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Research Article

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Relative Strength Performance Variance of Cement - Lime with Pozzolanaic Ash Used for Black Cotton Soils Stabilization

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Abstract The study comparatively examined performance characteristics of cementitious stabilizing agents of cement, lime and pozzolanaic ash products of irvinga gabonesis fibre ash, hybridized for the modification of weak subgrades as stabilizers. The soils classified as A - 7 - 6 / CH on the AASHTO classification schemes / Unified Soil Classification System as shown in table 3.1 and are less matured in the soils vertical profile and probably much more sensitive to all forms of manipulation that other deltaic lateritic soils are known for. The soil has unsoaked CBR values of 7.35%, 7.75%, 8.15%, and 7.85% and soaked CBR values of 6.35%, 6.23%, 7.05% and 5.55%, unconfined compressive strength values of 87.85kPa , 78.75kPa, 105.75kPa and 85.35kPa. Obtained percentile values of clay soil parameters at natural condition compaction test maximum dry density (MDD) and optimum moisture content (OMC) from sampled roads are, Iwofe, 1.031% and 1.030%, Chokocho, 1.018% and 1.017%, Ndoni 1.019%,and 1.029%, Ogbele 1.015% and 1.020% respectively of MDD and OMC. California bearing ratio (CBR) test unsoaked are 3.878%, 3.890%, 4.190%, 3.478% and soaked, 3.693%, 4.518%, 4.497%, 4.6713%, of Iwofe, Chokocho, Ndoni, and Ogbele respectively. Unconfined compressive strength test of sampled roads are; Iwofe 1.366%, Chokocho 1.638%, Ndoni 1.495% and Ogbele 2.076%, respectively. Consistency limits (Plastic index) at preliminary tests of 100% natural and at composite stabilized states are iwofe 0.958%, Chokocho 0.980%, Ndoni 0.992% and Ogbele 0.990%. Results of stabilized detailed compaction test maximum dry density (MDD) and optimum moisture content (OMC) showed that stabilized soils with composite materials showed incremental percentile values with increase in composite materials ratio to soil. Illustratively, figures 3.1 and 3.2 graphically represented strength difference between cement and lime composite parameters of stabilized soils with cement in higher values Entire results of both cementitious materials in hybridization showed incremental percentile rise with increase in ratio of composite materials to soils with peak combination of 85+7.5+7.5% and higher strength recorded in cement composition to lime and illustrated in graphically in figure 3.3. Results showed, unconfined compressive strength test incremental percentile values with respect to percentages inclusion of composite materials ratio to soils with peak values recorded in cement composition over lime, though, both cementious agents proved good in use with IGFA. Results of consistency limit test (Plastic index) showed decreased values with composite material inclusion to IGFA. The decreased rates correspond to ratio mix percentages as shown in tables. Entire results recorded demonstrated the potential of composite materials as good soil stabilizers.

Keywords Clay soils, Irvinga Gabonesis Fibre Ash, Cement, Lime, CBR, UCS, Consistency, Compaction

1. Introduction

Foundation of any infrastructural facilities such as roads, roadways and the likes is an important member for effective transmission of loads evenly to the sub-grade present beneath it, necessary mitigation measure employed by evolving new construction materials to suit various traffic and site conditions for economic and

safe design was jet another challenging task in road constructions. To achieve the required standards, soils needed to be improved before use. Stabilization is an obvious option and could be mechanical (if simply compacted with or without the addition of sand addition), chemical (if compacted with controlled proportions of stabilizing agents, including bitumen, lime and cement), thermal (which could produce dehydrated hard-pans) and even electrical (through, for example, electro-osmosis).

Charles *et al.* [1] investigated the problematic engineering properties of soils with high plasticity level, high swelling and shrinkage potentials used in pavement design in the Nigerian Niger Delta region. The application of stabilizing agents of cement and costus afer bagasse fibre (Bush Sugarcane Bagaase Fibre) were mixed in single and combines actions to improved their unique properties. Results showed that inclusion stabilizing material improved strength properties of the soils. Results of tests carried out show that the optimum moisture content increased with increasing cement ratios to both soils (clay) and (laterite). Treated soils with Cement decreased in liquid limits and increased in plastic limits. Soils with Cement and fibre products in combinations increased CBR values appreciably both at soaked and unsoaked conditions. At 8% of lime, CBR values reached optimum, beyond this range, cracks exist and 7.5% cement + 0. 75% BSBF, optimum value are reached.

Charles *et al.* [2] evaluated the geotechnical properties of an expansive clay soil found along Odioku – Odiereke Road in Ahoada-West, Rivers State, in the Niger Deltaic region. The application of two cementitious agents of cement and lime, hybridized with costus afer bagasse fiber to strengthen the failed section of the Rd. The preliminary investigation values indicated that the soils are highly plastic. The results showed the potential of using bagasse, BSBF as admixtures in cement and lime treated soils of clay and laterite with optimum values of 8 % cement and lime and 7.5% +7.5 % of cement / lime + BSBF.

Charles *et al.* [3] investigated and evaluated the engineering properties of an expansive lateritic soil with the inclusion of cement / lime and costus afer bagasse fibre ash (locally known as bush sugarcane fibre ash (BSBFA) with ratios of laterite to cement, lime and BSBFA of 2.5% 2.5%, 5.0% 5.0%, 7.5% 7.5% and 10% 10% to improve the values of CBR of less than 10%. At 8% of both cement and lime, CBR values reached optimum, beyond this range, cracks exist and 7.5% cement and lime 7.5% BSBFA, and 7.25% cement and lime 0. 7.5% BSBF, optimum value are reached. The entire results showed the potential of using bagasse, BSBFA as admixtures in cement and lime treated soils of laterite.

Agunwamba *et al* [4] states that soil stabilization with bagasse ash has come forth as a comely option to foresee low-cost roads construction and to achieve sufficient strength.

Manikandan and Moganraj [5] had found that the combined effect of bagasse ash and lime were more effective than the effect of bagasse ash alone in controlling the consolidation characteristics of expansive soil along with the improvement in other properties.

Sabat [6] studied the effects of polypropylene fiber on engineering properties of RHA-lime stabilized expansive soil. Polypropylene fiber added were 0.5 % to 2 % at an increment of 0.5 %.The properties determined were compaction, UCS, soaked CBR, hydraulic conductivity and P effect of 0 day, 7 days and 28 days of curing ware also studied on UCS, soaked CBR, hydraulic conductivity and swelling pressure. The optimum proportion of Soil: RHA: lime: fiber was found to be 84.5:10:4:1.5.

Ramakrishna and Pradeep [7] studied combined effects of RHA and cement on engineering properties of black cotton soil. From strength characteristics point of view they had recommended 8 % cement and 10 % RHA as optimum dose for stabilization.

Ganesan *et al.*, [8] studied on the use of bagasse ash (BA) as partial cement replacement material in respect of cement mortars. Up to 20 % of ordinary Portland cement can be optimally replaced with well-burnt bagasse ash without any adverse effect on the desirable properties of concrete. Several studies have been carried out on the effectiveness of clay stabilization by RHA admixing.

Basha, *et al.*, [9] studied the stabilization of residual soils by chemically using cement and RHA. In general, 6 %, 8 % of cement and 10 %, 15 % RHA show the optimum amount to reduce the plasticity of soil. CBR value determined maximum at 4% cement and 5 % RHA mixtures with soil. According to compressive strength and PI, 6 %, 8% of cement and 15 %, 20 % RHA showed the optimum amount to improve the properties of soils.

