variation of plasticity index of CKD and PSA treated soils for; (a) soil A and (b) soil B

### 3.4. Micrograph of Specimens

#### 3.4.1. Scanning Electron Microscope

Essentially, microstructural studies are employed with the use of aggregation scale to analyze the arrangement of particles, particle assemblies and pores and their contacts and connectivity in different soils [5, 22]. The micrographs of untreated and optimally stabilized soils with 10% CKD/8 % PSA are presented Figs. 5 & 6. The micrograph of untreated soil A is composed mainly of particles that appear as that a blocky arrangement of closely parked particles while that of soil B is mainly of smooth surface with lots of shrinkage cracks at the background which is suggestive of clay contents. Clay particles possesses some polar properties that allows them to absorb water easily. The presence of whitish particles at the background is perhaps more of SiO\textsubscript{2} probably due to its size in relation with the background. The morphology of the optimally treated soil consists of scaly and smooth surface. The surface being smooth might be due to the clay particles hovering around the surface of the silt particles during specimen treatment. While the surface being scaly on the other hand could be due to the clay minerals as undergoing both dissolution and precipitation combined as reported by Simms and Yanful [36], Monroy et al. [23] and Sani et al. [33]. Generally, for the optimally treated soils, pozzolanic reaction between the soil constituents and the additives between causes the formation of new minerals that are cementitious in nature. This is in agreement with the findings of Sathyapriya and Arumairaj [34], Jaritngam et al. [17], Negi et al. [26], Bhuvaneshwari et al. [10].

#### 3.4.2 Energy-Dispersive X-Ray Spectroscopy

The energy dispersive x-ray is incorporated in to the scanning electron microscope to make it more robust. The EDS of natural soil sample A and soil optimally stabilized with 10% CKD/8 % PSA cured for 28 days is presented in Figs. 7 & 8.
It was observed that the natural soil had a higher silicon and aluminum content of 27.46 and 24.85 % respectively than the optimally stabilized soil with a silicon and aluminium value of 21.14 and 19.82 %. The pozzolanic reaction that causes CSH and CAH to be formed which eventually leads to improved plasticity might have resulted in the reduction in aluminium and silicon content. Similar observations were made for both the natural and typically treated soil B as shown in Figs. 9 & 10.

Figure 5. Micrographs of natural soil A and B after 28 days curing at 80µm magnification.

Figure 6. Micrographs of soil + Optimal blend of 10% CKD/8%PSA viewed at 80µm magnification.

Figure 7. Spectroscopy of untreated soil A after 28 days curing.
Figure 8. Spectroscopy of optimally treated soil A (soil +10% CKD/8% PSA) after 28 days curing.

Figure 9. Spectroscopy of untreated soil B after 28 days curing.

Figure 10. Electron diffraction spectroscopy of typically treated soil B (soil +10% CKD/8% PSA) after 28 days curing.
4. Conclusions

The two soils under consideration based on AASHTO classification system were classified as A-7-5 (3) for soil A, and A-7-6 (7) for soil B. The USCS classification system classified both soils as CL, poorly graded with low plasticity. The Atterberg’s limits and plasticity characteristics of the two lateritic soils indicated that there was need for soil improvement. The Atterberg’s limits (LL, PL and PI) greatly reduced on addition of up to 15% CKD-6% PSA. The plasticity indices for both lateritic soils after stabilization was less than 12% which represents the benchmark for a material to be considered as subgrade material as specified by the Federal Ministry of Works and Housing, FMWH. Microanalysis conducted via scanning electron microscope showed that the treated soils were aggregated coupled with changes in the soil’s fabric orientation. The SEM micrographs also revealed the presence of crystalline hydration products of CSH and CAH which were presumed to be the major factors that reduce the plasticity indices of the soils. It can therefore be concluded that CKD and PSA proves to be a viable material for improving the plasticity indices of clay soils as sustainable construction materials.

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