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Original Research Article

Effect of Plantain Peel Ash on the Strength Properties of Tropical Red Soil

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ABSTRACT

The effect of plantain peel ash (PPA) on the strength properties of tropical red soil was studied. Natural soil was classified as Lean clay (CL) according to the Unified soil classification system or A-7-5 according to American Association of State Highway and Transportation Officials classification. Test method employed involved treating lateritic soil with plantain peel ash in concentration of 0, 2, 4, 6, 8 and 10% PPA by dry weight of soil. Test carried out include specific gravity, consistency tests, compaction test using British standard light (BSL), unconfined compression test (UCS) and California bearing ratio (CBR). Analysis of variance was carried out using Microsoft Office excel analysis tool pack. Test results shows that specific gravity initially decreased and thereafter increased with higher PPA content. Liquid limit, plastic limit, plasticity index and linear shrinkage decreased with higher PPA content. Maximum dry density (MDD) values increased while optimum moisture content (OMC) decreased. UCS increased from its natural value of 172.8 kN/m^2 to peak value of 286.9 kN/m^2 at 10% PPA content. CBR (unsoaked) increased from its natural value of 65.30% to 75% at 4 % PPA content and thereafter decreased to 22.6% at 10% PPA content. The PPA treated soil did not meet the criteria specified for use as base course material by the Nigerian general specification, however, PPA treated lateritic soil at 4% PPA content can be used as subgrade material in admixture stabilization with a more potent industrially made stabilizer (i.e., cement or lime) in order to lessen cost of road construction.

1. INTRODUCTION

Lateritic soils are reddish colour weathered pedogenic surface deposits that occur predominantly in the tropical and subtropical counties of the world. They form the most common materials for construction of highways, earth dams, embankments, foundation materials to sustain structures in such areas (Gidigasu,

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1976; Alhassan and Mustapha, 2015). Lateritic soil is a highly weathered material, rich in secondary oxides of iron, aluminum or both nearly void bases and primary silicates and contain large amount of quartz and kaolinite, either hard or capable of hardening on exposure to wetting and drying (Dowling, 1966). 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 to increase the strength and bearing capacity before use (Salahudeen and Ochepo, 2015).

Strength improvement of lateritic soil using chemical admixtures is a common method for stabilizing the swell-shrink propensity of lateritic soils which impedes its suitability for pavement and other geotechnical engineering applications (Osinubi *et al.,* 2015). Benefits of chemical stabilization are that they lessen the swell-shrink propensity of the soil by reducing its plasticity. The use of chemical admixtures for soil improvement is relatively expensive (Osinubi *et al.,* 2015). In track with that, developing a cheaper soil improvement additive having pozzolanic properties could help to improve the soil's engineering properties and reduce the overall cost of construction (Yohanna *et al.,* 2016; Etim *et al.,* 2017).

Research that has been on-going on the possibility of using agricultural wastes such as saw dust ash (SDA), plantain peel ash (PPA), rice husk ash (RHA), bagasse ash (BA) etc. because their pozzolanic nature in treatment of deficient soils have recorded positive results (Phanikumar and Sharma, 2004; Moses, 2008; Moses and Folagbade, 2010; Eberemu, 2011; Sani, 2012; Osinubi *et al.,* 2015; Yohanna *et al.,* 2016; Etim *et al.,* 2017). The increasing cost of conventional additives (cement and lime) additives has been a problem and the improvement of lateritic soil with plantain peel ash (PPA) having pozzolanic property may be relatively cheaper (Bello *et al.,* 2015).

This study was thus aimed at evaluating the effect of PPA on the strength properties of lateritic soil.

2. MATERIALS AND METHODS

2.1. Materials

The lateritic soils used for this work was sourced from Osogbo, (latitude 12°27'N and longitude 12°30'E) Osun State, Nigeria. The plantain peels use for the study was obtained from a dump site in Osogbo, Osun State. The plantain peels obtained were first air dried then burnt into ashes, followed by sieving through sieve No 200 (0.075 mm).

