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Stabilization of Laterite Soil with Coconut Waste Ashes as a Partial Replacement for Lime

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ABSTRACT: *Pavement engineers have long recognized the long term benefits of improving the strength and durability of pavement soil by mixing in a cementitious binder during reconstruction or new construction. In lieu of these, this research was carried out to study the effects of coconut waste ash (CWA) on lime stabilized lateritic soil for road construction. Natural lateritic soil was collected from a borrow pit location in Ikere Ekiti and Ado-Ekiti, Nigeria. Preliminary tests such as natural moisture content, specific gravity, particle size distribution and Atterberg limits were carried out on the soil for classification and identification purposes according to BS 1377 part 2 (1990). Strength tests such as compaction, California bearing ratio and unconfined bearing ratio were also carried out on the natural lateritic soil and stabilized soil according to BS 1924 (1990). The soil sample was mixed with lime in the proportions of 2, 4, 6, 8 and 10%, and were each subjected to Atterberg limits tests and strengths to determine the optimum quantity of lime for stabilizing soil. The plastic index varied from 13.93 – 9.33% and 23.64 – 14.46% for lime stabilized soils with optimum values obtained at 8 and 6% respectively. Plastic index decreased as the percentages of lime and CWA increased for CWA of ratio 1:1, 3:2 and 2:3 i.e. PI varied from 8.63 to 11.91%. Notable improvements were also observed in the MDD, UCS, OMC and CBR values of stabilized soil therefore coconut waste ash can be used to stabilize lateritic soil. Hence, the use coconut waste ash (CWA) should be encouraged in the construction industry to reduce the cost of lime.*

KEYWORDS*; Pavement, Laterite, Stabilization, Plasticity, Coconut Waste Ash.*

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I. INTRODUCTION

In recent times, civilization has taken the course of the history, hence everyday man plunges into deeper and wider depths of knowledge, increased activities such as development of various sectors of the economy leading to higher standards of living. Owing to this fact, transportation system plays a great role in spreading of knowledge; new precepts, materials and movement of man round the globe hence the development of a society. However the road transport system is the most effective and usual means of transportation and its efficiency is impaired by defects which include potholes, rutting, mud pumping, cracks, corrugations etc. These defects have various causes but most common is as a result of poor underlying layers of soil even if the pavement was well designed and installed (Robert, 2017).

In hot and wet tropical regions e.g. Southwestern part and some other parts of Nigeria, the most common type of soil readily available and commonly used for road pavement is Lateritic soil because it is a soil and rock type rich in iron and aluminum. Nearly all laterites are of rusty red coloration, because of high iron oxide content. Typical lateritic soil is porous and claylike. It contains the Iron oxide minerals, goethite ($HFeO_2$); lepidocrocite (FeO[OH]) and hematite(Fe_2O_3). It also contains titanium oxides and hydrated oxide of aluminum, the most common and abundant of which is gibbsite ($Al_2O_3.3H_2O$) (Arora, 2007, Nnochiri & Nnochiri, 2017). However soil varies in behavior due to formation, rock components, transportation, pressure, drainage, environment and other numerous factors (Arora, 2007).

In light of this perception, some Lateritic soils tend to have poor engineering properties hence the need for soil stabilization- which is a general term for any physical, chemical, biological, or combined method of changing a natural soil to meet an engineering purpose.Researchers (Ola, 1983; Balogun, 1991 and Osinubi,

1995) attempted to stabilize laterite soil have reported that the stabilization of this soil with bitumen: lime or cement is effective. Unfortunately, the costs of these stabilizers are on the high side making them economically unattractive as stabilizing agents. Hence recent research studies are aimed at determining the possibility of using other relatively cheap materials for soil stabilization. In light of this, the need to bring down the cost of waste disposal and the growing cost of soil stabilizers has led to intense global research towards economic utilization of wastes for engineering purposes. The safe disposal of industrial and agricultural waste products demands urgent and cost effective solutions because of the debilitating effect of these materials on the environment and to the health hazards that these wastes constitute (Oluremi et al., 2012 and Osinubi, 2009). The objectives of this study are to; determine the index and engineering properties of soil sample at natural state, assess the chemical composition of the stabilizing materials, evaluate the performance of coconut shell and husk ash on the index and strength properties of stabilized matrix.

II. MATERIALS AND METHODS

Soil

The soil used for the research was collected from borrow pits located at Ikere – Ekiti and Ado-Ekiti respectively. The borrow pit at Ikere – Ekiti is located at along Ado – Ikere road after Shasha market opposite Inland quarry at $7^0$30'29.93" N and $5^0$13'54.62" (sample A) while that of Ado Ekiti is located beside pavilion complex, new central bank road, Ado – Ekiti at 7^0 37' 2.85" N and 5^0 11' 40.03" E (sample B). The lateritic soils in this area are derived from porphyritic granite, biotite granite, charnockite, quartzite and gneiss migmatite. The main rock type is charnockitic rock which has undergone an intense weathering into reddish to dark brown medium grained lateritic layer of considerable thickness (Ogundana & Talabi 2014). It is a growing urban area within $7^0$37'16''N and $5^0$13'17''E with mean annual temperatures ranging from 24^0C -27^0C, while the annual rainfall vary between 1500mm and 3500mm.

