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Composite Materials Combine Action Influence on Strength and Volume Change Behavior of Expansive Soils

Charles Kennedy[1], Gbinu Samuel Kabari[2], Terence Temilade Tam Wokoma[2]

[1]Civil Engineering Department, University of Uyo, Akwa Ibom State, Nigeria
[2]School of Engineering, Department of Civil Engineering, Kenule Beeson Saro-Wiwa Polytechnic, Bori, Rivers State, Nigeria

Abstract This research work evaluated the effectiveness in the used of lime and costus afer fibre (Bush sugarcane bagasse fiber ash (BSBFA) in single and combined actions as soil stabilizer to improve its properties. Considering the fact that Niger Deltaic soils fall short of the minimum requirements for such applications on Specifications for road pavement structural materials (after FMW 1997). Compaction test results of maximum dry density (MDD) at 100% soil and lime + bagasse fibre ash treated soils of laterite and clay are, MDD increased from 1.640kN/m^3 to 1.73kN/m^3 (clay) and 1.803kN/m^3 and 1.838kN/m^3 , OMC results at 0, 2.5% to 10% increased from 12.93% to 14.37% (clay) and 11.79% to 12.405% (laterite). CBR results of soil + lime + bagasse fibre ash (BSBFA) at 100% soils, 2.5%, 5.0%, 7.5% and 10% of lime + BSBFA, increased from 7.6% to 17.8% (clay) and 9.8% to 32.2% (laterite). UCS results of soil + lime + BSBFA treated soils of clay and laterite at additives inclusion percentages range of 2.5%, 5.0%, 7.5% and 10% of lime and BSBFA increased from 78.6kPa to 223kPa (clay) and 155kPa to 299.1% (laterite) at optimum inclusion percentage of 85% (soil) + 7.5% (lime) + 7.5 (BSBFA). Beyond this specified percentage combination, crack was noticed and strength. Consistency limits results of soil + lime + BSBFA treated soils of clay and laterite, LL increased from 56.1% to 58.8% (clay) and 39% to 46.7% (laterite), PL increased from 22.4% to 28% (clay) and 22% to 27% (laterite), IP decreased from 33.7% to 30.8% (clay) and 17.7% to 15.8% (laterite). Entire results showed tremendous strength increased in soil properties with the inclusion of additives.

Keywords Clay and lateritic soils, Costus Afer ash , CBR, UCS, Consistency, Compaction

1. Introduction

Lime has remained one of the most important, widely used and relatively cheap chemical stabilizing agents for improving the strength of soils in general.

For lateritic soils specifically, observations by Ola [1] have opened up new opportunities for tropical residual soils when compared with their temperate counterparts. It was observed that cement stabilization not only improved the natural CBR of the selected lateritic soil material but that only about half of the 14 % cement content suggested for similar temperate soils by the PCA to achieve 80 % CBR was actually needed. This of course is a major economic advantage for the tropics considering the relative cost of cement and the large volume of materials usually employed in road earthworks.

For a temperate soil to be suitable for cement stabilization and useful in the construction of road pavement structure, the HRB specify that the percentage fines, liquid limit and plasticity index must not exceed 50 %, 40 % and 18 % respectively, while Millard and O'Reilly [2] specify that the product of the plasticity index and the percentage passing through a 425 μm sieve (no 40) must not exceed 1 000. However, these specifications may not be appropriate for tropical residual soils considering the widely observed and reported disparities between them and their temperate counterparts from which these specifications were actually derived. A typical example is the 'abnormal' but advantageous behavior observed by Terzaghi [3] for Kenyan Sasumua clay that exhibited very high plasticity but abnormally low compressibility and superior mechanical strength. In addition to the above mentioned and other requirements based on results of classification tests, the Nigerian Specifications on Road works [4] specify that for any cement stabilized soil to be usable in a road pavement structure, its hand-mixed specimens must achieve soaked CBR (tested to the same FMW Specifications) of 30 % and 180 % for sub-base and base-course respectively. The specific testing procedure [4] specifies that the compacted CBR specimen should be wax-cured for six days, soaked in water for 24 hours (after removal of wax) at the end of which it must be drained for about 15 minutes before CBR testing.

Studies have shown the effect of reinforcement on swelling behavior of clays [5]; reduction of soil swell potential with fibre reinforcement [6], and effect of fibres on swelling characteristics of bentonite [7].

Natural fibres have been used to reduce shrinkage cracks in clayey soils without the least environmental nuisances and at almost low performance costs [8]. They are obtained from the waste of palm fruits and have acceptable mechanical properties and durability in natural conditions [9-10].

