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Assessment of Lime Stabilized Soils Modified with Egg Shell Ash for Road Construction

Dr. Adetoro Adeyemi E.[1*], Dr. Oladapo Akinkunmi S.[2] & Olofintuyi Ilesanmi O.[3]

[1]*Department of Civil Engineering, Ladoke Akintola University of Technology, Ogbomoso, Nigeria.*
[1,2,3]*Department of Civil Engineering, Federal Polytechnic, Ado-ekiti, Nigeria. Email: yemmieadyt@yahoo.com**

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ABSTRACT

The need to have in-depth knowledge about the Engineering properties of soil and the sub-soil condition for road construction especially in the southwestern Nigeria brought about this study. Some strength properties (California Bearing Ratio (CBR), Compaction, Unconfined Compressive Strength (UCS), and direct Shear tests) of lime stabilized soils modified with Egg Shell Ash (ESA) were assessed. 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% ESA before the above-mentioned tests was conducted on them. The local additive was also subjected to a chemical analysis. Results showed that ESA additive has low SiO2 and high CaO compounds. Increase in ESA resulted in increase of all the strength properties (Maximum Dry Density (MDD), CBR, UCS, Cohesion (C), Shear strength (S) and Angle of Internal Friction (ϕ)) and reached peak at 8% ESA, thereafter decrease; albeit, Optimum Moisture Content (OMC) decreases. After the improvement process, almost all the unsuitable soil samples became suitable for use as pavement layer materials. Consequently, a blend of 6% lime and 8% ESA content is recommended for soil improvement, especially for road pavement layers in southwestern Nigeria.

Keywords: Chemical analysis, Egg shell ash, Lime, Local additive, Strength properties.

1. Introduction

In the pre-industrial era, there was no such thing as a road. Land transportation was confined to walking and the use of animal labour at the time, and items were transported in tiny amounts. Because waterways were the most efficient mode of transportation, the first civilizations arose along river systems for agricultural and commercial interests. The emergence of global industrialization, which resulted in rapid human population increase and urbanization, as well as a preference for industrial occupation over agriculture, necessitated massive road network development [1].

The road underneath soil determines the state of the road layers today and in the future. It is vital to have enough information about the Engineering qualities of soil and the sub-soil condition while building foundations in most Engineering structures. This is because reliable geotechnical data is used in the engineering planning, design, and building of such foundations. The majority of our road-building projects in Nigeria have failed due to a lack of critical geotechnical data, notably for primary preliminary engineering planning and designs, with failure occurring shortly after commissioning. As a result, the type of construction material used in road constructions is just as significant as other engineering design factors [2],[3].

In road pavement design, the soil (sub-base and base course) components used in pavement construction transport the axle-load to the sub-grade. As a result, the pavement's longevity is governed by the ease and stiffness with which the soil transmits stress to the sub-soil while preventing unnecessary deformation. Lateritic soils are used as road construction materials in tropical areas around the world, and they form the sub-grade of most highways. For low-cost highways with light to moderate traffic, they function as a sub-base and base course. In Nigeria, they are also used as a building material for the moulding of bricks [1]-[3].

Nevertheless, if a lateritic soil contains a significant amount of clay minerals, its strength and stability under load, especially in the presence of water, cannot be assured. These lateritic soils are also abundant in many tropical climates around the world, where it would be unwise to seek for alternative soil in most cases. The majority of the soil in our area does not meet the necessary standards to be regarded suitable, so it is rejected. In order to change the existing soil to meet the needed aim, this usually entails obtaining substitute materials from a distant burrow pit, which might be costly [2],[3].

Another approach is to stabilize the existing soil so that it may be used for construction; however, depending on the stabilizing chemicals employed, this could be costly. In geotechnical engineering, soil improvement can be achieved through both stabilization and modification. Soil modification is the process of changing the index properties of a soil by adding a modifier (such as cement, lime, fly ash, or bitumen), 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. The strength, bearing capacity, and long-term durability of the soil are all improved via soil alteration and stabilization [4]. Cement and lime are two ancient road-stabilizing materials that have been utilized since the dawn of civilization. Their prices, however, have climbed substantially over the last fifty years due to a dramatic increase in energy expenses. The overuse of traditional soil-improvement additives (cement, lime, etc.) has kept the cost of stabilizing a road and constructing a structure foundation high. As a result, emerging countries around the world have been unable to give accessible roads and safe structures to a larger percentage of their citizens (for example, Nigeria, which is mostly agriculturally dependent, poor, and still struggling with its economy). These countries must make do with what they have in order to achieve what they need, which in Nigeria includes converting waste (s) into indigenous road additives [1],[4].