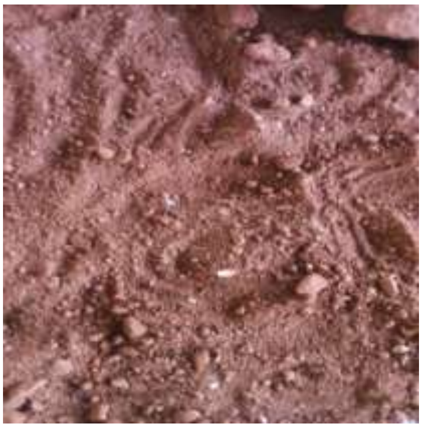

Fig. 1. lateritic soil

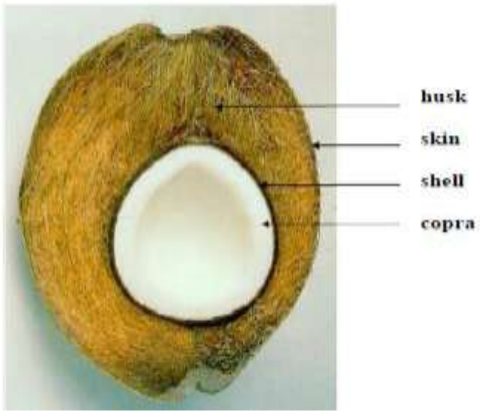

Fig. 2. Cross- section of coconut

Coconut Shell Ash

Coconut shells used for this work were obtained from a coconut seller in Ikole – Ekiti, Nigeria. Coconut Shell Ash (CSA) was produced by burning shells of coconut to ashes in an open metal drum (Amu et al., 2009). The ashes formed were allowed to cool down before sieving through 0.6 mm BS sieve.The ashes were therefore stored in air-tight containers to prevent moisture loss and any form of contamination.

Coconut Husk Ash

The coconut husk used in this work was obtained from a local vendor in Ikole – Ekiti.Coconut Husk Ash (CHA) was produced by burning to ashes in an open metal drum. The ashes formed were allowed to cool down before sieving through 0.425 mm BS sieve.The ashes were therefore stored in airtight containers to prevent moisture loss and any form of contamination.

Fig. 3. Coconut husk ash

Fig. 4. Coconut shell ash

III. EXPERIMENTAL PROGRAM OF WORK

Index and engineering properties tests were carried out on the soil samples at natural state in accordance with the procedures outlined in BS 1377 (1990) and stabilized state in accordance with the procedures outlined in BS 1924 (1990). Laboratory tests carried out includes; Natural moisture content, Consistency limit test, Specific gravity, Grain size analysis, Compaction test, California bearing ratio, Unconfined compressive strength. The soil sample was mixed with lime, CHA, CSA in proportions of 2, 4, 6, 8 and 10%, and were each subjected to Atterberg limits tests to determine the optimal quantity of stabilization materials which was the amount of stabilization material with the corresponding least value of plasticity index. Soil was mixed with lime (6,4,2%) and CHA:CSA (2,4,6%) with ratios of CHA:CSA in corresponding values of 3:2,2:3,1:1. Also the lateritic composition of the soil samples were determined using gravimetric method and the percentage oxide composition of the additives i.e. CSA and CWA using x- ray fluorescence method.