2. Materials and Methods

2.1 Materials

2.1.1 Soil

The soils used for the study were collected within failed sections of the at 1.5 m depth from Iwofe Town Rd, in Obio/Akpor Local Government Area, Chokocho Town Rd, in Etche Local Government Area, Ndoni Town Rd, in Ogba/Egbema/Ndoni Local Government Area and Ogbele Town Rd in ahoada – East Local Government Area, all in Rivers State, Nigeria.

2.1.2 Irvinga Gabonesis Fibre (Bush Mango)

The irvinga gabonesis, popularly called Bush mango, with Nigerian native name (Egbono) are widely spread plants across Nigerian bushes and farm land with edible fruits that bears the fibre , they are collected from at Olokuma village, a river side area in Ubie Clan, Ahoada-West, Rivers State, Nigeria.

2.1.3 Lime

The lime used for the study was purchased in the open market at Mile 3 market road, Port Harcourt

2.1.4 Cement

The cement used was Portland Cemenet, purchased in the open market at Mile 3 market road, Port Harcourt, Rivers State

2.2 Method

2.2.1 Sampling Locality

The soil sample used in this study were collected along Iwofe Town, (latitude 4.49° 41‘S and longitude 6.57° 24‘E), Chokocho Town, (latitude 4.9882° N ° 34‘S and longitude 7.0525° ° 13‘E), Ndoni Town, latitude 5.5487 ° 21‘S and longitude 6.5917° ° 39‘E), Ogbele Town, (latitude 4.9198 ° 23‘S and longitude 6.6751 ° 34‘E) all in Rivers State, Nigeria.

2.2.2 Test Conducted

Test conducted were (1) Moisture Content Determination (2) Consistency limits test (3) Particle size distribution (sieve analysis) and (4) Standard Proctor Compaction test, California Bearing Ratio test (CBR) and Unconfined compressive strength (UCS) tests.

2.2.3 Moisture Content Determination

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

2.2.4 Grain Size Analysis (Sieve Analysis)

This test is performed to determine the percentage of different grain sizes contained within a soil. The mechanical or sieve analysis is performed to determine the distribution of the coarser, larger-sized particles.

2.2.5 Consistency Limits

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.

2.2.6 Moisture – Density (Compaction) Test

This laboratory test is performed to determine the relationship between the moisture content and the dry density of a soil for a specified compactive effort.

2.2.7 Unconfined Compression (UC) Test

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

2.2.8 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.

3. Results and Discussions

Preliminary results on clay soils as seen in detailed test results given in Tables: 3.1 showed that the physical and engineering properties fall below the minimum requirement for such application and needs stabilization to improve its properties. The soils classified as A - 7 - 6 / CH on the AASHTO classification schemes / Unified Soil Classification System as shown in table 3.1 and are less matured in the soils vertical profile and probably much more sensitive to all forms of manipulation that other deltaic lateritic soils are known for. The soil has unsoaked CBR values of 7.35%, 7.75%, 8.15%, and 7.85% and soaked CBR values of 6.35%, 6.23%, 7.05% and 5.55%, unconfined compressive strength values of 87.85kPa , 78.75kPa, 105.75kPa and 85.35kPa.

3.1 Compaction Test Results

Obtained 100% natural preliminary compaction test of maximum dry density (MDD) and optimum moisture content (OMC) from sampled roads are, Iwofe, 1.031% and 1.030%, Chokocho, 1.018% and 1.017%, Ndoni 1.019%,and 1.029%, Ogbele 1.015% and 1.020% respectively of MDD and OMC. Stabilized clay soil results with composites materials of Iwofe samples MDD clay + cement + IGFA are 6.195%, 8.628%, 14.503%, 16.106% , clay + lime + IGFA 1.947%, 2.253%, 5.220%, 8.722%, OMC are clay + cement + IGFA 5.933%, 7.962%, 12.543%, 14.506%, clay + lime + IGFA 3.246%, 5.995%, 7.304%, 10.576%. Chokocho MDD clay + cement + IGFA are 3.637%, 5.655%, 7.306%, 10.548%, clay + lime + IGFA 1.854%, 3.301%, 4.708%, 7.154%, OMC are clay + cement + IGFA 3.290%, 4.826%, 6.238%, 8.818%, clay + lime + IGFA 2.078%, 5.026%, 6.807%, 7.790% . Ndoni MDD clay + cement + IGFA are 3.707%, 4.069%, 5.337%, 6.846%, clay + lime + IGFA 1.963%, 2.653%, 3.981%, 6.274%, OMC are clay + cement + IGFA 5.773%, 8.390%, 9.574%, 13.001%, clay + lime + IGFA 3.091%, 5.771%, 1.721%, 9.260%. Ogbele stabilized MDD clay + cement + IGFA are 3.041%, 6.282%, 7.284%, 8.757%, clay + lime + IGFA 1.1706%, 1.590%, 4.242%, 13.788%%, OMC clay + cement + IGFA 4.028%, 7.715%, 9.940%, 11.657%, clay + lime + IGFA 4.028%, 5.935%, 9.177%, 10.640%. Detailed compaction test maximum dry density (MDD) and optimum moisture content (OMC) results showed that stabilized soils with composite materials showed incremental percentile values with increase in composite materials ratio to soil. Illustratively, figures 3.1 and 3.2 graphically represented strength difference between cement and lime composite parameters of stabilized soils with cement in higher values

3.2 California Bearing Ratio (CBR) Test

Preliminary generated percentile results from table 3.3 into 3.3A of California bearing ratio (CBR) test at 100% generated percale values from tables 3.2 and 3.3 and summarized into 3.2A and 3.3A are unsoaked are 3.878%, 3.890%, 4.190%, 3.478% and soaked, 3.693%, 4.518%, 4.497%, 4.6713%, of Iwofe, Chokocho, Ndoni, and Ogbele respectively. Stabilized Iwofe unsoaked clay + cement + IGFA are 361.966%, 756.523%, 938.156%, 829.313%, clay + lime + IGFA; 323.267% , 587.893%, 840.818%, 738.233%, soaked clay + cement + IGFA), 342.212%, 734.338%, 975.283%, 831.976%, clay + lime + IGFA 312.982%, 609.045%, 874.400%, 812.510%. Chokocho stabilized unsoaked clay + cement + IGFA are 363.327%, 613.005%, 920.747%, 771.069%, clay + lime + IGFA, 338.470% , 538.599%, 853.953% , 673.308%, soaked clay + cement + IGF, 429.714%, 556.520%, 1066.151%, 853.149%, clay + lime + IGFA, 332.948%, 591.375%, 931.343%, 732.788%. Ndoni unsoaked clay + cement + IGFA are 395.153%, 666.932%, 940.552%, 727.423%, clay + lime + IGFA, 427.456%, 625.002%, 938.499%, 758.744%, soaked clay + cement + IGFA , 377.260%, 673.005%, 957.402%, 795.700, clay + lime + IGFA 414.139%, 688.465%, 948.040%, 789.884%. Ogbele unsoaked clay + cement + IGFA are 319.016%, 546.405%, 862.328%, 704.366%, clay + lime + IGFA are 336.884%, 530.896%, 848.986%, 723.508%, soaked clay + cement + IGFA, 379.783%, 670.774%, 1098.702%, 915.459%, clay + lime + IGFA , 499.648%, 695.504%, 1057.846%, 862.711%. Entire results of both cementitious materials in hybridization showed incremental percentile rise with increase in ratio of composite materials to soils with peak combination of 85+7.5+7.5% and higher strength recorded in cement composition to lime and illustrated in graphically in figure 3.3.

