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Effects of Cement and Lime – *Pozzolanic Irvinga Gabonesis* fibre Ash on Expansive Lateritic Soils for Highway Pavement

Ugo Kingsley[1], Charles Kennedy[2], Apeh Ocholi Adejoh Samuel[3]

[1]Department of Civil Engineering, Ken Saro-wiwa Polytechnics, Bori Rivers State, Nigeria
[2]Department of Civil Engineering, Faculty of Engineering, Rivers State University, Port Harcourt - Rivers State, Nigeria
[3]Department of Civil Engineering, Federal Polytechnic, Idah, Kogi State, Nigeria.

Author's E-mail:[1] **ugok1960c@gmail.com, [2]ken_charl@yahoo.co.uk, [3]engrsamapeh@gmail.com,**

ABSTRACT

This research work investigated the application of hybridize composite materials for the modification and treatment of problematic expansive lateritic soil prone to undue settlements that resulted from swells-shrinks. Comparative analysis of cement and lime mixed with irvinga gabonesis fibre ash (IGFA) and soil were performed to ascertain the characteristic engineering properties of soils at natural (100%) and stabilized conditions. Preliminary investigations on soils engineering properties showed that the soils did not conform to standard specification for soils or soil-based materials usable in road pavement structures. The test results revealed that the soils' maximum dry density (MDD), optimum moisture content (OMC), California bearing ratio (CBR) liquid limits (LL), plastic limits (PL) and unconfined compressive strength (UCS) increased as the content of soil was reduced in the hybridized stabilized materials, while the case was the reverse with plastic index (PI). Comparatively, it was observed that there was no significant distinction on the basis of performance between hybrids with cement and those with lime. Hence, both cementitious stabilizers showed exhibited good hybridization properties as there was significant improvement on MDD, OMC, CBR, LL, PL, PI and UCS of the soil samples.

Keywords: Lateritic soils, Irvinga Gabonesis Fibre Ash, Cement, Lime and Stabilizers

1.0 Introduction

The stabilization of soils is recognized by engineers as an important process of improving the performance of problematic soils and makes marginal soils perform better as civil engineering materials [1]. Soil stabilization is aimed at enhancing the engineering properties of deficient soils to enable them perform and sustain their intended engineering use [2-6] Studies have shown that solid minerals and agricultural wastes could be used for the stabilization of lateritic soils [7,8]. The over-dependence on the use of industrially manufactured soil-improving additives such as cement, lime, and bitumen etc. has kept the cost of construction of stabilized roads high. The cost of incorporating these additives is high and to reduce the cost of construction of stabilized roads, a practical alternative is to mix the soil blend with requisite quantities of a pozzolanic admixture such as fibre from plantain pseudostem.

Charles *et al.* [9] evaluated the geotechnical properties of an expansive clay soil found along Odioku – Odiereke road in Ahoada-West, Rivers State, in the Niger Delta region. The application of two cementitious agents,cement and lime, hybridized with *costus afer bagasse* fibre, locally known as bush sugarcane *bagasse* fibre (BSBF), helped to strengthen the failed section of the road. The preliminary investigation results indicated that the soils were highly plastic. The results further demonstrated the potential of (BSBF) as an admixture for cement and lime-treated clay soils and laterite with 8 % cement and lime and 7.5% + 7.5 % cement / lime + BSBF.

Charles *et al.* [10] investigated and evaluated the engineering properties of an expansive lateritic soil with the addition of cement / lime and *costus afer bagasse* fibre ash (BSBFA) with ratios of laterite to cement, lime and BSBFA of 2.5 to 2.5%, 5.0 to 5.0%, 7.5 to 7.5% and 10 to 10% to improve the values of California Bearing Ratio (CBR) of less than 10%. At 8% of cement and lime, CBR values reached optimum; beyond this range, cracks developed. However, at 7.5% cement and lime + 7.5% BSBFA, and 7.25% cement and lime + 7.5% BSBF, optimum values are reached. The entire results showed the potential of BSBFA as admixtures in cement and lime treated soils.

Charles *et al.* [11] investigated the problematic engineering properties of soils with high plasticity level, high swelling, and shrinkage potential used in pavement design in the Nigerian Niger Delta region. Stabilizing agents including cement and BSBF were mixed both individually and combined to improve the unique properties of the soil. Results showed that addition of the stabilizing materials improved the strength properties of the soils. Furthermore, the optimum moisture content increased with increasing cement ratios to both soils (clay) and (laterite). The liquid limits of the cement-treated soils decreased while the plastic limits increased. in. Soils with combinations of cement and fibre products increased CBR values appreciably both at soaked and un-soaked conditions. At 8% of lime, CBR reached optimum values, beyond which, cracks developed; and at 7.5% cement + 0. 75% BSBF, optimum value were reached.

Sharma *et al.*, [12] investigated the behavior of expansive clay stabilized with lime, calcium chloride, and RHA. In the absence of RHA, they reported that the optimum percentage of lime and calcium chloride were 4 and 1% respectively.. From UCS and CBR point of view when the soil was mixed with lime or calcium chloride, RHA content of 12 % was found to be the optimum. In expansive soil – RHA mixes, 4% lime and 1% calcium chloride were also found to be optimum.

2. MATERIALS AND METHODS

2.1 The study area

The lateritic soil sample used in this study were collected along Odioku Town (latitude 5.07° 14‘S and longitude 6.65° 80‘E) and Oyigba Town (latitude 7.33° 24‘S and longitude 3.95° 48‘E) in Ubie Clan, Ahoada-West Local Government; Oshika Town (latitude 4.05° 03‘S and longitude 5.02° 50‘E) and Upatabo Town (latitude 5.35° 34‘S and longitude 6.59° 80‘E) in Igbuduya Clan, Ahoada-West Local Government; and Ihubuluko Town (latitude 5.37° 18‘S and longitude 7.91° 20‘E) in Upata Clan, Ahoada- East, all in Rivers State, Nigeria.

2.2 Sample collection

The soils were collected via hand auger, beside the failed sections of the Unity linked Rds at 1.5 m depth, at Odiokwu Town Rd (CH 0+950), Oyigba Town Rd(CH 4+225), Anakpo Town Rd(CH6+950) , Upatabo Town Rd (CH8+650). The *Irvinga Gabonesis*, popularly called Bush mango or Ogbono in Igbo language, is a popularly grown plant across Nigerian with edible fruits that bear the fibre. They were collected from Olokuma village of Ubie Clan, Ahoada-West Local Government Area, Rivers State, Nigeria. The lime and Portland cement used for the study were purchased at Mile 3 market, Diobu, Port Harcourt, Rivers State.

2.3 Laboratory Tests Analysis

Tests were conducted on Moisture Content, Consistency limits, Particle size distribution (sieve analysis), Standard Proctor Compaction, California Bearing Ratio (CBR), and Unconfined compressive strength (UCS).

2.3.1 Moisture Content Determination

The sample as freshly collected was crumbled then, placed loosely in the containers, and weighed to the nearest 0.01g. Thereafter, the natural moisture content of the soil as obtained from the site was then determined in accordance with BS 1377 (1990) Part 2.

2.3.2 Grain Size Analysis (Sieve Analysis)

The grain size analysis of the soils was performed according to ASTM D422 Standard Test Method described by Reddy [13]. This test was performed to determine the percentage of different grain sizes contained within a soil. The mechanical or sieve analysis was used to determine the distribution of the coarser and larger-sized particles.

2.3.3 Consistency Limits

The consistency limits analysis of the soils was performed according to ASTM D4318 Standard Test Method described by Reddy [13]. The liquid limit (LL) is arbitrarily defined as the water content, in percent at which a part of soil in a standard cup and cut by a groove of standard dimensions will flow together at the base of the groove for a distance of 13 mm (1/2in.) when subjected to 25 shocks from the cup being dropped 10 mm in a standard liquid limit apparatus operated at a rate of two shocks per second.

2.3.4 Moisture – Density (Compaction) Test

The moisture-density analysis of the soils was performed according to ASTM D698 Standard Test Method described by Reddy [13]. This laboratory test was performed to determine the relationship between the moisture content and the dry density of a soil for a specified compactive effort.

2.3.5 Unconfined Compression (UC) Test

The moisture-density analysis of the soils was performed according to ASTM D2166 Standard Test Method described by Reddy [13]. The unconfined compressive strength is taken as the maximum load attained per unit area, or the load per unit area at 15% axial strain, whichever occurs first during the performance of a test. The primary purpose of this test is to determine the unconfined compressive strength, which is then used to calculate the unconsolidated undrained shear strength of the clay under unconfined conditions

2.3.6 California Bearing Ratio (CBR) Test

The California Bearing Ratio (CBR) test was developed by the California Division of Highways as a method of relegating and evaluating soil-subgrade and base course materials for flexible pavements. The method has been fully discussed and illustrated by Reddy [13].

