Stabilization of lateritic soil with cement – oil palm empty fruit bunch ash blend for California bearing ratio base course requirement

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Abstract. Lateritic soil obtained from a borrow pit at Maya Aladiye, Ijebu – Itokin Road, Ikorodu Local Government Area in Lagos state was classified as an A-6(8) using the American Association of State Highway and Transportation Officials (AASHTO) soil classification system or CL using the Unified Soil Classification System (USCS). It was treated with cement – oil palm empty fruit bunch ash (OPEFBA) blend in stepped concentrations of 0, 2, 4, 6 and 8 % cement as well as 0, 2, 4, 6 and 8 % of OPEFBA, respectively, by weight of dry soil. Index, cation exchange capacity (CEC), compaction and California bearing ratio (CBR) laboratory tests were carried out on the natural and treated soil specimens. Compaction was done using three different effort levels namely, the British Standard light (BSL), West African Standard (WAS) and the British Standard heavy (BSH). The 2-day CBR values (soaked) of the natural soil for the BSL, WAS and BSH compaction efforts increased from 10, 6 and 8 % to 105, 120 and 110 %, respectively, at an optimum 8 % Cement / 2 % OPEFBA treatment. These CBR values met the 80 % requirement for base course materials with a beneficial environmental advantage of utilizing a palm oil mill waste.

Keywords: Base course, California bearing ratio, Cement, Lateritic soil, Oil palm empty fruit bunch ash

1. Introduction

Lateritic soil is generally used for filling in embankments and road construction in Nigeria because of its availability across the country. However, lateritic soil containing a significant proportion of clay may expand when water is present and shrink when water present is very little. Cracks may develop due to the shrinkage which may lead to a reduction of some of the mechanical properties of the soil [1]. In areas where lateritic soil of this type is present, trying to obtain suitable alternative soil may not be cost effective. Hence, stabilization of the soil material to meet the required strength is inevitable [2]. However, [3] and [4] reported that laterite (or lateritic soil) in its compacted state has not provided the required durability expected with the lifespan of the road pavement as evident from the various failures observed on most highways across the country. Hence, there is a necessity to enhance the geotechnical characteristics of lateritic soil in Nigeria, especially for its use as a base course material in road construction.

Portland cement is generally used as a chemical additive in stabilization of soils. A lot of soils, devoid of organic matter and capable of being pulverized, can be stabilized with cement. Soil -
Cement mixture has been used in pavements for highways, airfields, and as base course material for heavy trafficked roads [5]. Some chemical agents are used for stabilizing the moisture in the soil and some for cementation of particles. Additionally, dispersants such as Polyvinyl Alcohol, Calcium Sulfonate have also been used [6].

The overdependence on only industrial additives (e.g., cement) for soil improvement has contributed to the high cost of stabilized roads. Thus, using by-products from agriculture (such as Oil Palm Empty Fruit Bunch, Rice Husk, Sugarcane Bagasse, etc.) will greatly reduce construction cost [7]. Studies have also shown that the use of ashes obtained from agricultural by-products such as cassava peel [8]; [9], sugarcane bagasse fibre [10], coconut shell husk [11] are cheaper alternatives for stabilizing soils which cannot fully satisfy their intended use in terms of their engineering properties.

Palm trees are cash crops generally grown in the southern part of Nigeria where the average yield of oil palm is about 95% of the total yield in Nigeria [12]. The oil palm industry generates a great quantity of by-products in the form of empty bunches, fibres etc. Presently, by-products such as oil palm empty fruit bunches are extracted in large amounts from the oil palm milling industry day by day, they are currently utilized in the production of organic fertilizers and biofuel in less developed areas [13].

There is a further need to put to use the potential of OPEFBA as hardener in the partial replacement of cement for enhancing lateritic soil properties for the construction of road pavements. The Government has continually been making efforts to ensure that durable roads are provided at a minimum cost. Hence, this study is aimed at the stabilization of lateritic soil with cement-oil palm empty fruit bunch blend to meet the California bearing ratio requirement for base course in road construction. Also, the soil improvement technique adopted in this study will potentially minimize the cost of providing durable roads with readily available lateritic soil across the country including the reduction of the environmental hazard connected with the disposal of oil palm empty fruit bunches.

