Oil palm empty fruit bunch ash as a sustainable stabilizer for laterite sub-base of highway pavements

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Abstract: Laterite characterized by its reddish-brown colour collected from Ikorodu North Local Government Area in Lagos state was treated with up to 14 % oil palm empty fruit bunch ash (EFBA) by the dry weight of the laterite soil then compacted using the West African Standard (WAS) compaction. Index, compactions and strength (unconfined compressive strength; UCS and California bearing ratio; CBR) assessments were carried out on the untreated and treated laterite soil samples. Tests results showed a general improvement on the engineering properties with the addition of oil palm EFBA. UCS results increased with days of curing to peak values of 310, 658 and 725 kN/m² for 7, 14 and 28 days respectively at 8 % oil palm EFBA treatment. The 725 kN/m² strength recorded at 28 days curing period is in line with the 687-1373 kN/m² strength requirement for the stabilization of material used for sub-base construction with additives other than lime or cement. Similarly, peak un-soaked and soaked values of 80 % and 50 % were recorded at 8 % oil palm EFBA treatment during the CBR test. These values also met with the 20 - 30 % CBR sub-base requirement specified by Nigerian General Specifications. Hence, laterite optimally treated with 8 % oil palm EFBA compacted with the WAS energy can be utilized for sub-base construction for low-volume traffic road. Advantages of its use include savings in the cost of soil improvement as well as the adverse environmental impact of oil palm empty fruit bunch waste.

Keywords: California bearing ratio, Laterite, Oil palm empty fruit bunch ash, Unconfined compressive strength, Stabilization

1. Introduction
The problem of dilapidated roads in Nigeria is increasing by the day and a bigger challenge faced is the high cost of constructing or rehabilitation these roads as the cost is increasing so fast that cheaper means of building these roads are of high priority [1]. A probable solution to the problem of dilapidated roads is to develop cheaper and durable road construction materials as alternatives to the conventional but expensive cement and lime stabilizers because the ability to keep the cost of road construction to a manageable limit depends on the quantity of the materials that can be sourced locally.

Laterite soil, which has been discovered to be a vital local soil for construction is abundant in the humid tropical regions for which Nigeria is included. Laterite soil is mostly used for flexible pavement construction of base course and/or sub-base however, this laterite has been reported to possibly consist of considerable amounts of silica like silicate minerals in clay form, which may affect parameters such as stability and strength as such, it is reported to lacks the required engineering properties to provide the necessary strength for durable roads [2]. In order to enhance its stability and strength, stabilization is mandatory especially at locations that have abundance of these laterite deposits for which the cost of suitable alternatives available
may be on a high side [2]. Research has shown that there is a demand to improve the strength of deficient soils through a process known as stabilization [3, 4].

Research on ashes obtained from agricultural wastes such as cassava peel [5, 6] coconut shell husk [7], rice husk [8] and sugar-cane [9] which were used as stabilizing agents on laterite for road construction were discovered to be beneficial for improving weak soil in a cost-effective way [9, 10]. Further studies showed that the ashes obtained from rice husk had the tendency to lower the proportion as well as the amount spent on cement during the stabilization of soils of lateritic origin [11]. It was also reported that utilization of the rice husk ash as a stabilizer could also reduce thereby abolish the categorization of rice husk as generated contaminants adulterating the environs [11].

The research carried out in this paper was focused at using the ash obtained from oil palm empty fruit bunch (an agricultural by-product) as a sustainable stabilizer for laterite sub-base of low traffic volume roads.

2. Materials
2.1. Laterite: The representative soil utilized in this research was obtained from a borrow pit situated along Itokin Road, (Latitude 6° 60' 0" N and Longitude 3° 50' 0" E), Adamo, Ikorodu North Local Government Area, Lagos state at a depth between 1.5 – 2.0 m to minimize organic content. The disturbed soil sampling method was used to obtain the laterite soil.

2.2. Oil Palm Empty Fruit Bunch Waste (EFB): The waste of the oil palm was obtained from an oil mill located in Atan (Latitude 6°46'0" N and Longitude 2°48'0" E), Ijebu North East Local Government Area, Ogun state. The waste was air-dried, heaped together on zinc plates in order to avoid contamination on the ash and burnt in open air at a burning temperature of about 650°C when the ashing process of empty bunches commenced. The obtained ash was left to cool and thereafter, they were collected into drums, which had air-tight covers that prevented the ash from hydrating.