3. RESULTS AND DISCUSSION

The results obtained for the various analyses carried out on the investigated soils have been presented in the tables and figures.

Table 1: Engineering Properties of Soil Samples

Location Description	Odiokwu Town Rd (CH 0+950)	Oyigba Town Rd (CH 4+225)	Anakpo Town Rd (CH6+950)	Upatabo Town Rd (CH8+650)	Ihubuluko Town Rd (CH10+150)
	(Laterite)	(Laterite)	(Laterite)	(Laterite)	(Laterite)
Depth of sampling (m)	1.5	1.5	1.5	1.5	
Percentage(%) passing BS sieve #200	28.35	40.55	36.85	33.45	39.25
Colour	Reddish	Reddish	Reddish	Reddish	Reddish
Specific gravity	2.65	2.50	2.59	2.40	2.45
Natural moisture content (%)	9.85	11.25	10.35	11.85	8.95
Consistency Limits					
Liquid limit (%)	39.75	36.90	36.75	36.85	37.65
Plastic limit (%)	22.45	22.67	21.45	19.35	21.55
Plasticity Index	17.30	14.23	15.20	15.50	16.10
AASHTO soil classification Unified Soil Classification System	A-2-6 SC	A-2-4 SM	A-2-4 SM	A-2-6 SC	A-2-4 SM
Compaction Characteristics					
Optimum moisture content (%)	12.39	14.35	13.85	11.79	10.95
Maximum dry density ($kN/m^{3)}$)	1.953	1.857	1.943	1.953	2.105
Grain Size Distribution					
Gravel (%)	6.75	5.35	5.05	8.25	7.58
Sand (%)	35.56	37.35	28.45	29.56	34.25
Silt (%)	33.45	35.65	39.45	38.85	33.56
Clay (%)	24.24	21.65	27.05	23.34	24.61
Unconfined compressive strength (kPa)	178	145	165	158	149
California Bearing capacity (CBR)					
Unsoaked (%) CBR	8.7	8.5	7.8	9.4	10.6
Soaked (%) CBR	8.3	7.8	7.2	8.5	9.8

Analysis conducted revealed that the soils are classified as A-2-6/SC and A-2-4/SM on the AASHTO classification schemes/Unified Soil Classification System as shown in Table 1, and are less matured in the soil vertical profile and probably much more sensitive to all forms of manipulation that other deltaic lateritic soils are known for. The soils which are dark grey in colour have plasticity index of 17.30%, 14.23%, 15.20%, 15.50%, and 16.10%; unsoaked CBR values of 8.7%, 8.5%, 7.8%, 9.4%, and 10.6%; soaked CBR values are 8.3%, 7.8%, 7.2%, 8.5% and 9.8 %; and unconfined compressive strength values of 178kPa, 145kPa, 165kPa, 158kPa and 149kPa for Odiokwu, Oyigba, Anakpo, Upatabo, Ihubuluko Town roads respectively.

3.1 Compaction Test Results

The compaction test analysis was performed on the various soils to determine the maximum dry density (MDD) and optimum moisture content (OMC), and they are presented in Tables 2 to 5.

Table 2: Results of Maximum Dry Density (MDD) of Niger Deltaic Lateritic Soils Subgrade with IGFA + Cement / Lime

RATIO %	100%	95+2.5 +2.5%	90+5.0 +5.0%	85+7.5 +7.5%	80+10.0 +10%
MDD (Laterite + Cement + IGFA) Odiokwu Town Road	1.95	1.96	1.98	2.00	2.05
MDD (kN/m3) (Laterite + Lime + IGFA)Odiokwu Town Road	1.95	1.96	1.97	1.99	2.10
MDD (Laterite + Cement + IGFA) Oyigba Town Road	1.86	1.87	1.89	1.93	1.95
MDD (kN/m3) (Laterite + Lime + IGFA)Oyigba Town Road	1.86	1.87	1.88	1.90	1.91
MDD (Laterite + Cement + IGFA) Anakpo Town Road	1.94	1.96	1.97	1.99	2.11
MDD (kN/m3) (Laterite + Lime + IGFA)Anakpo Town Road	1.94	1.95	1.96	1.97	1.99
MDD (Laterite + Cement + IGFA) Upatabo Town Road	1.76	1.77	1.79	1.81	1.84
MDD (kN/m3) (Laterite + Lime + IGFA) Upatabo Town Road	1.76	1.76	1.78	1.98	1.80
OMC%(Laterite + Cement + IGFA) Upatabo Town Road	11.79	11.92	12.18	12.43	12.77
MDD (Laterite + Cement + IGFA) Ihubuluko Town Road	2.11	2.12	2.24	2.45	2.69
MDD (kN/m3) (Laterite + Lime + IGFA)Ihubuluko Town Road	2.11	2.11	2.13	2.14	2.15

Table 3: Results of Maximum Dry Density (MDD) Percentile Increase / Decrease of Niger Deltaic Lateritic Soils Subgrade with IGFA + Cement/Lime

RATIO %	100%	95+2.5 +2.5%	90+5.0 +5.0%	85+7.5 +7.5%	80+10.0 +10%
MDD (Laterite + Cement + IGFA) Odiokwu Town Road	1.00%	0.82%	2.51%	2.51%	5.32%
MDD (kN/m3) (Laterite + Lime + IGFA)Odiokwu Town Road	1.00%	0.31%	2.00%	2.00%	7.37%
MDD (Laterite + Cement + IGFA) Oyigba Town Road	1.00%	1.07%	4.36%	4.36%	5.65%
MDD (kN/m3) (Laterite + Lime + IGFA)Oyigba Town Road	1.00%	0.86%	2.48%	2.48%	3.18%
MDD (Laterite + Cement + IGFA) Anakpo Town Road	1.00%	1.44%	3.08%	3.08%	9.05%
MDD (kN/m3) (Laterite + Lime + IGFA)Anakpo Town Road	1.00%	0.72%	1.54%	1.54%	2.52%
MDD (Laterite + Cement + IGFA) Upatabo Town Road	1.01%	1.02%	3.18%	3.18%	4.89%
MDD (kN/m3) (Laterite + Lime + IGFA) Upatabo Town Road	1.00%	0.23%	12.86%	12.86%	2.39%

OMC%(Laterite + Cement + IGFA) Upatabo Town Road	1.00%	2.19%	6.52%	6.52%	9.40%
MDD (Laterite + Cement + IGFA) Ihubuluko Town Road	1.00%	0.95%	16.86%	16.86%	28.03%
MDD (kN/m3) (Laterite + Lime + IGFA)Ihubuluko Town Road	1.00%	0.28%	1.71%	1.71%	2.42%

Table 4: Results of Optimum Moisture Content (OMC) of Niger Deltaic Lateritic Soils Subgrade with IGFA + Cement / Lime

RATIO %	100%	95+2.5 +2.5%	90+5.0 +5.0%	85+7.5 +7.5%	80+10.0 +10%
OMC%(Laterite + Cement + IGFA) Odiokwu Town Road	12.39	12.45	12.58	12.79	12.79
OMC%(Laterite + Lime + IGFA) Odiokwu Town Road	12.39	12.65	12.79	12.95	13.35
OMC%(Laterite + Cement + IGFA) Oyigba Town Road	14.35	14.58	14.83	14.97	15.18
OMC%(Laterite + Lime + IGFA) Oyigba Town Road	14.35	14.68	14.85	15.05	15.35
OMC%(Laterite + Cement + IGFA) Anakpo Town Road	13.85	13.93	14.23	14.58	14.75
OMC%(Laterite + Lime + IGFA) Anakpo Town Road	13.85	14.12	14.38	14.45	14.78
OMC%(Laterite + Cement + IGFA) Upatabo Town Road	11.79	11.92	12.18	12.43	12.77
OMC%(Laterite + Lime + IGFA) Upatabo Town Road	11.79	11.92	11.97	12.23	12.26
OMC%(Laterite + Cement + IGFA) Ihubuluko Town Road	10.95	11.23	11.48	11.80	11.94
OMC%(Laterite + Lime + IGFA) Ihubuluko Town Road	10.95	11.21	11.32	11.40	11.68

Table 5: Results of Optimum Moisture Content (OMC) Percentile Increase / Decrease of Niger Deltaic Lateritic Soils Subgrade with IGFA + Cement /Lime

