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Research Article

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Comparative Analysis of Base Course Stabilization using Cement and Reclaimed Asphalt Pavement

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Abstract Recycling in construction industries is the process of re-using the old pavement materials after some modifications have been made. The present practice in Nigeria is that the old pavement material is treated as solid waste. This work tried to compare the strength of Idu borrow pit soil stabilized proportionately with Reclaimed Asphalt Pavement (RAP) and cement. RAP was taken along Uyo - Ikot Ekpene road. Borrow pit soil sample was collected from Idu in Akwa Ibom State, Nigeria, and Portland Cement was acquired from the local market. Specimens used for the laboratory work were prepared by treating soil sample with cement and RAP in the proportion of 4%, 6%, 8%, 10% and 20%, 30%, 40%, 50% respectively. The soil-cement and soil-RAP were tested in the laboratory to compare their strength in accordance with the relevant codes. The results and analysis showed that at 100% British Standard compaction of cement-soil, there was a reduction in Optimum Moisture Content (OMC) from 13.1% to 6.3% while there was an increase in Maximum Dry Density (MDD) from 1.89kg/m^3 to 2.01kg/m^3. Similarly, there was a reduction in OMC from 13.1% to 9.55% and increase in MDD from 1.89kg/m^3 to 1.97kg/m^3 for RAP-soil material. This result implies that both cement and RAP additives are suitable for soil modification in engineering construction. The California Bearing Ratio (CBR) test result indicated that poor soil can be modified to achieve suitable material for base course with 50% RAP and 6% cement as additives.

Keywords Comparative analysis, Base course, Stabilization, Cement, Reclaimed asphalt pavement

Introduction

When a site is selected for constructing a road pavement or rehabilitating an old one, the in-place materials may be used as they occur. The materials may be removed and replaced with higher quality materials, or they may be modified in some manner to provide appropriate qualities. When the soils are chemically, physically, or mechanically modified, it is referred to as stabilization. The reasons for stabilizing soils include improving properties such as volume stability, strength, durability, and permeability, as described by Ingles and Metcalf [1]. The choice and use of materials are critical areas of this research. If the material is weak, an attempt should be made to make construction materials suitable by soil modification or stabilization, or both. Soil modification is the addition of a modifier such as cement or bituminous materials to soil to change its index properties, while soil stabilization is the treatment of soils with additives to improve their strength and durability to make them suitable for construction beyond their original classification as defined by Musa and Alhaji [2].

To successfully build an engineering structure on soils of varying engineering properties, a proper understanding of geotechnical properties of the varying soils is required. The relative abundance of soil and its suitability for various purposes can be enhanced through the modification of its properties. The stability of the underlying soils is the function of the long-term performance of the pavement structures. The engineering design of road pavement relies on the assumption that each layer in the pavement has the minimum specified structural quality to support and distribute the super-imposed loads. These layers must resist excessive deformation, resist shear, and avoid excessive deflection that may result in fatigue or cracking in overlying layers. Available earth materials do not always meet these requirements and may require improvements in their engineering properties to transform these inexpensive earth materials into effective construction materials. This is usually achieved through physical stabilization or chemical stabilization, or mechanical stabilization of the poor soils.

Chemical stabilization is the process of mixing additives such as bituminous materials in form of Reclaimed Asphalt Pavement (RAP) with laterite, and this would be adopted as a method of soil improvement in this study. Efforts are being made worldwide in recycling waste materials from road maintenance and rehabilitation.

RAP is acquired through scarification of the existing asphalted road under reconstruction or resurfacing. When mechanically crushed and sieved, the recycled asphalt pavement is made up of fine and coarse aggregates coated with bitumen of considerable quantity. The recycling of asphalt pavement is a sustainable development and environmentally friendly approach in the construction industry as described by Salman [3].

RAP material has been used as a waste for reclaiming borrow-pits sites over the years in some developing countries due to a lack of research on its potential significance if recycled in the road construction industry. Recently, most developing countries are experiencing economic recession and because of this, prices in construction materials have increased drastically. Therefore, there is a need for alternative use of materials in the road construction industry. In Niger Delta Region, crushed stone–base materials are conventionally used as base-course material. This conventional material could be replaced with composite material such as RAP – lateritic soil according to Joshua [4]. Hence, if proven with the use of laboratory tests that stabilization of poor soil material to obtain a base course material of higher CBR is satisfactory, then the conventional crushed stone base could be replaced with alternative RAP-soil materials for sustainable development.

