Effect of Palmyra Palm Leaf Ash on Cement Stabilization of Makurdi Shale

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Abstract

Makurdi Shale was treated with palmyra palm leaf ash (PPLA) and cement to assess its suitability as a material in construction of flexible pavement. Classification, Compaction, Consistency, California bearing ratio (CBR) and Unconfined compressive strength (UCS) tests, were conducted on the shale specimen treated with, cement and PPLA in a combined incremental order of 2% up to 10% of cement and 2% up to 14% of PPLA of dry weight of soil sample respectively. Results of tests showed that Makurdi shale is an A-7-6, high plasticity (CH) and high swell potential soil by the American Association of State Highway and Transportation Officials (AASHTO), Unified Soil Classification System (USCS) and Nigerian Building and Road Research Institute (NBRRI) classification systems respectively. The plasticity index (PI) reduced from 30.5% for untreated Makurdi shale to 4% at 10% cement +14% PPLA contents. The maximum soaked CBR and 7 day UCS values of 92% and 1041 kN/m^2 were obtained at 10% cement+14 % PPLA contents respectively. From the results, Makurdi shale treated with a combination of 10%cement+14% PPFA with a soaked CBR value of 92 %, 7 day UCS value of 1041 kN/m^2 and 82 % value of resistance to loss in strength, satisfied the requirement for sub-base specification. It is therefore recommended for use as sub-base materials in flexible pavement.

Keywords

Palmyra palm leaf ash; Cement; Stabilization; Makurdi Shale.

Introduction

Civil engineers are confronted with the challenge of suitable construction materials when constructing new roads in locations deposited with expansive soils. Shale is a typical example of expansive soils frequently encountered in road cuts and other construction sites. Shale is stubborn and unpredictable material with a twin problem of expansion and contraction in the presence of moisture [1,2].

Makurdi town, the headquarters of Benue State in Nigeria is extensively underlain with shale as confirmed by [3]. The shale deposit, like any other expansive soil, has caused extensive failure to buildings and roads in Makurdi. These defects are prominent on buildings in Makurdi town in form of cracks ranging from fraction of millimeters to about 10 mm, thereby reducing the lifespan of these structures and posing threat to lives and properties (Plates 1 and 2). This is in agreement with the observation in South Africa and Mokattam, Egypt where serious cracks were recorded on buildings and roads founded on shale [4,5].

Plate 1. *Cracks on Building founded on shale deposits located at the College of Engineering, University of Agriculture, Makurdi, Benue State, Nigeria.*

In order to make problem soils useful and meet engineering design standards, various industrial and agricultural waste have been used in soil improvement such as carbide waste, cement kiln dust, blast furnace slag, rice husk ash, groundnut shell ash, sugar cane bagasse, etc [7-12].

Plate 2. *Failed portion of the intra campus Road, University of Agriculture, Makurdi, Benue State, Nigeria.*

However, a study on the use of PPLA in soil improvement is rare, thus necessitated the study. The use of PPLA stems from, the need to use cheap and economic soil stabilizer in geotechnical and road work, as well as make the unsuitable natural soils fit for use in engineering work at economic cost, especially where avoiding or by-passing them is difficult.

Palmyra palm is a tropical tree; it grows naturally and artificially throughout the semi-arid to sub humid regions of Africa, from Senegal to the Central African Republic [13,14]. In Nigeria, it is largely grown in Middle Belt to Northern parts of the country.

The work was aimed at utilizing PPLA in cement stabilization of shale, for use in road work; thereby achieving improved geotechnical properties of the problem soil with PPLA replacement of cement.

Material and Method

Geology of the Study Area

Makurdi formation is comprised of three zones; the lower Makurdi sandstone, the upper Makurdi sandstone and the Wadata limestone [15]. The lower Makurdi sandstone, which could be found around the Makurdi Airport, consists of sandstones and mudrocks. They are micaceous throughout with mudrocks predominating. The upper Makurdi sandstone is similar to the lower sandstone but with mudsrocks being relatively less common, as found around the North Bank area of Makurdi. Sandstones and shales outcrop prominently and the sandstone range from very fine to medium in grain size. In this zone, there are shale units of mainly fissile siltstone, usually brownish grey in colour and often abundantly micaceous.

