



GEOTECHNICAL PROPERTIES OF LIME AND BAMBOO STEM ASH STABILIZED SOILS FOR ROAD CONSTRUCTION IN SOUTH-WESTERN NIGERIA

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Abstract

The state of any road layer today and in the future is primarily dictated by the soil beneath its foundation, and knowing enough about the Engineering qualities of soil and the sub-soil condition is crucial in foundation design. This research looked at the geotechnical qualities of soils stabilized with Lime-and-Bamboo Stem Ash (BSA) mixture. Soil samples were obtained from each state in the study area and transported to the laboratory, where they were stabilized with 6% lime and 0 to 10% BSA. California Bearing Ratio (CBR), Compaction, Unconfined Compressive Strength (UCS), and Triaxial tests were performed on the combined samples. The local additive was also subjected to a chemical examination. The results showed that BSA additive has a high SiO₂ content. As BSA content increases, all strength properties (Maximum Dry Density (MDD), CBR, UCS, Cohesion (C), Shear strength (S) and Angle of Internal Friction (ϕ)) increase and reached peak at 6% BSA content, thereafter decrease; however, Optimum Moisture Content (OMC) decreases. The peak values are 2475 kg/m³, 58.53%, 45.32%, 638.9 kN/m², 137 kN/m², 290.57 kN/m² and 41° for MDD, soaked CBR, unsoaked CBR, UCS, C, S and ϕ respectively. After going through the process, almost all of the unsuitable soil samples became suitable for use as pavement layer materials. As a result, a mixture of 6% lime and 6% BSA content is strongly recommended for soil improvement, particularly for road construction in South-Western Nigeria.

Keywords: Bamboo stem ash, chemical analysis, lime, strength properties

Introduction

Soil improvement can be accomplished through both stabilization and modification in geotechnical engineering. Soil modification is the process of adding a modifier (such as cement, lime, fly ash, or bitumen) to a soil to change its index properties, whereas soil stabilization is the process of treating soil to improve its strength and durability so that it can be used for construction beyond its original classification. Stabilization is another option for the available soil so that it may be used for construction; however, this might be costly depending on the stabilizing chemicals used. In geotechnical engineering, soil improvement could be achieved by both stabilization and modification. Soil modification is the addition of a modifier (cement, lime, fly ash, bitumen and so on) to a soil to change its index properties, while soil stabilization construction beyond their is the treatment of soil to enable their strength and durability to be improved such that they become totally suitable for original classification. Soil modification and stabilization improves the soil's strength, bearing capacity, and long-term durability (Kanyi, 2017).

Cement and lime are two traditional elements that have been used to stabilize road construction from the beginning of civilization. However, due to a dramatic

spike in energy costs, their prices have risen rapidly over the last fifty years. The over-reliance on traditional soil-improvement additives (cement, lime, and so on.) for road and structure usually resulted in high stabilizing cost. As a result, developing countries around the world (for example, Nigeria, which is primarily agriculturally dependent, poor, and still struggling with its economy) have been unable to provide accessible roads and safe structures to a larger percentage of their people. These countries must make do with what they have in order to obtain what they require, which in Nigeria entails the conversion of trash (s) into indigenous additives for road construction. This is owing to the fact that garbage may be found in large quantities in Nigeria (Hezmi et al., 2019; Oke and Olowoyo, 2019; Adetoro and Adam, 2015a; Amadi, 2013).

Economic reuse and effective management of items previously abandoned as garbage have resulted from technical innovation and the demand for a safer environment. The depletion of natural resources as a result of industrial activity is a process that can lead to the accumulation of waste materials and by-products. Because of the environmental and other health risks they pose, safe disposal of these wastes necessitates proper management (Kanyi, 2017). Unknowingly,

certain waste products are lying fallow within human habitats, awaiting disposal by the government. These waste products could be utilized to replace costly commodities (such as cement and lime) that are used to stabilize poor soil. When garbage is recycled or used as stabilization materials in road building, it relieves the strain of having to seek for expensive materials for stabilization, hence raising people's living standards. The rate at which emerging countries encourage the import of resources is worrisome, and it is one of the reasons why the poor continue to be poor. Waste recycling is a business that has gained a lot of attention in many industrialized countries across the world (Adetoro and Adam, 2015b).