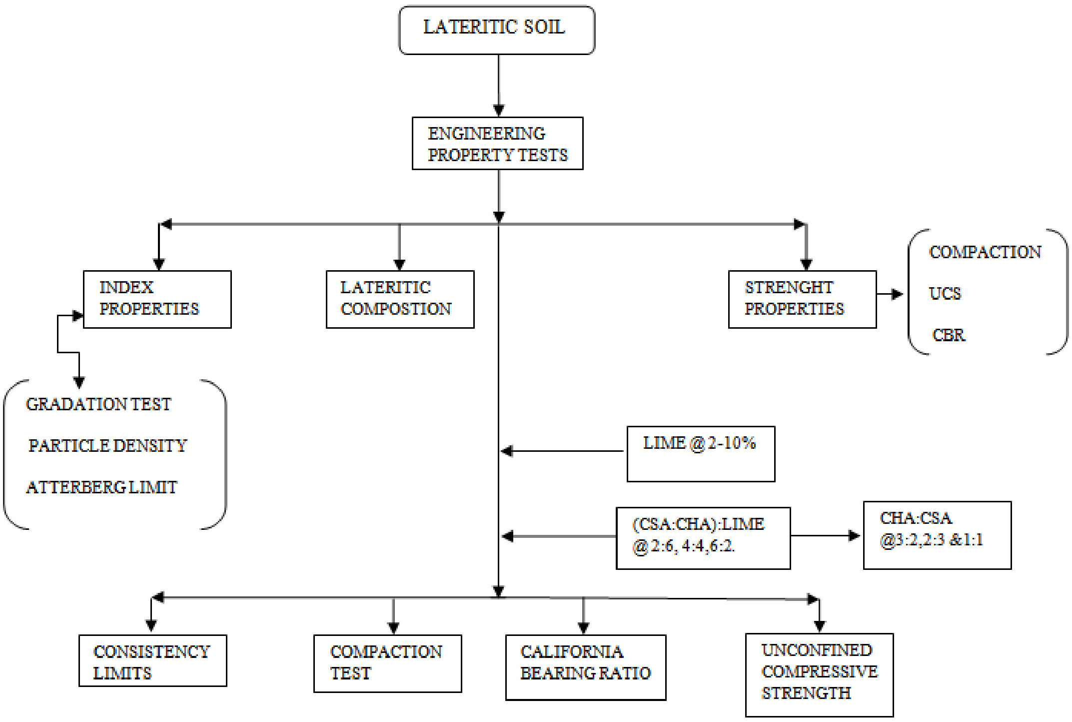

Fig. 5: Schematic diagram of experimental program of work

IV. RESULTS ANALYSIS AND DISCUSSION

TABLE 1. SUMMARY RESULT OF SOIL AT NATURAL STATE

SOIL PROPERTY		SAMPLE A	SAMPLE B
Natural moisture content (%)		9.87	9.34
Atterberg limit	Liquid limit (%)	40.2	40.4
	Plastic limit (%)	26.27	16.76
	Shrinkage limit (%)	5.36	2.86
	Plastic index	13.93	19.75
Specific gravity		2.36	2.3
% Passing 75 micron sieve		63.4	56.96
Maximum dry density (kg/m^3)		1845	1769
Optimum moisture content (%)		21	18
unconfined compressive strength (kN/m^2)		43	25
California bearing ratio		1.03	1.88
SOIL CLASS - AASHTO		A-7-5	A-7-5
SOIL CLASS – USCS		CL	CL

Chemical Composition of Lateritic Soil

The oxide composition of the laterite soils was carried out at the central research laboratory, science laboratory department, Federal polytechnic Ado using gravimetric method of analysis. Table 2 shows the percentage oxide composition of both soil samples. Since the ratio of silica to sesquioxides is less than 1.33, this implies that the position of both soils in lateritic profile is laterite.

Table 2. Percentage oxide composition of soil samples

Soil Samples	AL_2O_3	Fe_2O_3	SiO_2	$SiO_2/(Fe_2O_3 + Al_2O_3)$	Class
Sample A	30.05	36.2	23.96	0.3617	Laterite
Sample B	32.1	35.72	24.32	0.3586	Laterite

Chemical Composition of Additives

The oxide composition of the coconut shell ash and coconut husk ash was carried out at Lafarge Africa Plc using XRF (X-ray fluorescence), Vulcan machine and carbolite fusion machine. The result shows that the ashes had very low percentages of silicon, aluminum and iron oxides, hence the materials could be described to be non pozzolanic. Table 3 shows the percentage oxide composition of both ashes.

Table 3. Percentage oxide composition of additives.

SAMPLES	LOI	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO	Na_2O	K_2O	TiO_2	P_2O_5	Mn_2O	TOTAL
COCONUT	28.55	27.92	3.45	2.17	3.45	2.54	1.04	22.56	1.73	0.15	4.27	0.90	98.73
COCONUT SHELL	39.74	18.69	2.36	3.48	3.39	2.13	0.62	16.77	6.42	0.12	3.91	0.42	98.05

Table 4. Details of sample treatment (sample A)

Sample code	**Description**
A_{100}, B_{100}	Untreated soil sample
AL_2 BL_2	100% soil sample + 2% lime
AL_4 BL_4	100% soil sample + 4% lime
AL_6 BL_6	100% soil sample + 6% lime
AL_8 BL_8	100% soil sample + 8% lime
AL_{10} BL_{10}	100% soil sample + 10% lime

AL_2SH_6	100% soil sample + 2% lime + 6% CWA
AL_4SH_4	100% soil sample + 4% lime + 4% CWA
AL_6SH_2	100% soil sample + 6% lime + 2% CWA
BL_2SH_4	100% soil sample + 2% lime + 4% CWA
BL_3SH_3	100% soil sample + 3% lime + 3% CWA
BL_4SH_2	100% soil sample + 4% lime + 2% CWA