3. Methods
3.1. Index properties
Atterberg Limit Tests (Liquid Limit: LL, Plastic Limit: PL and Plasticity Index: PI), Sieve Analysis, Specific Gravity and Linear Shrinkage (LS) tests were carried out on the natural and oil palm empty fruit bunch ash (EFBA) treated soil to evaluate their respective index characteristics.

3.2. Compaction
Compaction tests are carried out as a guide used for specifications during field compactions. Compaction assessments performed on the natural occurring and oil palm EFBA stabilized laterite soil in order to achieve the correlation between the moisture content of the soil and the compacted dry density were carried out using the West African Standard (WAS) energy. These tests were performed respectively according to the required specifications [12-14]. The Standard Proctor mould having a volume of 1000 cm$^3$ was used.

The laterite was treated with oil palm EFBA in stepped concentrations of 2% up to 14% by the dry weight of the soil and compacted in 5 layers of relatively equal masses with every layer receiving 10 blows using a 4.5 kg rammer falling through 450 mm of height.

3.3. Strength
3.3.1. Unconfined compressive strength (UCS)
The UCS test was conducted on the natural occurring laterite and the oil palm EFBA treated laterite soil samples, which were prepared at their specific optimum moisture contents (OMCs) according to BS 1377:
1990 Part 4 and compacted adopting West African Standard (WAS) compaction. The compacted samples (3 each) having diameters and lengths of 38 and 76 mm respectively were extruded from their moulds and kept to air-cure respectively for 7, 14 and 28 days. When the curing periods had elapsed, the cured samples were positioned centrally on the bottom platen of the compression-testing machine and the compressive force was applied to the specimens using a strain guide at 0.10 % mm. Record of the axial deformation viz-a-viz the axial force at regular intervals were taken until the sample failed. The point on the stress-strain curve at which failure resulted was taken as the UCS of the sample.

3.3.2. *California bearing ratio (CBR)*
CBR is a familiar test used as an indicator to evaluate the strength of soils as well as their bearing capacities for the engineering design of pavement structures for road construction purposes. Soils stabilized with conventional stabilizers such as cement, lime etc. are often used for the construction of sub-base and base courses of flexible pavements, and so, the CBR test a common test carried out for the purpose of strength evaluation.

The CBR assessment was performed in conformity with specifications for the natural occurring laterite and oil palm EFBA stabilized laterite, respectively [12, 13]. CBR, expressed as the force exerted by the plunger in relation to its depth of penetration into the specimen is purposed at assessing the correlation the force applied and the penetration. It is therefore a necessity in the pavement design of natural gravel material.

5.0 kg of the natural / oil palm EFBA treated laterite soils were prepared at their respective OMCs in 2360 cm$^3$ moulds and compacted. The specimens each having five layers were compacted and each layer received 25 blows using a 4.5 kg rammer.

For the un-soaked CBR tests, after compaction was completed, the bottom plates were removed and the compacted samples in the moulds were put into plastic bags and sealed to allow for curing for 7 days. When the 7 days had elapsed, the natural / oil palm EFBA treated laterite soil samples were then placed on the CBR testing machine and stationed on the bottom plate of the CBR machine. The plunger was directed to penetrate the sample at a rate of 1.3 mm/min until failure of the sample occurred. Thereafter, the mould was brought out of the machine, inverted and the bottom plate was removed. The procedure was repeated but this time, for the bottom of the samples.

For soaked samples, after compaction was completed, the bottom plates were detached and the compacted samples in their respective moulds were put into plastic bags, sealed and allowed to cure for 6 days. When the 6 days had elapsed, the nylon-cured samples were transferred into tanks filled with water to allow for soaking. After 24 hours of soaking, the samples were brought out of the water tank and allowed to drain for 15 minutes and then tested.

4. Discussion of Results
4.1. Engineering properties
The engineering properties of the laterite soil in its natural form are compiled and shown in Table 1. Generally, a reduction in index properties of the reddish-brown fine-grained soil (see Figure 1) classified under A-7-6 (15) and CL using the AASHTO and USCS respectively was recorded. The LL, PL and PI reduced with higher oil palm EFBA content from 47, 24 and 23% for the natural soil to 26.1, 9 and 7%, respectively, at 14% oil palm EFBA treatment.
Table 1: Engineering properties of the natural laterite soil.