3.3 Unconfined Compressive Strength Test

Generated results into percentile relationship different from table 3.8 to 3.8A, preliminary test results at 100% natural soil unconfined compressive strength test of sampled roads are; Iwofe 1.366%, Chokocho 1.638%, Ndoni 1.495% and Ogbele 2.076%, respectively. Stabilized composite materials unconfined compressive strength of Iwofe clay + cement + IGFA are 63.388%, 193.155%, 278.528%, 456.103% , clay + lime + IGFA ,121.261%, 270.379%, 328.433%, 614.147%, Chokocho clay + cement + IGFA are 102.763%, 265.303%, 427.842%, 592.922%, clay + lime + IGFA 126.517%, 330.962%, 501.121%, 710.644%. Ndoni clay + cement + IGFA are 82.581%, 185.703%, 396.677%, 522.505%, clay + lime + IGFA 143.394%, 246.438%, 388.242%, 558.407% and Ogbele clay + cement + IGFA are 159.379%, 269.757%, 423.327%, 581.695%, clay + lime + IGFA 192.627%, 304.205%, 516.563%, 695.327%. Results showed, unconfined compressive strength test incremental percentile values with respect to percentages inclusion of composite materials ratio to soils with peak values recorded in cement composition over lime, though, both cementious agents proved good in use with IGFA.

3.4 Consistency Limits Test

Consistency limits (Plastic index) at preliminary tests generated percentile valus from tables 3.5, 3.6 and 3.7 to 3.5A, 3.6A, summarized into 3.7A of 100% natural and at composite stabilized states are iwofe 0.958%, Chokocho 0.980%,, Ndoni 0.992%, , and Ogbele 0.990%. Composite stabilized Iwofe clay + cement + IGFA are -8.677%, -10.060%, -9.899%, -11.603%, clay + lime + IGFA -8.006%, -8.745%, -9.710%, -11.318%. Percentile Chokocho stabilized clay + cement + IGFA are -4.116%, -4.971%, -6.112%, -7.782%, clay + lime + IGFA -1.144%, -2.610%, -3.466%, -4.362%. Ndoni clay + cement + IGFA are -1.617%, -2.712%, -4.032%, -4.644%., clay + lime + -7.215%, -7.924%, -9.244%, -10.243%. Ogbele clay + cement + IGFA are -1.999%, -2.994%, -4.082%, -4.890%, clay + lime + IGFA -1.372%, -2.305%, -3.300%, -2.274%. Results of consistency limits test (Plastic index) showed decreased values with composite material inclusion to IGFA as demonstrated in figures 3.4, 3.5 and 3.6 graphicaly with cement at peak.

Table 3.1: Engineering Properties of Soil Samples (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

Location Description	**Iwofe Rd Obio/Akpor L.G.A**	**Chokocho Rd Etche L.G.A**	**Ndoni Rd Ogba/Egbema/ Ndoni L.G.A**	**Ogbele Rd Ahoda East L.G.A**
Depth of sampling (m)	1.2	1.2	1.2	1.2
Percentage(%) passing BS sieve #200	76.35	80.25	83.65	78.25
Colour	greenish	Greenish	greenish	greenish
Specific gravity	2.52	2.58	2.45	2.44
Natural moisture content (%)	42.58	48.35	44.65	44.30
Consistency Limits				
Liquid limit (%)	68.35	53.85	62.40	58.75
Plastic limit (%)	37.25	29.30	31.35	26.58
Plasticity Index	31.10	24.55	31.05	32.17
AASHTO soil classification	A-7-6	A-7-6	A-7-6	A-7-6
Unified Soil Classification System	CH	CH	CH	CH
Optimum moisture content (%)	15.28	16.28	16.05	15.73
Maximum dry density ($kN/m^{3)}$	1.685	1.635	1.657	1.697
Compaction Characteristics				
Gravel (%)	0.0	0	0	0
Sand (%)	13.18	12.3	12.8	16.5
Silt (%)	42.3	48.5	42.3	48.2
Clay (%)	44.6	38.2	44.9	35.3
Unconfined compressive strength (kPa)	87.85	78.75	105.75	85.35
California Bearing Capacity (CBR)				
Unsoaked (%) CBR	7.35	7.75	8.15	7.85
Soaked (%) CBR	6.35	6.23	7.05	5.55

Table 3.2: Results of Maximum Dry Density (MDD) of Niger Deltaic Clay Soils Subgrade with IGFA + Cement / Lime of (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

RATIO %	**100%**	**95+2.5 +2.5%**	**90+5.0 +5.0%**	**85+7.5 +7.5%**	**80+10.0 +10%**
MDD (Clay + Cement + IGFA) IWOFE TOWN ROAD	1.69	1.74	1.78	1.88	1.91
MDD (kN/m^3) (Clay + Lime + IGFA) IWOFE TOWN ROAD	1.69	1.69	1.72	1.77	1.82
MDD (Clay + Cement + IGFA) CHOKOCHO TOWN ROAD	1.64	1.67	1.70	1.73	1.78
MDD (kN/m^3) (Clay + Lime + IGFA) CHOKOCHO TOWN ROAD	1.64	1.64	1.68	1.71	1.75
MDD (Clay + Cement + IGFA) NDONI TOWN ROAD	1.66	1.69	1.69	1.72	1.74
MDD (kN/m^3) (Clay + Lime + IGFA) NDONI TOWN ROAD	1.66	1.67	1.69	1.72	1.75
MDD (Clay + Cement + IGFA) OGBELE TOWN ROAD	1.70	1.72	1.78	1.80	1.82
MDD (kN/m^3) (Clay + Lime + IGFA) OGBELE TOWN ROAD	1.70	1.70	1.72	1.76	1.93

Table 3.2A: Results of Maximum Dry Density (MDD) Percentile Increase / Decrease of Niger Deltaic Clay Soils Subgrade with IGFA + Cement / Lime of (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

RATIO %	**100%**	**95+2.5 +2.5%**	**90+5.0 +5.0%**	**85+7.5 +7.5%**	**80+10.0 +10%**
MDD (Clay + Cement + IGFA) IWOFE TOWN ROAD	1.03%	6.19%	8.63%	14.50%	16.11%
MDD (kN/m^3) (Clay + Lime + IGFA) IWOFE TOWN ROAD	1.00%	0.95%	2.25%	5.22%	8.72%
MDD (Clay + Cement + IGFA) CHOKOCHO TOWN ROAD	1.02%	3.64%	5.66%	7.31%	10.55%
MDD (kN/m^3) (Clay + Lime + IGFA) CHOKOCHO TOWN ROAD	1.00%	0.85%	3.30%	4.71%	7.15%
MDD (Clay + Cement + IGFA) NDONI TOWN ROAD	1.02%	3.71%	4.07%	5.34%	6.85%
MDD (kN/m^3) (Clay + Lime + IGFA) NDONI TOWN ROAD	1.00%	0.96%	2.65%	3.98%	6.27%
MDD (Clay + Cement + IGFA) OGBELE TOWN ROAD	1.02%	3.04%	6.28%	7.28%	8.76%
MDD (kN/m^3) (Clay + Lime + IGFA) OGBELE TOWN ROAD	1.00%	0.71%	1.59%	4.24%	13.79%