Technical progress and the drive for a safer environment have led to cost-efficient reuse and effective management of goods previously discarded as waste. The depletion of natural resources as a result of industrial activity is a process that might result in waste materials and by-products accumulating. The safe disposal of these wastes is necessitated by good management because of the environmental and other health dangers they pose [2]. Certain waste materials are lying fallow within human habitats, waiting for the authorities to dispose of them. These waste products could be used to replace expensive materials required to maintain poor soil, such as cement and lime. When garbage is recycled or used as road stabilization materials, it removes the stress of needing to find expensive stabilization materials, hence enhancing people's living standards. The rate at which developing countries encourage resource imports is alarming, and it is one of the reasons why the poor remain poor. Waste recycling has gotten a lot of attention in a lot of industrialized countries across the world [4].

In the past, [4]-[6], and others established the viability of using waste materials for soil stabilization. Agricultural and industrial wastes are among the wastes that are commonly available in the area. These materials include bamboo leaf, coconut husk and shell, palm kernel shell, maize cobs, and so on. In the southern portion of Nigeria, this study looked into the optimization of lime stabilized soils amended with Egg Shell Ash (ESA) as a local supplement for road construction. This will aid in the development of waste treatment and road construction procedures that are cost-effective, feasible, and easily available. The paper promotes a "waste-to-wealth" strategy.

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2. Study Area

The states of Ekiti, Lagos, Ogun, Ondo, Osun, and Oyo make up southwestern Nigeria (Fig.1). It can be found at latitudes ranging from 6.214 to 9.000 °N and longitudes ranging from 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 that is hot and humid all year round. The study area is in southwestern Nigeria, where the climate is tropical monsoon (Köppen climatic classification "Am"). It's always drenched in torrential rain. It's possible that this is due to its proximity to the equatorial belt. Annual rainfall is at least 2,000 mm (78.7 in). The region experiences both dry and wet seasons. The first rainy season lasts from March through July. In August, there will be a two- to three-week dry spell (also known as August break). This hiatus is broken by the second rainy season, which comes between September and October. The dry season begins in November and lasts until March, after the second rainy season concludes in October [1].