2. Materials and Methods

2.1 Materials

2.1.1 Soil

The deltaic soils (laterite) are abundant in Rivers State within the dry flat country. The soils used for the study was collected from a borrow pit at 1.5 m depth, at Odioku – Odiereke Town Road, Ubie Clan, Ahoada-West, Rivers State, Nigeria, lies on the recent coastal plain of the North-Western of Rivers state of Niger Delta.

2.1.2 Lime

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

2.1.3 Costus Afer (Bush Sugarcane) Bagasse Fibre

The bush sugarcane bagasse fibre are abundant in Rivers State farmlands / bushes, they are wide plants and covers larger areas, collected from at Odioku Town Farmland / Bush, Ubie Clan, Ahoada-West, Rivers State, Nigeria.

2.2 Method

2.2.1 Sampling Locality

The soil sample used in this study were collected along Odioku Community road in Ahoada West Local Government, in Rivers state, of Nigeria, (latitude 5.07° 14'S and longitude 6.65° 80'E), from trial borrow-pits the various earthworks within the entire roads. The top soil was removed to a depth of 0.5 m before the soil samples were taken, sealed in plastic bags and put in sacks to avoid loss of moisture during transportation. All samples were air dried for about two weeks to take advantage of the aggregating potentials of lateritic soils upon exposure [11-12].

These tests were conducted to prove that fibre product at varying proportions to give positive effect on the stabilization of soil and with binding cementitious inclusions. A number of tests were conducted as these tests include (1) Moisture Content Determination (2) Atterberg limits test (3) Particle size distribution (sieve analysis) and (4) Standard Proctor Compaction test, Califonia Bearing Ratio test (CBR) and Unconfined compressive strength (UCS) tests;

2.3.1 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.

2.3.2 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.

2.3.3 Atterberg Limits
This test is performed to determine the plastic and liquid limits of a fine grained soil. 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. The plastic limit (PL) is the water content, in percent, at which a soil can no longer be deformed by rolling into 3.2 mm (1/8 in.) diameter threads without crumbling.

2.3.4 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. The compactive effort is the amount of mechanical energy that is applied to the soil mass. Several different methods are used to compact soil in the field, and some examples include tamping, kneading, vibration, and static load compaction. This laboratory will employ the tamping or impact compaction method using the type of equipment and methodology developed by R. R. Proctor in 1933, therefore, the test is also known as the Proctor test.

2.3.5 Unconfined Compression (UC) 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. According to the ASTM standard, the unconfined compressive strength (qu) is defined as the compressive stress at which an unconfined cylindrical specimen of soil will fail in a simple compression test. In addition, in this test method, 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.

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 classifying and evaluating soil- subgrade and base course materials for flexible pavements. CBR is a measure of resistance of a material to penetration. The CBR tests were performed in order to determine effect of fibre inclusion on CBR values of reinforced soils.

3. Results and Discussions
Prelimiary results of lateritic and clay soils obtained fron Odiokwu – Odiereke road at CH0+750 and CH6+300 are presented in tables 3.1.

3.1 Compaction Test Results
Tables 3.4 and 3.5 showed the results of the relationship between optimum moisture content (OMC) and maximum dry density (MDD) at 100% soil and lime + bagasse fibre ash treated soils of laterite and clay. OMC results at 0, 2.5% to 10% increased from 12.93% to 14.37% (clay) and 11.79% to 12.405% (laterite). MDD results increased from 1.640KN/m^3 and 1.73KN/m^3 (clay) and 1.803KN/m^3 and 1.838KN/m^3.

3.2 California Bearing Ratio (CBR) Test
Tables 3.4 and 3.5 presented the CBR results of soil + lime + bagasse fibre ash (BSBFA) at 100% soils, 2.5%, 5.0%, 7.5% and 10% of lime + BSBFA, increased from 7.6% to 17.8% (clay) and 9.8% to 32.2% (laterite) showing tremendous strength increased.

3.3 Unconfined Compressive Strength Test
Table 3.6 and figure 3.2 presented the results of soil + lime + BSBFA treated soils of clay and laterite at additives inclusion percentages range of 2.5%, 5.0%, 7.5% and 10% of lime and BSBFA. Results of UCS increased from 78.6kPa to 223kPa (clay) and 155kPa to 299.1% (laterite) at optimum inclusion percentage of 85% (soil) + 7.5% (lime) + 7.5 (BSBFA). Beyond this specified percentage combination, crack was noticed and strength.

