Effect of Plantain Peel Ash on Gradation and Compaction Characteristics of Tropical Soil

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Abstract — This study investigated the gradation and compaction properties of lateritic soil treated with plantain peel ash (PPA). PPA was used to improve lateritic soil with up to 10% PPA by dry weight of soil. Tests carried out to include specific gravity, particle size distribution, consistency tests, and compaction (using British Standard light, BSL and West African Standard, WAS) compaction energies. XLSTART 2018 Software was used to develop regression models for the test conducted between the self-determining factors and the dependent factors. The results of the study show that the specific gravity of the soil significantly decreased from its natural value of 2.55 to 2.43 at 4% PPA and thereafter increased to 2.48 at 10% PPA. The fines content reduced from 59.9% at the 0% PPA to 5% at 10% PPA respectively. MDD (BSL and WAS) reduced to 1.76 Mg/m³, 1.84 Mg/m³ at 4%, 6% PPA content and subsequently increased to 1.91 Mg/m³, 2.0 Mg/m³ at 10% PPA content respectively. OMC for BSL decreases to 11.8% at 10 PPA content while WAS was decreased to 8.6% at 10% PPA content. Regression models for MDD show that self-determining factors, primarily influence MDD of treated soil. However, in the case of OMC model, Gs and CE with higher coefficients have much more effect on the OMC compared to other variables. Based on the obtained results Gs, CE and PPA significantly affect grading and compaction characteristics of PPA treated soil.

Keywords — Compaction Characteristics, Grading Properties, Latertic soil, Plantain Peel Ash, Regression Models.

1 INTRODUCTION

Lateritic soil is a red hard or gravel-like residual soil that occurs naturally. Lateritic soils are formed in the tropical regions of the world where the soil has been leached of soluble minerals, leaving the insoluble iron and aluminum oxides and hydroxides (Gidigasu, 1976; Aginam, 2015; Nnochir and Aderinlewo, 2016). Lateritic soil is a highly weathered material, rich in secondary oxides of iron, aluminum or both nearly void bases and primary silicates and contains a large amount of quartz and kaolinite, either hard or capable of hardening on exposure to wetting and drying (Dowling, 1966; Quadri, 2012). Some lateritic soils are good in their natural form for engineering application while others are deficient in their natural form and need to be improved before use. The conventional improvement techniques used in the past were the industrially manufactured additives such as cement and lime for soil improvement. (Oriola and Moses, 2011; Etin et al., 2017).

Although the application of lime, cement, and bitumen for soil improvement has enhanced the engineering properties of soils, the rising cost of these additives has been a burden and the improvement of lateritic soil with plantain peel ash (PPA) which relatively considered as a cheap commodity. The study was aimed at evaluating the effect of PPA on the grading and compaction properties of lateritic soil (i.e soil with silica-alumina ratio (SiO₂/Al₂O₃) between 1.33 to 2.00 as reported by Gidigasu, 1976). The specific objective was to determine changes in the modified soil using PPA in step concentrations of 0, 2, 4, 6, 8 and 10% PPA content, with respect to its grading and compaction properties.

2 MATERIALS AND METHODS

2.1 MATERIALS

2.1.1 Lateritic Soils

The lateritic soil used for this work was collected from Osun State University, Osogbo, (latitude 12°27′N and longitude 12°30′E) Osun State, Nigeria. The XRF spectroscopy gives the oxide compositions of laterite as SiO₂ = 43.4%, Al₂O₃ =21.5%, Fe₂O₃ = 10.7%, K₂O = 0.22%, CaO = 0.09% and SiO₂ / Al₂O₃ : Fe₂O₃ value of 1.34 which makes it fall into classes of laterites and lateritic soil classes. A study of the geological and soil maps of Nigeria after Bello et al., (2015) shows that the parent material in the study area is the basic igneous rock which when weathered forms lateritic soils.

2.1.2 Plantain Peels

The plantain peel used for this study was obtained from an open dump site in Ikire, Osun State. The plantain peel was heaped on a galvanized roofing sheet, air dried and burnt in the open air at a temperature of 500°C which its residue turned into ash, then allowed to pass through sieve No 200 (0.075mm).