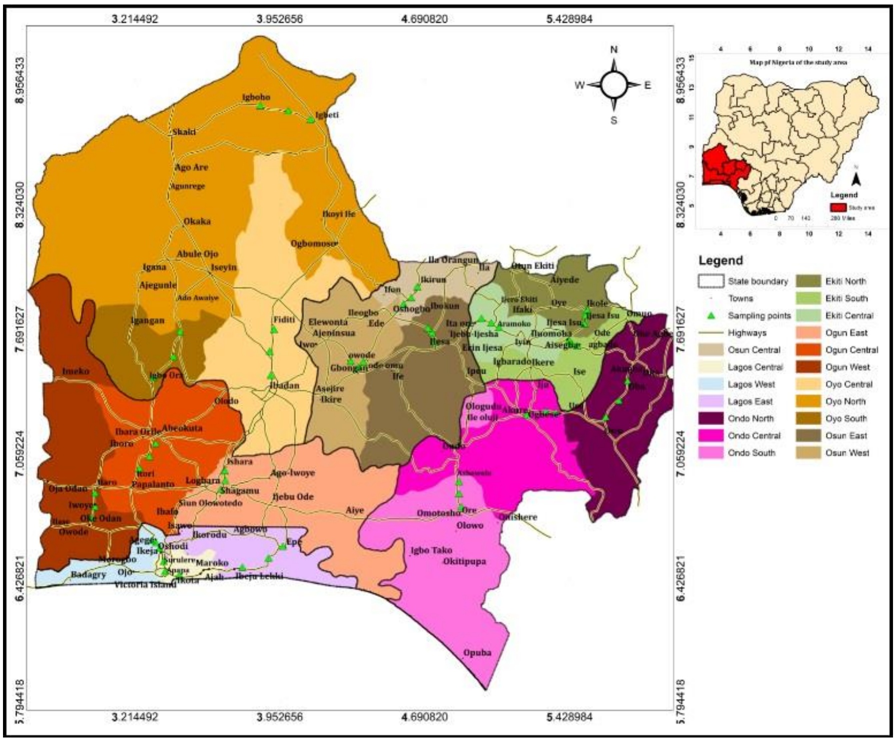

Fig.1. Location of the Study Area

The West African craton, which is made up of five tectonic events, includes the Nigeria basement complex (Fig.2). The Dahomey Precambrian rocks are obviously associated to this basement, which may be found virtually everywhere in Nigeria. Due to its petrology, the country's Precambrian basement complex is primarily composed of migmatite gneiss, schist, charnockitic rocks, older granites, and non-metamorphosed dolerite dykes. Sedimentary rocks cover the majority of Nigeria's surface, with crystalline igneous and metamorphic rocks comprising the remainder. Southwestern Nigeria has a varied spectrum of minerals, including metallic, non-metallic, industrial, and gemstone groups, due to the agglomeration of these rocks. The complex pegmatite

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that underpins the northern section of the research region comprises a range of gemstones like aquamarine, tourmaline, and agate, as well as commercial minerals like tantalite, marble, talc, and granites in many forms [1].

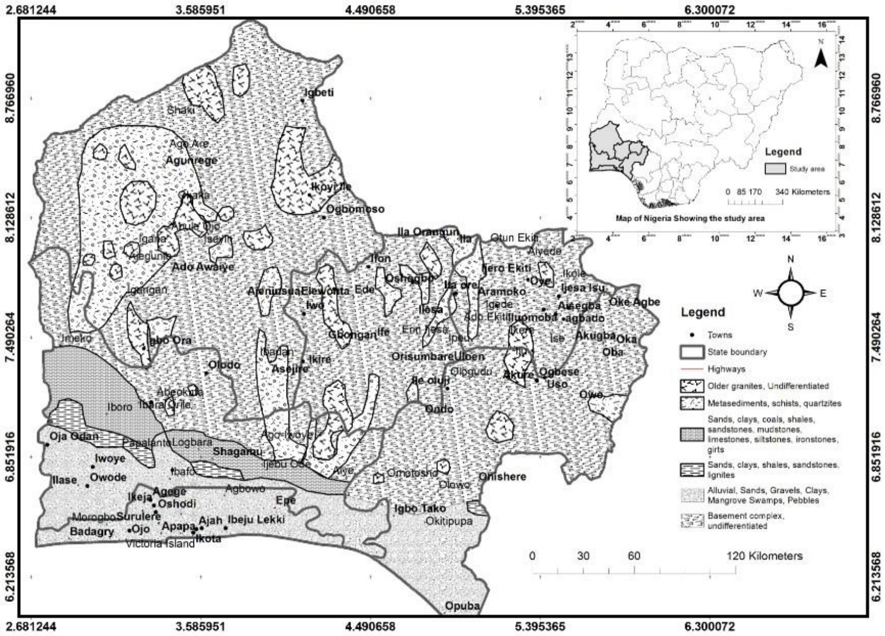

Fig.2. Geology of the Study Area

3. Materials and Methods

3.1. Materials

Soil samples, lime, Egg Shell Ash (ESA) and water were the materials used in this study.

A. Soil Samples

Three soil samples were obtained from borrow pits along Federal roads in the senatorial districts in each state in South-Western Nigeria. Table 1 lists the details of the samples. To prevent moisture loss, samples were immediately placed in polythene bags before being used. The soil was taken to the Department of Civil Engineering, Federal Polytechnic, Ado-Ekiti laboratory. The soil samples were then air-dried, pulverized, and sieved through British Standard (BS) sieves before being used in other assays.