RATIO %	100%	95+2.5 +2.5%	90+5.0 +5.0%	85+7.5 +7.5%	80+10.0 +10%
OMC%(Laterite + Cement + IGFA) Odiokwu Town Road	1.00%	0.97%	3.71%	3.71%	3.71%
OMC%(Laterite + Lime + IGFA) Odiokwu Town Road	1.02%	4.15%	6.58%	6.58%	9.80%
OMC%(Laterite + Cement + IGFA) Oyigba Town Road	1.02%	3.18%	5.90%	5.90%	7.36%
OMC%(Laterite + Lime + IGFA) Oyigba Town Road	1.02%	4.55%	7.13%	7.13%	9.22%
OMC%(Laterite + Cement + IGFA) Anakpo Town Road	1.01%	1.15%	5.85%	5.85%	7.07%
OMC%(Laterite + Lime + IGFA) Anakpo Town Road	1.02%	3.86%	6.24%	6.24%	8.63%
OMC%(Laterite + Cement + IGFA) Upatabo Town Road	1.01%	2.19%	6.52%	6.52%	9.40%
OMC%(Laterite + Lime + IGFA) Upatabo Town Road	1.01%	2.19%	4.82%	4.82%	5.08%

OMC%(Laterite + Cement + IGFA) Ihubuluko Town Road	1.03%	5.05%	10.26%	10.26%	11.53%
OMC%(Laterite + Lime + IGFA) Ihubuluko Town Road	1.02%	4.69%	6.43%	6.43%	8.99%

In Tables 3 and 5, the derived percentile of compaction test obtained for maximum dry density (MDD) and optimum moisture content (OMC) are Odioku: 1.006% and 1.010%, Oyigba: 1.012%, and 1.022%, Anakpo: 1.013% and 1.014%, Upatabo: 1.010% and 1.025% and Ihubuluko: 1.011% and 1.024% respectively at 100% natural soil. The stabilized clay soil results with composites materials of MDD are laterite + Cement + IGFA 0.817%, 2.506%, 2.506% and 5.321%, while laterite + lime + IGFA has 0.307%, 1.996%, 1.996% and 7.369%. Similarly, OMC for Laterite + Cement + IGFA are 0.966%, 3.710%, 3.710% and 3.710%, while in laterite + lime + IGFA, OMC are 4.154%, 6.575%, 6.575% and 9.804% for Odioku soil sample. In Oyigba soil, MDD for laterite + cement + IGFA are 1.074%, 4.359%, 4.359% and 5.651%, and for laterite + lime + IGFA MDD are 0.860%, 2.475%, 2.475%, 3.175%, while OMC for laterite + cement + IGFA 3.180%, 5.898%, 5.898%, 7.361%, and for laterite + lime + IGFA, OMC are 4.548%, 7.126%, 7.126% and 9.217%. Also in Anakpo soil, MDD for laterite + cement + IGFA are 1.436%, 3.083%, 3.083%, 9.053%, and for laterite + lime + IGFA, MDD are 0.719%, 1.543%, 1.543% ,2.521%, while OMC for laterite + cement + IGFA are 1.152%, 5.845%,5.845%, 7.072%, and for laterite + lime + IGFA , OMC are 3.862%, 6.244%, 6.244%, 8.627%. Again, in Upatabo soil, MDD for laterite + cement + IGFA are 1.021%, 3.183%, 3.183%, 4.889%, and for laterite + lime + IGFA, MDD are 0.227%, 12.855% ,12.855%, 2.389%, while OMC for laterite + cement + IGFA are 2.193%, 6.519% ,6.519%, 9.403%, and for laterite + lime + IGFA, OMC are 2.193%, 4.823%, 4.823%, 5.077%. Finally, in Ihubuluko soil, MDD for laterite + cement + IGFA are 0.948%, 16.862%, 16.862%, 28.026%, and for laterite + lime + IGFA, MDD are 0.285%, 1.710%, 1.710%, 2.423%, while OMC for laterite + cement + IGFA are 5.050%,10.256%, 10.256%, 11.534%, and for laterite + lime + IGFA, OMC are 4.694%, 6.429%, 6.429% and 8.986%. Hence, compaction test results for maximum dry density and optimum moisture content showed incremental percentile values to corresponding composite stabilizers inclusion percentages ratio to soils.

3.2 California Bearing Ratio (CBR) Test

The California Bearing Ratio (CBR) test was carried out on soaked and unsoaked soil obtained from the various locations, and they are presented in Tables 6 and 7. While Table 6 showed the CBR percentage, Table 7 showed the increase or decrease in CBR of the various soils.

Table 6: Results of California Bearing ratio (CBR) of Niger Deltaic Lateritic Soils Subgrade with IGFA + Cement / Lime

RATIO %	100%	95+2.5 +2.5%	90+5.0 +5.0%	85+7.5 +7.5%	80+10.0 +10%
UNSOAKED CBR (Laterite + Cement + IGFA) Odiokwu Town Road	8.70	32.45	54.35	88.40	73.33
UNSOAKED CBR (Laterite + Lime + IGFA) Odiokwu Town Road	8.70	27.30	41.50	74.18	68.65
SOAKED CBR(Laterite + Cement + IGFA) Odiokwu Town Road	8.30	29.45	49.73	75.53	69.53
SOAKED CBR (Laterite + Lime + IGFA) Odiokwu Town Road	8.30	22.85	38.60	69.85	65.85

UNSOAKED CBR (Laterite + Cement + IGFA) Oyigba Town Road	8.50	29.35	43.08	73.85	67.78
UNSOAKED CBR (Laterite + Lime + IGFA) Oyigba Town Road	8.50	24.35	36.35	69.15	63.80
SOAKED CBR(Laterite + Cement + IGFA) Oyigba Town Road	7.80	28.15	39.35	69.85	63.58
SOAKED CBR (Laterite + Lime + IGFA) Oyigba Town Road	7.80	21.60	28.40	66.35	58.17
UNSOAKED CBR (Laterite + Cement + IGFA) Anakpo Town Road	7.80	27.10	39.85	69.95	61.45
UNSOAKED CBR (Laterite + Lime + IGFA) Anakpo Town Road	7.80	22.25	33.60	68.35	57.30
SOAKED CBR(Laterite + Cement + IGFA) Anakpo Town Road	7.20	25.65	37.38	66.75	58.85
SOAKED CBR (Laterite + Lime + IGFA) Anakpo Town Road	7.20	18.95	30.62	64.75	54.18
UNSOAKED CBR (Laterite + Cement + IGFA) Upatabo Town Road	9.40	31.45	63.17	83.85	77.81
UNSOAKED CBR (Laterite + Lime + IGFA) Upatabo Town Road	9.40	30.15	52.68	81.30	72.45
SOAKED CBR(Laterite + Cement + IGFA) Upatabo Town Road	8.50	30.80	58.14	80.15	70.85
SOAKED CBR (Laterite + Lime + IGFA) Upatabo Town Road	8.50	28.63	48.80	76.25	67.80
UNSOAKED CBR (Laterite + Cement + IGFA) Ihubuluko Town Road TOWN ROAD	10.60	38.43	61.85	90.25	86.15
UNSOAKED CBR (Laterite + Lime + IGFA) Ihubuluko Town Road	11.60	33.85	58.10	83.30	77.25
SOAKED CBR(Laterite + Cement + IGFA) Ihubuluko Town Road	9.80	34.30	59.35	85.73	81.55
SOAKED CBR (Laterite + Lime + IGFA) Ihubuluko Town Road	10.30	29.45	55.20	79.83	72.33

Table 7: Results of California Bearing ratio (CBR) Percentile Increase / Decrease of Niger Deltaic Lateritic Soils Subgrade with IGFA + Cement/Lime

RATIO %	100%	95+2.5 +2.5%	90+5.0 +5.0%	85+7.5 +7.5%	80+10.0 +10%
UNSOAKED CBR (Laterite + Cement + IGFA) Odiokwu Town Road	3.73%	346.18%	989.28%	989.28%	816.06%
UNSOAKED CBR (Laterite + Lime + IGFA) Odiokwu Town Road	3.14%	281.92%	820.78%	820.78%	757.21%
SOAKED CBR(Laterite + Cement + IGFA) Odiokwu Town Road	3.55%	326.64%	881.82%	881.82%	809.53%
SOAKED CBR (Laterite + Lime + IGFA) Odiokwu Town Road	2.75%	238.98%	805.24%	805.24%	757.05%
UNSOAKED CBR (Laterite + Cement + IGFA) Oyigba Town Road	3.45%	316.33%	839.86%	839.86%	768.45%
UNSOAKED CBR (Laterite + Lime + IGFA) Oyigba Town Road	2.86%	251.56%	778.62%	778.62%	715.68%
SOAKED CBR(Laterite + Cement + IGFA) Oyigba Town Road	3.61%	333.19%	867.80%	867.80%	787.42%