CWA – Coconut waste ash i.e. coconut shell and husk ash

Atterberg limit

The result of liquid limit (LL%), plastic limit(PL%) and plasticity index (PI%) evaluated on the soil samples from the two study locations (Ikere and Ado) stabilized with lime and combination of additives and lime are shown in Table 5,Figure 6 and 7. The liquid limit varied between 40.4 – 37.1%, plastic limit 26.67 – 28.57%, plastic index 23.64 – 14.46% and shrinkage limit 2.86 – 5.36% for lime stabilized soil from location one and liquid limit varied between 40.4 – 37.1%, plastic limit 16.76 – 23.21%, plastic index 23.64 – 14.46% and shrinkage limit 5.54–7.5 % for location two. From table 5, it was observed that the liquid limit, plastic index decreased as the percentages of lime and CWA increased for CWA of ratio 1:1 i.e. LL decreased from 38 – 37%, PL decreased from 29.17 to 26.19%, PI varied from 8.63 to 11.91%, however other ratios of CWA showed fluctuations of the liquid limit, plastic limit and plastic index, hence optimum result is found at CWA of 1:1 at AL_6SH_2, while the shrinkage increased steadily as the percentage of CWA increased for sample A. Sample B on the other hand showed a consistent decrease in the liquid limit, plastic index, shrinkage limit and an increase in the plastic limit as the percentage of the CWA increased, optimum values were obtained at CWA of ratio 2:3 at BL_4SH_2.

Table 5. Result of consistency limit test (Sample A and B)

	SAMPLE A					SAMPLE B				
TYPE OF ADDITIVE	% additive	LL	PL	PI	SL	% additive	LL	PL	PI	SL
LIME	0	40.2	26.27	13.93	5.54	0	40.4	16.76	23.64	2.86
	2	39.6	27.27	12.33	6.36	2	40.2	20.45	19.75	4.14
	4	38.1	28.09	10.01	6.43	4	39.0	22.22	16.78	4.21
	6	37.9	28.57	9.33	6.79	6	37.1	22.64	14.46	4.29
	8	37.1	24.50	12.60	7.14	8	38.0	22.86	15.14	4.29
	10	37.0	25.00	13.51	7.50	10	39.9	23.21	16.69	5.36
LIME + CWA (CSA:CHA=1:1)	AL_6SH_2	37.8	29.17	8.63	7.14	BL_2SH_4	38.2	26.00	12.20	7.14
	AL_4SH_4	38.0	26.09	11.91	7.86	BL_3SH_3	39.0	27.00	12.00	7.14
	AL_2SH_6	37.0	26.19	10.81	9.29	BL_4SH_2	39.0	25.00	14.00	4.29
LIME + CWA (CSA:CHA=3:2)	AL_2SH_6	39.4	24.14	15.26	7.86	BL_2SH_4	37.5	25.71	11.79	5.71
	AL_4SH_4	42.0	23.93	18.07	8.57	BL_3SH_3	38.5	26.87	11.63	5.71
	AL_6SH_2	45.5	22.97	22.53	9.29	BL_4SH_2	36.5	24.44	12.06	5.36
LIME + CWA (CSA:CHA=2:3)	AL_2SH_6	41.8	21.80	20.00	7.86	BL_2SH_4	38.5	24.72	13.78	4.29
	AL_4SH_4	40.3	21.40	18.90	8.57	BL_3SH_3	40.5	22.45	18.05	6.43
	AL_6SH_2	39.0	23.08	15.92	9.29	BL_4SH_2	37.0	28.57	8.43	4.29