3.4 Consistency Limits Test
Tables 3.4 and 3.5 presented the results of soil + lime + BSBFA treated soils of clay and laterite with an increased values of LL decreased from 56.1% to 58.8% (clay) and 39% to 46.7% (laterite), PL increased from 22.4% to 28% (clay) and 22% to 27% (laterite), IP decreased from 33.7% to 30.8% (clay) and 17.7% to 15.8% (laterite).

Table 3.1: Engineering Properties of Soil Samples

	(Clay)	(Laterite)
Percentage(%) passing BS sieve #200	80.5	36.8
Colour	Grey	Reddish
Specific gravity	2.65	2.40
Natural moisture content (%)	45.5	31.2
Atterberg limits		
Liquid limit (%)	56.1	44.5
Plastic limit (%)	22.4	18.3
Plasticity Index	33.7	26.1
AASHTO soil classification	A-7-6	A-2-6
Compaction characteristics		
Optimum moisture content (%)	12.39	11.79
Maximum dry density ($kN/m^{3)}$	1.64	1.803
Grain size distribution		
Gravel (%)	0	5
Sand (%)	10	20
Silt (%)	48	38
Clay (%)	42	37
Unconfined compressive strength (kPa)	78.6	155
California Bearing capacity (CBR)		
Unsoaked (%) CBR	7.6	9.8
Soaked (%) CBR	7.4	9.2

Table 3.2: Properties of Bush sugarcane bagasse fibre. (Rivers State University of Science and Technology, Chemical Engineering Department, Material Lab.1)

Property	**Value**
Fibre form	Single
Average length (mm)	150
Average diameter (mm)	0.5
Tensile strength (MPa)	60 - 23
Modulus of elasticity (GPa)	1.1 – 0.35
Specific weight (g/cm^3)	0.52
Natural moisture content (%)	8.8
Water absorption (%)	150 - 223

Table 3.3: Composition of Bagasse. (Rivers State University of Science and Technology, Chemical Engineering Department, Material Lab.1)

Item	**%**
Moisture	49.0
Soluble Solids	2.3
Fiber	48.7
Cellulose	41.8
Hemicelluloses	28
Lignin	21.8

Source, 2018

Table 3.4: Results of Subgrade Soil (Lateritic) Test Stabilization with Binding Cementitious Products at Different percentages and Combination

S/no	Description of materials Bush sugarcane bagasses fibre products	Location of road/site	Depth	Chainage	MDD (kN/m^3)	OMC (%)	CBR (%)	LL(%)	PL(%)	PI(%)	SIEVE #200	AASHTO Class	Remarks
					LATERITE+ LIME								
1	LATERITE 100%	Odioku Rd(CH0+750)	1.5m	Borrow pit	1.803	11.78	9.8	39	22	17	36.8	A-2-6	POOR
2	LATERITE 98% + LIME 2%	Odioku Rd(CH0+750)	1.5m	Borrow pit	1.806	9.31	16.6	39	22.8	16.2	36.8	A-2-6	GOOD
3	LATERITE 96%+ LIME 4%	Odioku Rd(CH0+750)	1.5m	Borrow pit	1.838	10.06	20.5	37	23	14	36.8	A-2-6	GOOD
4	LATERITE 94%+ LIME 6%	Odioku Rd(CH0+750)	1.5m	Borrow pit	1.850	10.89	26.85	36	25	11	36.8	A-2-6	GOOD
5	LATERITE 92%+ LIME 8%	Odioku Rd(CH0+750)	1.5m	Borrow pit	1.860	12.05	40.80	36	26	10	36.8	A-2-6	GOOD
6	LATERITE 90%+ LIME 10%	Odioku Rd(CH0+750)	1.5m	Borrow pit	1.860	13.25	33.14	37.4	27	10.4	36.8	A-2-6	GOOD
					LATERITE+ LIME +BUSH SUGARCANE BAGASSE FIBRE ASH (BSBFA)								
7	LATERITE 95%+ LIME 2.5% +BSBFA 2.55%	Odioku Rd(CH0+750)	1.5m	Borrow pit	1.831	11.20	20.15	43.9	22	21.9	36.8	A-2-6	GOOD
8	LATERITE 90%+ LIME 5% +BSBFA 5%	Odioku Rd(CH0+750)	1.5m	Borrow pit	1.833	12.40	27.40	44.3	23.8	20..5	36.8	A-2-6	GOOD
9	LATERITE 85%+ LIME 7.5% +BSBFA 7.5%	Odioku Rd(CH0+750)	1.5m	Borrow pit	1.837	13.71	32.20	45.8	25	20.8	36.8	A-2-6	GOOD
10	LATERITE 80%+ LIME 10% +BSBFA 10%	Odioku Rd(CH0+750)	1.5m	Borrow pit	1.831	14.53	19.80	46.7	27	19.7	36.8	A-2-6	GOOD