Materials and Methods

The materials used in this research work were Ordinary Portland Cement, reclaimed asphalt pavement and Idu borrow pit soil. The need for soil improvement cannot be over-emphasized because soil modification is very essential in road construction. Often, some soil materials are too wet or lack necessary strength to support load bearing surfaces. Additives such as cement and RAP are added to chemically alter the soil composition, helping to reduce swell, plasticity index and moisture holding capacity while increasing stability and providing a solid working platform for asphalt layers. With cement and RAP, subgrade materials with lower CBR could be modified to achieve suitable base-course material with not less than 80 per cent California Bearing Ratio (CBR) as specified in Nigerian and British general standards for roads and bridges. Five experimental tests were adopted to determine the possibility of using RAP to enhance the geotechnical properties of borrow pit soil for base-course stabilization.

Extraction of Asphalt from the Reclaimed Material

The sample collected was crushed to smaller sizes by using sledgehammer. About 600 grams of the material was weighed and allowed to dissolve in benzene solution. The aggregates were then separated from the mixture of benzene and bitumen thereafter the benzene and bitumen solution were put in a conical flask for distillation. The Asphalt contents recovered was 5.2%. This proved that the asphalt content was relatively high.

Distillation of Benzene from the Mixture of Asphalt and Benzene

The Liebig distillation apparatus was used for this. Heat was applied to the solution of benzene with the use of Bunsen burner. The benzene distilled off at about 80^{o}C. As the distillation flask was slowly heated, benzene vaporized and again liquefied in the condensing tube and collected in the conical flask. With this process, the benzene and asphalt were separated. The extracted asphalt and the aggregates were weighed and subjected to tests.

Grain Size Analysis

Sieve analysis was conducted on the soil sample obtained from Idu borrow-pit to determine the particle size distribution. It was carried out in accordance with BS 1377 [5].

Atterberg's Limits Test

These tests (Plastic limit, liquid limit, and plasticity index) were carried out on the samples in accordance with American Standard Testing Method [6]. The calculation of the liquid limit is as shown in the test result. The result of the test was plotted, number of blows against moisture content.

California Bearing Ratio

The California bearing ratio test is a penetration test meant for the evaluation of sub grade strength of roads and pavements. This test was carried out in accordance with Federal Ministry of Works and Housing [7].

Compaction Test

Compaction by mechanical means increases the shear strength of the soil. It also decreases rate of settlement, compressibility, and soils permeability. Through compaction, Maximum Dry Density (MDD) against Optimum Moisture Content (OMC) graph is generated.

Unconfined Compressive Strength Test

This is a measure of a material strength. Unconfined Compressive Strength (UCS) is the maximum axial compressive stress that a right-cylindrical sample of material can withstand under unconfined conditions. This test was carried out in accordance with Federal Ministry of Works and Housing [7].

Results and Discussion

Field Moisture Determination

Table 1: Field moisture content of Idu borrow pit soil

Description	Idu Borrow Pit Soil
Weight of container: W_1g	30.6
Weight of wet sample + container: W_2g	80.7
Weight of dry sample + container: W_3g	73.7
Weight of water: $W_4 = W_2 - W_3$ g	7.0
Weight of water: $W_5 = W_3 - W_1$ g	43.1
Moisture content: $MC = \frac{W_4}{W_5} * 100\%$	16.2
Average Moisture Content (%)	16.1

This test was carried out to determine the capillary moisture of soil sample in accordance with recommended standards. It was conducted as at the time of soil investigation and by implication, the fluid retaining capillarity of such formation is measured in percentages. Oven dry method of moisture content determination was adopted to establish the natural moisture content (16.1%) of Idu borrow pit soil and the result is recorded in Table 1. Various researchers have confirmed that values of water content can vary from essentially 0% up to 1200%, and a water content of 0% indicates a dry soil.