2.2 METHODS

2.2.1 Specific Gravity Test

The specific gravity test was carried out in accordance with BS 1377 (1990), Test 6 for the natural and the treated
samples (BS 1924). First, the weight of the empty density bottle was determined as \( m_1 \). Air-dried sample was then poured in to a 50ml density bottle to fill about one-third its volume and then weighs as \( m_2 \), after which water was added to the sample to fill to volume mark. Then, the flask was weighed when filled with water and weighed as \( m_3 \). The procedure was repeated for specimens treated with 2 up to 10 % of plantain peel ash content in step concentration of 2% by mass of dry soil. The specific gravity was calculated using equation 1.

\[
Gs = \frac{m_2 - m_1}{(m_3 - m_1) - (m_3 - m_2)}
\]

Where; \( G_s \) = specific gravity, \( m_1 = \) weight of density bottle (g), \( m_2 = \) weight of density bottle + dry soil (g), \( m_3 = \) weight of bottle + soil + water (g), \( m_\ell = \) weight of bottle and water (g)

2.2.2 Particle Size Distribution
Particle size distribution was carried out in accordance with BS 1377(1990) Part 2. Wet sieving was conducted by measuring 200 g of the soil sample and soaked for 24 hours. The sample was then washed through BS No 200 sieve. The particles retained were then dried in an oven for 24 hours and dry sieving was carried out on the dried sample to obtain the particle size distribution.

2.2.3 Atterberg Limits
The Atterberg Limits test included the determination of liquid limits, plastic limits and plasticity index of the natural and modified soil samples. The tests were conducted were conducted in accordance with Test 1(A) B S 1377 (1990) Part 2 for the natural soil and BS 1924 (1990) for the treated soil.

Liquid limit: 200g of soil sample passing sieve 425 μm was placed on a clean glass plate. Water was added little by little, as it was mixed, using a palette knife or spatula to form a homogeneous paste. A proportion of the paste was placed in Casagrande apparatus and leveled parallel to the base of the chip and divided by drawing the grooving tool through the paste along diameter passing the centre of the hinge. The crank was turned to lift-drop the cup at the rate of 2 revs per second, noting the number of blows (falls) that would make the bottom two parts of the groove come together. A sample of it was taken and its moisture content determined. This test was repeated for well-sieved moisture. The determined moisture contents were plotted against a corresponding number of blows on a semi-logarithmic paper and liquid limit was determined at the moisture content corresponding to 25 blows on the graph. The same test was performed for each of the modified soils.

Plastic limit: Plastic limit is the minimum water content at which a soil will just begin to crumble when rolled into a thread approximately 3mm in diameter. Twenty grams (20g) of the dried natural soil passing 425 μm aperture sieve as put on a flat glass plate and mixed thoroughly enough to be shaped into a small ball. The ball was molded between fingers and then rolled on the glass plate with the palm of hand into a thread of about 3mm diameter and put in the oven for moisture content determination. The same test was performed for each of the modified soils.

Plasticity index: Plasticity index of the natural and modified soil samples was derived from the values of liquid limits and plastic limits using equation 2;

\[
I_p = w_L - w_P
\]

Where; \( I_p = \) Plasticity Index, \( w_L = \) Liquid Limit, \( w_P = \) Plastic Limit

2.2.4 Compaction
Compaction tests on the soil samples was carried out in accordance with BS 1377 (1990) Part A:3:3 using the British Standard light (BSL) and West African Standard (WAS) energy levels. For the BSL compaction, 3.0 kg of soil sample was thoroughly mixed with 5% water by weight of dry soil. The wet soil was placed in 1000 mm² mould and compacted in three equal layers; each layer receiving 27 blows of 2.5 kg rammer, falling through a height of 300 mm. After compaction, the samples were weighed with the mould and moisture content taken. The procedure is repeated with another 5% water until the weight of compacted samples start to decrease and moisture content is taken for each stage. The case of WAS compaction, samples were compacted in five layers using 4.5 kg rammer falling from 450 mm and each layer received 10 blows. The same procedure was followed to determine moisture content. The test was carried out for varying percentages of Plantain peel ash. The bulk density as calculated for each of the soil samples using equation 3.

\[
\rho = \frac{m_2 - m_1}{1000}
\]

Where; \( \rho = \) bulk density (Mg/m³), \( m_1 = \) mass of mould and base (g), \( m_2 = \) mass of mould, base, and soil (g).

Dry densities \( \rho_d \) of the samples were calculated from equation 4:

\[
\rho_d = \frac{\rho}{(1 + w)}
\]

Where \( w = \) water content (%)

Optimum moisture content (OMC), is the amount of water content corresponding to maximum dry density (MDD) of the sample read from the dry density/moisture content graph.