Table 1. Details of the Soil Samples

S.No.	State	Sample Label	Location (Road)	Coordinates	
				Latitude	Longitude
1.	**EKITI**	A1	Itawure–AramokoEkiti	07^{0} 32' 32"	08^{0} 49' 27”
		A2	Ikole–IjesaisuEkiti	07^{0} 45' 28”	05^{0} 31' 08”
		A3	Aisegba–Iluomo-obaEkiti	07^{0} 36' 38”	05^{0} 28' 08”
2.	**ONDO**	B1	Akure–Ogbese	07^{0} 56' 39"	08^{0} 04' 57"
		B2	Owo–Ikareakoko	08^{0} 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^{0} 29’ 28”	08^{0} 19’ 31”
		E2	Shagamu–Ishara	06^{0} 11’ 05”	08^{0} 06’ 33”
		E3	Ilaro–Papanlanto	05^{0} 32’ 36”	08^{0} 02’ 07”
6.	**LAGOS**	F1	Apapa wharf–Apapa	06º 27' 16"	03^{0} 22' 05"
		F2	Lekki–Ajah expressway	06º 26' 21"	03^{0} 31' 25"
		F3	Oshodi–Agege expressway	06^{0} 33' 33"	03^{0} 20' 21"

B. Lime

Hydrated lime was used for this study. The lime, which was obtained in 25 kg bags from a chemical store in Ado-Ekiti, was kept cool and dry away from rain and moisture.

C. Egg Shell Ash (ESA)

In the Ado - Ekiti city, chicken egg shell samples were obtained from domestic sources such as chick hatcheries, poultry, bakeries, fast food restaurants, and so on. At the Civil Engineering laboratory, Federal Polytechnic, Ado–Ekiti, Nigeria, the collected eggshells were oven dried at 110 °C and then heated to 450 °C in a furnace (5X1-1008 Model). The resulting ash was sieved to a size of 0.425 mm.

D. Water

In the laboratory of the Federal Polytechnic Ado-Ekiti, clean water devoid of dissolved solids and particles was utilized to prepare specimens.

3.2. 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 [7]. 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%, ESA was added to the lime-stabilized soil samples. Chemical analysis of the ESA local additive was performed using traditional method. The soil samples were subjected to engineering strength tests i.e. California Bearing Ratio (CBR), compaction, Unconfined Compression Strength (UCS), and direct (triaxial) shear testing.

A. California Bearing Ratio (CBR)

This is an empirical test for determining subgrade strength established by the California State Highway Department. According to [7], a specimen with height and diameter of 127 and 152 mm was crushed into the CBR mould. 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 [7] soil test requirements.

B. 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 [7]. As the provided compactive effort, a cylindrical metal mould (Proctor mould) of around 1000 cm^3 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 [7] soil test requirements.

C. 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 [7] soil test requirements.

D. 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 [7] soil test requirements.

4. Results and Discussions

A. Chemical Compositions of ESA Additive

Table 2 summarizes the results of chemical analysis of the ESA local additive that was utilized for stabilization. ESA has a high Calcium Oxide (CaO) content of 68.20%. The total amount of Silica, Aluminium, and Ferric oxides in it was 12.19%, which was very low.

Table 2. Chemical Composition of ESA

Composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	MgO	Na_2O	MnO	CuO	LoI	U	$SiO_2+Al_2O_3+Fe_2O_3$
ESA (%)	11.29	0.61	0.29	68.20	2.19	2.14	6.00	0.02	0.04	8.71	1.50	12.19