Determination of Particle Size Distribution

Table 2: Grain size distribution

Sieve Size		Retained on Sieve		Percent Passing Sieve [%]
		Weight (g)	[%]	
No. 14	1.18mm	15	3	97.0
No. 25	0.600mm	80	16	84.0
No. 36	0.425mm	128	25.6	74.4
No. 52	0.300mm	192	38.4	61.6
No. 100	0.150mm	301	60.2	39.8
No. 200	0.075mm	338	67.6	32.4

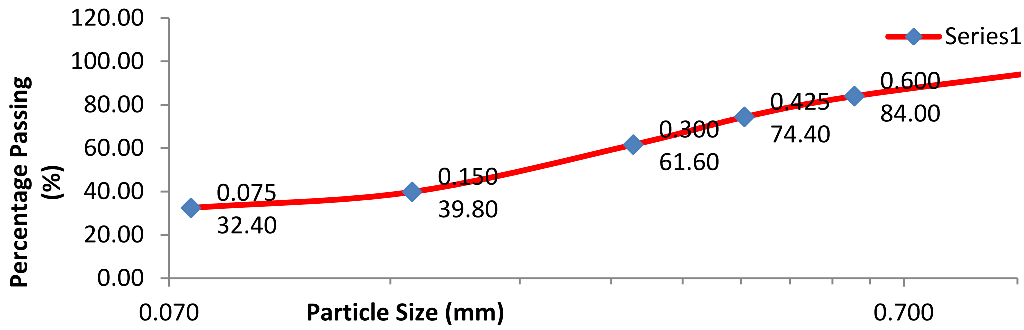

Figure 1: Grain size distribution curve

The grain size distribution data and curve for Idu borrow pit Soil are presented above in Table 2 and Figure 1 respectively. From the Table, it was recorded that 32.4% of Idu soil passed sieve No. 200 (0.0075mm). From the grain size distribution curve (Figure 1), the soil sample contains 32.4% of fine aggregates. Table 3 shows the Atterberg's limits test, Unified Soil Classification System (USCS) and American Association of State Highway and Transport Official (AASHTO) classification on Idu borrow pit soil sample.

Atterberg's Limits Test and Soil Classification

Table 3: Atterberg's limits test and soil classification on Idu borrow pit soil

Soil Type	Liquid Limit	Plastic Limit	Plasticity Index (%)	USCS Soil Classification	AASHTO Soil Classification
Idu Soil Sample	45.5	31.9	13.6	SC	A-2-7

From Table 3, the result shows that the soil sample contains high moisture in terms of liquid limit of 45.5% and plastic limit of 31.9%. Therefore, plasticity index which is the arithmetic difference between liquid limit and plastic limit is 13.6%. From the test, Idu soil sample falls under A-2-7 classification according to American Standard Testing Method [8] and American Association of State Highway and Transportation Officials [9].

Determination of maximum dry density and optimum moisture content

Table 4: Compaction test

OMC (%)	MDD (Kg/m^3)
9.30	1.55
11.20	1.70
13.10	1.79
15.00	1.74
17.10	1.65

The result of compaction test on Idu A-2-7 Soil is presented in Table 4. From Figure 2, the compaction curve shows that at optimum moisture content of 13.1%, the dry density of 1.79kg/m^3 is maximum.