Wastes are resources that are discarded after they have served their purpose. Its type, quantity, and composition vary according to the activity at hand, which can be agricultural, residential, or industrial in nature, and includes materials such as food, construction, paper, plastic, and other abandoned residual items (Kanyi, 2017). Economic activities in Abeokuta, Ado-Ekiti, Akure, Ibadan, Lagos, Oshogbo, and other developing towns and cities in Nigeria are booming and promising. Waste is strewn throughout the place, posing a threat to the ecology (Globally, waste materials are normally generated in large quantities). As a result, the proper disposal of these waste materials is a major concern — these waste products pose environmental hazards as well as disposal issues. These waste products, on the other hand, can become structural components of road pavement if they are appropriately treated, employed, or modified. As a result, utilizing locally accessible additives (which, if not properly managed, could result in air and land pollution) will significantly cut building costs while also decreasing the environmental risks they pose.

The utilization of agricultural wastes for soil improvement is extremely environmentally friendly. In South-Western Nigeria, it is possible to optimize lime stabilized soils with indigenous additives for road construction. Previous studies revealed that, while local additives enhanced the geotechnical qualities of lateritic soil, they could not be used as a stand-alone additive to meet the minimum strength requirements for road pavement, which is the foundation for this research. The traditional alteration of soil with lime and cement has been validated as stand-alone additives for road construction, but the cost of blending with the soil is typically very high. As a result, using agricultural waste in soil optimization will provide less expensive additives to replace traditional additives like cement, lime, and bitumen. The goal of this study was to investigate the utilization of an agricultural local additive (i.e. Bamboo Stem Ash – BSA) in stabilizing soils pre-modified with lime for road construction in South-Western Nigeria. This will aid in the development of cost-effective,

practically reliable, and readily available waste treatment and road construction techniques. The report advocates for a "waste-to-wealth" approach. As indicated in Figure 1, the geopolitical zone of South-Western Nigeria includes the states of Ekiti, Lagos, Ogun, Ondo, Osun, and Oyo. It is located at latitudes of 6.214 to 9.000 °N and longitudes of 2.681 to 9.000 °E. It was founded in 1967 when the Western Region was separated into the states of Lagos and Western State. Its capital was Ibadan, which was also the ancient region's capital. In 1976, the Western state was divided into three new states: Ogun, Ondo, and Oyo. In 1991 and 1996, the states of Osun and Ekiti were formed from the states of Old Oyo and Ondo, respectively.

Nigeria has a tropical climate, which is humid and wet throughout the year. The research region is located in South-Western Nigeria, which has a tropical monsoon climate (Köppen climatic classification "Am"). It is always drenched in a torrential downpour. This could be owing to the fact that it is so close to the equatorial belt. Annual rainfall averages 2,000 mm (78.7 in) or more. Dry and wet seasons are common in the region. Between March and July is the first rainy season. This is followed by a two- to three-week dry respite in August (also known as August break). The second rainy season, which occurs between September and October, interrupts this break. After the second rainy season ends in October, the dry season begins in November and lasts until March (Ayinla, 2014; Fasunwon et al., 2010). The Nigeria basement complex is part of the West African craton, which is made up of five tectonic events. This basement can be found almost everywhere in Nigeria, and it is clearly connected to Dahomey precambrian rocks. The country's precambrian basement complex is mostly made up of migmatite gneiss, schist, charnockitic rocks, older granites, and non-metamorphosed dolerite dykes due to its petrology. The majority of Nigeria's surface is covered by sedimentary rocks, with crystalline igneous and metamorphic rocks covering the remainder (Ayinla, 2014; Fasunwon et al., 2010).

Figure 2 shows the three lithological units of the migmatite-gneiss complex (quartzite, gneissic rocks), low to medium grade metasediments (Green schist's facies, namely quartz schist and mica schist), and Pan African Granitoids (older granites) that lie under South-Western Nigeria. The agglomeration of these rocks allows South-Western Nigeria to have a diverse range of minerals, including metallic, non-metallic, industrial, and gemstone groups. The northern section of the research area is underlain by complex pegmatite, which contains a variety of gemstones such as aquamarine, tourmaline, and agate, as well as industrial minerals such as tantalite, marble, talc, and granites in various forms (Ayinla, 2014).