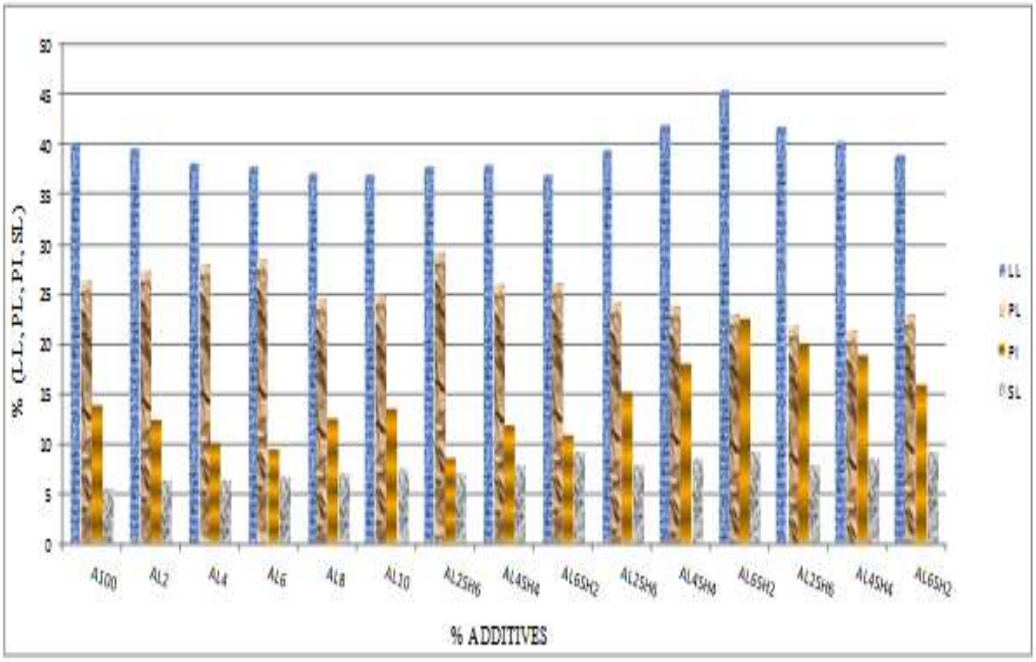

Fig. 6. Consistency limit of soil and additives (Sample A)

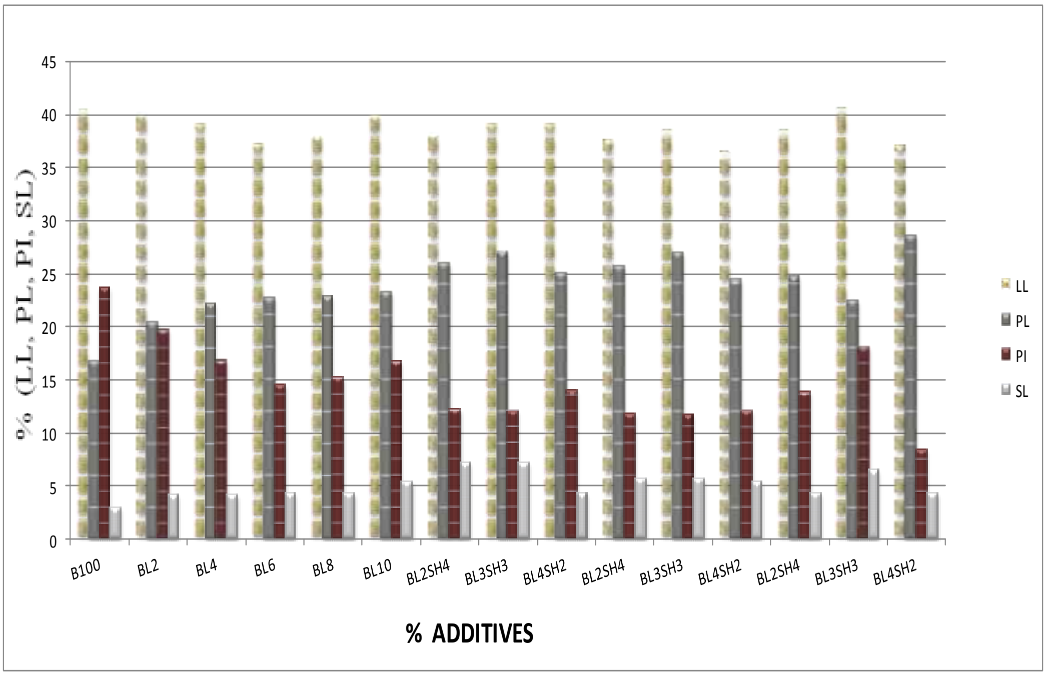

Fig. 7. Consistency limit of soil and lime (Sample B)

Compaction test

The results of the compaction test of soil samples stabilized with lime shows that the optimum moisture content decreased and the maximum dry density increased upon increase in lime addition, attained an optimum value at 8% and 6% for sample A and B respectively. From the results obtained as shown in Table 6 and figure 8 and 9, it was observed that the presence of CWA increased the MDD and decreased the OMC of both soil samples with optimum values obtained at AL_4SH_4 andBL_3SH_3 for both soil samples respectivelyand all ratios of CWA.

Table 6. Compaction result of soil at stabilized state –sample A and B

	% Additi	A_{100}	AL_2	AL_4	AL_6	AL_8	AL_{10}	AL_2SH_6	AL_4SH_4	AL_6SH_2	AL_2SH_6	AL_4SH_4	AL_6SH_2	AL_2SH_6	AL_4SH_4	AL_6SH_2
A	MDD (kg/m^3)	1845	1976	2024	2027	2066	1946	1808	2252	1931	1885	2359	1993	1845	2243	2065
A	OMC (%)	21	18	15	13	10	15	15	13	14	15	17	10	10	18	10
B	% Additi	B_{100}	BL_2	BL_4	BL_6	BL_8	BL_{10}	BL_2SH	BL_3SH	BL_4SH	BL_2SH	BL_3SH	BL_4SH	BL_2SH	BL_3SH	BL_4SH
B	OMC (%)	18	15	14.8	14.2	19.3	22.5	16	17	18	18	16	17	14	16	15
B	MDD (kg/m^3)	1769	1823	1861	1891	1836	1829	1834	2084	1861	1764	1978	1736	1703	2147	1875