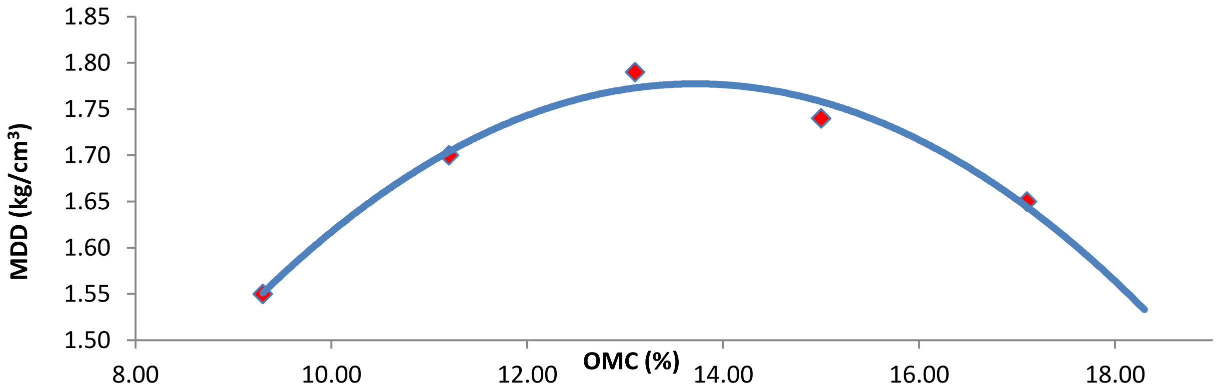

Figure 2: Determination of MDD and OMC of Idu A-2-7 soil

Determination of California Bearing Ratio

Table 5: Determination of California bearing ratio

Penetration (MM)	Load (KN)
0.50	0.20
1.00	0.40
2.00	0.90
2.50	1.20
3.75	2.10
5.00	3.00
7.50	4.10
10.00	5.50
12.50	5.80

The result of CBR test on Idu A-2-7 Soil sample is presented in Table 5. From Figure 3, the CBR curve indicates that the unsoaked CBR was 15.0% at penetration of 5.0mm. This means that the material is only suitable for subgrade layer.

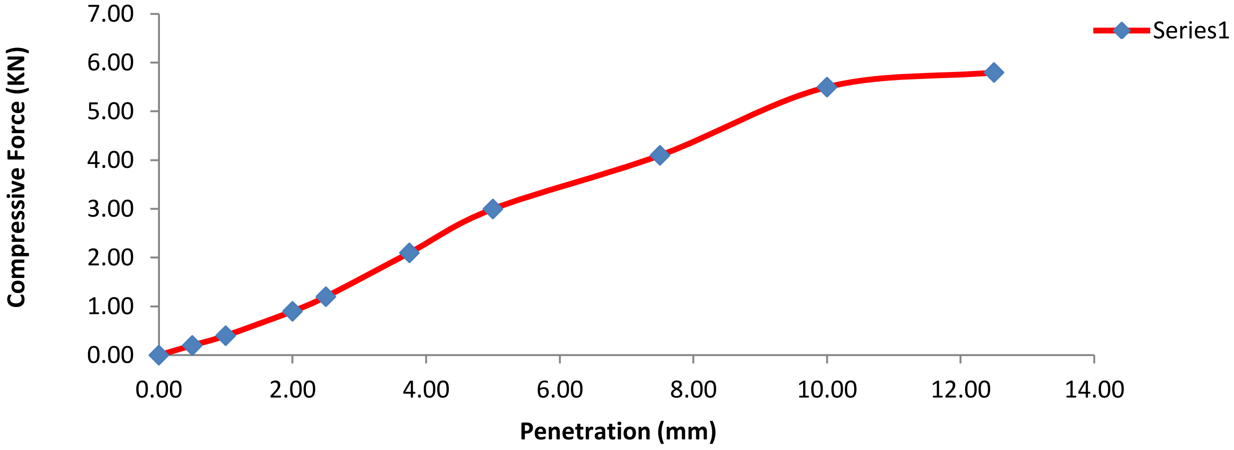

Figure 3: California bearing ratio (unsoaked)

Determination of unconfined compressive strength

Table 6: Determination of unconfined compressive strength

Duration (day)	Maximum Axial Strength (KN/m^2)	[7]
7	11.7	Very Soft [0 – 48]
14	17.2	Very Soft [0 – 48]
28	35.7	Very Soft [0 – 48]

From Table 6, the maximum axial stress at 7 days, 14 days and 28 days is 11.7 kN/m^2, 17.2 kN/m^2 and 35.7 kN/m^2 respectively. The strength keeps increasing at increased duration of curing.

Cement-Soil Stabilization

On introduction of additive (cement) to Idu A-2-7 Soil in required proportions, the following tests were used to ascertain cement-soil behaviour.

Cement-Soil Compaction Test

Table 7 shows the compaction test result of Cement – soil specimen. The result achieved from compaction test on treating 4%, 6% and 8% cement with 96%, 94% and 92% of Idu A-2-7 Soil.