Table 1: Details of the Soil Samples

S / No.	State	Sample Label	Location (Road)	Coordinates	
				LATITUDE	LONGITUDE
1	EKITI	A1	Itawure - AramokoEkiti	07° 32' 32"	08° 49' 27"
		A2	Ikole - IjesaisuEkiti	07° 45' 28"	05° 31' 08"
		A3	Aisegba - Iluomo-obaEkiti	07° 36' 38"	05° 28' 08"
2	ONDO	B1	Akure–Ogbese	07° 56' 39"	08° 04' 57"
		B2	Owo - Ikareakoko	08° 29' 11"	08° 01' 15"
		B3	Ondo– Ore	07° 06' 20"	07° 54' 13"
3	OSUN	C1	Osogbo–Ikirun	07° 47' 47"	04° 34' 16"
		C2	Ilesa - IjebuJesa	07° 38' 32"	04° 43' 14"
		C3	Owode - Ode omu	07° 33' 48"	04° 24' 00"
4	OYO	Da1	Ogbomoso–Oko	08° 31' 15"	04° 17' 12"
		Db1	Igbeti–Ogbomoso	08° 44' 43"	04° 08' 17"
		Dc1	Ibadan –Fiditi	07°34' 21"	03°55' 31"
5	OGUN	E1	Abeokuta –Itori	05° 29' 28"	08° 19' 31"
		E2	Shagamu – Ishara	06° 11' 05"	08° 06' 33"
		E3	Ilaro–Papanlanto	05° 32' 36"	08° 02' 07"
6	LAGOS	F1	Apapa wharf - Apapa expressway	06° 27' 16"	03°22' 05"
		F2	Lekki - Ajah expressway	06° 26' 21"	03° 31' 25"
		F3	Oshodi - Agege expressway	06° 33' 33"	03° 20' 21"

(b) Methods:-The soil samples were mixed on the ground to obtain representative samples, and then transferred to the laboratory to be cleaned of harmful elements such as roots. The soil samples used in the test were air-dried, broken down into particles with a mortar and pestle, and then sieved to eliminate big particles with a No. 10 sieve. The methodologies used for the various tests were in conformity with BS 1377 (1990). In their natural air-dried form, samples were subjected to classification and engineering tests, as detailed in preceding sections. Following that, the soil samples were lime stabilized by adding lime at a percentage of 6%. Then, at proportions of 2, 4, 6, 8, and 10%, BSA was added to the lime-stabilized soil samples. Chemical analysis of the BSA local additive was performed using the traditional method. The soil samples were subjected to engineering strength tests such as the California Bearing Ratio (CBR), compaction, unconfined compression strength (UCS), and triaxial shear testing.

(I) California Bearing Ratio (CBR):- This is an empirical test for determining subgrade strength established by the California State Highway Department. According to BS 1377 (1990), a specimen with height and diameter of 127 and 152 mm was crushed into the CBR mold. The specimens were prepared in 5 (five) layers with a strong rammer, each layer receiving 56 (fifty-six) blows. The load needed to cause a circle, 49.65 mm in diameter, to penetrate the specimen at a rate of 1.25 mm per minute was then calculated. The CBR value was computed from the test results by expressing the corrected values of plunger

forces for a specific penetration as a percentage of a standard force. The loads that induced the same penetration on the specimens were compared using the 2.5 and 5.0 mm penetration caused by 13.24 and 19.96 KN loads. This test was performed in accordance with the BS1377 (1990) soil test requirements.

(ii) Compaction Test:-With a given compactive effort, this test was used to estimate the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC). This test established the OMC for use in other performance tests that need compaction, such as CBR and UCS. Standard Proctor was used, as specified by BS 1377 (1990). As the provided compactive effort, a cylindrical metal mould (Proctor mould) of around 1000 cm³ volume and a rammer of 2.5 kg weight with a height drop of 300 mm were utilized. Each layer of three (3) received twenty-five (25) blows, and moisture content samples were obtained from the top and bottom of the mould. The MDD was calculated using the OMC as the moisture content. This test was performed in accordance with the BS1377 (1990) soil test requirements.