3 Results and Discussion

3.1 Natural Soil
Preliminary examination of the natural soil sample suggests that the soil is fine-grained, having a reddish brown colour. The various test conducted on the natural or unmodified soil shows that the percentage passing 0.075mm aperture sieve is 58.9 and is classified as CL according to the Unified soil classification system USCS (ASTM, 1992) or A-7-5 sub-group by the AASHTO classification (AASHTO, 1986). The soil has a liquid limit of 54.2 %, plastic limit of 30.85 % and a plasticity index of 23.35 %. The properties of the unmodified soil are summarized in Table 1. The oxide compositions of plantain peel ash are summarized in Table 2. The high content of K₂O (48.8 %) in the plantain peel ash was
attributed to incomplete combustion of plantain peel which shows the presence of carbon content.

Table 1. Properties of the Natural Soil

<table>
<thead>
<tr>
<th>Percentage passing 0.075mm sieve</th>
<th>59.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural moisture content %</td>
<td>11.4</td>
</tr>
<tr>
<td>Specific gravity %</td>
<td>2.55</td>
</tr>
<tr>
<td>Liquid limit %</td>
<td>54.2</td>
</tr>
<tr>
<td>Plastic limit %</td>
<td>30.85</td>
</tr>
<tr>
<td>Plasticity index %</td>
<td>23.35</td>
</tr>
<tr>
<td>Linear shrinkage %</td>
<td>10.7</td>
</tr>
<tr>
<td>AASHTO classification</td>
<td>A-7-5</td>
</tr>
<tr>
<td>Maximum dry density Mg/m³</td>
<td>1.84</td>
</tr>
<tr>
<td>British Standard light (BSL)</td>
<td>1.91</td>
</tr>
<tr>
<td>West African Standard (WAS)</td>
<td>1.91</td>
</tr>
<tr>
<td>Optimum moisture content %</td>
<td>13.5</td>
</tr>
<tr>
<td>British Standard light (BSL)</td>
<td>13.9</td>
</tr>
<tr>
<td>West African Standard (WAS)</td>
<td>10.4</td>
</tr>
</tbody>
</table>

Table 2. Oxide compositions of plantain peel ash

<table>
<thead>
<tr>
<th>Oxide</th>
<th>Plantain Peel Ash (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron oxide (Fe₂O₃)</td>
<td>2.88</td>
</tr>
<tr>
<td>Potassium oxide(P₂O₅)</td>
<td>4.35</td>
</tr>
<tr>
<td>Manganese oxide(MnO)</td>
<td>0.14</td>
</tr>
<tr>
<td>Copper Oxide (CuO)</td>
<td>0.05</td>
</tr>
<tr>
<td>Zinc oxide (ZnO)</td>
<td>0.18</td>
</tr>
<tr>
<td>Silica (SiO₂)</td>
<td>19.25</td>
</tr>
<tr>
<td>Alumina oxide (Al₂O₃)</td>
<td>3.05</td>
</tr>
<tr>
<td>Sodium oxide (Na₂O)</td>
<td>1.69</td>
</tr>
<tr>
<td>Potassium oxide (K₂O)</td>
<td>48.88</td>
</tr>
<tr>
<td>Lime (CaO)</td>
<td>5.75</td>
</tr>
<tr>
<td>Sulphur oxide (SO₃)</td>
<td>1.99</td>
</tr>
<tr>
<td>Loss on ignition</td>
<td>13.15</td>
</tr>
</tbody>
</table>

3.2 Influece of Plantain Peel Ash (PPA) on the Grading and Compaction Properties of Lateritic Soil

3.2.1 Specific gravity

The variation of specific gravity of lateritic soil with PPA content is shown in Fig. 1. The specific gravity of the soil significantly decreased from its natural value of 2.55 to 2.43 at 4% PPA treatment and thereafter increased to 2.48 at 10% PPA content. The initial decline in specific gravity may be associated with the lower specific gravity of the soil (2.55) compared to that of PPA (2.6). Upon further increase beyond 4% PPA, the increase could be due to the higher specific gravity of PPA than that of the soil which contributed to the increase in specific gravity. It has been reported by Osinubi et al., (2015) and Etim et al., (2017) that specific gravity of the admixtures significantly influences the density of the compacted soil. The higher specific gravity of admixtures gives rise to the higher density of the compacted soil which favours its suitability as a road construction material. The increase in specific gravity shows an improvement in the geotechnical properties of the treated soil. Therefore, such improvement makes the soil more suitable for use in the construction of roads and as a fill material, as increased density automatically increases the strength and shear resistance of the material (Osinubi et al., 2015; Etim et al., 2017).