Table 7: Compaction test result

Cement Content (%)	Optimum Moisture Content (%)	MDD (Kg/m^3)
2	3.00	1.03
4	4.50	1.93
6	6.30	2.31
8	7.80	1.94

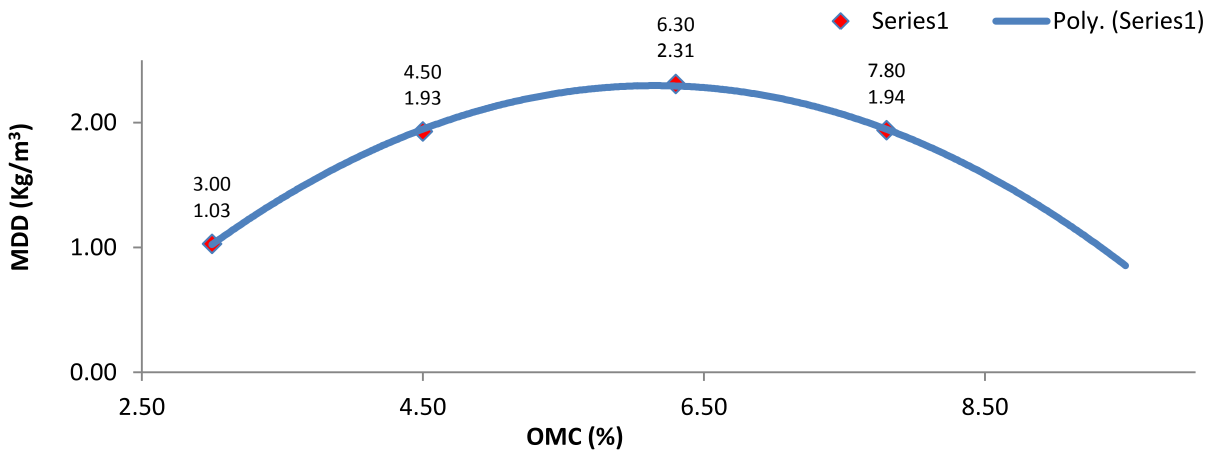

Figure 4: Determination of MDD and OMC of Idu A-2-7 soil

From Figure 4, the compaction curve shows that there is a reduction in optimum moisture content from 13.1% to 6.3% on introduction of different percentages of cement. Conversely, there is an increase in maximum dry density of the treated material from 1.89kg/m^3 to 2.31kg/m^3. It can be deduced that there is a remarkable modification of Idu A-2-7 Soil.

California Bearing Ratio Test (CBR)

Table 8 shows CBR test result obtained from Cement – soil stabilization. The sample specimens of 4%, 6% and 8% cement additive were used. From Table 8, the CBR of untreated Idu A-2-7 Soil increased from 15% to 60%, 80%, and 91%. The equivalent Resilient Modulus (M_R) increased from 242.10MPa to 309.02MPa for the CBR. Increase in CBR can be attributed to the hydration reaction of cement.

Table 8: Cement – soil stabilization CBR test result

Cement Content (%)	Lateritic Soil Content (%)	OMC (%)	MDD (Kg/m^3)	CBR$_{2.5}$ (%) = f/13.2KN	M_R (MPa) = $17.6(CBR)^{0.64}$	CBR$_{5.0}$ (%) = f/20KN	M_R (MPa) = $17.6(CBR)^{0.64}$
4	96	4.50	1.93	60.1	242.10	58.0	236.65
6	94	6.30	2.31	80.0	290.73	80.0	290.73
8	92	7.80	1.94	88.0	309.02	90.0	313.49

Figure 5 represents a plot of compressive load against penetration with resultant CBR values of respective Cement – soil specimen. The CBR curves for respective cement content show that the compressive load increases with increased penetration.