(iii) Unconfined Compressive Strength (UCS):- It demonstrates the soil's drainage condition as well as its ability to sustain compression failure. The UCS specimens were taken from the Proctor mould, and the results were adjusted by a factor of 1.04 to conform to cylindrical specimens with a height/diameter ratio of 2:1 or 150 mm cube specimens. The specimens were crushed, and the weight that caused the specimen to fail was divided by the cross sectional area of the

specimen to determine the soil's strength. This test was performed in accordance with the BS1377 (1990) soil test requirements.

(iv) Triaxial Shear Test (Direct Shear Test):- The direct shear test is a laboratory test that determines the shear strength of a soil. It is suitable for measuring the shear strength of lateritic soils since it can be done on both cohesive and cohesionless soil. It assesses the soil's cohesiveness (c) and internal friction (ϕ). This

test was performed in accordance with the BS1377 (1990) soil test requirements.

Results and Discussion

a) Chemical Composition of BSA Local Additive:- Table 2 summarizes the results of chemical analysis of the BSA local additive that was utilized for stabilization. BSA has a high Silica Oxide (SiO_2) content of 64.90 percent. The total amount of Silica, Aluminium, and Ferric oxides in it was 65.12%.

Table 2: Chemical Composition of BSA

Composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	MgO	Na_2O	MnO	CuO	LoI	U	$\text{SiO}_2+\text{Al}_2\text{O}_3+\text{Fe}_2\text{O}_3$
BSA(%)	64.9	0.10	0.12	12.45	0.68	6.02	0.88	0.02	0.09	2.05	12.69	65.12

U - Undetermined

b) CBR Test:- Generally, it was observed from Table 3 that there was increase in CBR (both soaked and unsoaked) as BSA content increases and reached the optimum at 6% of the additive content. The 0% values correspond to the optimum values obtained when the soil samples were stabilized with lime alone. The soaked CBR values of Ekiti state soil samples ranged from 31.85% (0% BSA) to 36.44% (6% BSA), while unsoaked CBR values ranged from 27.46% (0% BSA) to 38.90% (6% BSA). Ondo state soil samples ranged from 4.25% (0% BSA) to 6.14% (6% BSA) for soaked CBR, while unsoaked CBR ranged from 5.68% (0% BSA) to 8.27% (6% BSA).

The soaked CBR values of Osun state soil samples ranged from 7.77% (0% BSA) to 24.17% (6% BSA); while Osun state unsoaked CBR values ranged from 5.78% (0% BSA) to 11.71% (6% BSA). Oyo state soil samples have soaked CBR values that ranged from 11.00% (0% BSA) to 58.53% (6% BSA), while the unsoaked CBR values ranged from 8.10% (0% BSA) to

45.32% (6% BSA). The soaked CBR values of Ogun state soil samples ranged from 11.11% (0% BSA) to 25.36% (6% BSA) and 6.51% (0% BSA) to 19.54% (6% BSA) for unsoaked CBR values. Lagos state soil samples have soaked CBR values that ranged from 6.13% (0% BSA) to 8.14% (6% BSA), while unsoaked CBR values ranged from 4.11% (0% BSA) to 6.89% (6% BSA). Oyo state soil sample D₂ (Igbeti-Igboho Federal road) has the highest value of 58.53% and 45.32% for both soaked and unsoaked CBR respectively when stabilized with BSA content.

c) Compaction Test:- Table 4 shows the results of a compaction test on lime stabilized soil samples with BSA additive. For all the lime stabilized soil samples, the optimal Maximum Dry Density (MDD) was achieved at 6% BSA content. At 0% content, the local additive's OMC was found to be optimal (i.e. when the lime used for stabilization of the soil samples is 6 percent without any additive added). MDD for Ekiti state soil samples ranged from 1828 to Table 3: Results of CBR test on lime stabilized soil samples with BSA additive