3.2.2 Particle size distribution

The particle size distribution curves for the natural and modified soils are shown in Fig. 2. The grain size distribution of the treated soils show that the soil became progressively coarser as PPA content increased from 0% to 10% by dry weight of soil. The percentages passing through BS sieve No. 200 declined considerably from 59.9% to 5% at 0 and 10% PPA respectively. This conforms to a previous study by (Dennis et al., 2006) who recorded a significantly decreased from 96.6% to 0.4% with the admixture addition from 0% to 10% by dry weight of soil. The reduction in the fines content of the soil with PPA content favours the suitability of the modified soil for engineering applications. For instance, increase in grain size increases the frictional strength of the material particles, therefore improving the geotechnical and engineering properties of the material and making it suitable for use in engineering construction as structural fill material and for the embankment. Similar behaviour was noticed by Osinubiet al., (2015).

3.2.3 Atterberg limit tests

Liquid limit: Result showing variation of the liquid limit with plantain peel ash (PPA) content is shown in Fig. 3. A general trend of decline in the liquid limit of the soil from its natural value of 54.2% to 45.3% at 10% PPA treatment was observed. However, slight changes were observed at 2% and 6% PPA, which may be due to the laboratory or environmental factors that influenced such deviations. The general declined may be associated with cation exchange reaction or pozzolanic reaction between the exchangeable cations in the soil structure and PPA that led to decrease in Liquid limit. Similar observations were made by Osinubi et al. (2015) and Etim et al. (2017) on the tropical black clay admixed with cement-iron ore tailing and lime-iron ore tailing mixture respectively. Also, Al-Zoubi (2008) and Portelinha et al. (2012) reported similar observations.
Similar statements were reported by Phanikumar (2015). A decline in plasticity index may be as a result of low specific gravity of soil (i.e. 2.55) compared to the natural value of 2.60. An improvement in the engineering properties for pavement applications or embankment purposes. Since PPA is non-plastic in nature, the addition of PPA to lateritic soil-PPA mixtures could be responsible for the decrease in the plastic limit. It has been reported by previous researchers (Portelinha et al., 2012; Ramesh et al., 2013; Osinubi et al., 2015; Etim et al., 2017) that addition of non-plastic additives to the soil reduces the plastic limit of the treated soil.

**Plastic Limit:** The plastic limit is a measure of soil’s cohesive properties and an indicative of the amount and nature of clay in the soil. Soils with higher PI may be difficult to work with in construction because of their instability and stickiness when wet. Fig. 3 shows the variation of the plasticity index with PPA content. The plasticity index value initially increased from 23.35 % for the natural soil to 29.65 % at 2 % PPA content and thereafter decreased to 18.3 % at 10 % PPA content. The decline in plasticity index may be presumed to be related to the pozzolanic nature of PPA that facilitated the pozzolanic reaction between soil element and the PPA in the presence of moisture added to the soil. The natural soil treated from 0 to 10 % PPA content failed to meet not more than 12 % maximum plasticity index value specified by Nigeria General Specification. However, reduction in plasticity index with PPA addition signifies an improvement in the engineering properties for pavement applications or embankment purposes.

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### 3.2.4 Compaction Characteristics

**Maximum dry density:** The variations of maximum dry density (MDD) with plantain peel ash (PPA) content for British standard light and West African Standard compaction is shown in Fig. 4. Generally, MDD initially decreased for both compactive efforts and thereafter increased with higher PPA content. For BSL compaction energy, MDD value reduced from natural value of 1.84 to 1.76 Mg/m^3 at 4 % PPA and thereafter increased to 1.91 Mg/m^3 at 10 % PPA content. In the case of WAS compaction energy, MDD value reduced from the natural value of 1.91 to 1.84 Mg/m^3 at 6 % PPA and thereafter increased to 2.0 Mg/m^3 at 10 % PPA content. The initial decrease in MDD values could be due to the low specific gravity of soil (i.e. 2.55) compared to the PPA (i.e. 2.6) thereby reducing the density of the soil. Similar statements were reported by Phanikumar et al., (2004), Kumar and Puri (2013) and Osinubi et al., (2015). The later increase in MDD with higher PPA content may be associated with a high specific gravity of the additive (PPA) replacing the soil thereby increasing the density of the soil. The increase in the MDD could also be associated with flocculation and agglomeration leading to a volumetric decrease in density (Moses and Folagbade, 2010).