2.2. Methods

2.2.1. Specific gravity test

The specific gravity test was done as specified in BS 1377 (1990), Test 6 for the natural and the treated samples. First, the weight of empty density bottle was determined as W_1. Air-dried sample was then poured in to a 50 ml density bottle to fill about one-third of its volume and then weigh as W_2, after which water was added to the sample to fill to volume mark. The flask was then sealed and shaken for proper mixing and weighed as W_3. The flask was weighed when filled with water and noted as W_4. The procedure was repeated for specimens treated with 2 up to 10% of plantain peel ash content in increment of 2% by mass of dry soil. The specific gravity was calculated using Equation 1.

$$\text{Gs} = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)} \tag{1}$$

Where G_s = specific gravity, W_1= weight of bottle (g), W_2 = weight of bottle + dry soil (g), W_3 = weight of bottle + soil + water (g), W_4 = weight of bottle + water (g).

2.2.2. Atterberg limits

The Atterberg limits test was carried out as specified in Test 1(A) B S 1377 (1990) Part 2 for the natural soil and BS 1924 (1990) for the modified soil. Tests conducted include liquid limits, plastic limits and plasticity index of the natural and treated soil.

2.2.2.1. *Liquid limit*

Liquid limit is the minimum moisture at which soil will flow under its own weight and can also be the moisture content in percent at which the soils change from liquid to plastic state. In this test moisture content of the soil sample was determined and plotted against the corresponding number of blows on a semi-logarithmic graph. The moisture content determined at corresponding 25 blows on the graph is the liquid limit. The same test was performed for each of the modified soils.

2.2.2.2. *Plastic limit*

Plastic limit is the minimum water content at which a soil will just begin to crumble when rolled into a thread approximately 3 mm in diameter. In this test moisture contents were obtained in accordance with British Standard 1377 (1990) and British Standard 1924 (1990) for the natural and modified soil samples.

2.2.2.3. *Plasticity index*

Plasticity index of the natural and treated soil samples was derived from the values of liquid limits and plastic limits using Equation 2.

$$PI = LL - PL \tag{2}$$

Where PI = Plasticity index, LL= Liquid limit, PL= Plastic limit

2.2.3. Compaction

Compaction tests was carried out on the soil samples in accordance with BS 1377 (1990) Part 4:3:3 using the British Standard light (BSL) energy level. The soil sample (3 kg) was mixed properly with 5% water by weight of dry soil. The wet soil was placed in 1000 mm^3 mould and compacted in three equal layers, with 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 was repeated with another 5% water until the weight of compacted samples started to decrease and moisture content taken for each stage. Test was carried out for varying percentages of plantain peel ash. The bulk density in (Mg/m^3) was calculated for each of the soil samples using Equation 3.

$$\rho = \frac{W_2 - W_1}{1000} \tag{3}$$

Where ρ = bulk density (Mg/m^3), W_1 = mass of mould and base (g), W_2 = mass of mould, base and soil (g).

Dry densities ρ_d of the samples were calculated using Equation 4.

$$\rho_d = \frac{\rho}{(1 + w)} \tag{4}$$

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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.

2.2.4. Unconfined compression test (UCS)

The test was carried out in accordance with the BS 1377: Part 7 (1990). Soil sample (3 kg) passing 4.76 mm sieve was weighed and mixed with water at optimum moisture content of British Standard Light (BSL) compaction energy. The compacted samples were extruded from the mould using extruding machine and three cylindrical samples (36 mm diameter and 78 mm height) were obtained. After extrusion, the samples were sealed in a polythene bag and cure for 7 days. The samples were then placed centrally on the pedestal of the compression machine between the upper and lower platens. The machine was then adjusted so that contact is just made between the specimen, upper platen and the force measuring device. The axial deformation gauge was adjusted to read zero for a convenient initial reading, and the initial readings of the force and compressions gauges were recorded. This was repeated for the other two specimens and for the three samples of 2, 4, 6, 8 and 10 % PPA treated soil. The unconfined compressive strength (UCS) was calculated using Equation 5.

$$\delta = \frac{R \times C_v \times (100 - E\,\%) \times 100}{100 \times A_0} \tag{5}$$

Where δ= deformation stress (kN/m^2), R = deformation value, C_V = calibration of dial gauge used, E% = Strain on sample (in percentage), A_o = Cross-sectional area of sample (m^2)

E = is given as:

$$E = \frac{\Delta l}{lo} \tag{6}$$

Where Δl =change in height of sample (m), l = Original height of sample (m)