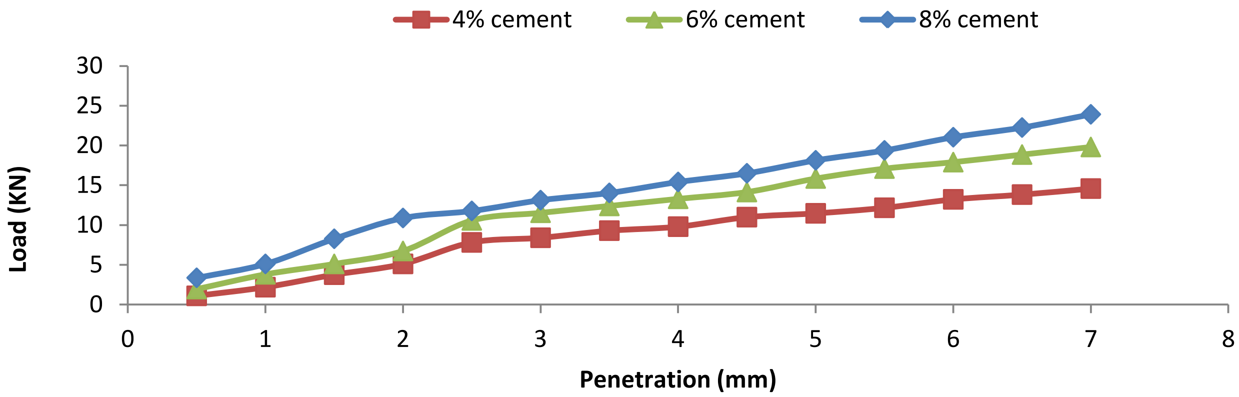

Figure 5: Determination of CBR of Idu soil

Unconfined Compressive Strength Test (UCS)

The summary result of UCS on cement-soil sample is presented in Table 9. From the Table 9, at 14 days curing and 4% Cement, the maximum axial strength was 155.8KN/m^2 for medium material according to Federal Ministry of Works and Housing [7]. At 28 days curing and 8% cement, the maximum axial strength was 195.2KN/m^2. The later result falls under "stiff" material according to the Nigerian standard as mentioned above.

Table 9: Unconfined compressive strength test result

Additive (%)	**7days**	**14days**	**28days**	FMWH [7]
	Maximum Axial Strength (KN/m^2)			
2	62	68.2	74.8	Soft [48 – 96]
4	92.4	155.8	126.3	Medium [96 – 192]
6	144.6	153.4	169.3	Medium [96 – 192]
8	173.4	184.2	195.2	Stiff [192 – 384]
10	197.6	197.5	214.3	Stiff [192 – 384]

RAP-Soil Stabilization

The following tests were used in the laboratory to determine the RAP – Idu A-2-7 Soil behaviour.

RAP – Idu A-2-7 Soil Compaction Test

The result achieved from compaction test on treating 20%, 30%, 40% and 50% RAP with 80%, 70%, 60% and 50% of Idu A-2-7 Soil is presented in Table 10. From Figure 6, the compaction curve shows that there is a reduction in OMC from 13.1% to 5.8% on introduction of different percentages of RAP. Conversely, there is an increase in MDD of the treated material from 1.89kg/m^3 to 2.19kg/m^3. It can be concluded that there is a significant modification of Idu A-2-7 Soil.