| Engineering Properties | Quantity |
|------------------------|----------|
| Liquid limit (%)       | 47.0     |
| Plastic limit (%)      | 24.0     |
| Plasticity index (%)   | 23.0     |
| Linear shrinkage (%)   | 9.40     |
| Specific gravity (%)   | 2.62     |
| OMC (%)                | 17.1     |
| MDD (Mg/m³)            | 1.600    |
| UCS (28 days) kN/m²    | 285      |
| CBR; un-soaked (%)     | 17       |
| CBR (24 hours soaking) (%) | 13     |
| AASHTO Classification  | A-7-6    |
| Group Index            | 15       |
| USCS                   | CL       |
| Colour                 | Reddish brown |

A decrease in LL was as a result of the effect of the Ca²⁺ in the oil palm EFBA on the elevated compatibility for Si/Al from the silt and clay fractions in the laterite soil as well as the agglomeration and flocculation exhibited by the particles of the clay soil which resulted in a switch of ions on the exterior of the clay fragments [15, 16].

The reduction recorded in the PL could be as a result of the cation exchange reaction which gave-off absorbed water molecules on the surface layers of the treated laterite soil which resulted in the modification and accumulation of the soil [17, 18].
The decreased PI observed could be ascribed to the recessed double layer thickness as a result of cation exchange initiated by the potassium, calcium and ferric ions. This decrease also gave a suggestion of a better stable soil with distinct increase in workability [19].

Similarly, the linear shrinkage value of the natural soil decreased from 9.4% to 3.9% at 14% oil palm EFBA treatment. This decrease can be attributed to the input of the oil palm EFBA with a relatively high lime content (see Table 3), which reduced the fine-grained soils with the formation of coarser fractions. This is a sign of improvement on the soil properties.

The difference in the values of specific gravity of the laterite soil with oil palm EFBA treatments shows that there was a gradual decrease from 2.62 for the untreated soil to a minimum of 2.03 at 14 % oil palm EFBA content. The observed trend could be as a result of a reduced combined specific gravity of oil palm EFBA (2.31) substituting the soil fragments with a higher specific gravity of 2.62. This observation reconfirms the results published by other researchers [10, 20].

4.2. Oxide compositions of laterite and oil palm empty fruit bunch ash
Chemical analyses were performed on the laterite soil as well as on the ash and the results are summarized in Tables 2 and 3. From Table 2, the silica-sesquioxides ratio i.e. $\text{SiO}_2/(\text{Fe}_2\text{O}_3+\text{Al}_2\text{O}_3)$ is calculated as 1.22. This is less than 1.33, which implies that the laterite soil used in this study is a true laterite. This is in conformity with specifications [21].

The oxide compositions of the oil palm empty fruit bunch ash (EFBA) obtained is summarized in Table 3. The combination of $\text{SiO}_2$, $\text{Al}_2\text{O}_3$ and $\text{Fe}_2\text{O}_3$, compositions in the EFBA used for this study did not satisfy the requirement for pozzolanas, which stipulates a minimum combined proportion of 70 % [22]. However, the ash has relatively high CaO contents of 52.15 %, which is responsible for the hardening observed.

4.3. Compaction
4.3.1. Maximum dry density (MDD)
The dissimilarity of MDD of laterite with oil palm EFBA proportions is presented in Figure 2. An initial increase from 1.60 Mg/m$^3$ for the untreated soil to 1.62 Mg/m$^3$ at 2 % oil palm EFBA content was observed, thereafter a steady decrease with increasing oil palm EFBA content to 1.49 Mg/m$^3$ at 14 % oil palm EFBA content was recorded. This initial increment in MDD value gives an indication of soil improvement [23]. The reduction in MDD may be attributed to reactions resulting to cation exchange. The reduction may also
be as a result of the oil palm EFBA possessing the voids inside the matrix of the soil in addition to the coagulation and accumulation of the clay fragments due to ion exchange [24-26].

4.3.2. Optimum moisture content (OMC)
The varying values of the OMC of laterite treated with oil palm EFBA content is presented in Figure 3. From the results obtained, there was a general increment in OMC with increasing oil palm EFBA content. The OMC increased from 17.1 % for the natural soil to 20.1 % at 14 % oil palm EFBA additive. The observed increase in OMC with increased oil palm EFBA content correlates with the findings published [18, 27, 28,]. These trends are also in agreement with established trend for stabilization of laterite using rice husk ash [8] and bamboo leaf ash [19]. The increment was as a result of adding the oil palm EFBA, which reduced the amount of unconfined clay and silts fractions which allowed for larger surfaces having coarser materials to be formed, which means that additional water was required so as to densify the soil-EFBA mixtures [18, 29].
4.4. Strength attributes