2.2.5. California bearing ratio (CBR) test

The California bearing ratio (CBR) test was carried out in accordance with BS 1377: Part 4 (1990). The soil sample used was air-dried and pulverized sufficiently to run through BS sieve No. 4 (4.76mm). Various percentages of PPA (2, 4, 6, 8 and 10%) were mixed with the portion of the soil sample. These blends were further mixed thoroughly with the required percentage of water based on dry weight until a uniform consistency was achieved. The specimens were compacted in a standard CBR mould using a 2.5 kg rammer falling through a height of 300 mm. The compaction was done in three layers, each being given 62 blows, followed by 6 days curing before the test was carried out. The unsoaked CBR was calculated as:

$$\text{CRB} = \frac{\text{Measured Load}}{\text{Standard Load}} \times 100 \tag{7}$$

3. RESULTS AND DISCUSSION

3.1. Natural Soil

The natural soil is fine-grained, having reddish brown colour. The percentage passing 0.075 mm aperture sieve is 58.9 and is classified as lean clay (CL) according to the Unified standard classification system USCS (ASTM, 1992) or A-7-5 sub-group by the American Association of State Highway and Transportation Officials classification (AASHTO, 1986). The soil has liquid limit of 54.2%, plastic limit of 30.85% and plasticity index of 23.35 %. The other properties of the natural soil are shown in Table 1. The oxide composition of plantain peel ash is shown in Table 2.

Table 1: Basic properties of the natural soil used

Properties	Value
Percentage passing 0.075 mm sieve	59.50
Natural moisture content (%)	11.40
Specific gravity (%)	2.55
Liquid limit (%)	54.20
Plastic limit (%)	30.85
Plasticity index (%)	23.35
Linear shrinkage (%)	10.70
AASHTO classification	A-7-5
USCS	CL
Maximum dry density (Mg/m^3)	1.84
Optimum moisture content (%)	13.90
Unconfined compressive strength (kN/m^2)	172.80
California bearing ratio (%)	65.30
Colour	Reddish brown

Table 2: Oxide compositions of plantain peel ash (Agbolade 2018)

Oxide	Plantain peel ash
Iron oxide (Fe_2O_3)	2.88
Potassium oxide (P_2O_5)	4.35
Manganese oxide (MnO)	0.14
Copper Oxide (CuO)	0.05
Zinc oxide (ZnO)	0.18
Silica (SiO_2)	19.25
Alumina (AL_2O_3)	3.05
Alkali (Na_2O)	1.69
Alkali (K_2O)	48.88
Lime (CaO)	5.75
Sulphur oxide (SO_3)	1.99
Loss on ignition	13.15

3.2. Specific Gravity

Figure 1 shows changes in specific gravity of lateritic soil with PPA content. The specific gravity of the soil considerably declined from its natural value of 2.55 to 2.43 at 4% plantain peel treatment and thereafter increased to 2.48 at 10% PPA. The initial decrease could be due to low specific gravity of the soil (2.55) when compared to that of PPA (2.6). Upon further increase beyond 4% PPA, the increase could be based on higher specific gravity of PPA compared to that of the soil which caused the increase in specific gravity

(George and Oriola, 2010). The increase in specific gravity shows an improvement in the geotechnical properties of the treated soil (George and Oriola, 2010). 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). Statistical examination of test results by means of one-way analysis of variance for specific gravity of lateritic soil–PPA mixtures is presented in Table 3. The impact of PPA on the specific gravity was not significant ($F_{CAL} = 2.736 < F_{CRIT} = 4.965$; $p > 0.05$) at 5% significance level.

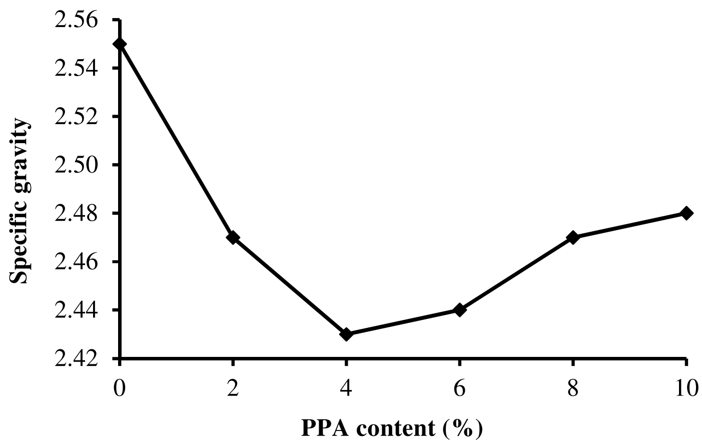

Figure 1: Variation of specific gravity of lateritic soil with PPA content

Table 3: One-way analysis of variance results for specific gravity of lateritic soil – PPA mixtures