SOAKED CBR (Laterite + Lime + IGFA) Oyigba Town Road	2.77%	240.81%	814.53%	814.53%	709.66%
UNSOAKED CBR (Laterite + Cement + IGFA) Anakpo Town Road	3.47%	318.65%	868.01%	868.01%	759.04%
UNSOAKED CBR (Laterite + Lime + IGFA) Anakpo Town Road	2.85%	250.20%	841.23%	841.23%	699.56%
SOAKED CBR(Laterite + Cement + IGFA) Anakpo Town Road	3.56%	328.18%	899.01%	899.01%	789.29%
SOAKED CBR (Laterite + Lime + IGFA) Anakpo Town Road	2.63%	225.20%	861.31%	861.31%	714.51%
UNSOAKED CBR (Laterite + Cement + IGFA) Upatabo Town Road	3.35%	304.69%	862.13%	862.13%	797.88%
UNSOAKED CBR (Laterite + Lime + IGFA) Upatabo Town Road	3.21%	289.57%	833.72%	833.72%	739.57%
SOAKED CBR(Laterite + Cement + IGFA) Upatabo Town Road	3.62%	334.76%	915.34%	915.34%	805.93%
SOAKED CBR (Laterite + Lime + IGFA) Upatabo Town Road	3.37%	307.13%	867.37%	867.37%	767.96%
UNSOAKED CBR (Laterite + Cement + IGFA) Ihubuluko Town Road	3.63%	334.96%	823.83%	823.83%	785.15%
UNSOAKED CBR (Laterite + Lime + IGFA) Ihubuluko Town Road	2.92%	257.54%	683.83%	683.83%	631.68%
SOAKED CBR(Laterite + Cement + IGFA) Ihubuluko Town Road	3.50%	321.43%	846.22%	846.22%	803.57%
SOAKED CBR (Laterite + Lime + IGFA) Ihubuluko Town Road	2.86%	250.95%	740.07%	740.07%	667.26%

Derived results of California Bearing Ratio (CBR) test results from Table 6 at 100% for unsoaked are 4.644%, 4.447%, 3.696%, 4.835% and 4.467%, while for soaked, it is 4.382%, 4.321%, 3.576%, 4.921% and 4.551% for Odioku, Oyigba, Anakpo, Upatabo and Ihubuluko respectively. Results of percentile values recorded from Odioku stabilized unsoaked laterite + cement + IGFA are 346.178%, 989.281%, 989.281% and 816.063%; laterite + lime + IGFA are 281.925%, 820.776%, 820.776%, 757.212%, while soaked laterite + cement + IGFA are 326.636%, 881.817%, 881.817% and 809.527%; soaked laterite + lime + IGFA are 238.977%, 805.242%, 805.242% and 757.050%. Oyigba stabilized unsoaked laterite + cement + IGFA are 316.333%, 839.863%, 839.863% and 768.451%; unsoaked laterite + lime + IGFA are 251.563%, 778.622%, 778.622% and 715.681%, while soaked laterite + cement + IGFA are 333.189%, 867.804%, 867.804% and 787.420%; soaked laterite + lime + IGFA are 240.812%, 814.530%, 814.530% and 709.658%. Anakpo unsoaked laterite + cement + IGFA are 318.654%, 868.013%, 868.013% and 759.038%; unsoaked laterite + lime + IGFA are 50.200%, 841.226%, 841.226% and 699.559%, while soaked laterite + cement + IGFA are 328.180%, 899.013%, 899.013% and 789.291%; soaked laterite + lime + IGFA are 225.200%, 861.311%, 861.311% and 714.505%. Upatabo unsoaked laterite + cement + IGFA are 304.686%, 862.133%, 862.133% and 797.877%; unsoaked laterite + lime + IGFA are 289.567%, 833.716%, 833.716%, 739.567%, while soaked laterite + cement + IGFA are 334.756%, 915.344%, 915.344% and 805.932%; soaked laterite + lime + IGFA are 307.134%, 867.370%, 867.370% and 767.958%. Finally, Ihubuluko unsoaked laterite + cement + IGFA are 34.965%, 823.832%, 823.832% and 785.153%; unsoaked laterite + lime + IGFA are 257.542%, 683.835%, 683.835% and 631.679%; soaked laterite + cement + IGFA are 321.429%, 846.224%, 846.224% and 803.571%; soaked laterite + lime + IGFA 250.948%, 740.074%, 740.074% and 667.258%. California bearing ratio (CBR) results stabilized with cement, lime and IGFA showed incremental percentile values with optimum percentile ratio of 85+7.5+7.5%. Recorded results further confirmed that both cementitious stabilizers proved to show good hybridization properties with IGFA and cement compositions at higher peaks to lime.

3.3 Consistency Limits Test

Consistency limits test were carried to determine the liquid limit (LL), plastic limit (PL) and plastic index (PI) of unstabilized and stabilized lateritic soils at varying percentages ratio. The consistency limits results and percentage increase or decrease is shown in Tables 8 to 13.

Table 8: Results of Liquid Limit (LL) of Niger Deltaic Lateritic Soils Subgrade with IGFA + Cement / Lime

RATIO %	100%	95+2.5 +2.5%	90+5.0 +5.0%	85+7.5 +7.5%	80+10.0 +10%
LL(Laterite + Cement + IGFA) Odiokwu Town Road	39.75	39.95	40.15	40.35	40.35
LL (Laterite + Lime + IGFA)Odiokwu Town Road	39.75	40.25	40.41	40.28	41.15
LL(Laterite + Cement + IGFA) Oyigba Town Road	36.90	37.18	37.32	37.58	37.82
LL (Laterite + Lime + IGFA)Oyigba Town Road	36.90	37.18	37.32	37.65	38.80
LL(Laterite + Cement + IGFA) Anakpo Town Road	36.75	36.94	37.21	37.52	37.88
LL (Laterite + Lime + IGFA) Anakpo Town Road	36.75	36.86	37.19	37.41	37.67
LL(Laterite + Cement + IGFA) Upatabo Town Road	36.85	36.96	37.25	37.44	37.85
LL (Laterite + Lime + IGFA) Upatabo Town Road	36.85	37.22	37.56	37.83	38.10
LL(Laterite + Cement + IGFA) Ihubuluko Town Road	37.65	37.93	38.25	38.57	38.83
LL (Laterite + Lime + IGFA)Ihubuluko Town Road	37.65	38.06	38.48	38.87	39.15

Table 9: Results of Liquid Limit (LL) Percentile Increase / Decrease of Niger Deltaic Lateritic Soils Subgrade with IGFA + Cement / Lime

RATIO %	100%	95+2.5 +2.5%	90+5.0 +5.0%	85+7.5 +7.5%	80+10.0 +10%
LL(Laterite + Cement + IGFA) Odiokwu Town Road	1.01%	1.00%	2.01%	2.01%	2.01%
LL (Laterite + Lime + IGFA)Odiokwu Town Road	1.01%	2.50%	2.58%	2.58%	4.76%
LL(Laterite + Cement + IGFA) Oyigba Town Road	1.01%	1.51%	2.60%	2.60%	3.25%
LL (Laterite + Lime + IGFA)Oyigba Town Road	1.01%	1.51%	2.79%	2.79%	5.90%
LL(Laterite + Cement + IGFA) Anakpo Town Road	1.01%	1.03%	2.61%	2.61%	3.59%
LL (Laterite + Lime + IGFA) Anakpo Town Road	1.00%	0.60%	2.09%	2.09%	2.80%
LL(Laterite + Cement + IGFA) Upatabo Town Road	1.00%	0.60%	1.90%	1.90%	3.01%
LL (Laterite + Lime + IGFA) Upatabo Town Road	1.01%	2.00%	3.65%	3.65%	4.39%

LL(Laterite + Cement + IGFA) Ihubuluko Town Road	1.01%	1.48%	3.18%	3.18%	3.87%
LL (Laterite + Lime + IGFA)Ihubuluko Town Road	1.01%	2.17%	4.32%	4.32%	5.06%

Table 10: Results of Plastic Limit (PL) of Niger Deltaic Lateritic Soils Subgrade with IGFA + Cement / Lime

RATIO %	100%	95+2.5 +2.5%	90+5.0 +5.0%	85+7.5 +7.5%	80+10.0 +10%
PL(Laterite + Cement + IGFA) Odiokwu Town Road	22.45	23.08	23.35	23.61	23.61
PL (Laterite + Lime + IGFA) Odiokwu Town Road	22.45	23.13	23.51	24.06	24.54
PL(Laterite + Cement + IGFA) Odiokwu Town Road	22.67	22.87	22.93	23.21	23.48
PL (Laterite + Lime + IGFA) Oyigba Town Road	22.67	23.10	23.44	24.02	24.66
PL(Laterite + Cement + IGFA) Anakpo Town Road	21.45	21.72	21.99	22.23	22.81
PL (Laterite + Lime + IGFA) Anakpo Town Road	21.45	21.75	22.32	22.81	23.14
PL(Laterite + Cement + IGFA) Upatabo Town Road	19.35	19.71	20.18	20.38	20.85
PL (Laterite + Lime + IGFA) Upatabo Town Road	19.35	19.84	20.44	20.96	21.38
PL(Laterite + Cement + IGFA) Ihubuluko Town Road	21.55	21.84	22.35	22.78	23.78
PL (Laterite + Lime + IGFA) Ihubuluko Town Road	21.55	22.23	22.82	23.24	23.73

