Acta Technica Napocensis: Civil Engineering & Architecture
Volume 60, No. 1, (2017)
Journal homepage: http://constructii.utcluj.ro/ActaCivilEng
ISSN 1221-5848

Assessment of Beach Sand as Lateritic Soil Stabilizer

Memudu Quadri[1], Oluwatosin Alao[2], Oluwaseun Akindipe[3] and Olufikayo Aderinlewo*[4]

[1,2,3,4] *Department of Civil and Environmental Engineering, Federal University of Technology, Akure, Nigeria*
**Corresponding author's Email: oluade2010@gmail.com*

(Received 30 March 2016; Accepted 21 February 2017)

Abstract

In this study, the geotechnical properties of lateritic soil stabilized with beach sand were determined and compared with those of the same lateritic soil stabilized with cement. The beach sand and cement were added in percentages of 0, 2.5, 5, 7.5, 10, 12.5 and 15% by weight of the soil. Preliminary tests such as natural moisture content, specific gravity, particle size analysis and Atterberg limits tests were performed on the control soil sample for identication and classification of the soil. The lateritic soil was classified as fair to poor clayey soil. The tests carried out on the lateritic soil after adding the beach sand and cement were the California Bearing Ratio (CBR) test and compaction test. Results of the CBR (soaked) test showed an increase in value from 4.53% for the control to 5.96% at 15% beach sand addition while the CBR (unsoaked) showed an increase in value from 3.46% for the control to 34.85% at 15% beach sand addition. Chemical tests were also performed on the beach sand to determine its composition.

Keywords: Geotechnical properties, preliminary tests, California bearing ratio, Atterberg limits, compaction.

1. Introduction

Lateritic soils are the products of intensive weathering that occur under tropical and subtropical climatic condition resulting in the accumulation of hydrated iron and aluminum oxides [1, 2,]. Nearly all lateritic soils are rusty-red because of the presence of iron oxides. Lateritic soils are the most readily available construction materials at sites in many tropical countries of the world; hence, the best option is to modify the properties of the soil so that it meets the pavement design requirements [3, 4]. This has led to the development of soil stabilization techniques.

Pavement designers have always been searching for technical and economical solutions for the improvement of the geo-technical properties of soil. Soil stabilization technique, which is normally used for the improvement of local soils, is considered an economical solution in places where granular materials are not available. Hydrated lime and Portland cement have been considered excellent stabilizers for the improvement of different soils and have been extensively used in the past decades. Beneficial effects of compacted soil-lime and soil-cement mixtures on geotechnical properties have been discussed in technical literature [5-7]. Ordinarily, these stabilizers can promote plasticity reduction, grain size distribution alterations caused by flocculation reactions, and expressive mechanical strength increase. Soil improvement by mechanical or chemical means is widely adopted in order to stabilize soils for improving strength and durability [8, 9].

Lateritic soils are known to exhibit unstable properties. One means of dealing with this problem is through stabilization by adding some other material which could alter the physical and engineering properties of the soil thereby improving such properties [10]. In this study, beach sand is being proposed as an affordable and easily sourced alternative stabilizer for lateritic soils. Hence, an assessment of beach sand as a lateritic soil stabilizer was carried out in comparison with cement stabilized soil. The underlying objectives include determination of the engineering characteristics of the lateritic soil, determination of the chemical composition of the beach sand, assessment of the response of the of the lateritic soil to stabilisation with beach sand and comparison of the properties of the lateritic soil stabilized with beach sand with that stabilized with cement.

2. Background Literature

Soil Stabilization is the process by which the engineering properties of soil layers can be improved or treated by addition of other soil types, mineral materials or by mixing the appropriate chemical additive into the pulverized soil and then compacting it [11]. It is aimed at improving the soil density, increasing its cohesion and friction angle and reducing its plasticity index. However, it is a must to obtain adequate relevant information concerning the ground condition and soil properties relative to the grading and any layer of the soil.

Two general methods of stabilization are mechanical and chemical. In mechanical method of soil stabilization, improvement of soil engineering properties is carried out by the addition of other soil particles which are missing from its natural grading. In ground improvement projects, this normally leads to soil compaction, both deep and superficial. The soil as a material is densified by mechanical means and is used as fill in the construction of embankments, earth dams and subgrade of roads [12]. The increase in density is achieved by decreasing the air voids content while the water content remains approximately the same [13].