Property	Source of variation	Degree of freedom	F_{CAL}	p-value	F_{CRIT}	Remark
Specific gravity	PPA	5	2.736	0.1291	4.965	$F_{CAL} < F_{CRIT}$, No significant effect

3.3. Atterberg Limit Tests

3.3.1. Liquid limit

Figure 2 shows variation of liquid limit with plantain peel ash (PPA) content. A general trend of decrease in liquid limit of the soil from its natural value of 54.2% to 45.3% at 10 % PPA treatment was noticed, although minor changes were observed at 2 and 6% PPA which may be due to laboratory or environmental features that influenced such divergences (Amu and Adetuberu, 2010). The decline could be linked to cation exchange reaction or pozzolanic reaction between the exchangeable cation ions in the soil structure and PPA that led to decrease in liquid limit. Similar remarks were made by Osinubi *et al.* (2015) and Etim *et al.* (2017) who both worked with 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. Statistical examination of test results by means of one-way analysis of variance for liquid limit of lateritic soil–PPA mixtures is presented in Table 4. The impact of PPA on the liquid limit was significant ($F_{CAL} = 207.131 > F_{CRIT} = 4.965$; $p < 0.05$) at 5% significance level.

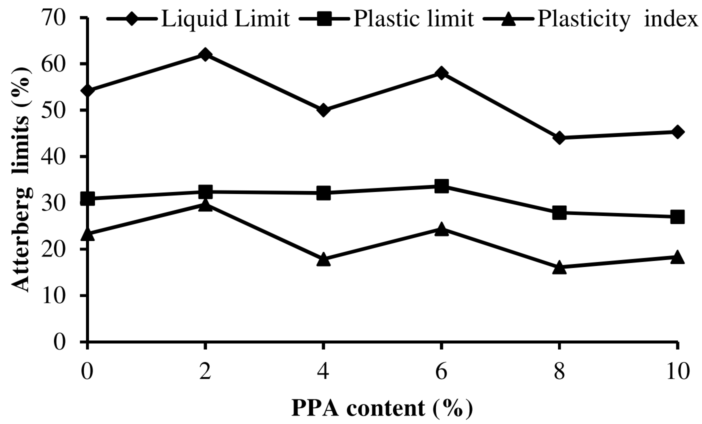

Figure 2: Variation of Atterberg limits of lateritic soil with PPA content

Table 4: One-way analysis of variance results for Atterberg limits and linear shrinkage

Property	Source of variation	Degree of freedom	F_{CAL}	p-value	F_{CRIT}	Remark
Liquid limit	PPA	5	207.131	5.2E-08	4.965	F_{CAL}>F_{CRIT}, Significant effect
Plastic limit	PPA	5	188.419	8.18E-08	4.965	F_{CAL}>F_{CRIT}, Significant effect
Plasticity index	PPA	5	41.307	7.57E-05	4.965	F_{CAL}>F_{CRIT}, Significant effect
Linear shrinkage	PPA	5	8.180	0.016955	4.965	F_{CAL}>F_{CRIT}, Significant effect

3.3.2. Plastic limit

The variation in plastic limit with PPA content is shown in Figure 2. A slight increase in plastic limit was noted from 0 up to 6% PPA and thereafter decreased to 10% PPA content. Since PPA is non-plastic in nature, addition of PPA to lateritic soil-PPA mixtures could be responsible for the decrease the plastic limit. It has been reported by previous researches that addition of non-plastic additives to soil reduces the plastic limit of the treated soil (Portelinha *et al.,* 2012; Ramesh *et al.,* 2013; Osinubi *et al.,* 2015; Etim *et al.,* 2017). Statistical examination of test results by means of one-way analysis of variance for plastic limit of lateritic soil–PPA mixtures is presented in Table 4. The impact of PPA on the plastic limit was significant (F_{CAL} = 188.419> F_{CRIT} = 4.965; $P < 0.05$) at 5% significance level.