![Maximum dry density graph](image)

**Optimum moisture content:** The results show a general trend of decreasing OMC with PPA content as shown in Fig. 5. For BSL energy, OMC of natural value (13.9 %) decrease to 12.6 % at 2 % PPA content, thereafter increase to peak value (14.2%) at 6 % PPA content, further addition of PPA decrease its value to 11.8% at 10 PPA content. For WAS compaction energy OMC values decrease from natural value (10.4 %) to 9.0 % at 4 % PPA content, thereafter increase to 9.4% at 6 % PPA, further addition of PPA content decline the OMC to 8.6% at 10 PPA content. The decrease in OMC with an increase in PPA content could be due to decreasing demand for water by various cations and the clay mineral particles to undergo hydration reaction (Osinubi and Stephen 2006; Moses 2008). However, reports of researches (Jadha and Nagarnaik, 2008; Kumar and Puri, 2013 and Osinubi et al., 2015) proposed that decline in OMC values with increasing additive content may be as a result of low hydration caused by self-desiccation when no water movement is allowed to or from soil-PPA matrix, the available water is used up in the hydration reaction allowing low water content to saturate the soil surfaces, hence reduction in the soil relative humidity.

![Optimum moisture content graph](image)

### 3.2.5 Regression analysis

The multi-linear regression model shows relationship between the self-determining factors (i.e Plantain Peel Ash (PPA); Plasticity Index (PI); Percentage Fine (PF); Specific Gravity (Gs) and Compactive Effort (CE)) and the dependent factors (Maximum Dry Density (MDD) and (Optimum Moisture Content (OMC)). From the
modeled equation (5) for MDD, it is evident that a fairly good relationship exists between the self-determining factors and the dependent factor with regression coefficient value of 67.3%. All the variables have positive coefficients. Results show that an increase in all the self-determining factors leads to an increase in the MDD values. However, the remedial effect of Gs followed by CE and PPA is more on the MDD with higher coefficients in the regression model than other variables (i.e. PI and PF). This implies that Gs, CE, and PPA are factors that primarily influence the MDD of compacted lateritic soil–PPA mixtures and should be carefully considered during field compaction and applications, also in other engineering purposes to achieve desired density in the field.

\[
MD = -2.018 + 0.029PPA + 4.309 \times 10^{-3}PI + 1.911 \times 10^{-2}PF + 1.447Gs + 0.025CE
\]

\[R^2 = 67.3\%\]

In the case of OMC model (see equation 6), good relationship occurred between the OMC and the self-determining factors (i.e. PPA; PI; PF; Gs and CE), with a regression coefficient value of 84.8%. From the equation, an increase in PPA and CE lead to a decline in OMC values because of their negative coefficient while the reverse is the case for PI, PF, and Gs with a positive coefficient. However, Gs and CE with higher coefficients have much more effect on the OMC compared to other variables and should be carefully studied during field compaction.

\[
OMC = -1.101 - 4.419 \times 10^{-2}PPA + 2.779 \times 10^{-2}PI + 1.340 \times 10^{-2}PF + 4.524Gs - 1.758CE
\]

\[R^2 = 84.8\%\]

The plot of the relationship between laboratory measured values MDD and OMC values and the predicted MDD and OMC values from the regression models are shown in Figs 6 and 7 respectively. A strong relationship was established between predicted values and the laboratory measured values with a coefficient of determination of 0.8215 and 0.9171 for MDD model and OMC model respectively.

\[
y = 0.8215x + 0.3375
\]

\[R^2 = 0.8215\]

\[
y = 0.9171x + 0.9201
\]

\[R^2 = 0.9171\]

4 CONCLUSION

Preliminary investigation results show that the lateritic soil belongs to A-7-5(6) or CL in American Association of State Highway and Transportation Officials (AASHTO) and Unified Soil Classification System (USCS), respectively. Results show that the specific gravity of the soil significantly decreased up to 4% PPA and thereafter increased up to 10% PPA. The fines content of the soil reduced by 59.9% from 59.9 at the 0% PPA to 5% at 10% PPA respectively. The liquid limit, plastic limit, and plasticity index generally decreased with higher PPA content. The MDD initially decreased and thereafter increase with higher PPA content. In the case of OMC, a general trend of decrease was noticed for both energies. Regression model for MDD shows that Gs, CE, and PPA primarily influence the MDD of treated soil. However, in the case of OMC model; Gs and CE with higher coefficients have much more effect on the OMC compared to other variables. The plot of the relationship between laboratory measured values and the predicted values from the regression models for MDD model and OMC shows a coefficient of determination of 0.8215 and 0.9171 for MDD model and OMC model respectively. Based on the obtained results Gs, CE and PPA significantly affect grading and compaction characteristics of PPA treated soil and are carefully considered during field compaction and applications in other engineering purposes to achieve desired density in the field.

REFERENCES