2. Materials and Methodology

2.1. Materials

2.1.1. Soil sample. The procurement of the lateritic soil from the borrow pit considered in this research was situated close to Maya Aladiye Bus-stop, Ijebu-Itokin Road (6° 35' 58.4" N 3° 30' 01.5" E), Ikorodu LGA, Lagos state in a cut about 2.5 m deep from the topsoil using disturbed sampling. In consideration to the deposit extent, lateritic soil is not restricted to the study area alone because it is widespread across several parts of Nigeria. The soil sample was air-dried rather than oven-dried so as to enable it retain its natural properties. Tests were carried out to determine the chemical and physical properties of the lateritic soil.

2.1.2. Oil palm empty fruit bunch ash (OPEFBA). Oil palm empty fruit bunches were procured from various palm oil mills in Edo State. The empty fruit bunches were sun-dried to get it as close as possible to a very dry state for ease of burning under a controlled temperature. After the empty fruit bunch ash cooled, it was sieved and stored in water-tight containers to prevent hydration. Chemical analysis was also carried out to ascertain the chemical composition of the OPEFBA.

2.1.3. Ordinary Portland cement (OPC). The Lafarge brand of OPC (32 N) was used for the study. The fundamental materials used in the production of cement comprise lime, silica, alumina and iron oxide. When these materials react with one another at high temperature in the kiln, they materialize into complex compounds. In addition to cooling rate and fineness, the relative proportions of materials are required for having an effect on cement properties [14].
2.2. Methods

The particle size distribution, index, compaction and strength tests were carried out in accordance with the guidelines provided in [15] and [16], for the natural lateritic soil and cement – OPEFBA treated soil, respectively. The following tests were carried out: sieve analysis (dry sieving for soil passing the 4.76 mm aperture), Atterberg limits, cation exchange capacity, compaction and California bearing ratio (soaked).

3. Results and Discussion

3.1. Natural lateritic soil

The results of various precursory experiments performed on the natural lateritic soil in order to evaluate its properties are shown in Figure 1 and Table 1. The soil was classified as A-6(8) group in the AASHTO soil classification system or CL group in the USCS [17]; [18]. Chemical analysis results of the natural soil are shown in Table 2. Additionally, based on the results in Table 2, the natural lateritic soil has silica – sesquioxide ratio of 1.40.

3.2. Oil palm empty fruit bunch ash

The chemical analysis of the OPEFBA is shown in Table 2. The OPEFBA did not fall under class C, F or N pozzolana since the addition of the percentages of SiO₂, Fe₂O₃ and Al₂O₃ did not sum up to 50 % for class C or 70 % for class F or N [19]. However, the high percentage of CaO indicates the hardening potential of the OPEFBA in soils.

3.3. Cement

The oxide compositions of the Lafarge brand ordinary Portland cement 32N (Grade 32 normal setting cement) is shown in Table 2. However, the percentage of CaO of 62.34 % indicates the hardening potential of the cement in soils.

![Figure 1](image.png)

*Figure 1. Particle size distribution curve for the natural lateritic soil*
Table 1. Physical properties of the natural lateritic soil used in the study

| Property                                              | Quantity |
|-------------------------------------------------------|----------|
| Natural Moisture Content (%)                          | 18.5     |
| Percentage Passing No. 200 Sieve (75 μm aperture)     | 57.7     |
| Liquid Limit (%)                                      | 39.5     |
| Plastic Limit (%)                                     | 20.6     |
| Plasticity Index (%)                                  | 18.9     |
| Maximum Dry Density (Mg/m³)                           |          |
| British Standard light                                | 1.75     |
| West African Standard                                 | 1.80     |
| British Standard heavy                                | 1.89     |
| Optimum Moisture Content (%)                          |          |
| British Standard light                                | 19.8     |
| West African Standard                                 | 19.0     |
| British Standard heavy                                | 17.3     |
| California Bearing Ratio (2 Days Soaking) (%)         |          |
| British Standard light                                | 10       |
| West African Standard                                 | 6        |
| British Standard heavy                                | 8        |
| Colour                                                | Reddish- brown |

Table 2. Chemical analysis results of the various materials considered in this study

| Oxide   | Lateritic Soil (%) | OPEFBA (%) | Cement (%) |
|---------|---------------------|------------|------------|
| SiO₂    | 45.89               | 17.06      | 19.06      |
| Al₂O₃   | 32.35               | 3.42       | 4.18       |
| Fe₂O₃   | 0.32                | 2.12       | 1.05       |
| K₂O     | 0.054               | 0.74       | 0.72       |
| Na₂O    | 0.062               | 0.82       | 0.79       |
| CaO     | 0.05                | 58.46      | 62.34      |
| MgO     | 0.03                | 2.05       | 3.58       |
| SO₃     | 0.01                | 1.06       | 1.18       |
| L.O.I.  | 0.005               | 7.12       | 0          |
3.4. Atterberg Limits