U – Undetermined

B. CBR Test Result

Generally, it was observed from Table 3 that there was increase in CBR (both soaked and unsoaked) as ESA content increases and reached the optimum at 8% of the additive content. The soaked CBR values of Ekiti state soil samples ranged from 31.85 (0% ESA) to 36.44% (8% ESA), while unsoaked CBR ranged from 27.46 (0% ESA) to 33.61% (8% ESA). The soaked CBR values of Ondo state soil samples ranged from 4.25 (0% ESA) to 6.26% (8% ESA), while unsoaked CBR ranged from 5.68 (0% ESA) to 8.50% (8% ESA). The soaked CBR values of Osun state soil samples ranged from 7.77 (0% ESA) to 24.47% (8% ESA), while unsoaked CBR ranged from 5.78 (0% ESA) to 12.08% (8% ESA). The soaked CBR values of Oyo state soil samples ranged from 11.00 (0% ESA) to 61.18% (8% ESA), while unsoaked CBR ranged from 8.10 (0% ESA) to 50.79% (8% ESA). The soaked CBR values of Ogun state soil samples ranged from 11.11 (0% ESA) to 24.80% (8% ESA), while unsoaked CBR ranged from 6.51 (0% ESA) to 19.03% (8% ESA). The soaked CBR values of Lagos state soil samples ranged from 4.11 (0% ESA) to 8.02% (8% ESA), while unsoaked CBR ranged from 6.13 (0% ESA) to 8.89% (8% ESA).

C. Compaction Test Result

The results of compaction test on lime stabilized soil samples with ESA additive are shown in Table 4. MDD ranged from 1828 to 2250 kg/m^3 for Ekiti state soil samples, from 1909 to 2080 kg/m^3 for Ondo state soil samples, from 1920 to 1998 kg/m^3 for Osun state soil samples, from 2050 to 2515 kg/m^3 for Oyo state soil samples, from 1925 to 2060 kg/m^3 for Ogun state soil samples; while the MDD for Lagos state soil samples ranged from 1420 to 2150 kg/m^3. There was increase in Maximum Dry Density (MDD) and decrease in Optimum Moisture Content (OMC) with increase in Additive Content (AC). Optimum MDD was attained at 8% of ESA content for the lime stabilized soil samples. The optimum OMC was attained at 0% content (i.e. when the lime used for stabilization of the selected soil samples is 6% without any additive added).

D. UCS Test Result

Table 5 shows the results of UCS tests on optimum lime stabilized soil samples with ESA additive. The UCS values ranged from 464.10 to 1032.20 KN/m^2, 218.40 to 429.80 KN/m^2, 253.00 to 807.10 KN/m^2, 126.00 to 531.00 KN/m^2, 174.00 to 590.30 KN/m^2 and 292.30 to 390.40 KN/m^2 for Ekiti, Ondo, Osun, Oyo, Ogun and Lagos state soil samples respectively. The UCS values increased with local Additive Content (AC) and reached the optimum at 8% of ESA content.

E. Direct Shear Test

The results of direct shear test on lime stabilized soil samples with ESA additive is shown in Table 6. The C, Ø and S values ranged from 80 to 121 KN/m^2, 20 to 25^0 and 153.25 to 203.94 KN/m^2 respectively for Ekiti state soil samples; from 108 to 137 KN/m^2, 20 to 33^0 and 186.71 to 244.77 KN/m^2 respectively for Ondo state soil samples; from 34 to 101 KN/m^2, 15 to 26^0 and 94.11 to 150.56 KN/m^2 respectively for Osun state soil samples; from 87 to 127 KN/m^2, 12 to 17^0 and 122.61 to 166.91 KN/m^2 respectively for Oyo state soil samples. Ogun state soil samples have C, Ø and S values that ranged from 99 to 116 KN/m^2, 8 to 14^0 and 135.94 to 168.16 KN/m^2 respectively; while C, Ø and S values for Lagos state soil samples ranged from 8 to 118 KN/m^2, 22 to 40^0 and 91.98 to 233.03 KN/m^2 respectively. It was observed that the cohesion (C), angles of internal friction (Ø) and shear strength (S) values of the direct shear tests on the 6% lime stabilized soil samples with 0 – 10% additive contents increased and reached the optimum at 8% of ESA contents.