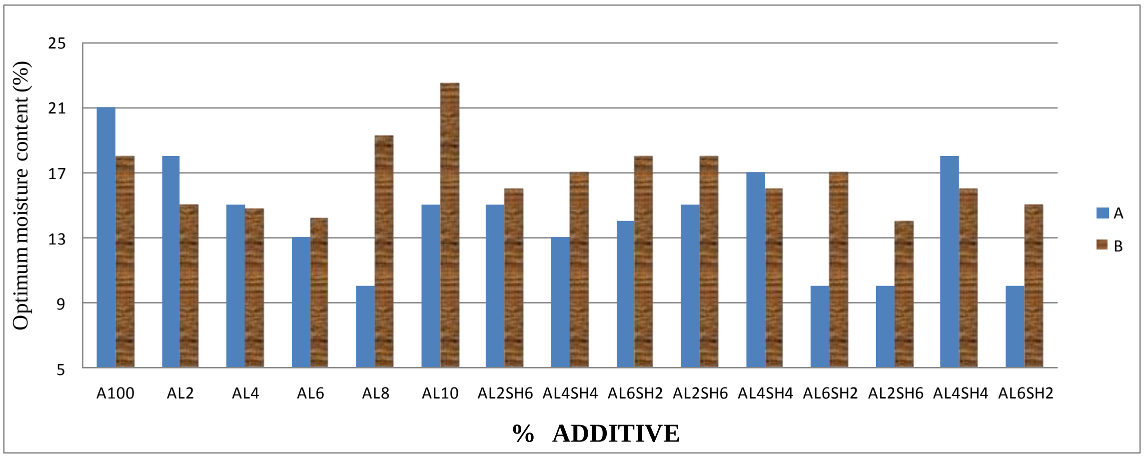

Fig. .8: Optimum moisture content of soil and Additives (Sample A and B)

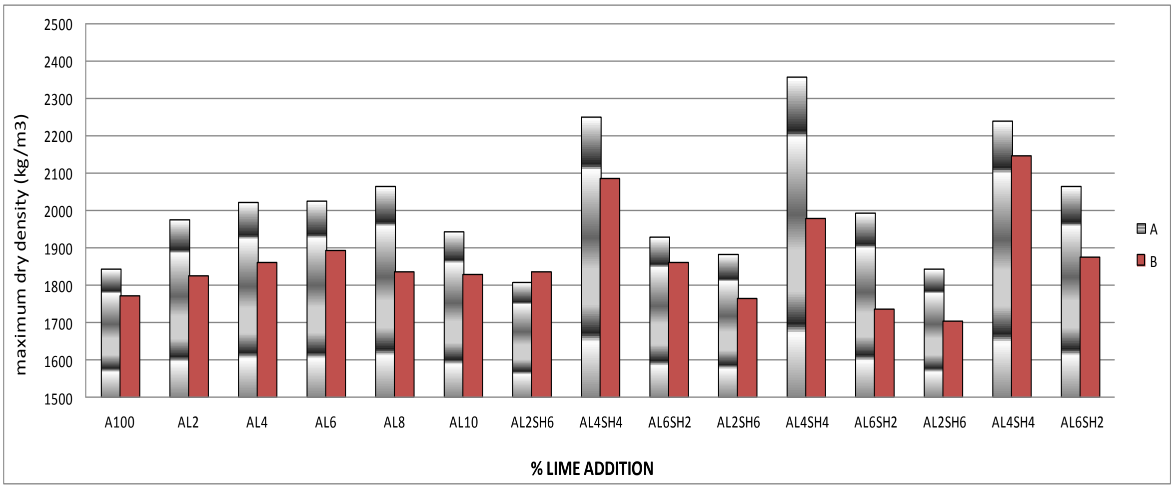

Fig. 9: Maximum dry density of soil and Additives (Sample A and B)

California Bearing Ratio

One of the common tests widely used in the design of base and sub basematerials for pavement is California Bearing Ratio since it can be used to evaluatethe strength of the stabilized soils (Ogunribido,2011). Table 7 and figure 10 shows the results of the unsoaked CBR for both soil samples respectively. The result shows that the CBR of both samples at natural states are 1.03 and 1.9% respectively. This implies that both samples are not adequate as sub grade material since the minimum value of unsoaked CBR for sub grade is 10%

(BS 1377, 1990; AASHTO, 1986; Overseas Road Note 31, 1993; Amu et. al, 2011; Ashworth, 1996). The results of the California bearing ratio test of soil samples stabilized with lime shows that the CBR value increased upon increase in lime addition, attained an optimum value at 8% and 6% for sample A and B respectively. From the results obtained, it was observed that the presence of CWA increased the CBR values of both soil samples with optimum values obtained at AL_6SH_2 and BL_4SH_2 for both soil samples respectively.