Wadata limestone also consists of several limestone occurrences; most outcrops are shelly limestone often closely associated with mudrocks which is the most extensive component of the Makurdi formation [16]. The sandstones in this zone are generally fine to medium grained, moderately sorted, micaceous and feldsphatic. In some parts, they are calcareous, micaceous and shelly. Various types of cement like iron oxides, silica, carbonates and clay were shown to be present in the Makurdi sandstone.

Test Samples

The shale sample was obtained from a road cut, at the entrance of Engineering complex, University of Agriculture Makurdi, Benue State, Nigeria. Makurdi town is located on 7º43’50’’N and 8º32’10’’E, on the geographical map of Nigeria [16]. The sample was collected at a depth of 2m, conveyed in sack bags to soil mechanics laboratory of the Department of Civil Engineering, University of Agriculture Makurdi, where tests were performed. Ordinary Portland cement (OPC) was obtained from Makurdi in Benue State, Nigeria, while palmyra palm leaves were obtained from Logo Local Government Area of Benue State, Nigeria, where the plants are readily available in large quantities (Plate 3).

Plate 3. *Palmyra Palm Plant*

The leaves were sun dried, burnt in an open air and then heated in furnace at 600ºC for two hours at the Metallurgy Laboratory, Department of Mechanical Engineering, University of Agriculture, Makurdi. Laboratory tests were performed on the sample in accordance with BS 1377 [17] for the natural shale and BS 1924 [18] for shale treated with cement and palmyra palm leaf ash (C-PPLA).

The following tests were performed on the natural soil and C-PPLA treated soil: Atterberg limits, Grain size analysis, Specific gravity, Compaction, UCS and CBR tests. The CBR tests were conducted in accordance with the Nigerian General Specification [19] which stipulates that, specimens be cured in the dry for six days and then soaked for 24 hours before testing. Compaction was at the energy level of the British standard (BS) light compactive effort only, because this is easily achieved in the field. The resistance to loss in strength was determined as a ratio of the UCS value of specimens cured for 7 days under controlled conditions, which were subsequently immersed in water for another 7 days to the UCS value of specimens cured for 14 days. The conventional criterion of a maximum allowable loss in strength of 20 %, which translates to 80 % resistance to loss in strength [20] was adopted.

X –ray fluorescence analysis was carried out on the PPLA, OPC and shale samples, using Philips PW 1450/20 spectrometer to aid in the determination of their oxide composition. Different percentages of PPLA and cement in a combined incremental order of 2% up to 10% of cement and 2% up to 14% of PPLA of dry weight of soil sample respectively were used.

Results and Discussions

Index Properties of Makurdi Shale

Table 1, summarizes the results of test carried out on natural Makurdi shale. The results of index properties of natural Makurdi shale shows that, it is an A–7–6, CH and high swell potential soil according to the AASHTO, USCS and NBRRI [21] classification systems respectively.

Table 2, summarizes the result of oxide compositions of PPLA, cement and Makurdi shale as used in the study. The results showed that silicon oxide followed by calcium oxide were the major oxides found in PPLA, while calcium oxide and silicon oxide were the predominant oxide in cement and Makurdi shale respectively.

Table 1. Index Properties of Natural Makurdi Shale

Property		Quantity
Percentage Passing BS No. 200 Sieve Natural Moisture Content Liquid Limit % Plastic Limit % Plasticity Index % Linear Shrinkage % Specific Gravity AASHTO Classification USCS NBRRI Classification Maximum Dry Density (Mg/m^3) Optimum Moisture Content California Bearing Ration %		88 30.43 46.5 31.0 15.3 13.9 2.42 A – 7 – 6 CH High swell potential 1.63 18.6 6
Unconfined Compressive Strength Test (kN/m^2)	7 days 14 days 28 days	72.8 92.1 104.4
Colour Gravel Content Sand Content (%) Silt Content (%) Clay Content (%) Free Swell (%)		Grey - 18 51 31 49

Table 2. Chemical compositions of palmyra palm leaf-ash, cement and Makurdi shale as used.