Table 3: Results of CBR test on lime stabilized soil samples with BSA

Test	Additive Content (%)	SAMPLING LABEL																	
		A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	E1	E2	E3	F1	F2	F3
CBR (SOAKED) (%)	0	31.85	33.99	32.60	4.25	4.70	5.53	7.77	20.44	10.19	11.00	51.99	35.22	11.11	19.91	17.53	6.13	7.40	6.75
	2	32.85	34.55	33.04	5.29	4.88	5.76	10.57	21.34	11.33	12.84	52.68	38.71	13.61	21.28	20.14	6.26	7.64	6.76
	4	33.23	35.50	34.37	5.48	5.01	5.89	11.33	22.66	13.60	13.22	55.14	41.16	13.83	23.42	22.42	6.64	8.02	7.01
	6	34.55	36.44	35.69	5.76	5.29	6.14	12.27	24.17	14.78	14.74	58.53	45.13	14.33	25.36	24.62	7.01	8.14	7.26
	8	25.18	24.05	24.55	5.66	5.14	6.10	11.64	21.90	14.03	11.33	56.65	43.45	13.02	24.72	23.25	6.76	7.77	6.89
	10	23.60	23.98	23.92	5.51	5.01	6.04	11.02	21.29	11.27	10.95	53.66	38.14	12.61	23.61	22.37	6.51	7.52	6.76
CBR (UNSOAKED) (%)	0	27.46	29.34	29.27	5.68	7.13	7.23	5.78	9.78	6.27	8.10	34.33	19.69	6.51	16.90	8.76	4.11	4.98	4.48
	2	37.39	29.83	34.04	6.01	7.74	7.36	6.61	9.82	7.55	9.44	37.76	22.85	13.61	17.42	10.99	6.01	5.89	5.01
	4	37.58	31.53	34.93	6.14	7.93	7.55	7.74	11.14	8.69	10.20	43.43	25.65	13.83	18.03	11.52	6.14	6.14	5.39
	6	38.90	33.61	35.31	6.80	8.27	8.02	10.01	11.71	10.52	11.33	45.32	29.27	14.33	19.54	11.77	6.26	6.89	5.51
	8	21.90	22.66	33.80	6.64	8.14	7.93	8.50	10.95	12.65	10.01	42.48	26.81	13.18	14.16	10.50	5.89	6.51	5.26
	10	16.62	20.67	32.85	6.39	8.12	7.83	7.55	10.02	9.89	8.81	39.09	25.30	12.83	13.79	10.38	5.76	5.26	5.14

Table 4: Results of Compaction Test on Lime Stabilized Soil Samples with BSA Additive

Test	Additive Content (%)	SAMPLING LABEL																	
		A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	E1	E2	E3	F1	F2	F3
COMPACTION MDD (kg/m ³)	0	1828	2127	2026	1909	1962	2033	1930	1948	1920	2050	2412	2339	1925	1961	1970	1420	1995	1868
	2	1909	2140	2078	1931	1976	2056	1950	1959	1932	2069	2420	2365	1945	1990	1982	1654	2050	1970
	4	2088	2152	2084	1945	1972	2060	1971	1972	1955	2210	2425	2365	1954	2024	1997	1888	2080	2012
	6	2198	2177	2120	2123	1975	2090	1975	1998	1975	2225	2475	2375	1980	2025	2025	1940	2140	2088
	8	1942	2100	2047	1920	1968	2034	1948	1951	1932	2175	2250	2250	1935	1994	1990	1885	2038	2011
	10	1828	2075	2016	1887	1942	1953	1899	1924	1847	1999	2150	2150	1930	1972	1975	1780	1910	1975
COMPACTION OMC (%)	0	19.80	14.20	13.98	17.95	17.00	20.41	15.35	15.23	14.29	15.20	12.00	13.80	13.33	16.58	14.11	11.30	12.30	14.15
	2	15.00	14.03	12.32	17.74	16.70	18.58	15.00	14.30	13.80	15.00	11.39	12.40	12.85	15.82	13.55	11.00	11.00	14.00
	4	13.55	13.15	10.89	15.10	16.30	17.00	14.80	13.80	12.70	13.60	11.05	10.60	12.25	14.45	12.65	10.30	10.50	13.50
	6	12.90	12.17	10.46	15.00	16.00	15.38	13.10	12.40	12.20	12.30	10.00	10.40	11.98	14.45	12.30	10.00	9.50	12.40
	8	12.25	11.01	9.98	14.55	15.50	14.41	12.70	12.30	11.90	11.30	9.60	9.60	11.50	14.20	11.85	9.20	9.20	11.10
	10	11.60	10.03	9.50	14.20	15.20	13.45	12.50	12.30	11.40	10.20	9.40	9.20	10.75	11.75	11.45	9.00	9.00	10.30