Table 3.3: Results of Optimum Moisture Content (OMC) of Niger Deltaic Clay Soils Subgrade with IGFA + Cement / Lime of (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

RATIO %	**100%**	**95+2.5 +2.5%**	**90+5.0 +5.0%**	**85+7.5 +7.5%**	**80+10.0 +10%**
OMC% (Clay + Cement+ IGFA) IWOFE TOWN ROAD	15.28	15.74	16.05	16.75	17.05
OMC% (Clay + Lime + IGFA) IWOFE TOWN ROAD	15.28	15.53	15.95	16.15	16.65
OMC% (Clay + Cement+ IGFA) CHOKOCHO TOWN ROAD	16.28	16.55	16.80	17.03	17.45
OMC% (Clay + Lime + IGFA) CHOKOCHO TOWN ROAD	16.28	16.45	16.93	17.22	17.38
OMC% (Clay + Cement+ IGFA) NDONI TOWN ROAD	16.05	16.52	16.94	17.13	17.68
OMC% (Clay + Lime + IGFA) NDONI TOWN ROAD	16.05	16.30	16.73	16.08	17.29
OMC% (Clay + Cement+ IGFA) OGBELE TOWN ROAD	15.73	16.05	16.63	16.98	17.25
OMC%(Clay + Lime + IGFA) OGBELE TOWN ROAD	15.73	16.05	16.35	16.86	17.09

Table 3.3A: Results of Optimum Moisture Content (OMC) Percentile Increase / Decrease of Niger Deltaic Clay Soils Subgrade with IGFA + Cement / Lime of (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

RATIO %	**100%**	**95+2.5 +2.5%**	**90+5.0 +5.0%**	**85+7.5 +7.5%**	**80+10.0 +10%**
OMC% (Clay + Cement+ IGFA) IWOFE TOWN ROAD	1.03%	5.93%	7.96%	12.54%	14.51%
OMC% (Clay + Lime + IGFA) IWOFE TOWN ROAD	1.02%	3.25%	5.99%	7.30%	10.58%
OMC% (Clay + Cement+ IGFA) CHOKOCHO TOWN ROAD	1.02%	3.29%	4.83%	6.24%	8.82%
OMC% (Clay + Lime + IGFA) CHOKOCHO TOWN ROAD	1.01%	2.08%	5.03%	6.81%	7.79%
OMC% (Clay + Cement+ IGFA) NDONI TOWN ROAD	1.029%	5.773%	8.390%	9.574%	13.001%
OMC% (Clay + Lime + IGFA) NDONI TOWN ROAD	1.016%	3.091%	5.771%	1.721%	9.260%
OMC% (Clay + Cement+ IGFA) OGBELE TOWN ROAD	1.020%	4.028%	7.715%	9.940%	11.657%
OMC% (Clay + Lime + IGFA) OGBELE TOWN ROAD	1.020%	4.028%	5.935%	9.177%	10.64%

Table 3.4: Results of California Bearing Ratio (CBR) of Niger Deltaic Clay Soils Subgrade with IGFA + Cement / Lime of (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

RATIO %	100%	95+2.5 +2.5%	90+5.0 +5.0%	85+7.5 +7.5%	80+10.0 +10%
UNSOAKED CBR (Clay + Cement + IGFA) IWOFE TOWN ROAD	7.35	28.50	57.50	70.85	62.85
UNSOAKED CBR (Clay + Lime + IGFA) IWOFE TOWN ROAD	7.35	25.85	45.30	63.89	56.35
SOAKED CBR(Clay + Cement+ IGFA) IWOFE TOWN ROAD	6.35	23.45	48.35	63.65	54.55
SOAKED CBR (Clay + Lime + IGFA) IWOFE TOWN ROAD	6.35	21.73	40.53	57.38	53.45
UNSOAKED CBR (Clay + Cement + IGFA) CHOKOCHO TOWN ROAD	7.75	30.15	49.50	73.35	61.75
UNSOAKED CBR (Clay + Lime + IGFA) CHOKOCHO TOWN ROAD	7.75	28.35	43.86	68.30	54.30
SOAKED CBR(Clay + Cement+ IGFA) CHOKOCHO TOWN ROAD	6.23	28.15	36.05	67.80	54.53
SOAKED CBR (Clay + Lime + IGFA) CHOKOCHO TOWN ROAD	6.23	22.47	38.57	59.75	47.38
UNSOAKED CBR (Clay + Cement + IGFA) NDONI TOWN ROAD	8.15	34.15	56.30	78.60	61.23
UNSOAKED CBR (Clay + Lime + IGFA) NDONI TOWN ROAD	8.15	36.65	52.75	78.30	63.65
SOAKED CBR(Clay + Cement+ IGFA) NDONI TOWN ROAD	7.05	28.35	49.20	69.25	57.85
SOAKED CBR (Clay + Lime + IGFA) NDONI TOWN ROAD	7.05	30.81	50.15	68.45	57.30
UNSOAKED CBR (Clay + Cement + IGFA) OGBELE TOWN ROAD	7.85	27.30	45.15	69.95	57.55
UNSOAKED CBR (Clay + Lime + IGFA) OGBELE TOWN ROAD	7.85	28.60	43.83	68.80	58.95
SOAKED CBR(Clay + Cement+ IGFA) OGBELE TOWN ROAD	5.55	22.45	38.60	62.35	52.18
SOAKED CBR (Clay + Lime + IGFA) OGBELE TOWN ROAD	5.55	28.80	39.67	59.78	48.95

Table 3.4A: Results of California Bearing Ratio (CBR) Percentile Increase / Decrease of Niger Deltaic Clay Soils Subgrade with IGFA + Cement / Lime of (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

RATIO %	100%	95+2.5 +2.5%	90+5.0 +5.0%	85+7.5 +7.5%	80+10.0 +10%
UNSOAKED CBR (Clay + Cement + IGFA) IWOFE TOWN ROAD	3.88%	361.97%	756.52%	938.16%	829.31%
UNSOAKED CBR (Clay + Lime + IGFA) IWOFE TOWN ROAD	3.52%	323.27%	587.89%	840.82%	738.23%
SOAKED CBR(Clay + Cement+ IGFA) IWOFE TOWN ROAD	3.69%	342.21%	734.34%	975.28%	831.98%
SOAKED CBR (Clay + Lime + IGFA) IWOFE TOWN ROAD	3.42%	312.98%	609.05%	874.40%	812.51%
UNSOAKED CBR (Clay + Cement + IGFA) CHOKOCHO TOWN ROAD	3.89%	363.33%	613.00%	920.75%	771.07%
UNSOAKED CBR (Clay + Lime + IGFA) CHOKOCHO TOWN ROAD	3.66%	338.47%	538.60%	853.95%	673.31%
SOAKED CBR (Clay + Cement+ IGFA) CHOKOCHO TOWN ROAD	4.52%	429.71%	556.52%	1066.15%	853.15%
SOAKED CBR (Clay + Lime + IGFA) CHOKOCHO TOWN ROAD	3.61%	332.95%	591.38%	931.34%	732.79%
UNSOAKED CBR (Clay + Cement + IGFA) NDONI TOWN ROAD	4.19%	395.15%	666.93%	940.55%	727.42%
UNSOAKED CBR (Clay + Lime + IGFA) NDONI TOWN ROAD	4.50%	427.46%	625.00%	938.50%	758.74%
SOAKED CBR (Clay + Cement+ IGFA) NDONI TOWN ROAD	4.02%	377.26%	673.00%	957.40%	795.70%
SOAKED CBR (Clay + Lime + IGFA) NDONI TOWN ROAD	4.37%	414.14%	688.47%	948.04%	789.88%
UNSOAKED CBR (Clay + Cement + IGFA) OGBELE TOWN ROAD	3.48%	319.02%	546.40%	862.33%	704.37%
UNSOAKED CBR (Clay + Lime + IGFA) OGBELE TOWN ROAD	3.64%	336.88%	530.90%	848.99%	723.51%
SOAKED CBR (Clay + Cement+ IGFA) OGBELE TOWN ROAD	4.05%	379.78%	670.77%	1098.70%	915.46%
SOAKED CBR (Clay + Lime + IGFA) OGBELE TOWN ROAD	5.19%	499.65%	695.50%	1057.85%	862.71%