3.3.3. Plasticity index

Figure 2 shows the variation of 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 pozzolanic reaction between soil element and the PPA in the presence of moisture added to the soil (Bello, 2015). The natural soil treated from 0 to 10% PPA content did not meet the minimum requirement of not more than 12% maximum plasticity index value as specified by Nigeria General Specification (1997). However, reduction in plasticity index with PPA addition indicates progress in the engineering properties of the soil for pavement applications (Salahudeen and Ocheop, 2015). Statistical examination of test results by means of one-way analysis of variance for plasticity index of lateritic soil–

PPA mixtures is presented in Table 4. The impact of PPA on the plasticity index was significant (F_{CAL} = 41.307> F_{CRIT} = 4.965; $p < 0.05$) at 5% significance level.

3.4. Linear Shrinkage

The variation of linear shrinkage with plantain peel ash content is shown in Figure 3. The linear shrinkage recorded showed a decrease from its natural value of 10.70% to 8.50% at 10% PPA content. The decrease could be due to chemical reactions that took place between PPA and lateritic soil, which in turn resulted in a reduction in the plasticity properties and related shrinkage strain (Kariuki *et al.*, 2006). Statistical examination of test results by means of one-way analysis of variance for linear shrinkage of lateritic soil–PPA mixtures is presented in Table 4. The impact of PPA on the linear shrinkage is significant (F_{CAL} = 8.180 > F_{CRIT} = 4.965; $P < 0.05$) at 5% significance level.

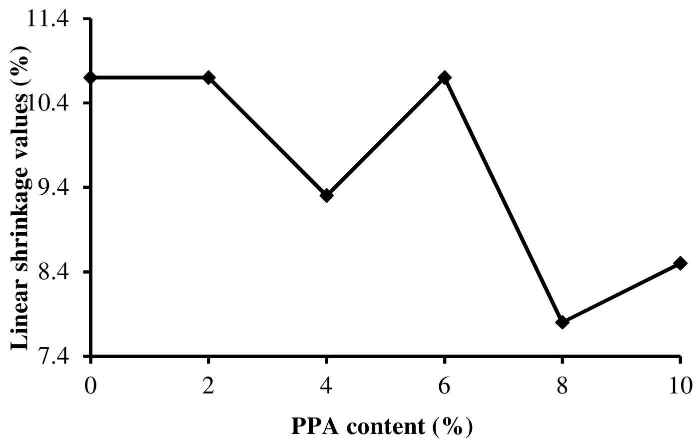

Figure 3: Variation of linear shrinkage of lateritic soil with PPA content

3.5. Compaction Characteristics

3.5.1. Maximum dry density

The variation of maximum dry density (MDD) with plantain peel ash (PPA) is given in Figure 4. MDD initially decreased and thereafter increased with higher PPA content. MDD value reduced from its 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. 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 observations were reported by Phanikumar and Sharma. (2004), Kumar and Puri (2013) and Osinubi *et al.* (2015). The later increase in MDD with higher PPA content may be associated with high specific gravity of the additive (PPA) partially replacing the soil thereby increasing the density of the soil (Ishola, 2014). The increase in the MDD could also be linked with flocculation and agglomeration leading to volumetric decrease in density (Moses and Folagbade, 2010). Statistical examination of test results by means of one-way analysis of variance for maximum dry density of lateritic soil–PPA mixtures is presented in Table 5. The impact of PPA on the maximum dry density was not significant (F_{CAL} = 4.211< F_{CRIT} = 4.965; $P > 0.05$) at 5% significance level.

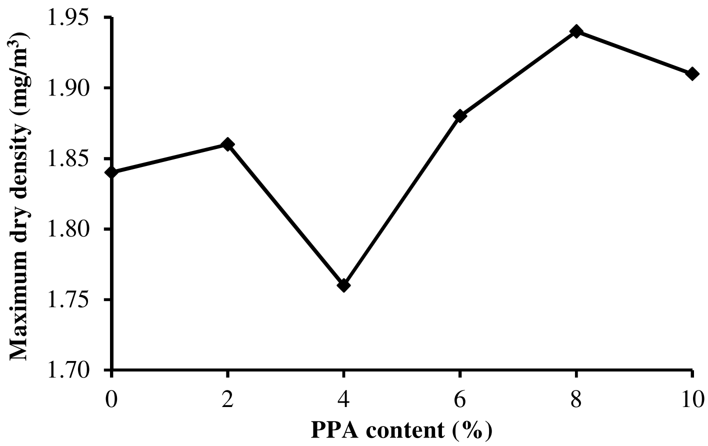

Figure 4: Variation of maximum dry density of lateritic soil with PPA content

Table 5: One-way analysis of variance results for compaction properties

Property	Source of variation	Degree of freedom	F_{CAL}	p-value	F_{CRIT}	Remark
Maximum dry density	PPA	5	4.211	0.067277	4.965	$F_{CAL} < F_{CRIT}$, No significant effect
Optimum moisture content	PPA	5	24.585	0.000571	4.965	$F_{CAL} > F_{CRIT}$, Significant effect