2198 kg/m³, 1909 to 2123 kg/m³ for Ondo state soil samples, 1920 to 1998 kg/m³ for Osun state soil samples, 2050 to 2475 kg/m³ for Oyo state soil samples, 1925 to 2025 kg/m³ for Ogun state soil samples, and 1420 to 2140 kg/m³ for Lagos state soil samples. As BSA increased, the MDD increased but the Optimum Moisture Content (OMC) decreased. When stabilized with BSA content, Oyo state soil sample D2 (Igbeti - Igbobo Federal road) had the highest value of 2475 kg/m³.

(d) UCS test:- In general, the Unconfined Compressive Strength (UCS) test rose and reached its peak at 6% BSA concentration. Table 5 shows the results of UCS testing on lime stabilized soil samples with BSA addition. For Ekiti, Ondo, Osun, Oyo, Ogun, and Lagos state soil samples, the UCS values ranged from 464.10 to 1210.70 kN/m², 218.40 to 414.10 kN/m², 253.00 to 768.60 kN/m², 126.00 to 638.90 kN/m², 174.00 to 622.60 kN/m², and 292.30 to 392.70 kN/m². When stabilized with BSA content, Ekiti state soil sample A1 (Ado - Itawure road) had the maximum value of 1210.7 kN/m².

(e) Triaxial test:-Table 6 illustrates the results of triaxial testing on optimum lime stabilized soil samples with BSA additive. The cohesion (C), angles

of internal friction (ϕ) and shear strength (S) values of the triaxial tests on the 6% lime stabilized soil samples with 0 – 10% additive content improved in general and achieved the optimum at 6% BSA content. The C, ϕ and S values ranged from 80 to 120 kN/m², 20 to 24° and 153.25 to 216.04 kN/m² respectively for Ekiti state soil samples; from 108 to 137 kN/m², 20 to 37° and 186.71 to 290.51 kN/m² respectively for Ondo state soil samples; from 34 to 93 kN/m², 15 to 26° and 94.11 to 183.22 kN/m² respectively for Osun state soil samples; from 87 to 130 kN/m², 12 to 15° and 122.61 to 170.03 kN/m² respectively for Oyo state soil samples. Ogun state soil samples have C, ϕ and S values that ranged from 99 to 115 kN/m², 8 to 12° and 135.94 to 162.86 kN/m² respectively; while C, ϕ and S values for Lagos state soil samples ranged from 8 to 120 kN/m², 22 to 41° and 91.98 to 232.93 kN/m² respectively. Ondo state soil sample B₃ (Ondo - Ore Federal road) has the highest value of 137 kN/m² (Cohesion) when stabilized with BSA content. Lagos state soil sample F₂ (Lekki - Ajah road) has the highest value of 41°, while Ondo state soil sample B₂ (Owo - Akoko road) has the highest value of 290.57 kN/m² (Shear strength) when stabilized with BSA content.

Table 5: Results of UCS Test On Lime Stabilized Soil Samples with BSA Additive

Test	AC (%)	SAMPLING LABEL																	
		A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	E1	E2	E3	F1	F2	F3
UCS (kN/m ²)	0	475.2	937.4	464.1	238.0	255.7	218.4	253.0	588.8	524.9	237.0	279.0	126.0	174.0	241.0	228.0	322.8	292.3	321.9
	2	828.2	1022.5	646.1	261.3	292.0	286.5	386.3	597.4	530.6	349.1	464.8	237.6	356.5	342.0	364.8	338.4	293.3	331.4
	4	949.9	1035.9	847.9	305.4	318.7	316.4	458.5	606.1	546.4	504.0	512.7	246.3	580.4	479.7	489.1	355.7	334.9	338.4
	6	1210.7	1116.4	1079.5	414.1	338.2	357.4	473.4	768.6	702.2	551.9	638.9	264.6	622.6	539.3	592.7	392.7	342.9	359.7
	8	1166.6	1030.8	1054.0	357.4	334.3	355.8	429.8	666.5	602.9	490.9	490.9	235.9	587.4	400.4	416.1	372.4	331.0	339.2
	10	902.8	859.7	999.4	330.6	317.2	307.0	407.8	532.3	595.1	260.3	444.8	184.5	441.6	377.6	401.2	325.9	302.8	325.9