Chemical composition	Concentration (% by Weight)		
	PPLA	Cement	Makurdi Shale
SiO2	45.22	19.53	49.02
Al_2O_3	4.77	6.0	25.24
Fe_2O_3	5.90	4.0	8.37
CaO	22.76	62.0	0.26
MgO	0.98	1.40	1.16
Na_2O	0.69	0.50	2.57
K_2O	1.99	0.62	1.85
SO_3	5.53	-	-
T_1O_2	0.15	0.37	1.98
MnO	0.87	-	0.03
P_2O_5	3.65	-	0.50
BaO	0.18	-	-
ZnO	0.89	-	-
Re_2O_7	0.07	-	-
Eu_2O_3	0.08	-	-
LOI	15.0	2.0	-

Effect of Cement - Palmyra Palm Leaf Ash (C-PPLA)

The addition of cement +PPLA to Makurdi shale showed improvement of its Atterberg limits, as the plasticity index reduced from 30.5 % for untreated Makurdi shale to 4% at 10% cement plus 14% PPFA (figure 1). This is due to the presence of Ca_{2+} and Si_{2+} cations released from C-PPLA that reacts with shale.

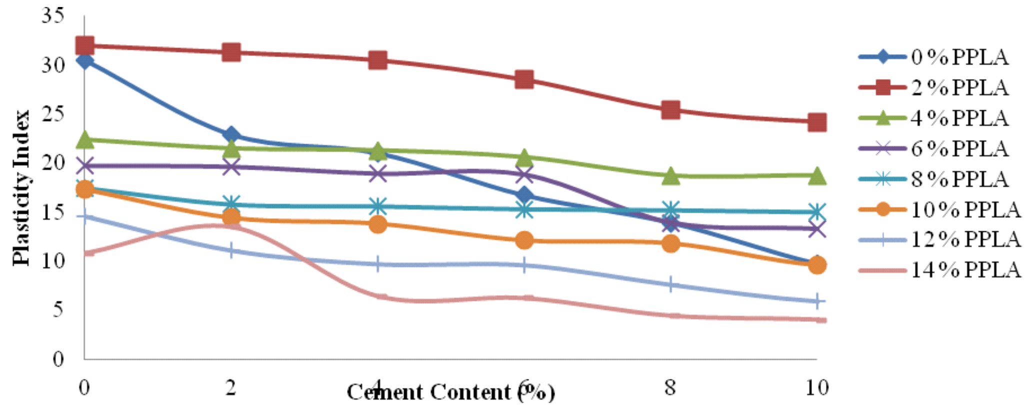

Figure 1. *Variation of Plasticity Index of Makurdi Shale with Cement and Palmyra Palm Leaf Ash Content.*

Figure 2 shows the result of free swell of Makurdi Shale treated with cement-palmyra palm leaf ash content. The results indicates that, there is substantial improvement in free swell of Makudi shale, as free swell reduced from 49 % for natural shale to 24 %, at 10 % cement +14 % PPLA contents.