Table 7. CBR values of soil at stabilized state –sample A and B

ADDITIVE	A_{100}	AL_2	AL_4	AL_6	AL_8	AL_{10}	AL_2SH_6	AL_4SH_4	AL_6SH_2	AL_2SH_6	AL_4SH_4	AL_6SH_2	AL_2SH_6	AL_4SH_4	AL_6SH_2
SAMPLE A	1.03	16	21	23	30	26	16	21	23	15	20	25	25	10	14
SAMPLE B	1.89	12	18	21	16	17	19	17	15	16	19	20	19	17	20

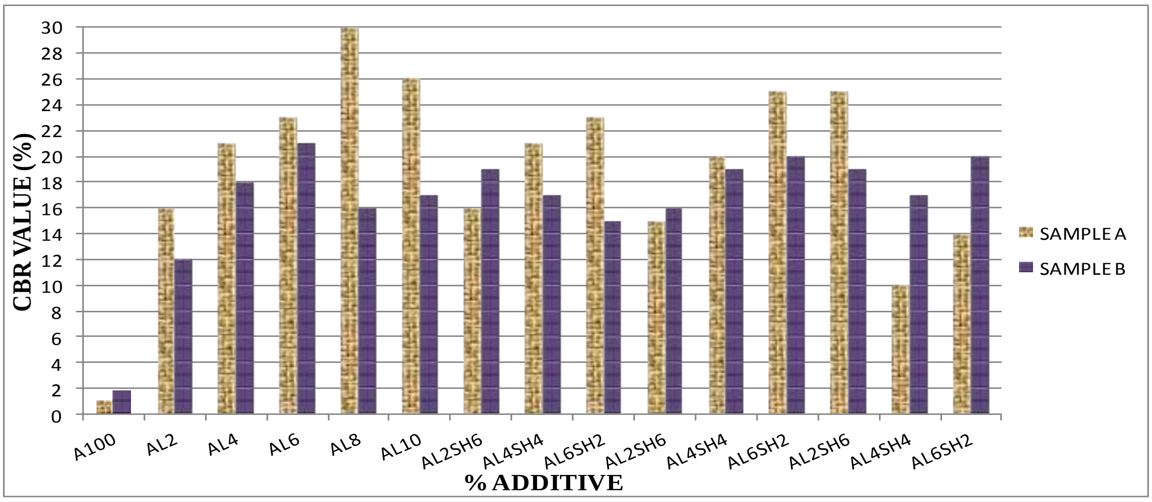

Fig. 10. California bearing ratio of soil and Additives for Sample A and B

Unconfined Compressive Strength

The unconfined compressive strength (UCS) test is a special type of unconsolidated-undrained test that is commonly used for clay specimens where the confining pressure (σ3) is zero and the major principal stress (σ1) is the unconfined compressive strength (qu) (Bello et al., 2015). Unconfined compressive strength is also the test for the determination of the required amount of additives to be used in the stabilization of the soil (Ogunribido, 2011). The results of the unconfined compressive strength test of soil samples from the two study locations gave the unconfinedstrength to be 43 and 25 kN/m^2 respectively.

The results of the unconfined compressive strength test of soil samples stabilized with lime shows that the UCS value of the soil samples increased upon increase in lime addition, attained an optimum value at 8% and 6% for sample A and B respectively. From the results obtained, it was observed that the presence of CWA also increased the unconfined compressive strength of both soil samples with optimum values obtained at AL_2SH_6 and BL_2SH_4 at CWA ratios of 2:3 and 3:2 for both soil samples respectively. This result is in agreement with results obtained by preceding researchers. (Amu et al., 2011; Manikandan et al., 2017; Oluremi et al., 2012; Athira & Ashish, 2017; Nnochiri&Ogundipe, 2017). Table 8 and figure 11 and 12 shows the results of unconfined compressive strength of soil samples at stabilized state.

Table 8. Unconfined compressive strength test result of soil at stabilized state –sample A and B

% ADDITIVE	A_{100}	AL_2	AL_4	AL_6	AL_8	AL_{10}	AL_2SH_6	AL_4SH_4	AL_6SH_2	AL_2SH_6	AL_4SH_4	AL_6SH_2	AL_2SH_6	AL_4SH_4	AL_6SH_2
UCS A (kN/	43	50	100	188	292	10 0	219	148	151	151	258	175	310	175	254
% ADDITIVE	B_{100}	BL_2	BL_4	BL_6	BL_8	BL_{10}	BL_2SH_4	BL_3SH_3	BL_4SH_2	BL_2SH_4	BL_3SH_3	BL_4SH_2	BL_2SH_4	BL_3SH_3	BL_4SH_2
UCS B (kN/	25	65	91	100	74	74	137	133	190	250	162	250	225	151	118