Table 6: Results of Triaxial Test on Lime Stabilized Soil Samples with BSA Additive

Test	AC (%)	SAMPLING LABEL																	
		A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	E1	E2	E3	F1	F2	F3
COHESION (C) (kN/m ²)	0	107.00	117.00	80.00	108.00	112.00	118.50	65.00	90.00	34.00	87.00	112.00	119.00	99.00	110.00	109.00	8.00	9.00	108.00
	2	108.00	117.00	100.00	116.00	116.00	125.00	66.00	90.00	35.00	89.00	113.00	124.00	99.00	111.00	110.00	13.00	11.00	112.00
	4	109.00	118.00	104.00	112.00	125.00	133.00	67.00	91.00	36.00	91.00	114.00	128.00	101.00	112.00	111.00	15.00	16.00	117.00
	6	111.00	120.00	109.00	131.00	133.00	137.00	67.00	93.00	38.00	93.00	114.00	130.00	109.00	115.00	113.00	20.00	25.00	120.00
	8	103.00	117.00	104.00	126.00	130.00	134.00	65.00	88.00	36.00	91.00	107.00	124.00	101.00	111.00	112.00	14.00	20.00	114.00
	10	98.00	105.00	102.00	125.00	128.00	131.00	64.00	86.00	35.00	89.00	106.00	118.00	99.00	110.00	110.00	8.00	13.00	110.00
	0	21.50	20.00	22.00	24.00	20.00	23.00	24.00	15.00	18.00	13.00	12.00	13.00	10.00	8.00	11.00	31.00	35.00	22.00
	2	22.00	20.00	23.00	25.00	26.00	24.00	24.50	16.00	19.00	13.50	12.50	13.50	10.50	11.00	11.00	36.00	36.00	24.00
	4	22.50	22.00	24.00	28.00	28.00	29.00	25.00	17.00	20.00	14.00	13.00	14.00	11.00	12.00	11.50	38.00	38.00	28.00
	6	24.00	23.00	24.00	37.00	34.00	34.00	26.00	18.00	21.00	15.00	14.00	15.00	12.00	12.00	12.00	40.00	41.00	32.00
SHEAR STRENGTH (kN/m ²)	8	23.00	23.00	23.00	34.00	31.00	32.00	24.00	15.00	17.00	13.00	13.00	13.00	11.00	10.00	11.00	37.00	39.00	25.00
	10	22.00	22.00	23.00	33.00	29.00	26.00	23.00	14.00	16.00	12.00	12.00	13.00	10.00	10.00	11.00	34.00	37.00	23.00
	0	185.44	191.47	153.25	201.38	186.71	210.08	139.11	136.65	94.11	122.61	149.76	161.05	135.94	140.81	152.82	91.98	106.79	186.55
	2	188.96	195.10	181.24	228.45	222.29	224.98	164.93	140.03	99.26	124.88	152.10	163.44	137.18	154.03	153.97	108.87	118.09	206.44
	4	192.16	206.79	191.18	250.34	247.27	245.50	175.83	143.81	100.82	126.61	153.94	167.10	144.03	159.60	155.60	134.93	142.17	226.54
	6	196.36	216.04	199.50	279.63	290.57	265.52	183.22	148.59	115.05	130.08	156.81	170.03	156.52	162.86	157.60	141.17	153.19	232.93
	8	189.92	210.42	193.73	274.60	277.57	253.21	172.38	144.58	108.22	128.00	153.71	163.78	144.11	150.63	155.90	128.36	137.00	215.82
	10	186.38	194.29	190.18	251.91	259.67	242.30	165.40	139.38	96.72	124.15	152.53	162.56	137.54	148.76	153.90	101.77	114.61	198.99

Conclusion

The following conclusions were made from the investigation: that, BSA has a high SiO₂ content and that with the exception of OMC, all strength attributes increase as BSA increases.

The results indicate that the soils were stabilized using lime and a local BSA additive. As a result, a blend of 6% lime and 6% BSA is strongly suggested for soil improvement, particularly in South-Western Nigeria.

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