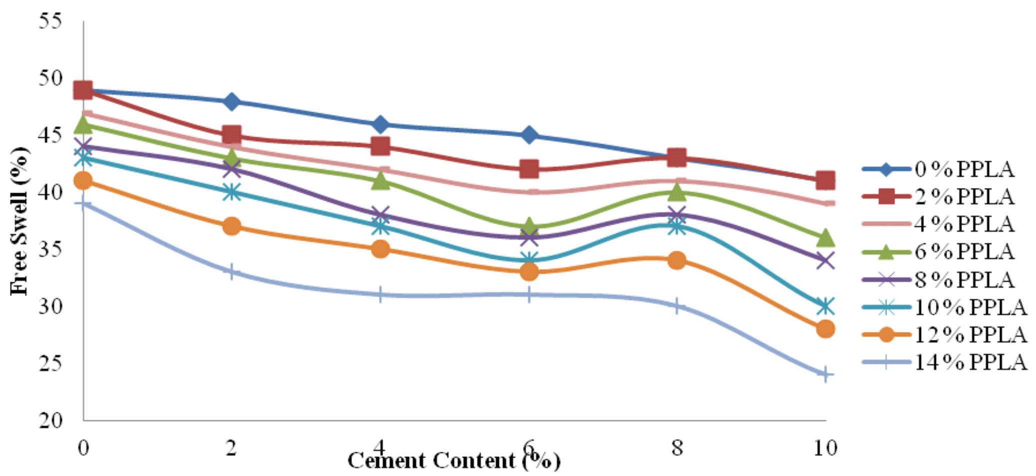

Figure 2. *Variation of Free Swell of Makurdi Shale with Palmyra Palm Fronds Ash-Cement Content.*

The results of maximum dry density (MDD) and optimum moisture content (OMC) of Makurdi shale treated with C-PPLA content is as shown in figures 3 and 4 respectively. The value of MDD decreased, while that of OMC increased with C-PPLA content for all percentages. The value of MDD decreased from 1.63 Mg/m^3 at 0 % C–PPLA content to the least value of 1.56 Mg/m^3 at 10 % PPLA + 14 % cement content. The decrease in density according to Ola [22] and Lees et al. [23] is as a result of the flocculated and agglomerated clay particles occupying larger spaces leading to a corresponding decrease in dry density.

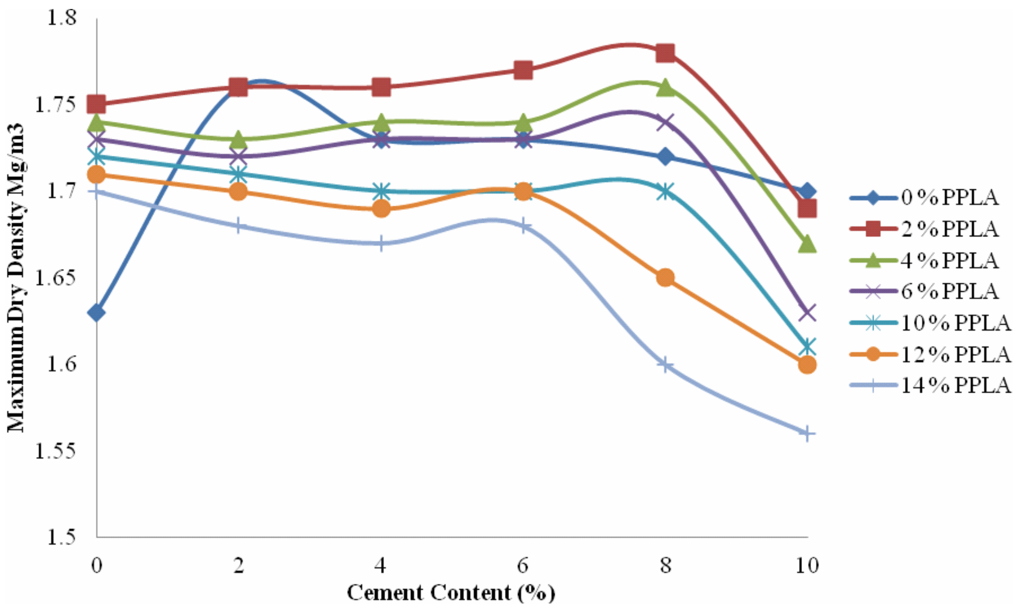

Figure 3. *Variation of Maximum Dry Density of Makurdi Shale with Cement–Palmyra Palm Leaf Ash Content.*

The increase in OMC with higher C-PPLA treated up to 10 % Cement + 14 % PPLA, with the least and peak values of 15 % and 21 % respectively, is as a result of extra water required for the hydration of cement and pozzolanic reactions of PPLA.