3.5.2. Optimum moisture content

The variation of optimum moisture content (OMC) with PPA content is shown in Figure 5. The results show a general trend of decrease in OMC. OMC values of 13.9, 12.6, 12.8, 14.2, 11.8 and 11.8% were recorded at 0, 2, 4, 6, 8 and 10% PPA content respectively.

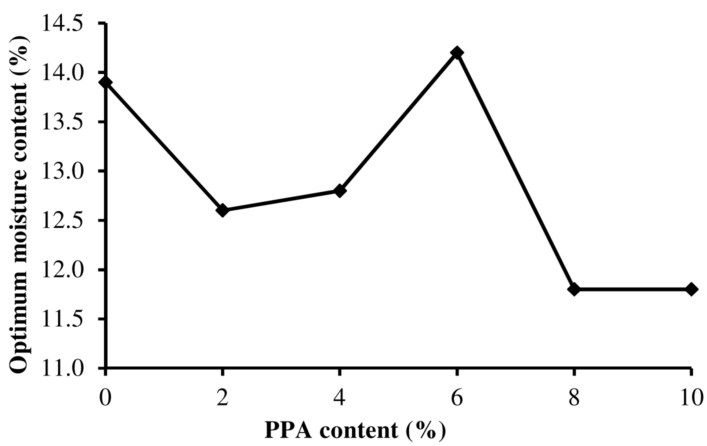

Figure 5: Variation of optimum moisture content of lateritic soil with PPA content

The decline in OMC with 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 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, as the available water is used up in the hydration reaction allowing low water content to saturate the soil surfaces (Jadha and Nagarnaik, 2008; Kumar and Puri, 2013 and Osinubi *et al.,* 2015). Statistical examination of test results by means of one-way analysis of variance for optimum moisture content of lateritic soil–PPA mixtures is presented in Table 5. The impact of PPA on the optimum moisture content was significant (F_{CAL} = 24.585 > F_{CRIT} = 4.965; p< 0.05) at 5% significance level.

3.6. Unconfined Compressive Strength (UCS)

The variation of unconfined compressive strength with PPA content is shown in Figure 6. The results show that the UCS increased from its natural value of 172.8 kN/m^2 to a peak value of 286.9 kN/m^2 at 10% PPA treatment. The 7 days peak UCS value of 286.9 kN/m^2 at 10% PPA content fell short of the 1710 kN/m^2 specified by TRRL (1977) for use as pavement material. The increase in UCS values could be due to the formation of various compounds such as calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH) which may be responsible for strength increase. Similar observations were made by Sani (2012). Krishma (1997) reported a trend of increase in UCS values with glass cullet content from 210 kN/m^2 to 320 kN/m^2 when the content of glass cullet was increased from 0% to 10% by weight of dry soil. The recorded increase in strength of the modified soil, suggest improvement in their geotechnical properties and making them suitable for engineering applications. Statistical examination of test results by means of one-way analysis of variance for UCS of lateritic soil–PPA mixtures is presented in Table 6. The impact of on the UCS was significant (F_{CAL} = 161.369> F_{CRIT} = 4.965; P < 0.05) at 5% significance level.