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Table 3. Results of CBR Test on Lime Stabilized Soil Samples with ESA Additive

Test	AC (%)	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	4.11	4.98	4.48
	2	31.91	35.12	32.85	4.88	4.76	5.89	10.95	21.92	11.27	13.15	54.76	36.25	12.25	20.80	18.63	4.36	6.01	4.88
	4	32.67	35.69	33.80	5.01	4.88	6.01	12.27	22.92	12.03	14.90	57.78	38.71	12.39	21.53	20.25	4.67	6.76	5.31
	6	33.99	35.88	34.18	5.26	5.01	6.23	14.28	23.17	14.84	15.91	59.86	40.22	12.53	22.92	22.43	4.86	7.01	5.88
	8	**35.50**	**36.25**	**36.44**	**5.85**	**5.14**	**6.26**	**16.28**	**24.47**	**15.67**	**17.18**	**61.18**	**43.81**	**13.16**	**24.80**	**23.93**	**5.01**	**8.02**	**6.76**
	10	19.66	23.41	23.05	5.51	4.88	6.23	11.02	21.92	13.97	13.22	58.62	41.16	10.80	14.31	22.37	4.76	6.14	4.51
CBR (UNSOAKED) (%)	0	27.46	29.34	29.27	5.68	7.13	7.23	5.78	6.27	5.78	8.10	34.33	19.69	6.51	16.90	8.76	6.13	7.40	6.75
	2	27.76	29.83	30.21	6.04	7.74	7.55	7.55	7.55	6.76	9.25	38.70	21.15	13.78	17.02	10.31	6.81	7.52	7.14
	4	28.32	30.59	31.34	6.26	7.93	7.74	8.87	7.74	8.69	10.39	42.48	24.74	14.67	17.59	11.83	7.14	7.77	7.39
	6	30.02	31.53	32.10	6.39	8.31	7.93	10.64	7.93	10.95	11.14	46.26	27.68	13.03	18.46	12.67	7.26	7.89	8.14
	8	**31.72**	**33.61**	**33.04**	**6.61**	**8.50**	**8.12**	**12.08**	**8.12**	**11.90**	**12.84**	**50.79**	**29.83**	**13.83**	**19.03**	**12.91**	**7.84**	**8.52**	**8.89**
	10	12.78	16.05	12.08	6.51	8.39	7.93	7.93	7.93	10.01	9.44	44.95	28.13	12.68	16.62	10.87	6.01	7.39	6.64

Table 4. Results of Compaction Test on Lime Stabilized Soil Samples with ESA Additive

Test	AC (%)	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	4.11	4.98	4.48
	2	31.91	35.12	32.85	4.88	4.76	5.89	10.95	21.92	11.27	13.15	54.76	36.25	12.25	20.80	18.63	4.36	6.01	4.88
	4	32.67	35.69	33.80	5.01	4.88	6.01	12.27	22.92	12.03	14.90	57.78	38.71	12.39	21.53	20.25	4.67	6.76	5.31
	6	33.99	35.88	34.18	5.26	5.01	6.23	14.28	23.17	14.84	15.91	59.86	40.22	12.53	22.92	22.43	4.86	7.01	5.88
	8	**35.50**	**36.25**	**36.44**	**5.85**	**5.14**	**6.26**	**16.28**	**24.47**	**15.67**	**17.18**	**61.18**	**43.81**	**13.16**	**24.80**	**23.93**	**5.01**	**8.02**	**6.76**
	10	19.66	23.41	23.05	5.51	4.88	6.23	11.02	21.92	13.97	13.22	58.62	41.16	10.80	14.31	22.37	4.76	6.14	4.51
CBR (UNSOAKED) (%)	0	27.46	29.34	29.27	5.68	7.13	7.23	5.78	6.27	5.78	8.10	34.33	19.69	6.51	16.90	8.76	6.13	7.40	6.75
	2	27.76	29.83	30.21	6.04	7.74	7.55	7.55	7.55	6.76	9.25	38.70	21.15	13.78	17.02	10.31	6.81	7.52	7.14
	4	28.32	30.59	31.34	6.26	7.93	7.74	8.87	7.74	8.69	10.39	42.48	24.74	14.67	17.59	11.83	7.14	7.77	7.39
	6	30.02	31.53	32.10	6.39	8.31	7.93	10.64	7.93	10.95	11.14	46.26	27.68	13.03	18.46	12.67	7.26	7.89	8.14
	8	**31.72**	**33.61**	**33.04**	**6.61**	**8.50**	**8.12**	**12.08**	**8.12**	**11.90**	**12.84**	**50.79**	**29.83**	**13.83**	**19.03**	**12.91**	**7.84**	**8.52**	**8.89**
	10	12.78	16.05	12.08	6.51	8.39	7.93	7.93	7.93	10.01	9.44	44.95	28.13	12.68	16.62	10.87	6.01	7.39	6.64