Table 3.5: Results of Liquid Limit (LL) of Niger Deltaic Clay Soils Subgrade with IGFA + Cement / Lime of (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

RATIO %	100%	95+2.5 +2.5%	90+5.0 +5.0%	85+7.5 +7.5%	80+10.0 +10%
LL(Clay + Cement+ IGFA) IWOFE TOWN ROAD	68.35	68.57	68.90	69.23	69.46
LL (Clay + Lime + IGFA) IWOFE TOWN ROAD	68.35	68.52	68.75	69.05	69.38
LL (Clay + Cement+ IGFA) CHOKOCHO TOWN ROAD	53.85	54.12	54.58	54.89	55.41
LL (Clay + Lime + IGFA) CHOKOCHO TOWN ROAD	53.85	54.06	54.35	54.62	54.95
LL (Clay + Cement+ IGFA) NDONI TOWN ROAD	62.40	62.58	62.94	63.21	63.48
LL (Clay + Lime + IGFA) NDONI TOWN ROAD	62.40	62.78	62.91	63.05	63.28
LL (Clay + Cement+ IGFA) OGBELE TOWN ROAD	58.25	58.65	58.93	59.18	59.37
LL (Clay + Lime + IGFA) OGBELE TOWN ROAD	58.25	58.53	58.72	58.93	59.20

Table 3.5A: Results of Liquid Limit (LL) Percentile Increase / Decrease of Niger Deltaic Clay Soils Subgrade with IGFA + Cement / Lime of (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

RATIO %	100%	95+2.5 +2.5%	90+5.0 +5.0%	85+7.5 +7.5%	80+10.0 +10%
LL(Clay + Cement+ IGFA) IWOFE TOWN ROAD	1.00%	0.64%	1.13%	1.61%	1.94%
LL (Clay + Lime + IGFA) IWOFE TOWN ROAD	1.00%	0.50%	0.83%	1.27%	1.76%
LL(Clay + Cement+ IGFA) CHOKOCHO TOWN ROAD	1.01%	1.00%	1.85%	2.43%	3.40%
LL (Clay + Lime + IGFA) CHOKOCHO TOWN ROAD	1.00%	0.78%	1.32%	1.82%	2.43%
LL(Clay + Cement+ IGFA) NDONI TOWN ROAD	1.003%	0.576%	1.153%	1.586%	2.018%
LL (Clay + Lime + IGFA) NDONI TOWN ROAD	1.006%	1.214%	1.423%	1.647%	2.016%
LL(Clay + Cement+ IGFA) OGBELE TOWN ROAD	1.007%	1.369%	1.849%	2.279%	2.605%
LL (Clay + Lime + IGFA) OGBELE TOWN ROAD	1.005%	0.959%	1.285%	1.646%	2.109%

Table 3.6: Results of Plastic Limit (PL) of Niger Deltaic Clay Soils Subgrade with IGFA + Cement / Lime of (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

RATIO %	100%	95+2.5 +2.5%	90+5.0 +5.0%	85+7.5 +7.5%	80+10.0 +10%
PL(Clay + Cement + IGFA) IWOFE TOWN ROAD	37.25	38.95	39.80	40.61	41.18
PL (Clay + Lime + IGFA) IWOFE TOWN ROAD	37.25	38.69	39.25	39.88	40.61
PL(Clay + Cement + IGFA) CHOKOCHO TOWN ROAD	29.30	30.10	30.81	31.36	32.03
PL (Clay + Lime + IGFA) CHOKOCHO TOWN ROAD	29.30	29.71	30.53	31.05	31.79
PL(Clay + Cement + IGFA) NDONI TOWN ROAD	31.35	31.88	32.42	33.00	33.69
PL (Clay + Lime + IGFA) NDONI TOWN ROAD	31.35	32.63	33.21	33.89	34.47
PL(Clay + Cement + IGFA) OGBELE TOWN ROAD	26.58	26.73	27.40	27.99	28.70
PL (Clay + Lime + IGFA) OGBELE TOWN ROAD	26.58	26.70	27.28	27.53	27.71

Table 3.6A: Results of Plastic Limit (PL) Percentile Increase / Decrease of Niger Deltaic Clay Soils Subgrade with IGFA + Cement / Lime of (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

RATIO %	100%	95+2.5 +2.5%	90+5.0 +5.0%	85+7.5 +7.5%	80+10.0 +10%
PL(Clay + Cement + IGFA) IWOFE TOWN ROAD	1.05%	8.93%	11.21%	13.38%	14.91%
PL (Clay + Lime + IGFA) IWOFE TOWN ROAD	1.04%	7.59%	9.09%	10.78%	12.74%
PL(Clay + Cement + IGFA) CHOKOCHO TOWN ROAD	1.03%	5.39%	7.81%	9.69%	11.98%
PL (Clay + Lime + IGFA) CHOKOCHO TOWN ROAD	1.01%	2.78%	5.58%	7.35%	9.88%
PL(Clay + Cement + IGFA) NDONI TOWN ROAD	1.017%	3.353%	5.076%	6.926%	9.127%
PL (Clay + Lime + IGFA) NDONI TOWN ROAD	1.041%	8.006%	9.856%	12.02%	13.87%
PL(Clay + Cement + IGFA) OGBELE TOWN ROAD	1.006%	1.126%	3.646%	5.866%	8.537%
PL (Clay + Lime + IGFA) OGBELE TOWN ROAD	1.005%	0.901%	3.083%	4.024%	4.701%

Table 3.7: Results of Plastic Index (PI) of Niger Deltaic Clay Soils Subgrade with IGFA + Cement / Lime of (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

RATIO %	100%	95+2.5 +2.5%	90+5.0 +5.0%	85+7.5 +7.5%	80+10.0 +10%
PI (Clay + Cement + IGFA) IWOFE TOWN ROAD	31.10	29.78	29.35	29.40	28.87
PI (Clay + Lime + IGFA) IWOFE TOWN ROAD	31.10	29.88	29.65	29.35	28.85
PI (Clay + Cement + IGFA) CHOKOCHO TOWN ROAD	24.55	24.05	23.84	23.56	23.15
PI (Clay + Lime + IGFA) CHOKOCHO TOWN ROAD	24.55	24.41	24.05	23.84	23.62
PI (Clay + Cement + IGFA) NDONI TOWN ROAD	31.05	30.80	30.46	30.05	29.86
PI (Clay + Lime + IGFA) NDONI TOWN ROAD	31.05	29.95	29.73	29.32	29.01
PI (Clay + Cement + IGFA) OGBELE TOWN ROAD	32.17	31.85	31.53	31.18	30.92
PI (Clay + Lime + IGFA) OGBELE TOWN ROAD	32.17	31.95	31.65	31.33	31.66