Table 3.5: Results of Subgrade Soil (Clay) Test Stabilization with Binding Cementitious Products at Different percentages and Combination

S/no	Description of materials Bush sugarcane bagasses fibre products	Location of road/site	Depth	Chainage	MDD (kN/m^3)	OMC (%)	CBR (%)	LL(%)	PL(%)	PI(%)	SIEVE #200	AASHTO Class	Remarks
					CLAY+ LIME								
1	CLAY 100%	Odioku Rd(CH6+300)	1.5m	Borrow pit	1.64	10.37	7.6	56.1	22.4	33.7	74.4	A-7-6.	POOR
2	CLAY 98% + LIME 2%	Odioku Rd(CH6+300)	1.5m	Borrow pit	1.716	10.94	8.4	50.3	22	27.7	74.4	A-7-6.	POOR

3	CLAY 96%+ LIME 4%	Odioku Rd(CH6+300)	1.5m	Borrow pit	1.725	11.61	11.6	48.4	24.2	24.2	74.4	A-7-6.	GOOD
4	CLAY 94%+ LIME 6%	Odioku Rd(CH6+300)	1.5m	Borrow pit	1.737	12.02	13.8	46.7	24.9	21.6	74.4	A-7-6.	GOOD
5	CLAY 92%+ LIME 8%	Odioku Rd(CH6+300)	1.5m	Borrow pit	1.755	13.32	16.4	44.3	26	18.3	74.4	A-7-6.	GOOD
6	CLAY 90%+ LIME 10%	Odioku Rd(CH6+300)	1.5m	Borrow pit	1.758	14.93	12.3	43.4	26.8	16.6	74.4	A-7-6.	GOOD
				CLAY+ LIME + BUSH SUGARCANE BAGASSE FIBRE ASH(BSBFA)									
7	CLAY 95%+ LIME 2.5% +BSBFA 2.5%	Odioku Rd(CH6+300)	1.5m	Borrow pit	1.50	15.8	11.3	54	25	29	74.4	A-7-6.	GOOD
8	CLAY 90 %+ LIME 5% +BSBFA 5%	Odioku Rd(CH6+300)	1.5m	Borrow pit	1.47	16.3	13.8	55.7	28	27.7	74.4	A-7-6.	GOOD
9	CLAY 85%+ LIME 7.5% +BSBFA 7.5%	Odioku Rd(CH6+300)	1.5m	Borrow pit	1.46	16.8	15.3	57	29.6	26.6	74.4	A-7-6.	GOOD
10	CLAY 80%+ LIME 10% +BSBFA 10%	Odioku Rd(CH6+300)	1.5m	Borrow pit	1.43	16.8	17.8	58.8	28	30.8	74.4	A-7-6.	GOOD

Table 3.5: Results of Unconfined Compressive strength Soils (Clay and Laterite) Test Stabilization with Binding Cementitious additives + fibre Products at different Percentages and Combinations

			CLAY SOILS UNCONFINED COMPRESSIVE STRENGTH (UCS) TEST SUMMARY RESULTS AT (CH6+300)					LATERITIC SOILS UNCONFINED COMPRESSIVE STRENGTH (UCS) TEST SUMMARY RESULTS AT (CH0+750)				
S/NO	**DESCRIPTION OF MATERIALS BUSH SUGARCANE BAGASSES FIBRE PRODUCTS**	**LOCATION OF ROAD/SITE**	**2 DAYS CURING PERIODS**	**7 DAYS CURING PERIODS**	**14 DAYS CURING PERIODS**	**21 DAYS CURING PERIODS**	**28 DAYS CURING PERIODS**	**2 DAYS CURING PERIODS**	**7 DAYS CURING PERIODS**	**14 DAYS CURING PERIODS**	**21 DAYS CURING PERIODS**	**28 DAYS CURING PERIODS**
					Soil + Lime							
1	SOILS 100% + LIME 0%	Odioku Rd(CH0+750) and (CH6+300)	78.6	-	-	-	-	155	-	-	-	-
2	SOILS 98% + LIME 2%	Odioku Rd(CH0+750) and (CH6+300)	116.1	123.6	131.1	143.1	150.6	193.6	20.5	218.2	231.6	244.3
3	SOIL 96%+ LIME 4%	Odioku Rd(CH0+750) and (CH6+300)	158.6	176.4	191.4	208.7	223	231.6	253.6	264.6	284.1	295.6
4	SOIL 94%+ LIME 6%	Odioku Rd(CH0+750) and (CH6+300)	203.6	218	235	258.6	272	271.1	284.1	299.4	308.4	321.4
5	SOIL 92%+ LIME 8%	Odioku Rd(CH0+750) and (CH6+300)	238.7	256.3	271.4	288	306	303.4	324.4	339.6	353.6	374.8
6	SOIL 90%+ LIME 10%	Odioku Rd(CH0+750) and (CH6+300)	280.3	299.4	307.1	319.4	325	331.7	346.4	361.4	378.4	381.1
				Soil + Lime + Bush Sugarcane Bagasse Fibre Ash (BSBFA)								
11	SOIL 95%+ LIME 2.5% +BSBFA 2.5%	Odioku Rd(CH0+750) and (CH6+300))	136.4	144.8	163.8	173.1	183.8	214.1	221.3	236.1	253.1	268.1
12	SOIL 90 %+ LIME 5% +BSBFA 5%	Odioku Rd(CH0+750) and (CH6+300)	154.8	161.3	174.3	191.3	208	234.1	248.1	256.1	256.1	273.1
13	SOIL 85%+ LIME 7.5% +BSBFA 7.5%	Odioku Rd(CH0+750) and (CH6+300)	184.2	189.4	196.6	212	223	256.6	259.1	267.4	283.1	299.1
14	SOIL 80%+ LIME 10% +BSBFA 10%	Odioku Rd(CH0+750) and (CH6+300)	138.8	149.6	154.1	156.3	181.1	236.3	253.1	271.2	286.5	300.5