Table 10: RAP – Idu soil compaction test result

OMC [%]	**MDD [Kg/m^3]**
3.40	1.50
4.70	1.85
5.80	2.19
7.80	1.60

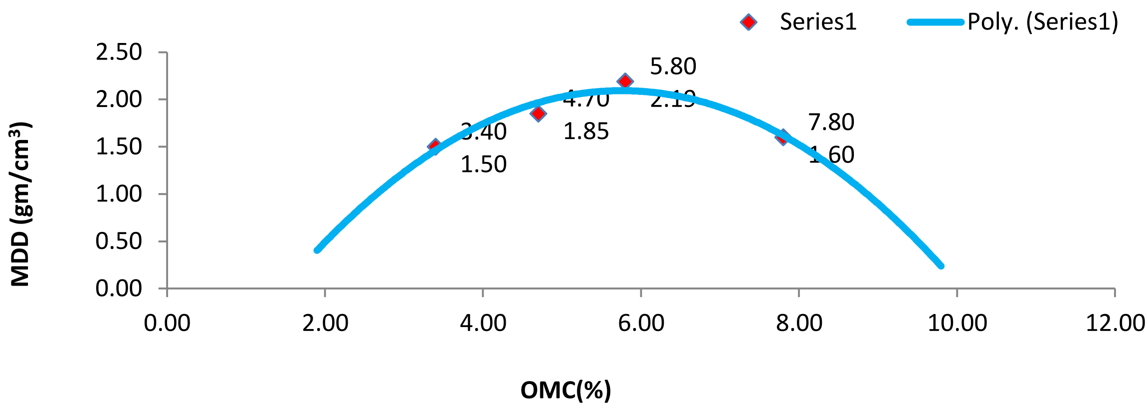

Figure 6: Determination of MDD and OMC of RAP – Idu soil

California Bearing Ratio Test

The CBR test result is presented in Table 11 for 20%, 30% 40% and 50% RAP additive. From Table 11, the CBR of untreated Idu A-2-7 Soil increased from 15% to 80% soaked and 82.0% unsoaked when treated with 50% RAP additive. The equivalent Resilient Modulus (M_R) increased from 93.54MPa to 291.66 MPa for the soaked CBR while M_R increased from 153.53 MPa to 295.36 MPa for the unsoaked CBR. Increase in M_R can be attributed to the inherent shear strength resulting from the granular nature of the RAP material. According to FMWH [7], it can be deduced that at 50% RAP, a minimum soaked CBR of 80% was achieved using a poor Idu A-2-7 Soil for base course road layer. In Figure 7, the CBR curves for respective RAP content show that the compressive load increases with increased penetration.

Table 11: RAP – Idu Soil Stabilization CBR Test Result

RAP Content (%)	A-2-7 Soil Content (%)	OMC (%)	MDD (kg/m³)	$CBR_{2.5}$ (%) = f/13.2KN	*M_R (MPa) = 17.6(CBR)$^{0.64}$*	$CBR_{5.0}$ (%) = f/13.2KN	*M_R (MPa) = 17.6(CBR)$^{0.64}$*
				Soaked		**Unsoaked**	
20	80	3.40	1.50	13.6	93.54	29.5	153.530
30	70	4.70	1.85	31.1	158.81	26.5	143.350
40	60	5.80	2.19	46.1	204.31	53.6	224.998
50	50	7.80	1.60	80.4	291.66	82.0	295.360

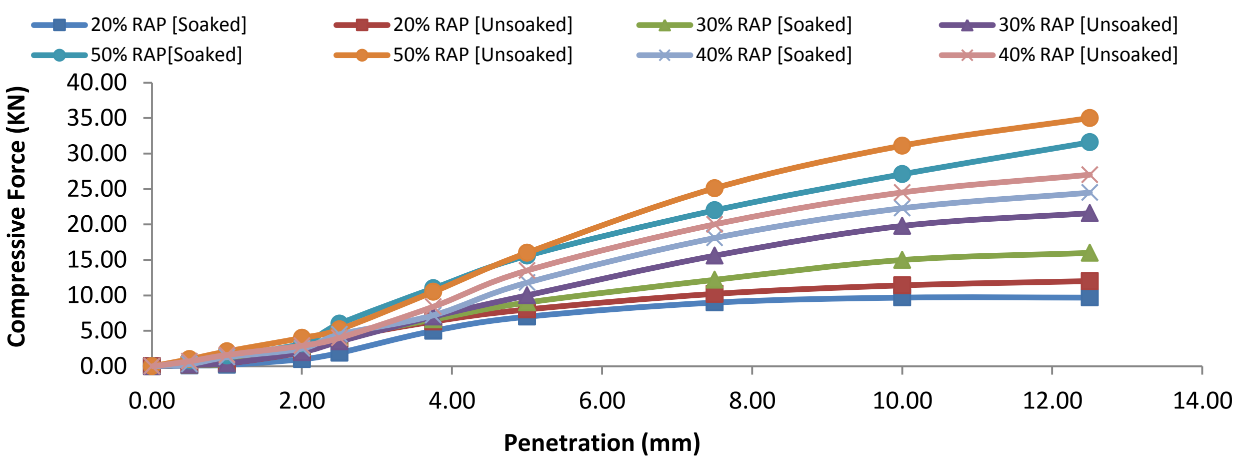

Figure 7: RAP – Idu A-2-7 soil stabilization CBR test result

RAP – Idu A-2-7 Soil Unconfined Compressive Strength Test (UCS)

The summary result of UCS on RAP – Idu A-2-7 Soil is presented in Table 12. From Table 12, at 28 days curing and 50% RAP, the maximum axial strength was 178.8KN/m^2 for medium material.