Table 5. Results of UCS Test on Lime Stabilized Soil Samples with ESA Additive

Test	AC (%)	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	792.2	1006.8	644.7	266.1	321.1	272.1	364.3	603.0	592.0	305.5	418.7	135.8	341.9	431.0	432.6	338.4	306.3	322.8
	4	924.8	1014.7	887.1	305.4	340.1	302.2	439.2	698.7	617.1	315.1	460.5	151.5	357.2	469.5	449.8	347.1	321.0	328.0
	6	963.3	1023.7	945.2	346.4	353.9	332.2	467.9	775.4	635.1	344.7	478.8	156.0	410.1	469.8	476.5	364.4	346.8	334.0
	8	**980.6**	**1032.2**	**952.6**	**429.8**	**377.8**	**368.4**	**499.0**	**807.1**	**784.0**	**374.3**	**531.0**	**162.8**	**590.3**	**574.6**	**499.3**	**390.4**	**349.4**	**357.1**
	10	734.0	869.1	694.8	384.1	363.7	322.7	460.5	580.9	505.6	311.6	313.4	137.5	315.6	223.7	433.4	331.4	295.0	325.4

Table 6. Results of Triaxial Test on Lime Stabilized Soil Samples with ESA Additive

Test	**AC (%)**	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	118.00	86.00	120.00	119.00	126.00	66.00	91.00	35.00	90.00	113.00	112.00	99.00	111.00	110.00	12.00	12.00	111.00
	4	109.00	119.00	89.00	127.00	124.00	129.00	68.00	96.00	37.00	91.00	116.00	123.00	101.00	113.00	111.00	15.00	15.00	113.00
	6	110.00	120.00	92.00	131.00	129.00	133.00	70.00	101.00	38.00	92.00	118.00	123.00	102.00	114.00	115.00	16.00	19.00	115.00
	8	**111.00**	**121.00**	**98.00**	**137.00**	**131.00**	**137.00**	**71.00**	**101.00**	**38.00**	**93.00**	**120.00**	**127.00**	**104.00**	**114.00**	**116.00**	**18.00**	**20.00**	**118.00**
	10	98.00	116.00	95.00	134.00	127.00	132.00	67.00	96.00	37.00	92.00	117.00	118.00	100.00	110.00	109.00	16.00	14.00	110.00

INTERNAL FRICTION (Φ°)	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	21.00	20.00	22.00	27.00	24.00	25.00	24.00	15.00	19.00	13.00	13.00	14.00	10.00	8.00	12.00	34.00	37.00	24.00
	4	22.00	21.00	23.00	35.00	27.00	27.00	25.00	16.00	19.50	14.00	13.00	15.00	11.00	9.00	12.00	35.00	38.00	26.00
	6	22.00	21.00	24.00	37.00	31.00	28.00	26.00	17.00	19.50	14.00	14.00	16.00	12.00	9.00	13.00	36.00	39.00	27.00
	8	**22.00**	**22.00**	**25.00**	**39.00**	**33.00**	**33.00**	**26.00**	**18.00**	**20.00**	**15.00**	**15.00**	**17.00**	**13.00**	**10.00**	**14.00**	**39.00**	**40.00**	**30.00**
	10	17.00	19.00	22.00	36.00	28.00	30.00	23.00	15.00	18.00	13.00	13.00	14.00	11.00	10.00	13.00	33.00	37.00	23.00
SHEAR STRENGTH	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	187.82	195.02	165.02	212.68	218.98	214.63	140.9	138.15	96.34	123.82	150.76	162.7	136.08	141.93	157.6	107.1	126.36	198.04
	4	189.24	197.73	169.83	226.88	235.59	223.77	142.39	143.45	99.58	125.27	154.68	164.7	138.23	147.61	158.77	121.5	135.91	211.76
	6	190.70	198.84	171.85	237.11	238.29	229.44	146.97	145.97	103.04	126.22	156.77	165.86	142.83	148.88	165.28	128.01	143.05	220.20
	8	**195.90**	**203.94**	**176.36**	**241.40**	**244.77**	**233.03**	**150.56**	**147.29**	**107.51**	**127.74**	**158.26**	**166.91**	**145.14**	**152.69**	**168.16**	**132.28**	**157.85**	**233.03**
	10	191.74	200.12	171.81	230.62	235.22	225.17	147.59	141.36	104.46	124.14	152.56	160.23	140.75	146.57	160.45	105.51	128.36	207.01