The results of the variation of 7 day UCS of Makurdi Shale treated with various C-PPLA content are shown in Figure 5.

The results show an increase in 7 day UCS from 72.8kN/m^2 for untreated Makurdi shale to a maximum value of 1041 kN/m^2 at 10 % cement +14% PPLA content. The values of 7 day UCS at 8 % content for all combinations however, fall but rose at 10 % cement content. The UCS at 7, 14 and 28 days showed improvement as the number of days increased. This showed that C – PPLA combination has a long time strength improvement capacity, which implies that progressive increase in strength will enhance the stability of the pavement. The peak 7 day UCS value of 1041 kN/m^2 fall short of 1710 kN/m^2, for base materials but met with sub base material required value of 687-1373 kN/m^2 [24,25].

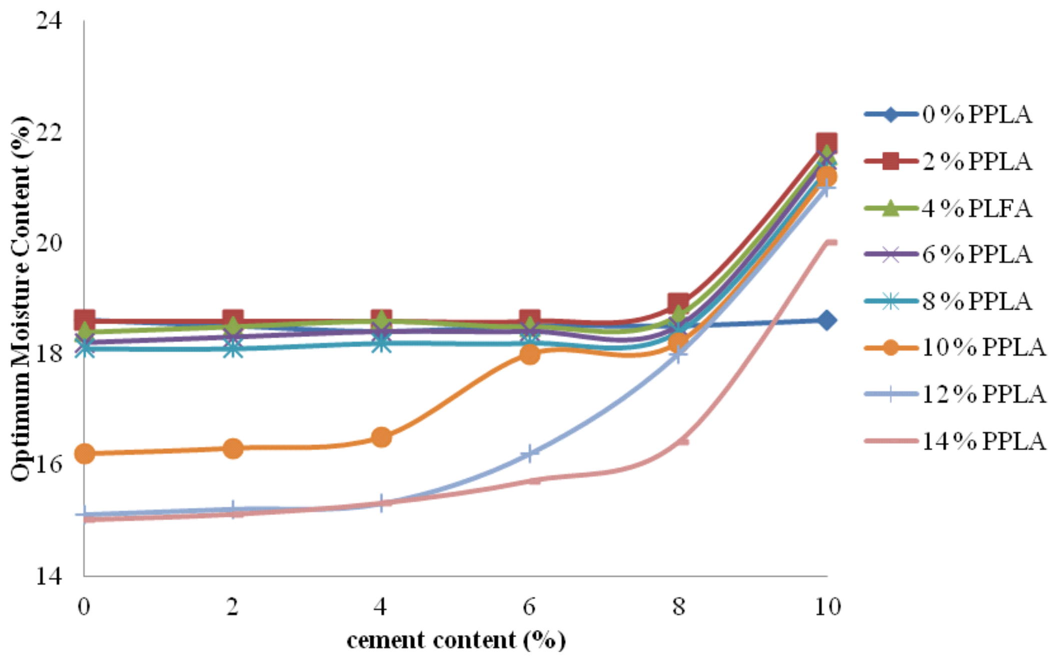

Figure 4. *Variation of Optimum Moisture Content of Makurdi Shale with Cement–Palmyra Palm Leaf Ash Content.*