Table 3.7A: Results of Plastic Limit (PL) Percentile Increase / Decrease of Niger Deltaic Clay Soils Subgrade with IGFA + Cement / Lime of (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

RATIO %	100.00%	95+2.5 +2.5%	90+5.0 +5.0%	85+7.5 +7.5%	80+10.0 +10%
PI (Clay + Cement + IGFA) IWOFE TOWN ROAD	0.96%	-8.68%	-10.06%	-9.90%	-11.60%
PI (Clay + Lime + IGFA) IWOFE TOWN ROAD	0.96%	-8.01%	-8.75%	-9.71%	-11.32%
PI (Clay + Cement + IGFA) CHOKOCHO TOWN ROAD	0.98%	-4.12%	-4.97%	-6.11%	-7.78%
PI (Clay + Lime + IGFA) CHOKOCHO TOWN ROAD	0.99%	-1.14%	-2.61%	-3.47%	-4.36%
PI (Clay + Cement + IGFA) NDONI TOWN ROAD	0.99%	-1.62%	-2.71%	-4.03%	-4.64%
PI (Clay + Lime + IGFA) NDONI TOWN ROAD	0.96%	-7.22%	-7.92%	-9.24%	-10.24%
PI (Clay + Cement + IGFA) OGBELE TOWN ROAD	0.99%	-2.00%	-2.99%	-4.08%	-4.89%
PI (Clay + Lime + IGFA) OGBELE TOWN ROAD	0.99%	-1.37%	-2.30%	-3.30%	-2.27%

Table 3.8: Results of Unconfined Compressive Strength (UCS of Niger Deltaic Clay Soils Subgrade with IGFA + Cement / Lime of (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

RATIO %	100%	95+2.5 +2.5%	90+5.0 +5.0%	85+7.5 +7.5%	80+10.0 +10%
UCS(KPa) (Clay + Cement + IGFA) IWOFE TOWN ROAD	87.85	120.00	234.00	309.00	465.00
UCS(KPa) (Clay + Lime + IGFA) IWOFE TOWN ROAD	87.85	156.00	287.00	338.00	589.00
UCS(KPa) (Clay + Cement + IGFA) CHOKOCHO TOWN ROAD	78.75	129.00	257.00	385.00	515.00
UCS(KPa) (Clay + Lime + IGFA) CHOKOCHO TOWN ROAD	78.75	143.00	304.00	438.00	603.00
UCS(KPa) (Clay + Cement + IGFA) NDONI TOWN ROAD	105.70	158.00	267.00	490.00	623.00
UCS(KPa) (Clay + Lime + IGFA) NDONI TOWN ROAD	105.78	206.00	315.00	465.00	645.00
UCS(KPa) (Clay + Cement + IGFA) OGBELE TOWN ROAD	83.35	173.00	265.00	393.00	525.00
UCS(KPa) (Clay + Lime + IGFA) OGBELETOWN ROAD	83.35	196.00	289.00	466.00	615.00

Table 3.8A: Results of Unconfined Compressive Strength (UCS) Percentile Increase / Decrease of Niger Deltaic Clay Soils Subgrade with IGFA + Cement / Lime of (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

RATIO %	100%	95+2.5 +2.5%	90+5.0 +5.0%	85+7.5 +7.5%	80+10.0 +10%
UCS(KPa) (Clay + Cement + IGFA) IWOFE TOWN ROAD	1.366%	63.39%	193.15%	278.53%	456.10%
UCS(KPa) (Clay + Lime + IGFA) IWOFE TOWN ROAD	1.776%	121.26%	270.38%	328.43%	614.15%
UCS(KPa) (Clay + Cement + IGFA) CHOKOCHO TOWN ROAD	1.638%	102.76%	265.30%	427.84%	592.92%
UCS(KPa) (Clay + Lime + IGFA) CHOKOCHO TOWN ROAD	1.816%	126.52%	330.96%	501.12%	710.64%
UCS(KPa) (Clay + Cement + IGFA) NDONI TOWN ROAD	1.495%	82.58%	185.70%	396.68%	522.51%
UCS(KPa) (Clay + Lime + IGFA) NDONI TOWN ROAD	1.947%	143.39%	246.44%	388.24%	558.41%
UCS(KPa) (Clay + Cement + IGFA) OGBELE TOWN ROAD	2.076%	159.38%	269.76%	423.33%	581.69%
UCS(KPa) (Clay + Lime + IGFA) OGBELETOWN ROAD	2.352%	192.63%	304.21%	516.56%	695.33%

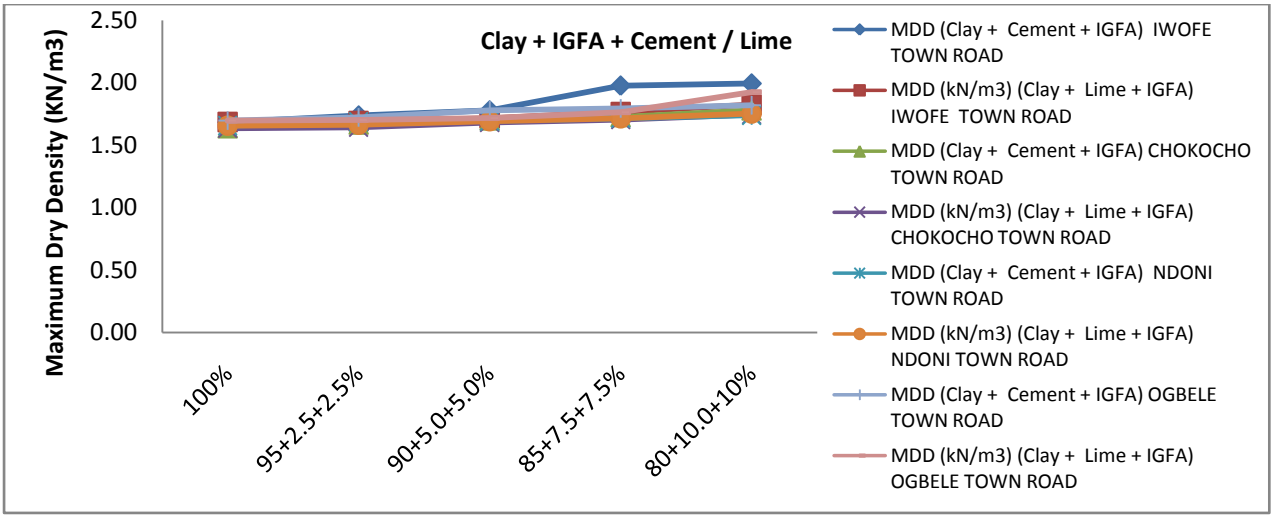

Figure 3.1: Maximum Dry Density (MDD) of Niger Deltaic Clay Soils Subgrade with IGFA + Cement / Lime of (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