Table 12: RAP – Idu soil unconfined compressive strength test result

Additive [%]	**7days**	**14days**	**28days**	FMWH [7]
	Maximum Axial Strength (KN/m^2)			
20	44.6	74.4	94.1	Soft [48 – 96]
30	68.8	107.9	126.7	Medium [96 – 192]
40	74.3	129.2	153.7	Medium [96 – 192]
50	94.9	161.4	178.8	Medium [96 – 192]

Results and Discussion

The results (Table 7) achieved from compaction test on treating 4%, 6% and 8% cement with 96%, 94% and 92% of Idu A-2-7 Soil show that there is a reduction in optimum moisture content of untreated Idu soil sample from 13.1% to 6.3% on introduction of different percentages of cement with resultant increase in maximum dry density of the treated material from 1.89kg/m^3 to 2.31kg/m^3. These variations in compaction characteristics of soil mixtures reported in Figure 4 is like the effect of lime and other additives on black Cotton soil as discussed by Osinubi *et al* [10]. Increase in maximum dry density with cement content according to Amu *et al* [11] is indicative of improvements in the soil properties.

The California bearing ratio of untreated Idu soil sample was observed to increase from 15% to a maximum value of 88% when treated with 8% cement (Table 8). The remarkable increase was seen in the work of [12] when Cement and Lime were compared for the modification of Ikpayongo lateritic soil. The remarkable increase in California bearing ratio with cement can be attributed to the hydration reaction of cement, while that associated with the use of lime, can be attributed to the cation exchange and pozzolanic reaction of lime.

The CBR test result (Table 11) for 20%, 30% 40% and 50% RAP additive shows that the CBR of untreated Idu A-2-7 Soil increased from 15% to 80% soaked and 82.0% unsoaked when treated with 50% RAP additive. The equivalent Resilient Modulus (M_R) increased from 93.54MPa to 291.66 MPa for the soaked CBR while M_R increased from 153.53 MPa to 295.36 MPa for the unsoaked CBR. Increase in M_R can be attributed to the inherent shear strength resulting from the granular nature of the RAP material. Similarly, Lime was used as an alternative stabilizer in modifying lateritic soil sample to material of higher geotechnical properties as recorded by Manasseh and Joseph [12]. Increase in California bearing ratio value associated with the use of lime can be attributed to the cation exchange and pozzolanic reaction of lime.

Conclusions

The result of Atterberg's limit test indicated that the A-2-7 Soil consisted of mostly high plasticity with clay content having water content of about 16.1% higher than the plastic limit of the soil.

The grain size distribution curve showed that 32.4% of Idu A-2-7 Soil passed BS No. 200 sieve which means that the soil sample contains 32.4% of fine aggregates. According to the Unified Soil Classification System, the soil sample used in this work falls under A-2-7 classification, meaning that the soil material naturally can only be used as a fill material for subgrade in road pavement.

Compaction test results indicated that at 100% BS compaction of cement-soil, there was a reduction in optimum moisture content from 13.1% to 6.3% while there was an increase in maximum dry density from 1.89kg/m^3 to 2.01kg/m^3. Similarly, there was a reduction in optimum moisture content from 13.1% to 9.55% and increase in maximum dry density from 1.89kg/m^3 to 1.97kg/m^3 for RAP-soil material. This result implies that both cement and RAP additives are suitable for soil modification in engineering construction.

The California Bearing Ratio Test result indicated that poor soil (A-2-7) can be modified to achieve suitable material for base course with 50% RAP and 6% cement as additives. According to FMWH [7], 50% RAP gave a minimum CBR of 80% for road base material.

Unconfined Compressive Strength test confirmed that at 14 days curing and at 30% RAP, the maximum axial strength was 107.9KN/m^2 for 'medium' material while cement gave a maximum axial strength of 155.8KN/m^2 for 'medium' material at 14 days curing and at 4% according to Nigerian standard.

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