Table 11: Results of Plastic Limit (PL) Percentile Increase / Decrease of Niger Deltaic Lateritic Soils Subgrade with IGFA + Cement /Lime

RATIO %	100%	95+2.5 +2.5%	90+5.0 +5.0%	85+7.5 +7.5%	80+10.0 +10%
PL(Laterite + Cement + IGFA) Odiokwu Town Road	1.03%	5.54%	7.90%	7.90%	7.90%
PL (Laterite + Lime + IGFA) Odiokwu Town Road	1.03%	5.97%	10.11%	10.11%	12.25%
PL(Laterite + Cement + IGFA) Odiokwu Town Road	1.01%	1.76%	3.26%	3.26%	4.45%
PL (Laterite + Lime + IGFA) Oyigba Town Road	1.02%	3.76%	7.82%	7.82%	10.64%
PL(Laterite + Cement + IGFA) Anakpo Town Road	1.01%	2.50%	4.88%	4.88%	7.58%
PL (Laterite + Lime + IGFA) Anakpo Town Road	1.01%	2.78%	7.72%	7.72%	9.26%
PL(Laterite + Cement + IGFA) Upatabo Town Road	1.02%	3.69%	7.15%	7.15%	9.58%
PL (Laterite + Lime + IGFA) Upatabo Town Road	1.03%	5.00%	10.79%	10.79%	12.96%
PL(Laterite + Cement + IGFA) Ihubuluko Town Road	1.01%	2.67%	7.04%	7.04%	11.68%

PL (Laterite + Lime + IGFA) Ihubuluko Town Road	1.03%	6.21%	10.90%	10.90%	13.17%

Table 12: Results of Plastic Index (PI) of Niger Deltaic Lateritic Soils Subgrade with IGFA + Cement / Lime

RATIO %	100%	95+2.5 +2.5%	90+5.0 +5.0%	85+7.5 +7.5%	80+10.0 +10%
PI (Laterite + Cement + IGFA) Odiokwu Town Road	17.30	16.87	16.80	16.74	16.74
PI (Laterite + Lime + IGFA) Odiokwu Town Road	17.30	17.12	16.90	16.72	16.61
PI (Laterite + Cement + IGFA) Oyigba Town Road	14.23	14.31	14.39	14.37	14.34
PI (Laterite + Lime + IGFA) Oyigba Town Road	14.23	14.08	13.88	13.63	13.42
PI (Laterite + Cement + IGFA) Anakpo Town Road	15.30	15.22	15.22	15.19	15.07
PI (Laterite + Lime + IGFA) Anakpo Town Road	15.30	15.11	14.87	14.60	14.53
PI (Laterite + Cement + IGFA) Upatabo Town Road	17.50	17.25	17.07	17.06	17.00
PI (Laterite + Lime + IGFA) Upatabo Town Road	17.50	17.38	17.12	16.87	16.72
PI (Laterite + Cement + IGFA) Ihubuluko Town Road	16.10	16.09	15.90	15.59	15.78
PI (Laterite + Lime + IGFA) Ihubuluko Town Road	16.10	15.83	15.66	15.63	15.42

Table 13: Results of Plastic Limit (PL) Percentile Increase / Decrease of Niger Deltaic Lateritic Soils Subgrade with IGFA + Cement / Lime

RATIO %	100%	95+2.5+2.5%	90+5.0+5.0%	85+7.5+7.5%	80+10.0+10%
PI (Laterite + Cement + IGFA) Odiokwu Town Road	0.98%	-5.03%	-5.79%	-5.79%	-5.79%
PI (Laterite + Lime + IGFA) Odiokwu Town Road	0.99%	-2.09%	-4.40%	-4.40%	-5.04%
PI (Laterite + Cement + IGFA) Oyigba Town Road	1.01%	-3.12%	-4.54%	-5.54%	-6.33%
PI (Laterite + Lime + IGFA) Oyigba Town Road	0.99%	-2.12%	-5.28%	-5.28%	-6.76%
PI (Laterite + Cement + IGFA) Anakpo Town Road	0.99%	-1.05%	-1.24%	-1.24%	-2.03%
PI (Laterite + Lime + IGFA) Anakpo Town Road	0.99%	-2.50%	-5.83%	-5.83%	-6.29%
PI (Laterite + Cement + IGFA) Upatabo Town Road	0.99%	-2.88%	-3.96%	-3.96%	-4.31%
PI (Laterite + Lime + IGFA) Upatabo Town Road	0.99%	-1.38%	-2.86%	-2.86%	-5.15%

PI (Laterite + Cement + IGFA) Ihubuluko Town Road	1.00%	-0.12%	-3.23%	-3.23%	-2.05%
PI (Laterite + Lime + IGFA) Ihubuluko Town Road	0.98%	-3.38%	-4.62%	-4.62%	-5.93%

The summarized percentile results of consistency limits for liquid limit test are shown in Tables 9; for plastic limit, it is shown in Table 11, while for plastic index, it is shown in Table 13. For instance, the percentage plastic index test results at 100% natural condition from the sampled roads are Odioku 0.995%, Oyigba 0.989%, Anakpo 0.988%, Upatabo 0.997% and Ihubuluko 0.987%. But the percentile derived stabilized values for Odioku: laterite + cement + IGFA are -5.034%, -5.786%, -5.786% and -5.786%; laterite + lime + IGFA -2.092%, -4.404%, -4.404% and -5.040%. Oyigba: laterite + cement + IGFA are 1.121%, 1.543%, 1.543% and 1.332%; laterite + lime + IGFA are -2.119%, -5.282%, -5.282% and -6.758%. Anakpo: laterite + cement + IGFA are -1.048%, -1.245%,-1.245% and -2.029%; laterite + lime + IGFA are -1.048%, -1.245%,-1.245% and -2.029%. Upatabo: laterite + cement + IGFA are -2.88%, -3.96%, -3.96% and -4.31%; laterite + lime + IGFA are -1.38%, -2.86%, -2.86% and -5.15%. Ihubuluko: Laterite + cement + IGFA are -0.12%, -3.230%, -3.230% and -2.050%; laterite + lime + IGFA are -3.383%, -4.625%, -4.625% and -5.929%. Here, consistency limits for plastic index test showed the percentile decreased with increase in composite materials to soil ratio.

3.4 Unconfined Compressive Strength Test

The unconfined compressive strength test was carried on all the soil samples. The corresponding values as well as the percentage increase or decrease is shown in Tables 14 and 15 respectively.

Table 14: Results of Unconfined Compressive Strength (UCS) of Niger Deltaic Lateritic Soils Subgrade with IGFA + Cement / Lime

RATIO %	100%	95+2.5 +2.5%	90+5.0 +5.0%	85+7.5 +7.5%	80+10.0 +10%
UCS (Laterite + Cement + IGFA) Odiokwu Town Road	178.00	215.00	365.00	458.00	644.00
UCS(Laterite + Lime + IGFA) Odiokwu Town Road	178.00	195.00	315.00	408.00	585.00
UCS (Laterite + Cement + IGFA) Oyigba Town Road	145.00	174.00	265.00	398.00	574.00
UCS(Laterite + Lime + IGFA) Oyigba Town Road	145.00	169.00	278.00	378.00	564.00
UCS(Laterite + Cement + IGFA) Anakpo Town Road	165.00	210.00	246.00	334.00	625.00
UCS (Laterite + Lime + IGFA) Anakpo Town Road	165.00	182.00	295.00	395.00	581.00
UCS (Laterite + Cement + IGFA) Upatabo Town Road	158.00	208.00	253.00	328.00	597.00
UCS(Laterite + Lime + IGFA) Upatabo Town	158.00	178.00	286.00	377.00	578.00

Road					
UCS (Laterite + Cement + IGFA) Ihubuluko Town Road	145.00	182.00	245.00	356.00	597.00
UCS(Laterite + Lime + IGFA) Ihubuluko Town Road	145.00	172.00	262.00	383.00	573.00

Table 15: Results of Unconfined Compressive Strength (UCS) Percentile Difference of Niger Deltaic Lateritic Soils Subgrade with IGFA + Cement / Lime