The plot of liquid limits (LL) of the lateritic soil with oil palm empty fruit bunch ash content is depicted in Figure 2. The LL values slightly decreased from 39.5 % for the natural soil to 34.2 % at 8 % OPEFBA content. The reduction in the LL of the treated lateritic soil could be due to the effect of the OPEBA and the high affinity for H+ of the clay – silt fractions in the soil in addition to the clay particles flocculating and agglomerating [20].

The plot of plastic limits (PL) of the lateritic soil with oil palm empty fruit bunch ash content is depicted in Figure 2. There was an increment in PL from 20.6 % for the natural lateritic soil to 28.1 % at 8 % OPEFBA content. The reduction in the PL of the lateritic soil with the addition of OPEFBA content are not consistent with the results reported by [21]. The increase observed may be due to the plastic nature of the lateritic soil – OPEFBA reaction [22]; [23].

The plot of plasticity indexes (PI) of lateritic soil with OPEFBA content is depicted in Figure 2. Broadly, the PI values decreased with increasing OPEFBA content. The PI of the soil decreased from its natural value of 18.9 % to 6.1 % at 8 % OPEFBA content. The decrease in PI gives a manifestation of a stable soil showing an increasing workability with a corresponding increase in OPEFBA content [24]; [25].

![Figure 2. Plot of Atterberg limits of lateritic soil versus oil palm empty fruit bunch ash content](image)

3.5. Cation Exchange Capacity

The ability of the soil to draw, hold on to and swap cation elements is regarded as cation exchange capacity (CEC). CEC can also be regarded to as the amount of negative charges within the soil that is available to join positively charged ions (cations) [26]; [27]. The modification of the CEC of lateritic soil – cement mixtures with OPEFBA content is shown in Figure 3. It is observed that the most of the high CEC values were recorded at 4 % OPEFBA content. The peak CEC value of 5.391 meq/100g (or cmol/kg) was recorded for 8 % Cement / 4 % OPEFBA treatment. Table 3 shows the CEC values for all mix ratios adopted in this research.
| Cement | OPEFBA | OPEFBA | OPEFBA | OPEFBA | OPEFBA |
|--------|--------|--------|--------|--------|--------|
| 0% Cement | 0.469 | 0.429 | 0.262 | 0.808 | 1.296 |
| 2% Cement | 0.519 | 0.535 | 1.064 | 1.314 | 1.485 |
| 4% Cement | 1.478 | 0.782 | 3.217 | 1.568 | 1.768 |
| 6% Cement | 1.884 | 0.851 | 4.671 | 1.829 | 1.921 |
| 8% Cement | 1.904 | 0.928 | 5.391 | 1.952 | 2.089 |

Figure 3. Plot of cation exchange capacity of lateritic soil – cement mixtures versus oil palm empty fruit bunch ash content

3.6. Compaction

3.6.1. Maximum dry density (MDD). The change in MDD of the lateritic soil – cement mixtures with oil palm empty bunch ash content for the three compaction efforts are depicted in Figures (4 – 6) a. It can be observed that the MDD values decreased with an increment OPEFBA content for all cement contents. There was a reduction in the MDD values from 1.75 Mg/m³, 1.80 Mg/m³ and 1.89 Mg/m³ for the natural soil (i.e., 0 % Cement / 0 % OPEFBA) to a minimum values of 1.56 Mg/m³ at 2 % Cement / 8 % OPEFBA, 1.61 Mg/m³ at 8 % Cement / 8 % OPEFBA and 1.64 Mg/m³ at 8 % Cement / 8 % OPEFBA when the samples were subjected to the BSL, WAS and BSH compaction efforts, respectively. The general decrease of the MDD for all compaction efforts considered may be due to the clay particles flocculating and agglomerating to take up larger spaces with respect to cation exchange causing a reduction in dry density [20]; [28]. Additionally, the decrease may be associated to the lamination of the soil – cement by the OPEFBA thereby leading to bigger particles with lower density and substantial voids [7]; [29].