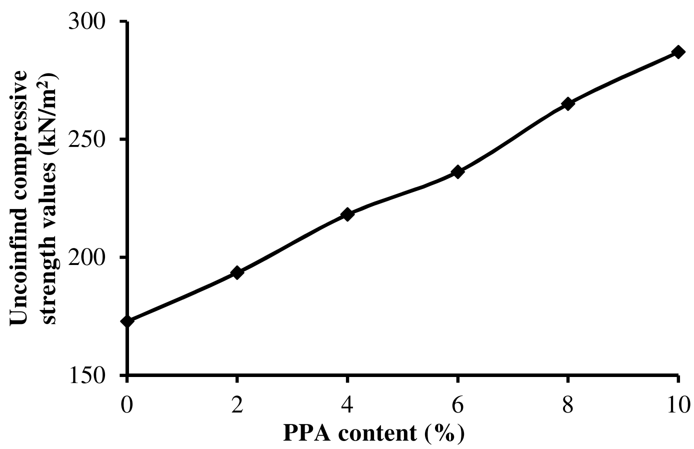

Figure 6: Variation of unconfined compressive strength of lateritic soil with PPA content

Table 6: One–way analysis of variance results for strength properties

Property	Source of variation	Degree of freedom	F_{CAL}	p-value	F_{CRIT}	Remark
unconfined compressive strength	PPA	5	161.369	1.71E-07	4.965	F_{CAL}>F_{CRIT}, Significant effect
California bearing ratio	PPA	5	31.436	0.000226	4.965	F_{CAL}>F_{CRIT}, Significant effect

3.7. California Bearing Ratio (CBR)

The relationship between California bearing ratio (CBR) and PPA content is shown in Figure 7. The result shows that CBR (Unsoaked) increased from its natural value of 65.30% to 75% at 4% PPA content and thereafter decreased to 22.6% at 10% PPA content. The motivation factor for the slight improvenment in the CBR value may be due to some amount of calcium available for the formation of calcium silicate hydrate (CSH), which is the major compound responsible for the strength gain (Koteswara Rao *et al.,* 2012; Yohanna *et al.,* 2016). The PPA treated soil did not meet the criterion specified for use as base course material (180% for cement stabilized material) by the Nigerian General Specification (1997). However, PPA treated soil can be used as subgrade material in admixture stabilization with a more potent industrially made stabilizer (i.e. cement or lime) in order to lessen cost of road construction (Agbolade, 2018). Statistical examination of test results by means of one-way analysis of variance for CBR of lateritic soil–PPA mixtures is presented in Table 6. The impact of PPA on the CBR was significant (F_{CAL} = 31.436> F_{CRIT} = 4.965; $P < 0.05$) at 5% significance level.

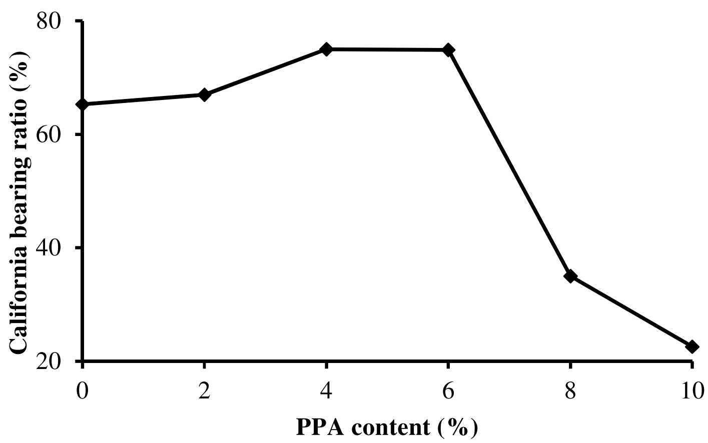

Figure 7: Variation of California bearing ratio of lateritic soil with PPA content

4. CONCLUSION

Based on the study, the following conclusion was made

1. Natural soil was classified as lean clay (CL) according to the Unified standard classification system (USCS) or A-7-5 according to American Association of State Highway and Transportation Officials classification (AASHTO).

2. Test results shows that specific gravity initially decreased and thereafter increased with higher PPA content. Liquid limit, plastic limit and plasticity index decreased with higher PPA content. Maximum dry density (MDD) values increased while optimum moisture content (OMC) decreased. UCS increased from its natural value of 172.8 kN/m^2 to peak value of 286.9 kN/m^2 at 10% PPA treatment. CBR increased from its natural value of 65.30% to 75% at 4% PPA content and thereafter decreased to 22.6% at 10% PPA content.

3. Although the PPA treated soil did not meet the criterion specified for use as base course material by the Nigerian general specification, However, PPA treated lateritic soil at optimally 4% PPA content can be used as subgrade material in admixture stabilization with a more potent industrially made stabilizer(i.e., cement or lime) in order to lessen cost of road construction.

5. ACKNOWLEDGMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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