RATIO %	100%	95+2.5 +2.5%	90+5.0 +5.0%	85+7.5 +7.5%	80+10.0 +10%
UCS (Laterite + Cement + IGFA) Odiokwu Town Road	1.21%	38.00%	174.51%	174.51%	279.01%
UCS(Laterite + Lime + IGFA) Odiokwu Town Road	1.10%	18.27%	137.93%	137.93%	237.37%
UCS (Laterite + Cement + IGFA) Oyigba Town Road	1.20%	36.67%	191.15%	191.15%	312.53%
UCS(Laterite + Lime + IGFA) Oyigba Town Road	1.17%	30.75%	174.89%	174.89%	303.17%
UCS(Laterite + Cement + IGFA) Anakpo Town Road	1.27%	48.70%	123.85%	123.85%	300.22%
UCS (Laterite + Lime + IGFA) Anakpo Town Road	1.10%	19.64%	148.73%	148.73%	261.46%
UCS (Laterite + Cement + IGFA) Upatabo Town Road	1.32%	55.68%	131.63%	131.63%	301.89%
UCS(Laterite + Lime + IGFA) Upatabo Town Road	1.13%	23.89%	149.84%	149.84%	277.06%
UCS (Laterite + Cement + IGFA) Ihubuluko Town Road	1.26%	45.85%	165.85%	165.85%	332.05%
UCS(Laterite + Lime + IGFA) Ihubuluko Town Road	1.19%	34.32%	179.84%	179.84%	310.87%

Results of Unconfined compressive strength test from sampled roads are Odioku 1.393%, Oyigba 1.483%, Anakpo 1.636%, Upatabo 1.633% and Ihubuluko 1.441% respectively at 100% natural state. The results are summarized in Table 15. The stabilized composite materials of unconfined compressive strength for Odioku laterite + cement + IGFA are 37.996%, 174.513%, 174.513% and 279.007%; laterite + lime + IGFA are 18.269%, 137.931%, 137.931% and 237.370%. Oyigba laterite + cement + IGFA are 36.667%, 191.149%, 191.149% and 312.529%; laterite + lime + IGFA are 30.753%, 174.891%, 174.891% and 303.167%. Anakpo laterite + cement + IGFA are 48.701%, 123.853%, 123.853% and 300.216%; laterite + lime + IGFA are 19.644%, 148.735%, 148.735% and 261.462%. Upatabo laterite + cement + IGFA are 55.684%, 131.633%, 131.633% and 301.887%; laterite + lime + IGFA are 23.894%, 149.844%, 149.844% and 277.059%, while for Ihubuluko laterite + cement + IGFA, the unconfined compressive strength are 45.847%, 165.847%, 165.847% and 332.054%; laterite + lime + IGFA 34.318%, 179.836%, 179.836% and 310.870%. it followed that unconfined compressive strength test of stabilized soils with cement/lime + IGFA showed incremental percentile rise to corresponding ratios of composite materials to soil for both cement and lime with maximum values recorded in cement compositions to lime. However, both cementitious agents posed good incremental values.

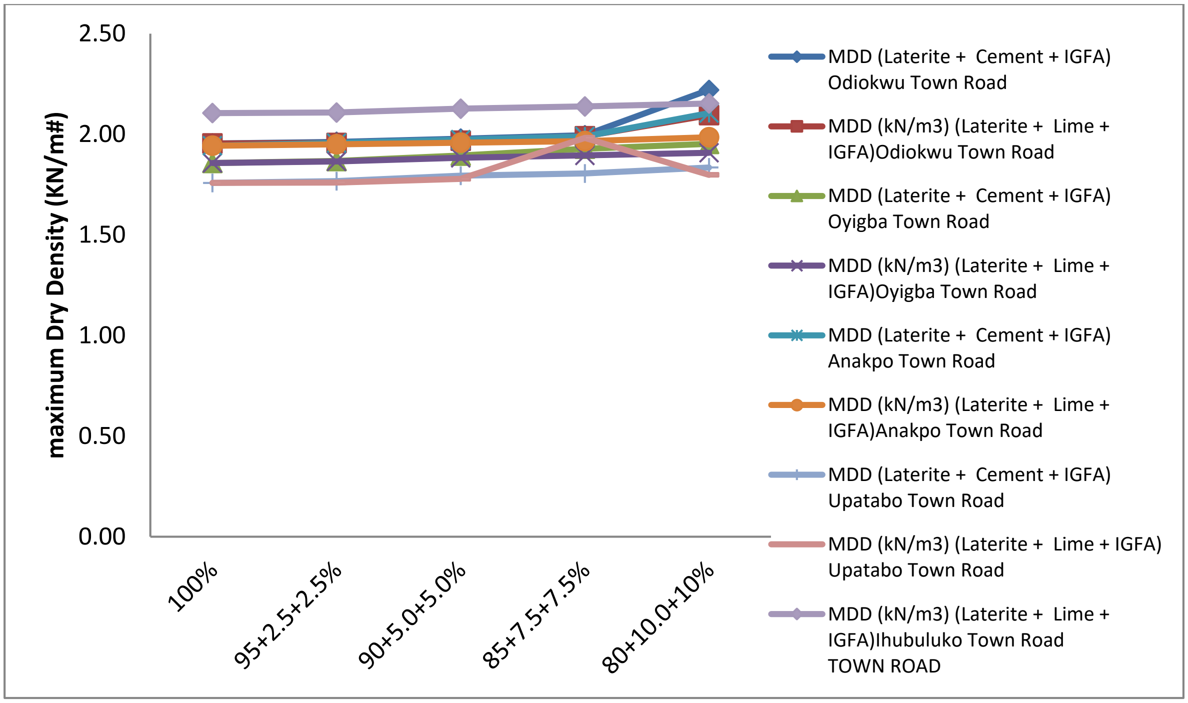

Figure 1: Maximum Dry Density (MDD) of Niger Deltaic Lateritic Soils Subgrade with IGFA + Cement/ Lime

Figure 1 showed the behaviors of MDD for unstabilized and stabilized soils with cement having peak values over lime. In comparison to soil location, hybrid of laterite+ lime+ IGFA from Ihubuluko Town road soil exhibited high MDD, while the lowest MDD was recorded in hybrid of laterite+ cement+ IGFA from Upatabo Town road soil. The behavior of the soil maximum dry density is synonymous with earlier observations reported in previous works using other stabilized materials [14- 15], though, IGFA as a stabilized material has lower MDD compared to the stabilized materials used in some of the soils reported.

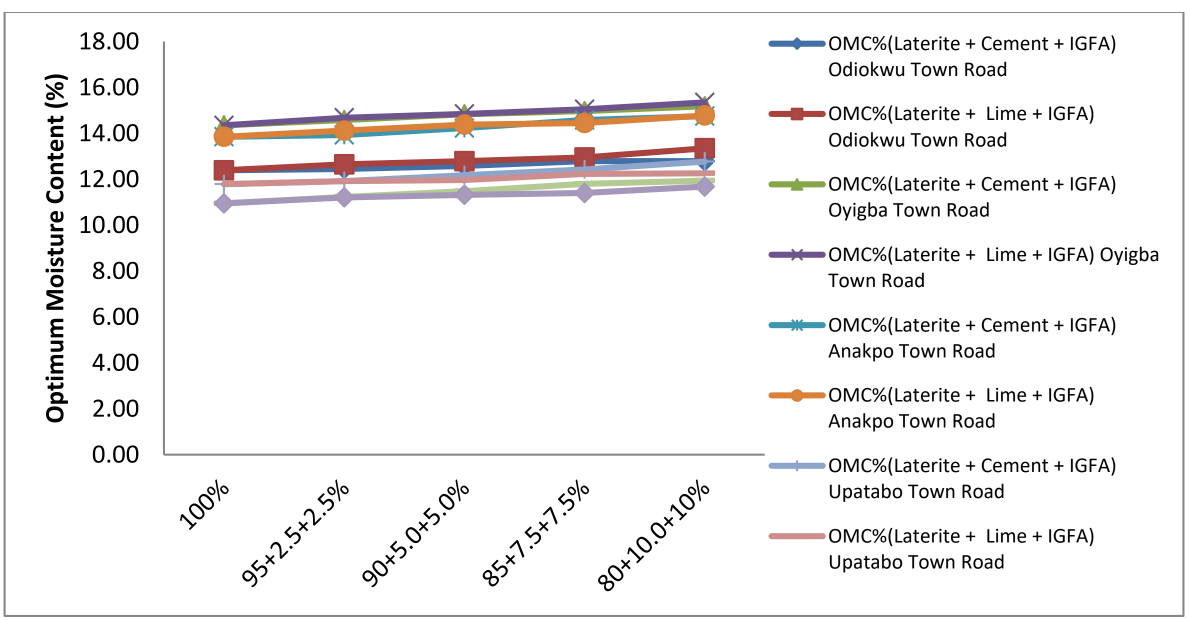

Figure 2: Optimum Moisture Content (OMC) of Niger Deltaic Lateritic Soils Subgrade with IGFA + Cement/Lime

Figure 2 showed the behaviors of OMC for unstabilized and stabilized soils with cement having peak values over lime. Again, in comparison to soil location, laterite+ lime+ IGFA from Oyigba Town road soil has the highest OMC, while laterite+ lime+ IGFA obtained from Ihubuluko Town road soil recorded the lowest OMC. Again, the trends in the soil optimum moisture content agree with previously reported works on the use of stabilized materials in soils for highway or structural applications [14-17].