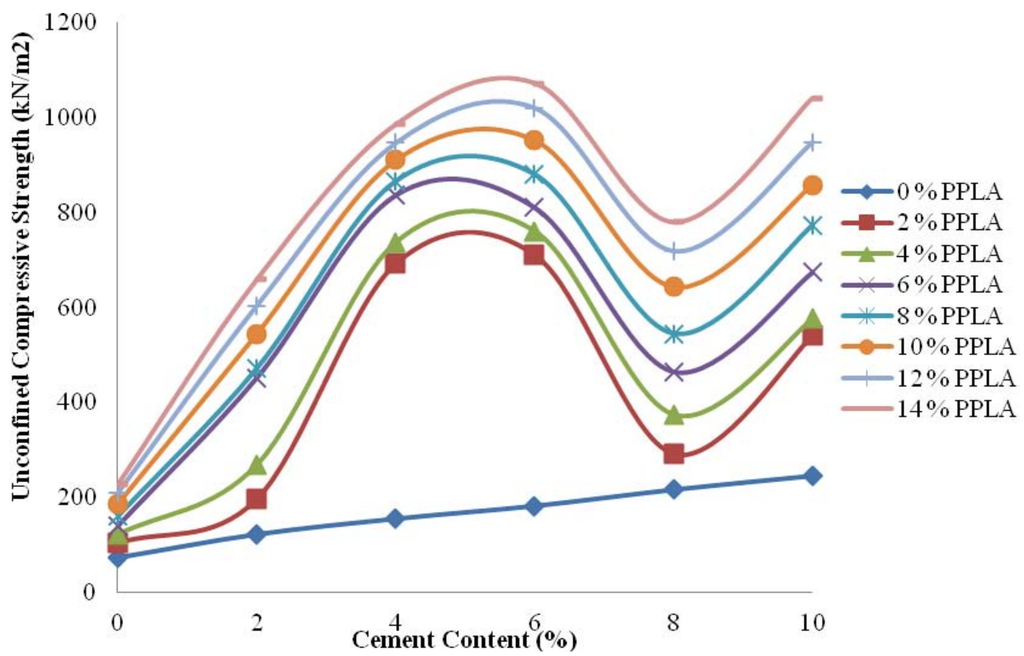

Figure 5. *Variation of Unconfined Compressive Strength (UCS) of Makurdi Shale with Cement-Palmyra Palm Leaf Ash Content.*

Figure 6 shows the results of soaked CBR values of Makurdi shale treated with C-PPLA. The soaked CBR values increased with C-PPLA content, with the peak soaked CBR value of 92 % at 10 % cement +14% PPLA. The soaked CBR value of 92 met the requirement of minimum CBR value of 80 % (lightly trafficked roads) and 30 % respectively for base and sub base materials in flexible pavements [26].

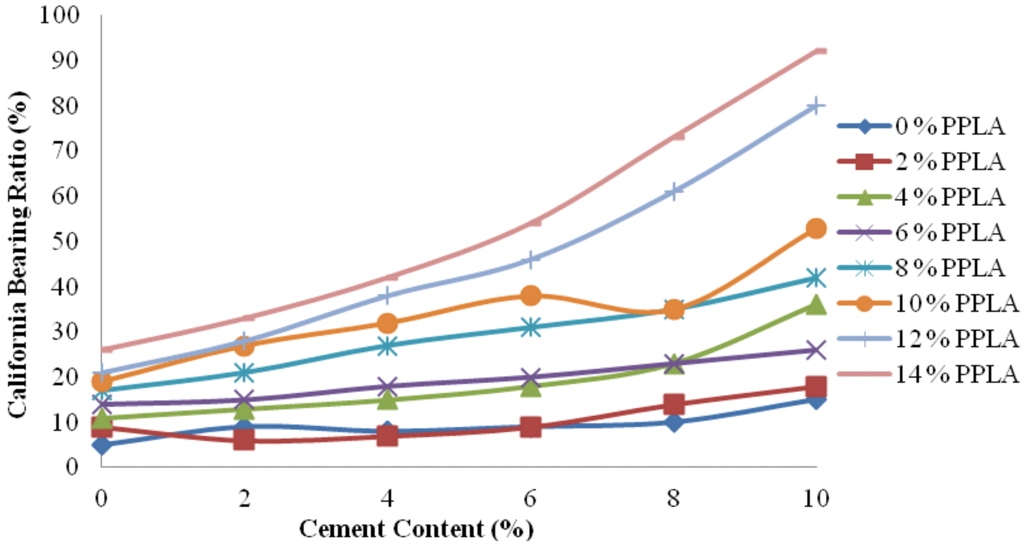

Figure 6. *Variation of Soaked California Bearing Ratio (CBR) of Makurdi Shale with Cement-Palmyra Palm Leaf Ash Content*