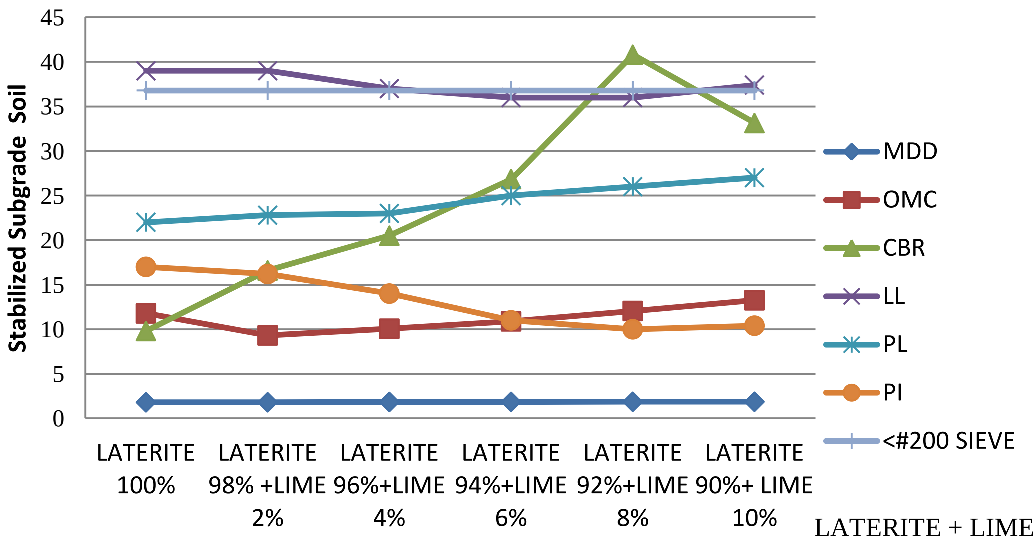

Figure 3.1: Subgrade Stabilization Test of Laterite Soil from Odioku in Ahoada-West L.G.A of Rivers State with Lime at Different Percentages and Combination