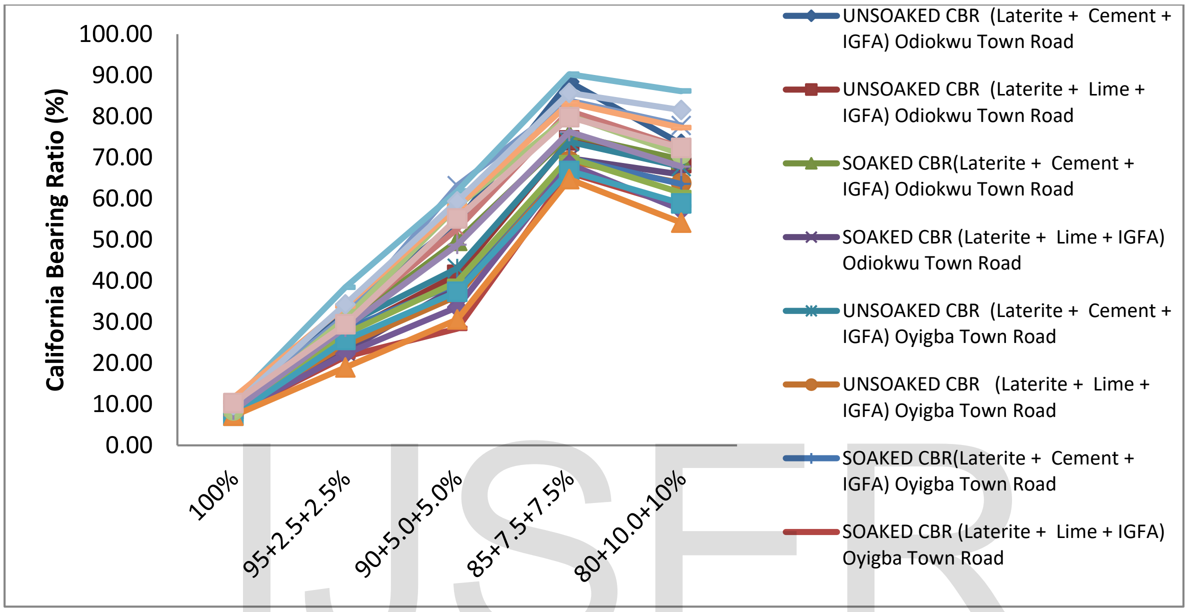

Figure 3: California Bearing Ratio (CBR) of Niger Deltaic Lateritic Soils Subgrade with IGFA + Cement/ Lime

Figure 3 showed the profiles of california bearing ratio (CBR) of Niger deltaic lateritic soils subgrade hybridized with composite materials. The CBR at 100% was very low, but significantly improved when IGFA and lime or cement was added. The percentage of CBR in all the samples increased as lateritic soil content was reduced in the mixture, but beyond 85% soil content, the CBR was seen to decrease. In comparison, Ihubuluko Town road soil with laterite+ cement+ IGFA has the highest CBR effect, while laterite+ lime+ IGFA obtained from Anakpo Town road soil recorded the lowest CBR. These trends also agree with previously reported works on the use of stabilized materials in soils for highway or structural applications [15].

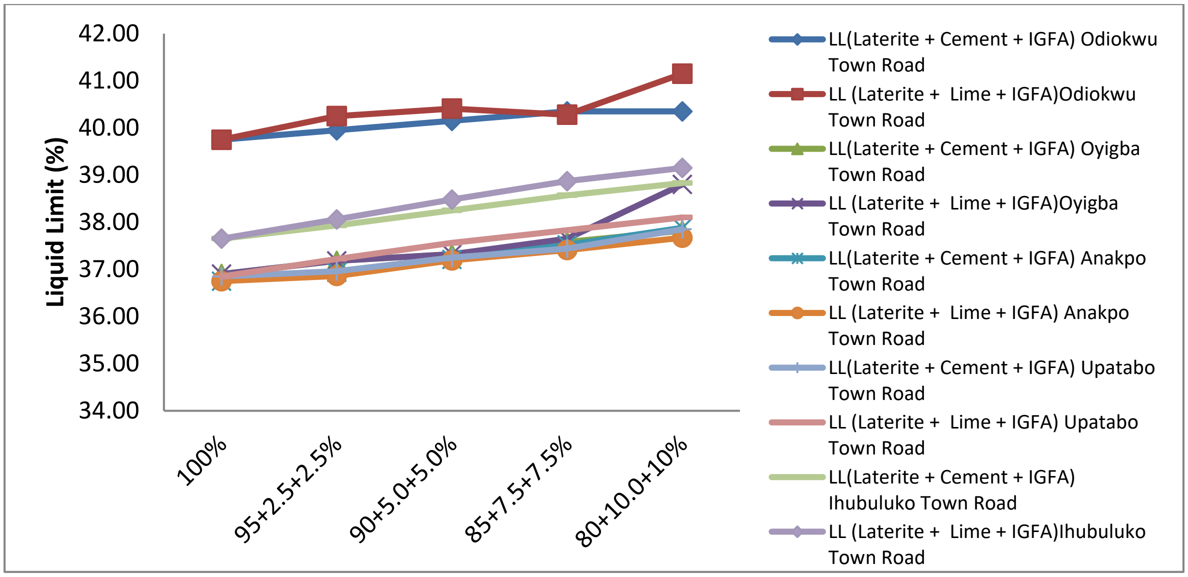

Figure 4: Liquid Limit (LL) of Niger Deltaic Lateritic Soils Subgrade with IGFA + Cement/Lime

Figure 4 showed the characteristics consistency limits for liquid limit (LL) for unstabilized and stabilized lateritic soils at varying percentages ratio. The LL at 100% was lower compared to when the soil was stabilized with composite materials. Thus, the percentage of LL in all the samples increased proportionally as lateritic soil content was reduced in the mixture. In comparison, Odiokwu Town road sample with laterite+ lime+ IGFA has the highest LL percentage, while Anakpo Town road sample with laterite+ lime+ IGFA recorded the lowest LL.

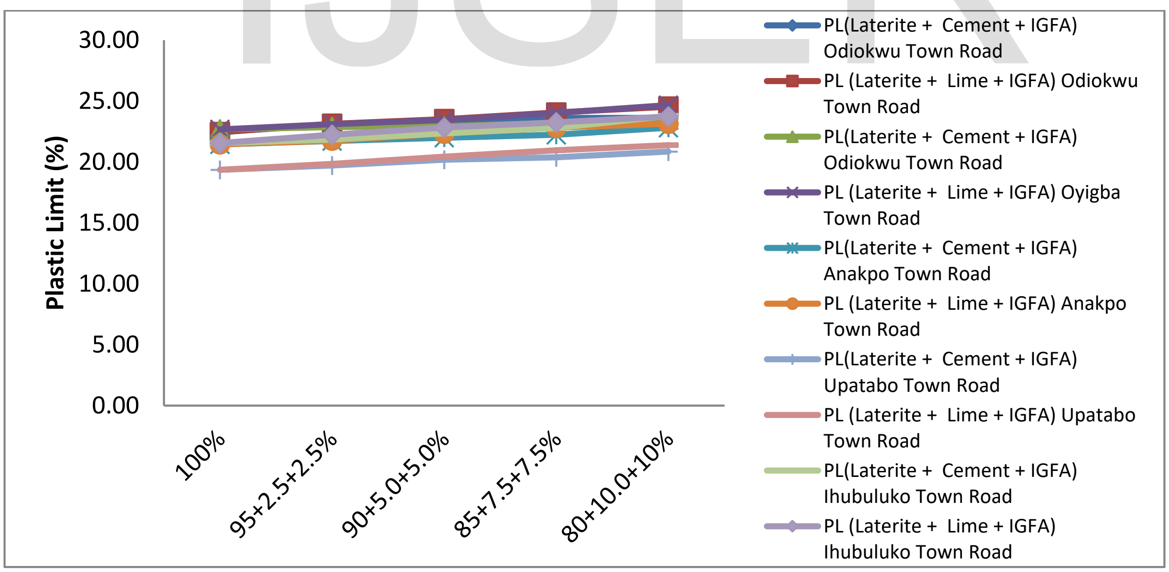

Figure 5: Plastic Limit (PL) of Niger Deltaic Lateritic Soils Subgrade with IGFA + Cement

Figure 5 showed the characteristics consistency limits for plastic limit (PL) for unstabilized and stabilized lateritic soils at varying percentages ratio. Again, like the LL at 100%, PL values were lower compared to when the soil was stabilized with composite materials. Thus, the percentage of PL in all the samples increased proportionally as lateritic soil content was reduced in the mixture. In comparison, Odiokwu and

Oyigba Town road samples with laterite+ lime+ IGFA has the highest PL percentage, while Upatabo Town road sample with laterite+ lime+ IGFA recorded the lowest PL.