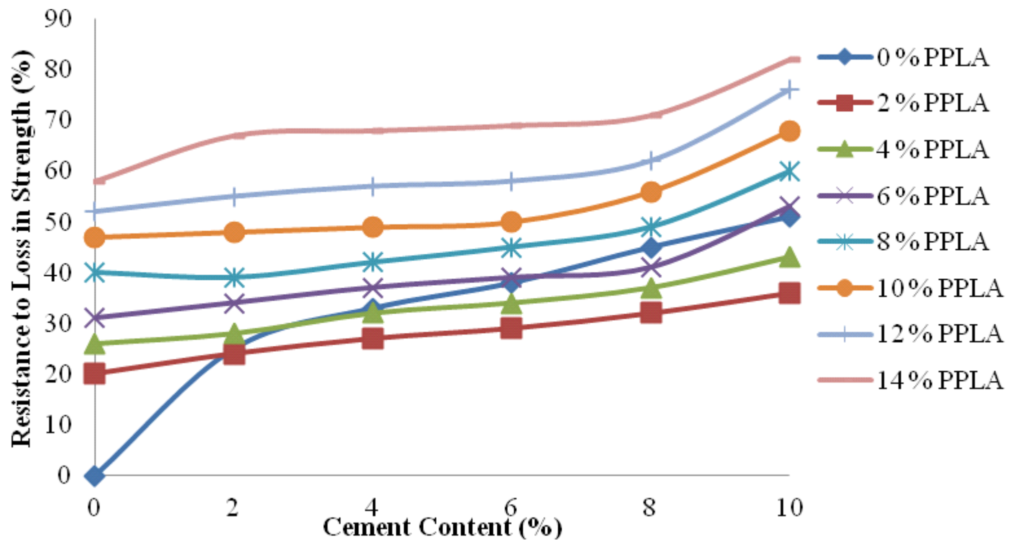

Figure 7. *Variation of Resistance to Loss in Strength of Makurdi Shale Treated with Cement-Palmyra Palm Leaf Ash Content.*

Makurdi shale treated with C-PPLA mixture, offered good resistance to loss of strength as shown in Figure 7. The value of resistance to loss of strength increased with C-PPLA content. The peak resistance to loss of strength of 82 % was achieved at 10 % cement + 14 % PPLA. These values meet the minimum acceptable value of 80 % for resistance to loss of strength [20].

From the results of this study, the soil is classified as A-7-6 and CH by AASHTO and USCS classification systems respectively.

Conclusions

- The treatment of Makurdi shale with a combination of cement and palmyra palm leaf ash (C-PPLA) improved the swelling properties of the soil.
- The treatment of Makurdi shale with a combination of 10 % cement + 14 % PPLA result to a soaked CBR value of 92 %, 7 day UCS value of 1041 kN/m^2 and resistance to loss in strength value of 82 %.
- Based on combined criteria of CBR, UCS and Durability, the treatment of Makurdi shale with 10 % cement and 14 % PPLA met the requirement for sub base material for use in flexible pavement.
- The stabilization of Makurdi shale with a combination of 10 % cement + 14 % PPLA content is therefore recommended for use as sub-base material in flexible pavement.
- The Nigeria General Specification (1997) did not specify CBR requirement for the combined use of cement and palmyra palm leaf ash in soil stabilization, hence results from this study can serve as a guide in the formulation of specifications for the treatment of soil using cement and palmyra palm leaf ash.

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