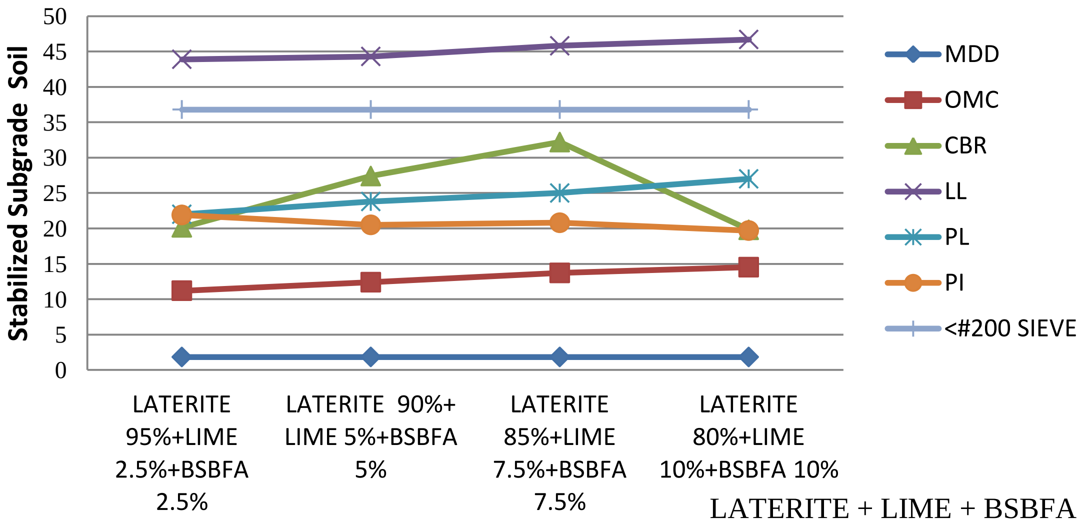

Figure 3.2: Subgrade Stabilization Test of Laterite Soil from Odioku in Ahoada-West L.G.A of Rivers State with Lime and BSBFA at Different Percentages and Combination

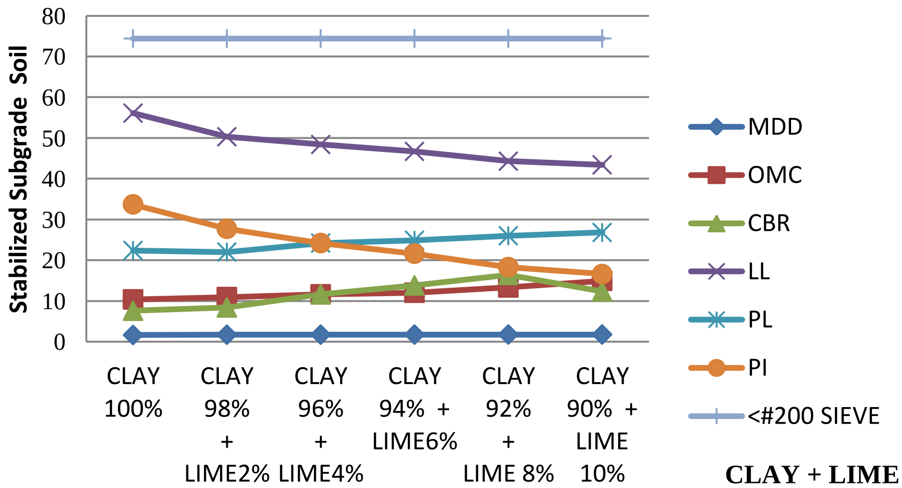

Figure 3.3: Subgrade stabilization test of clay soil from Odioku in Ahoada-West L.G.A of Rivers State with lime at different percentages and combinations

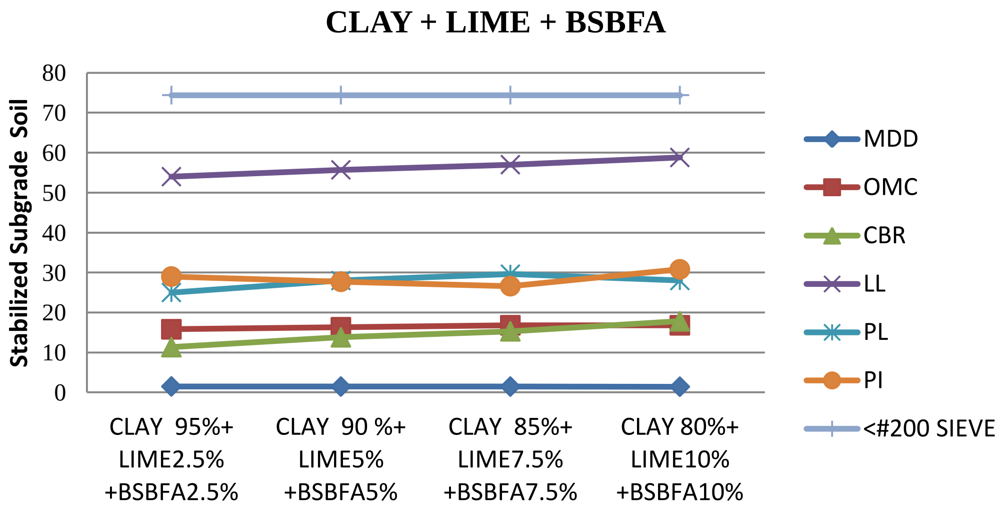

Figure 3.4: Subgrade Stabilization Test of Clay Soil from Odioku in Ahoada-West L.G.A of Rivers State with Lime and BSBFA at Different Percentages and combination