4.4.1. Unconfined compressive strength (UCS)
Figure 4 shows the changes in the UCS values of laterite treated with oil palm EFBA content. The UCS values at 7, 14 and 28 days showed a steady increment from 213, 250 and 285 kN/m² for the untreated laterite to optimum values of 310, 658 and 725 kN/m² at 8% oil palm EFBA content and thereafter the values decreased to 244, 438 and 691 kN/m² at 14% EFBA content. The increment recorded in the values were essentially as a result of the formation of compounds having various hydrates such as calcium aluminate hydrates (CAH) and calcium silicates hydrates (CSH) which also includes micro fabric modifications, that mainly caused the strength developed [30-33]. This increase could also be credited to exchange of ions that occur at the exterior of the clay fragments. In addition, a reaction between the calcium cation (Ca²⁺) in the ash and the lower valence metallic ions present within the clay microstructure occurred and this reaction resulted in coagulation and accumulation of the clay particles within the mixture [34].

![Figure 4. Variance of unconfined compressive strength (UCS) of laterite with oil palm empty fruit bunch ash (EFBA) content.](image)

4.4.2. California bearing ratio (CBR)
The subgrade strength is the main parameter to be determined in order to calculate the required thickness of a flexible pavement either for roads or airfields. The strengths of the subgrade, sub-base and base course layers are summarized in terms of their respective CBR values. Figure 5 shows the changes in CBR of laterite and oil palm EFBA additive for soaked and un-soaked conditions.

4.4.2.1. Un-soaked condition
The un-soaked condition of the CBR showed an increase from 17 % for the natural soil to an optimum value of 80 % at 8 % EFBA additive, which reduced to 45 % at 14 % oil palm EFBA content. The increase in the CBR could be as a result of sufficient proportions of calcium needed for the development of calcium
aluminate hydrate (CAH) and calcium silicate hydrate (CSH) that are the compounds that majorly result in strength gain [6].

A recommended CBR value of 180% is to be achieved during laboratory experiments for cement-stabilized soil materials to be constructed using the mix-in-place technique [14]. Minimum CBR values of 60 - 80 % for base specification and 20 - 30 % for sub-base specification are usually required when compacting both at 100 % West African Standard and at optimum moisture content [14, 35, 36]. In accordance with this, the soil-oil palm EFBA mixture meets with sub-base and base specifications where a value of 80 % was obtained at 8 % EFBA content. The laterite – oil palm EFBA mixture with a value of 80 % at 8 % optimum content meets with the minimum CBR requirement of 20 - 30 % for materials suitable for sub-base course construction when compacted with the WAS energy [14].

4.4.2.2. Soaked condition

Variations of CBR values (24 hours soaked conditions) for natural and EFBA-stabilized soil are also presented in Figure 5. A similar trend to the un-soaked condition was recorded. A peak value of 50 % was recorded at 8 % oil palm EFBA content however lower values were recorded in comparison to the un-soaked CBR values. The low values were as a result of water ingress into the soaked samples, which led to a reduction in strength. The result shows that the CBR values did not decrease very significantly when soaked. However, relating with the required specifications for sub-base course construction of 20 - 30 %, the 50 % meets the requirements [14].

Figure 5. Variance of California bearing ratio (CBR) of laterite with oil palm empty fruit bunch ash (EFBA) content.
5. Conclusion
Laterite soil which was classified using the American Association of State Highway and Transportation Officials (AASHTO) or Unified Soil Classification System (USCS), as A-7-6 (15) and CL respectively was collected from an active borrow pit at Ikorodu North Local Government Area in Lagos state. The representative samples were air-dried and treated with oil palm empty fruit bunch ash (EFBA) in stepped concentrations of 2% up to 14% by dry weight of the laterite soil and compacted with West African Standard compactive effort. Tests results obtained reveal that Atterberg limits, linear shrinkage, specific gravity, unconfined compressive strength, compaction and California bearing ratio improved. Optimum UCS reading of 725 kN/m$^2$ for specimens cured for 28 days curing period and CBR (soaked condition) reading of 50 % were recorded at 8 % oil palm EFBA treatment of laterite. Further to the strength results, an 8 % optimum blend of oil palm EFBA and laterite is recommended as a sub-base stabilizer to laterite soil material for low-volume road construction. The advantages of applying the oil palm EFBA also entail a decrease in the cost of soil enhancement and the deleterious environmental impact of oil palm empty fruit bunch waste.

6. Recommendation
From results of the study carried out, an optimal 8 % oil palm EFBA treated laterite when compacted with West African Standard energy has the recommended strength required for use as a sub-base construction material for sub-base course in low-volume traffic roads.

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