F. Summary: Impact of ESA on the 6% Lime Stabilized Soil Samples

Generally, there were increase in CBR (soaked and unsoaked), MDD, C, ϕ, S and UCS as ESA content increases and reached the optimum at 8% of the additive content. The increment in soaked CBR values at 8% ESA content made some soil samples (i.e. B1, B2 and F1) that were not suitable as subgrade materials to become suitable.

The increment in MDD values at 8% ESA content made some soil samples (i.e. A1, B1, E1, E2, E3, F2, and F3) that were not suitable as sub-base and base materials to become suitable. The increment resulted in reduction of the percentages of finer particles of the soil samples and cohesive qualities of the binder resulting from the clay or fine contents which make the soil samples better. As the percentage of additive added increases, the soil samples tend towards meeting the required specification for pavement layer materials. However, it requires more ESA content in order to attain the required strength due to lower percentage of SiO_2 and higher percentage of CaO [8],[9].

5. Conclusions

From the above study, it could be deduced that Egg Shell Ash (ESA) has a low SiO_2 and high CaO contents. All the strength parameters increase with increase in ESA content. The results show that the soils were stabilized using lime and a local ESA additive. Therefore, a combination of 6% lime and 8% ESA is highly recommended for soil stabilization especially in Southwestern Nigeria.

Declarations

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Consent for publication

Authors declare that they consented for the publication of this research work.

References

[1] Amu O O, Faluyi S O, Adetoro A E, (2022). Stabilization of Laterite Soil with Eggshell Powder and Sodium Silicate used as Fill Material in Road Construction. Federal University of Technology, Akure Journal of Environmental and Engineering Technology, 15(2).

[2] M. I. Kanyi, (2017). Soil Stabilization Using Lime: Cement Stabilization of Lateritic Soil using Iron Ore Tailing as Admixture. Unpublished MSc Dissertation, Department of Civil Engineering, Ahmadu Bello University, Nigeria, Zaria.

[3] Osinubi K J, Oluremi J R, Eberemu A O, Ijimdiya S T, (2017). Interaction of Landfill Leachate with Compacted Lateritic Soil - Waste Wood Ash Mixture. Proceedings of Institution of Civil Engineers: Waste and Resource Management, Vol. 170(34): 128-138. https://doi.org/10.1680/jwarm.17.00012.

[4] Oladapo S A, Adetoro E A, (2020). Investigation of Properties of Lateritic Bricks Stabilized with Cement and Rice Husk Ash. Journal of Engineering and Earth Sciences, 13(1): 1-10.

[5] Oke J A, Olowoyo M K, (2019). Stabilization of Laterite Soil with Eggshell Powder and Sodium Silicate used as Fill Material in Road Construction. Arid Zone J. of Engineering, Technology and Environment 15(3): 586-597.

[6] Hezmi M A, Ahmad K, Yunus N Z M, Kassim K A, Rashid A S A, Hassan N A, (2019). Compaction Characteristics of Lime-Treated Tropical Soil. Materials Science and Engineering, 527: 1-8.

[7] British Standard 1377 (BS 1377), British Standard Methods of Test for Soils for Civil Engineering Purposes. British Standards Institution, London, UK.

[8] Ugwu E I, Famuyibo D A, (2014). Analysis of the Effect of Blending Nigeria Pure Clay with Rice Husk: A Case Study of Ekulu Clay in Enugu State. American J. of Materials Engineering and Technology, 2(3): 34-37.

[9] Abe E O, Adetoro A E, (2017). Study of Mechanical Properties of Stabilized Lateritic Soil with Additives. International Journal of Advanced Engineering Research and Science, 4(11): 28-32.