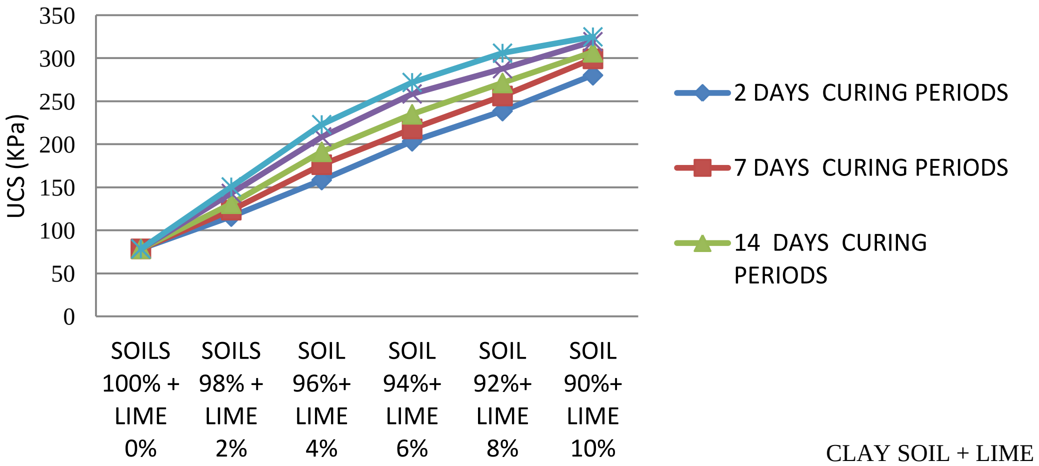

Figure 3.5: Unconfined Compressive Strength (UCS) of Clay soil from Odioku in Ahoada-WestL.G.A of Rivers State with Lime at Different Percentages and Combinations

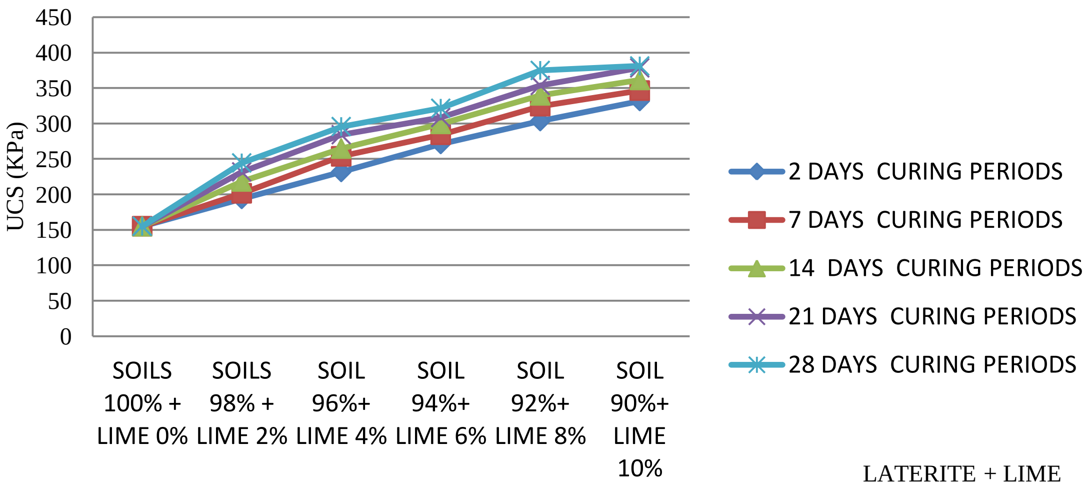

Figure 3.6: Unconfined Compressive Strength (UCS) of Laterite Soil from Odioku in Ahoada-West L.G.A of Rivers State with Lime at Different Percentages and Combinations