3.6.2. Optimum moisture content (OMC). The change in OMC of the lateritic soil – cement mixtures with oil palm empty bunch ash content for the three compaction efforts are shown in Figures (4 – 6) b. It can be noted that the OMC values generally had a steady increase with higher OPEFBA contents for all cement contents considered. There was an increment in the OMC values from 19.8 %, 19.0 % and 17.3 % for the natural soil (i.e., 0 % Cement / 0 % OPEFBA) to peak values of 28.6 % at 8 % Cement / 8 % OPEFBA, 27.9 % at 2 % Cement / 8 % OPEFBA and 26.0 % at 8 % Cement / 8 %
OPEFBA when the samples were subjected to the BSL, WAS and BSH compaction efforts, respectively. Therefore, additional water content was required to compact the treated soil mixture for higher percentages of the addition of additives. It was also observed that OMC decreased with greater compaction efforts which is in concordance with previous research works [30]; [31].

The general reduction in the OMC values at greater compaction efforts considered may also be ascribed to the calcium ion taking up the place of the cations of other elements present [30]; [32]; [33]. This may have made it possible to disintegrate aggregates that have undergone flocculation, break down shear planes and destroy substantial pores at greater compaction efforts [21]; [33].

**Figure 4.** Bar charts of compaction characteristics versus oil palm empty fruit bunch ash content: (a) MDD (b) OMC (BSL compaction)

**Figure 5.** Bar charts of compaction characteristics versus oil palm empty fruit bunch ash content: (a) MDD (b) OMC (WAS compaction)
3.7. California bearing ratio (soaked condition)

The change in 2-day soaking California bearing ratio (CBR) of lateritic soil – cement mixtures with OPEFBA content for the three compaction efforts are depicted in Figure 7 (a – c). It can be discerned that there was an increment of CBR values from 10 %, 6 % and 8 % for the natural soil (i.e., 0 % Cement / 0 % OPEFBA) to peak values of 110 % at 6 % Cement / 0 % OPEFBA, 122 % at 8 % Cement / 0 % OPEFBA and 111 % at 8 % Cement / 0 % OPEFBA when the samples were subjected to the BSL, WAS and BSH compaction efforts, respectively. The peak values recorded for the compaction efforts considered met the CBR requirement of 80 % for base course materials [34]. The formation of secondary cementitious materials that developed from the interaction between the OPEFBA and the calcium hydroxide from the cement hydration could be accountable for the slightly greater values of the CBR recorded for samples of the 8 % cement contents [35]. Although, the recorded peak values for all compaction efforts considered are low when compared with the CBR value of 180 % which [34] recommends for the laboratory mix – in – place method for the construction of cement – stabilized materials for road pavements.

It can be inferred from the results obtained that lateritic soil treated with 8 % cement / 2 % OPEFBA can be utilized for base course construction of low–volume roads when compacted with at least the BSL compaction effort. There is also an observed increase in CBR values with increase in cement content, which signifies that higher percentages of cement contents beyond 8 %, for the cement – OPEFBA treatment may meet the requirement of [34] for the mix – in – place method in the construction of cement stabilized materials for road pavements.
Figure 7. Bar charts of California bearing ratio (2 days soaking) versus oil palm empty fruit bunch ash content (a) BSL (b) WAS (c) BSH compaction

4. Conclusion

Lateritic soil belonging to the A-6(8) soil group of the AASHTO soil classification system or CL group in the USCS was treated with 0, 2, 4, 6 and 8 % cement as well as 0, 2, 4, 6 and 8 % of OPEFBA, respectively, by weight of dry soil. Compaction was done using BSL, WAS and BSH compaction efforts.

The results obtained established the following for the lateritic soil used in the study:

1. Atterberg limits (the liquid limit, the plastic limit and the plasticity index) improved with greater concentrations of cement – OPEFBA treatment.

2. Maximum dry density decreased while optimum moisture content increased with higher concentrations of cement – OPEFBA treatment and compaction effort.

3. Peak soaked CBR values of 105, 120 and 110 % at 8 % Cement / 2 % OPEFBA treatment were obtained for BSL, WAS and BSH compaction efforts, respectively.
4. Based on the 80% CBR requirement for base course materials, an optimal blend of 8% Cement / 2% OPEFBA treatment of lateritic soil is recommended as a base course material in light – traffic volume road pavement construction.

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