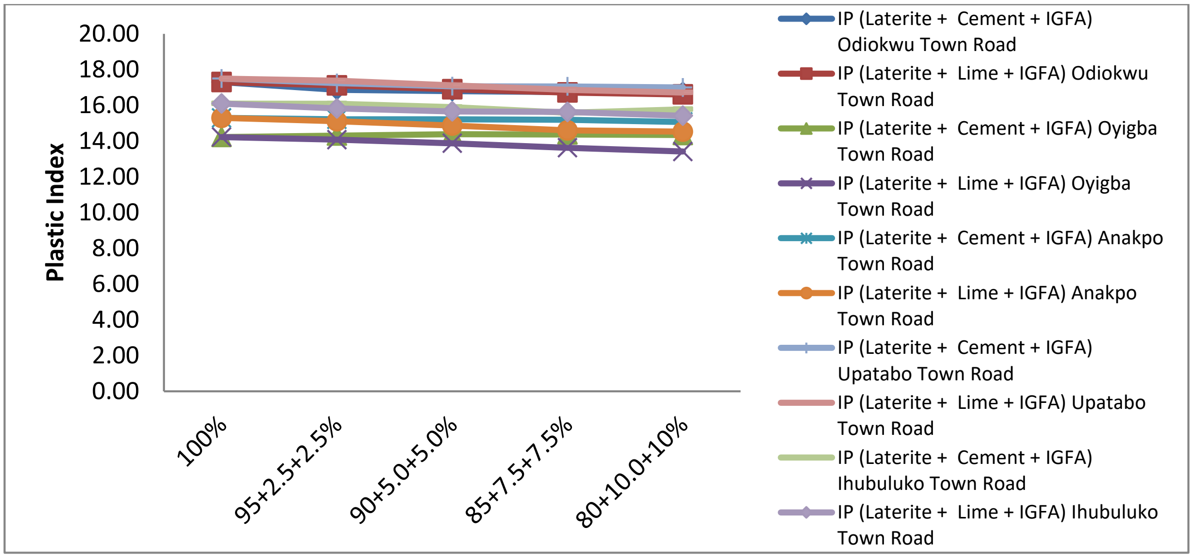

Figure 6: Plastic Index (PI) of Niger Deltaic Lateritic Soils Subgrade with IGFA + Cement/lime

Figure 6 showed the characteristics consistency limits for plastic Index (PI) for unstabilized and stabilized lateritic soils at varying percentages ratio. Here, unlike the LL and PL at 100%, PI values were higher compared to when the soil was stabilized with composite materials. Thus, the percentage of PI in all the samples generally decreased as lateritic soil content was reduced in the mixture. In comparison, Upatabo Town road samples with laterite+ lime/cement+ IGFA has the highest PL percentage, while Oyigba Town road sample with laterite+ lime+ IGFA recorded the lowest PI in the corresponding hybrids. Interestingly, previous work showed that plastic index increased with reduction in lateritic soil content [14], while Charles et al. reported both increase and decrease in PI as lateritic soil content was reduced [16]. However, the trends in PI obtained in this work agree with other works [15, 17].

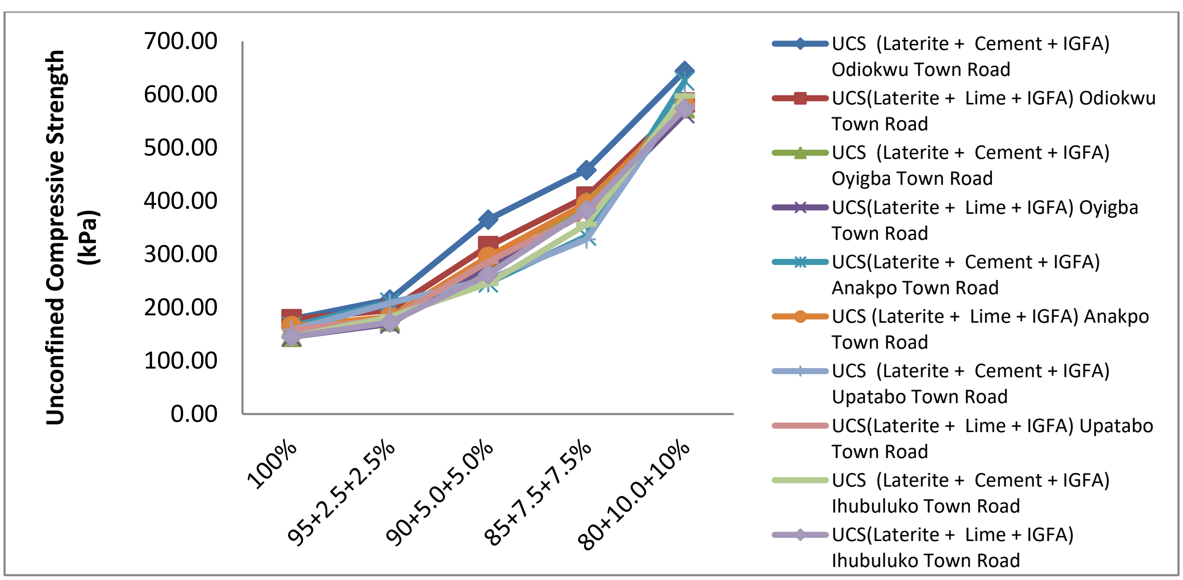

Figure 7: Unconfined Compressive Strength (UCS) of Niger Deltaic Laterite Soils Subgrade with IGFA +

Cement/Lime

Figure 7 showed the profiles of unconfined compressive strength (UCS) of Niger deltaic lateritic soils subgrade hybridized with composite materials. Again, the UCS of the soil samples at 100% was very low, but significantly improved when IGFA and lime or cement was added. Thus, the percentage of UCS of all the samples increased progressively as lateritic soil content was reduced in the mixture. In comparison, Odiokwu Town road soil with laterite+ cement+ IGFA has the highest UCS percent, while Upatabo Town road soil with laterite+ cement + IGFA recorded the lowest UCS values. The trends in UCS of the soil samples also agree with previously reported works [14-15].

4. CONCLUSION

The following conclusions were made from the experimental research results.

i. Preliminary investigations conducted on soils engineering properties in table 3.1 showed that the soils did not conform to standard specification for soils or soil-based materials usable in Road pavement structures as stated by the FMW Specifications (1997).

ii. Comparative results of sampled roads on statistical percentile variations has the results as; Obtained results of compaction test maximum dry density (MDD) and optimum moisture content (OMC) are Odioku, 1.006% and 1.010%, Oyigba 1.012%, and 1.022%, Anakpo 1.013% and 1.014%, Upatabo 1.010% and 1.025%, Ihubuluko 1.011% and 1.024% respectively of MDD and OMC at 100% natural soils

iii. California Bearing Ratio (CBR) test results at 100% are unsoaked 4.644%, 4.447%, 3.696%, 4.835%, 4.467% and soaked, 4.382%, 4.321%, 3.576%, 4.921%, 4.551%, for Odioku, Oyigba, Anakpo, Upatabo and Ihubuluko respectively.

iv. Results of Unconfined compressive strength test from sampled roads are Odioku 1.393%, Oyigba 1.483%, Anakpo 1.636%, Upatabo 1.633% and Ihubuluko 1.441% respectively at 100% natural state. Consistency limits (Plastic index) test results at 100% natural condition from sampled roads are Odioku 0.995%, Oyigba 0.989%, Anakpo 0.988%, Upatabo 0.997% and Ihubuluko 0.987%.

v. Results of percentile increases/ reductions and differences in tables 3.2 – 3.19 and figures 3.1 – 3.6 detailed that compaction test results obtained of maximum dry density (MDD) and optimum moisture content (OMC) showed incremental percentile values to corresponding composite stabilizers inclusion percentages ratio to soils.

vi. California bearing ratio (CBR) results stabilized with cement, lime and IGFA showed incremental percentile values with optimum percentile ratio of 85+7.5+7.5%. Recorded results further confirmed that both cementitious stabilizers proved to show good hybridization properties with IGFA.

vii. Unconfined compressive strength test of stabilized soils with cement / lime + IGFA showed incremental percentile rise to corresponding ratios of composite materials to soil.

viii. Both cementitious agents with + IGFA proved as good soil stabilizers with cement combinations at higher side.

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