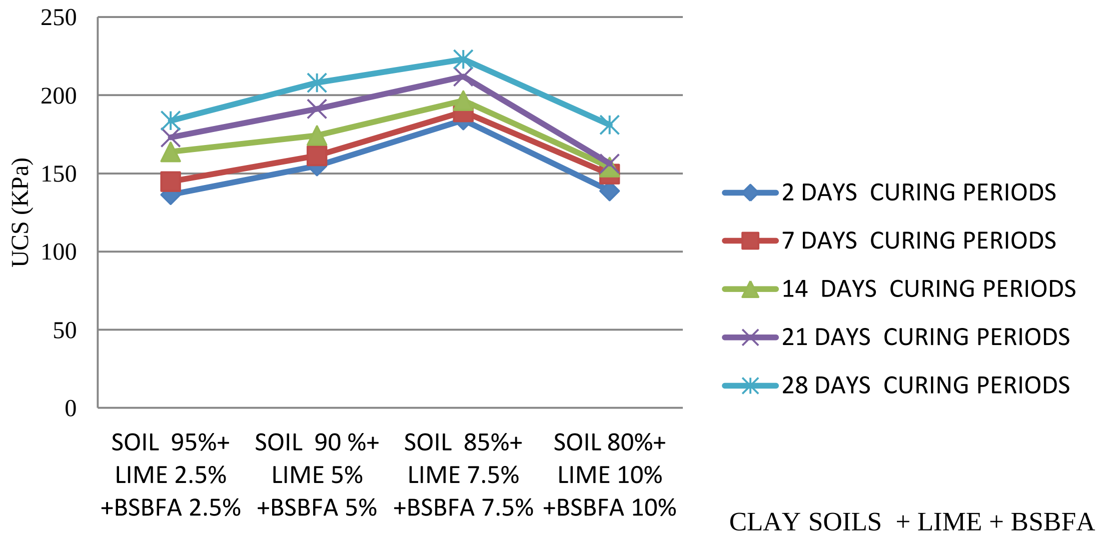

Figure 3.7: Unconfined Compressive Strength (UCS) of Clay soil from Odioku in Ahoada-West L.G.A of Rivers State with Lime and BSBFA at Different Percentages and Combinations

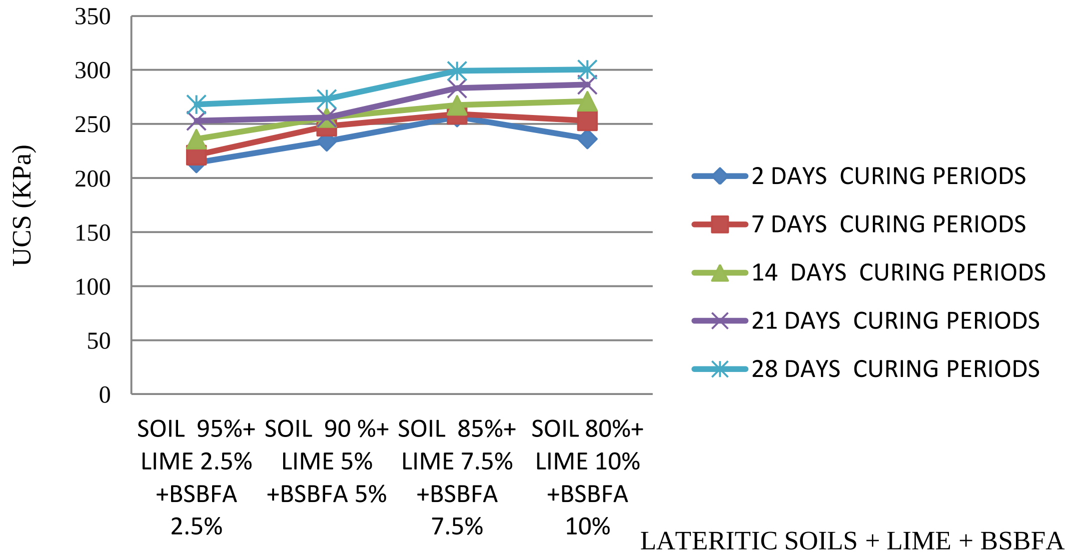

Figure 3.8: Unconfined Compressive Strength (UCS) of Laterite soil from Odioku in Ahoada-West L.G.A of Rivers State with Lime and BSBFA at Different Percentages and Combinations

4. Conclusions

The following conclusions were made from the experimental research:

i. The entire results showed the potential of using bagasse BSBFA as admixture in lime treated soils of clay and laterite with 8 % lime + 7.5% lime + BSBFA.

ii. Preliminary investigations of the engineering Properties of soils at natural state are percentage (%) passing BS sieves #200 are 80.5% (clay) and 36.8 % (laterite).

iii. The soils deposit belonged to the group A-2-7 and A-7-6 of American Association of State and Transport Officials (AASHTO) soil classification system.

iv. The soils from wet to dry states are dark grey and reddish brown in color with consistency limit properties of liquid limit of 56.1 % and 44.5 %, plastic limit of 22.4 %

v. Treated soils with Lime decreased in liquid limits and increased in plastic limits.
vi. Soils with Lime and fibre products in combinations increased CBR values appreciably both at soaked and unsoaked conditions from 7.6 % to 9.8 %, and 8.5 % to 10.9 % (clay) and (laterite) respectively
vii. At 8% of both cement and lime, CBR values reached optimum, beyond this range, cracks exist and 7.5% lime+ 7.5% BSBFA, optimum value are reached.

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