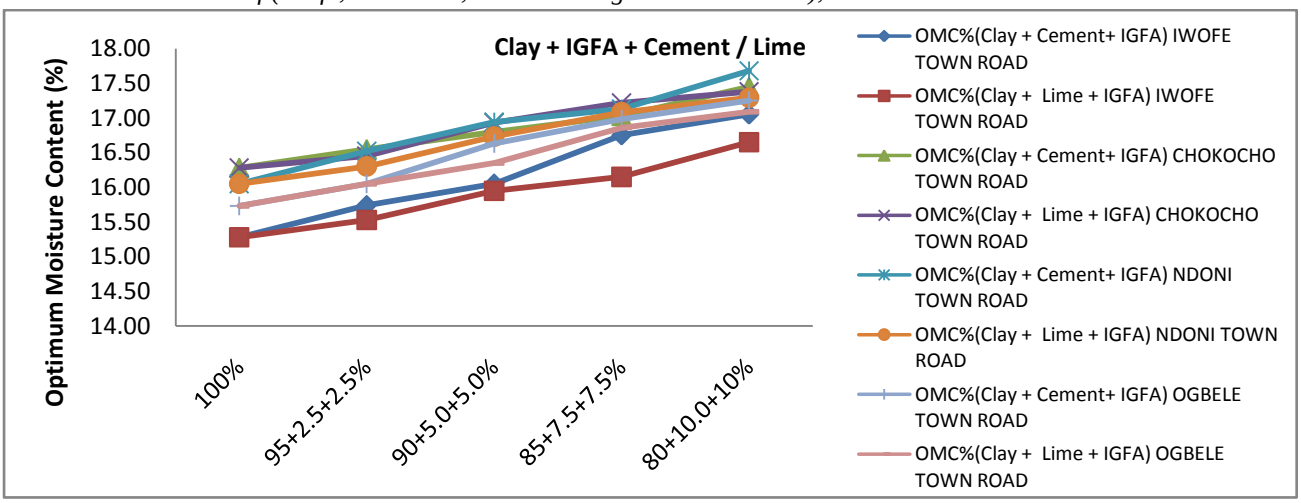

Figure 3.2: Optimum Moisture Content (OMC) of Niger Deltaic Clay Soils Subgrade with IGFA + Cement / Lime of (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

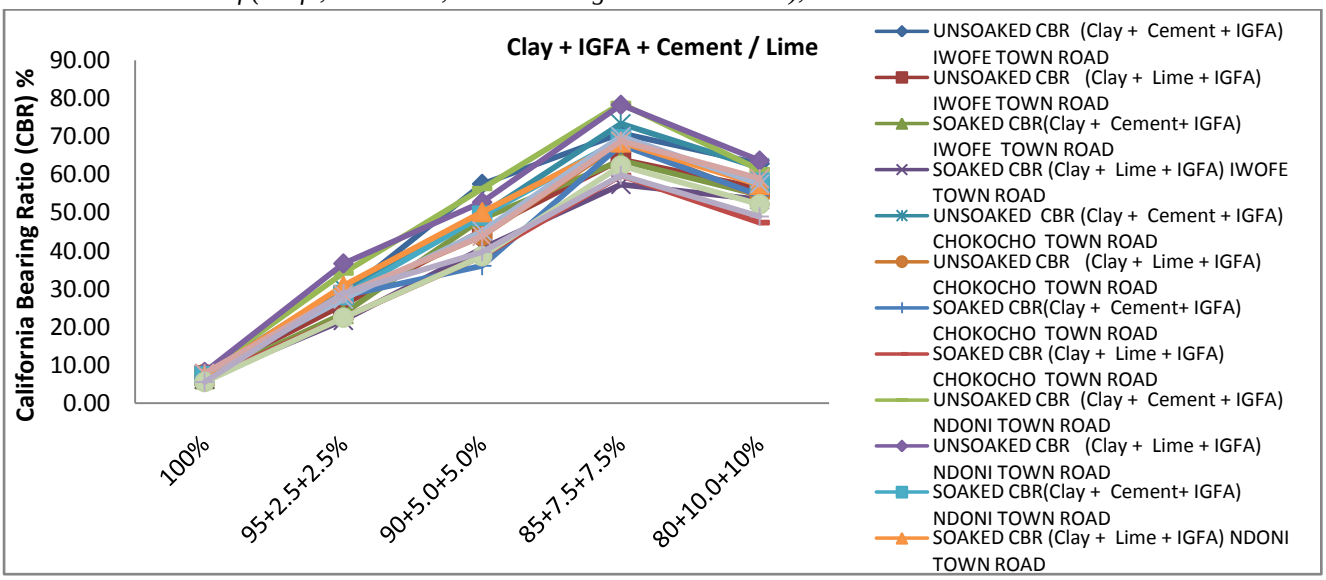

Figure 3.3: California Bearing Ratio (CBR) of Niger Deltaic Clay Soils Subgrade with IGFA + Cement / Lime of (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

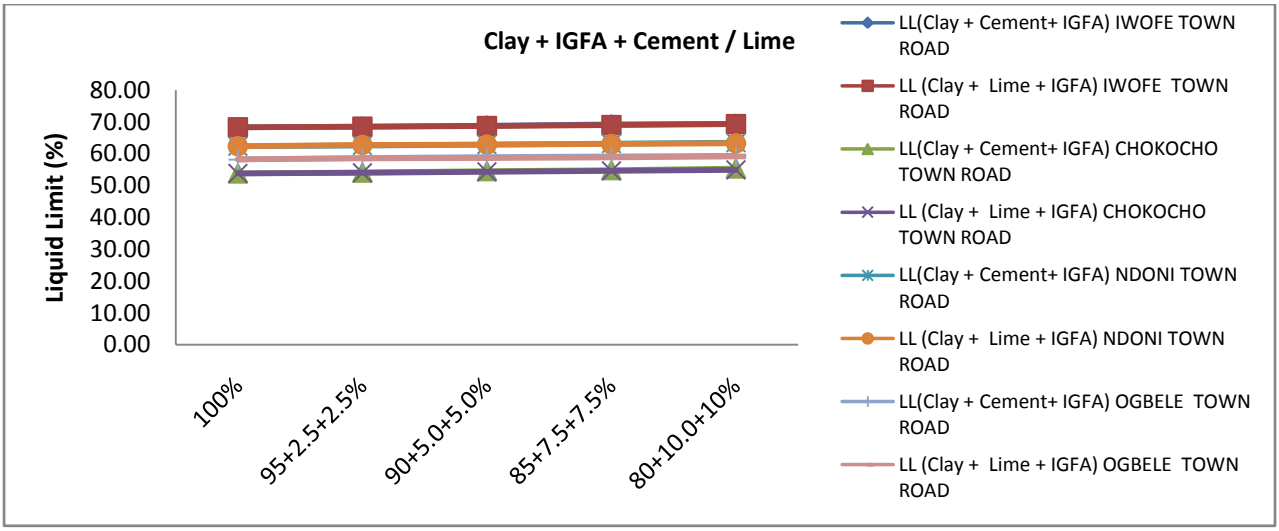

Figure 3.4: Liquid Limit (LL) of Niger Deltaic Clay Soils Subgrade with IGFA + Cement / Lime of (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