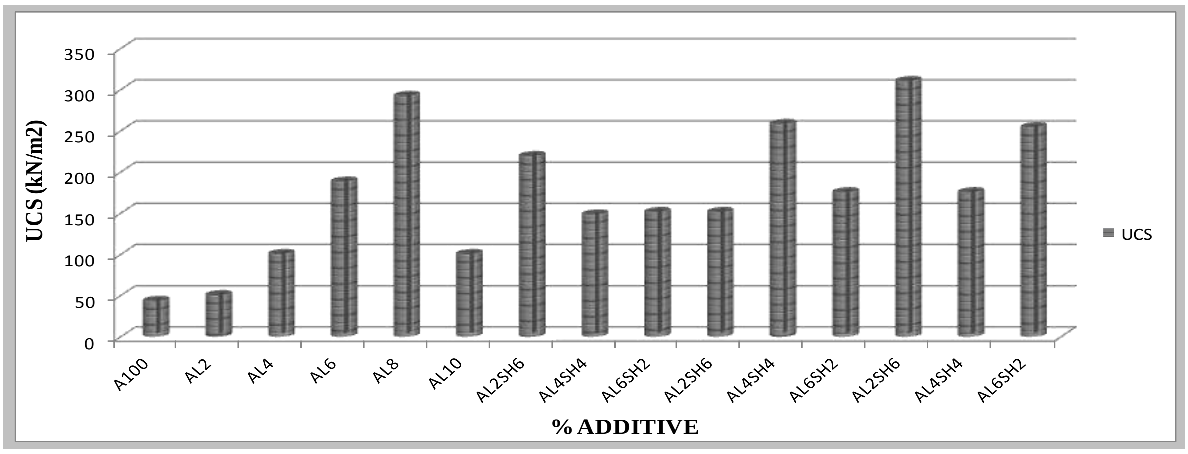

Fig. 11. Unconfined compressive strength of sample A and additive

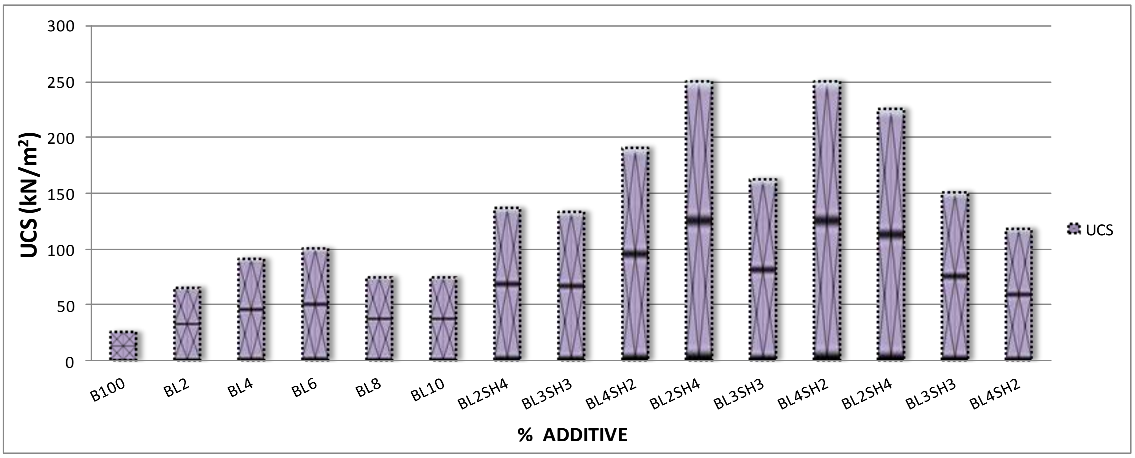

Fig. 12. Unconfined compressive strength of sample B and additive

V. CONCLUSIONS

From the observation and analysis of results of laboratory experiment carried out from this study, the following conclusions were drawn;

i. The soil samples used for the study were laterite since the value of silica sesquioxides ratio was less than 1.33.

ii. The soil samples were classified according to AASHO and USCS as A-7-5 and organic clay of low plasticity (CL) respectively.

iii. The additives CSA and CHA burnt openly with an uncontrolled temperature are non pozzolanic.
iv. The consistency limit test performed on the lime stabilized soil samples enhanced the index properties of the soil under review making the material suitable as sub-grade material.
v. The compaction test performed shows that as the lime content increases the MDD were enhanced and OMC decreased consistently up to 8 and 6% for sample A and B respectively. There was also a consequent increase in the MDD and UCS values of soil stabilized with lime and CWA.
vi. The CBR test performed shows that as the lime content increases the strength CBR value also increases consistently up to 8 and 6% for sample A and B respectively while the optimum values obtained at AL_6SH_2 andBL_4SH_2 for both soil samples respectively.

VI. RECOMMENDATION

Durability test should be carried out on soil samples with additives for further study. The use coconut waste ash (CWA) should be encouraged in the construction industry to reduce the cost of lime. The comparative cost analysis between the use of lime and coconut waste ash should be carried out. The government and all government agencies at national and local level should endeavor to sensitize all industries in the use of local source material for construction.

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