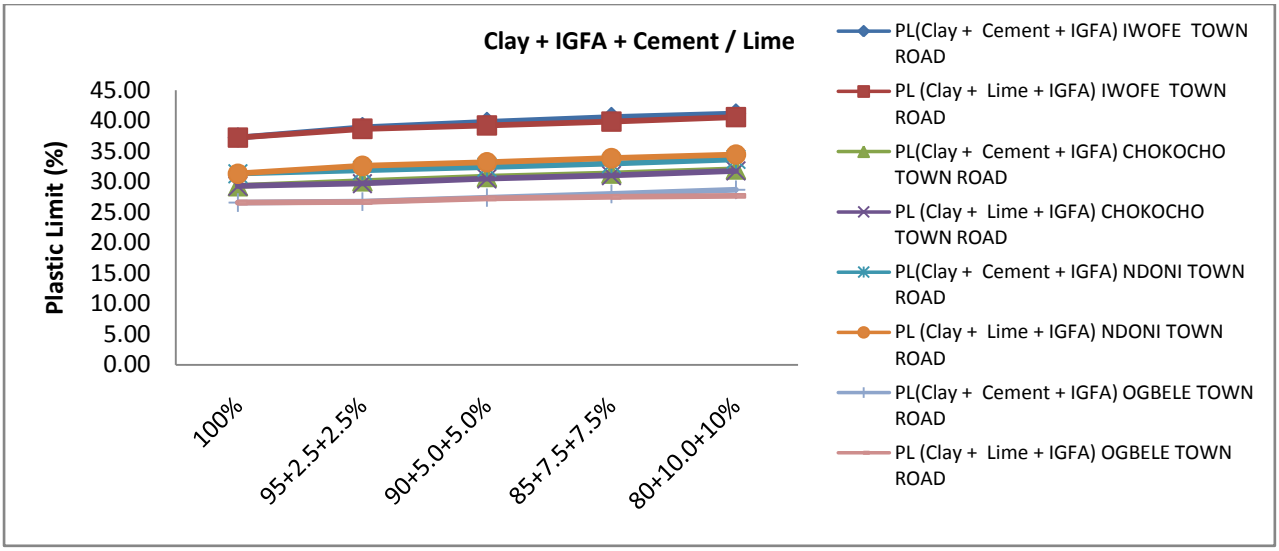

Figure 3.5: Plastic Limit (PL) of Niger Deltaic Clay Soils Subgrade with IGFA + Cement / Lime of (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

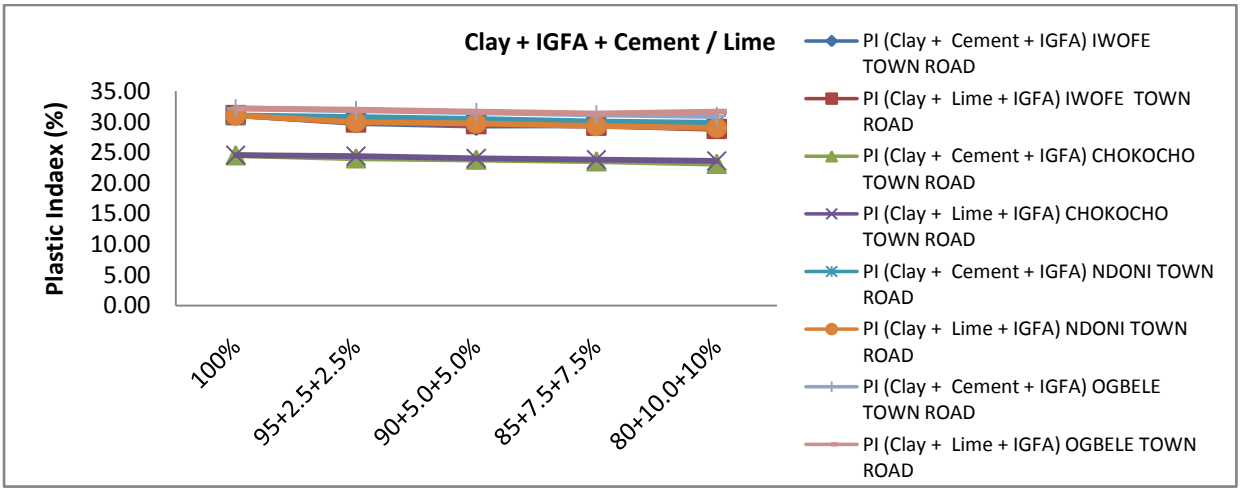

Figure 3.6: Plastic Index (PI) of Niger Deltaic Clay Soils Subgrade with IGFA + Cement / Lime of (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

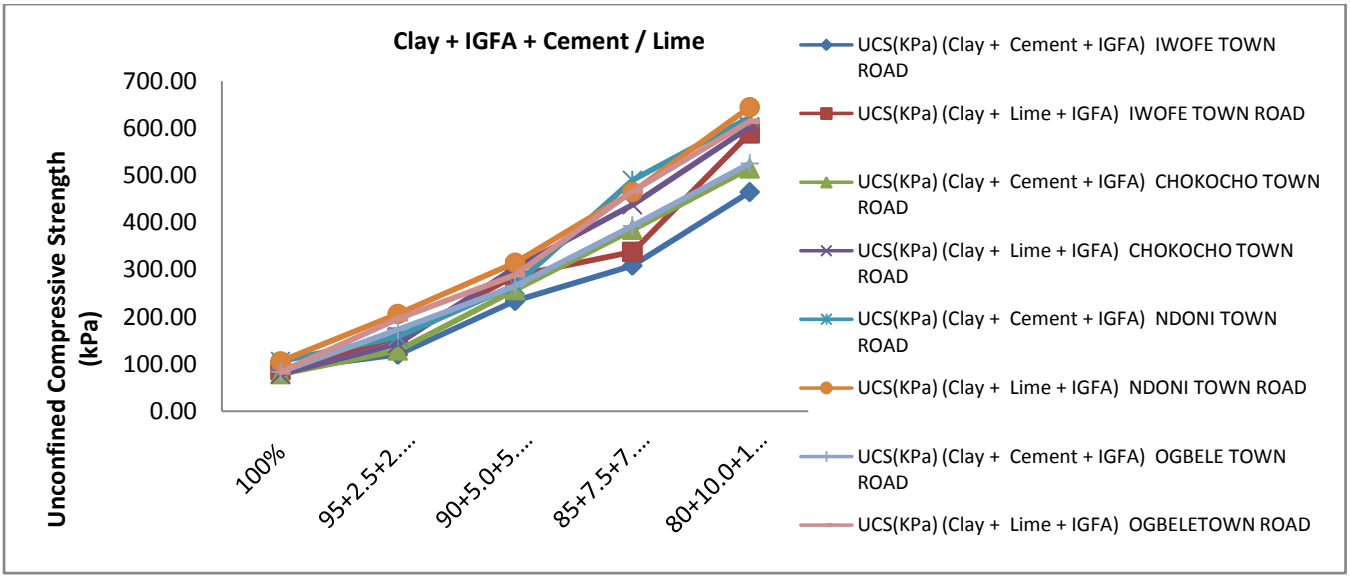

Figure 3.7: Unconfined Compressive Strength (UCS) of Niger Deltaic Clay Soils Subgrade with IGFA + Cement / Lime of (Iwofe, Chokocho, Ndoni and Ogbele Town Roads), Rivers State

4. Conclusions

The following conclusions were made from the experimental research results.

i. The soils classified as A – 7 – 6 on the AASHTO classification System

ii. Detailed compaction test maximum dry density (MDD) and optimum moisture content (OMC) results showed that stabilized soils with composite materials showed incremental percentile values with increase in composite materials ratio to soil.

iii. California bearing ratio (CBR) unsoaked and soaked results of composite materials stabilized soils with percentile ratios shown in table 3.2. Entire results of both cementitious materials in hybridization showed incremental percentile rise with increase in ratio of composite materials to soils with peak combination of 85+7.5+7.5%.

iv. Results showed, unconfined compressive strength test incremental percentile values with respect to percentages inclusion of composite materials ratio to soils.

v. Results of consistency limit test (Plastic index) showed decreased values with composite material inclusion to IGFA. The decreased rate correspond to ratio mix percentages as shown in table 3.2

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