Soil stabilization through compaction is mostly carried out by field compaction which involves the use of different compacting equipment. This equipment varies from hand punners to heavy vibrating plates, power rammer, jumping frog rammer and also comprises of many types of rollers such as rubber-tyre roller, wobbly wheel, sheep-foot and smooth steel-tyre. Some of these rollers pulverize, moisten, mix, lay and compact soil on one or more passes of the machine. It is possible to have 100% proctors and 100% modified proctor compaction in the field [14]. Relative compaction is the ratio of field dry density to maximum dry density multiplied by 100 [15].

In chemical stabilization, materials such as Portland cement, lime, lime-cement-fly ash, bitumen (alone or in combination) are added to the soil to improve its properties. The selection of these products depends upon the soil classification and degree of improvement in soil quality desired. Modification method of soil stabilization usually results in something less than a thoroughly cemented, hardened or semi-hardened material [16-19]. The type of stabilization may be accomplished by compacting, mechanical blending, adding cementing materials in small amounts or adding chemical modifiers.

Calcium chloride or sodium chloride is added to the soil to retain moisture, to hold fine material for better compaction, and to reduce frost heave by lowering the freezing point of water in the soil. Bituminous materials, such as cutback asphalts or asphaltic penetrative soil binder, and certain chemicals such as polyvinyl acetate emulsion are used to waterproof the soil surface to control dust [20]. Sandy and gravel soils, sandy soils as well as silty and clayey soils could be effectively stabilized with lime and cement.

2.1. Beach Sand and its properties

Beach sand, which is the type of stabilizer adopted in this project is a type of sand that is mainly composed of feldspar, phosphorus and can be formed through weathering of igneous rocks and metamorphic rocks. Beach sand has low capacity to retain water and is nutrient poor, with little organic matter. Beach sands are made up of quartz because the sands are derived from the weathering and erosion of the land masses and their mountains. The land masses and mountains are composed of rocks that are in turn themselves composed of many common minerals, such as quartz, feldspar, pyroxenes, amphiboles and mica. Most igneous rocks (like the kind of rocks that form major mountain ranges like the sierras and the rocky mountains) have a lot of quartz and feldspar and relatively little of the others.

During weathering, feldspar (an aluminosilicate) rather rapidly converts to clays, while quartz, being unreactive silicon dioxide, survives the weathering process and eventually makes it’s way to accumulate along the beaches. The clays that were formed by the alteration of the feldspars are winnowed out from the surf zone and washed away to the open ocean to accumulate on the continental shelf and beyond. The quartz remains behind, traveling down the coastline as a narrow ribbon of sand in what’s called long shore or littoral drift [21].

3. Methodology and Materials

The materials used in carrying out this project are lateritic soil, beach sand, cement and water. The soil sample was collected from a trial pit (to a depth of 1m) beside the Niger Delta Development Corporation (NDDC) water tower, located behind the Federal University of Technology, Akure (FUTA) sports complex using auger and stored in nylon bags to prevent moisture loss. Figure 1 shows a sample of the lateritic soil used.

Figure1. The Lateritic soil sample

The beach sand was collected from Bar beach, along Ahmadu Bello way located in Lagos Island, Lagos, Nigeria. Figure 2 shows a sample of the beach sand used. The cement used in this experiment is the Ordinary Portland Cement which is an efficient agent in improving the geo-technical properties of lateritic soils. Different percentages of Portland cement were used ranging from 0% to 15% in order to stabilize the lateritic soils. Potable water used for this project was collected from a bore-hole located beside the Geotechnical laboratory of the Federal University of Technology, Akure.

Figure 2. The Beach sand sample

3.1. Laboratory Experiments

A number of experiments were carried out in order to determine the properties of the lateritic soil as well as to assess the performance of beach sand as a lateritic soil stabilizer. These include the Moisture Content, Specific gravity, Sieve analysis, Atterberg Limits, Compaction and California Bearing ratio tests.

The natural moisture content test is usually carried out to determine the amount of moisture content present in a soil as percentage of its dry mass. The soil samples used for the natural moisture content determination test were collected from in-situ soil mass and were tested immediately. The value of specific gravity depends on the mineralogical composition of the constituent soil particles. The apparatus used for this test are 50ml glass jar, a weighing balance, distilled water and oven dried sample.

The method employed in the soil classification is wet sieving. This process involves washing of the lateritic soil sample in order to be free from silt and clay. The apparatus used include a set of sieves from sizes 4.7mm down to the pan, sieve of aperture opening 0.075mm, and 500g of soil sample.

The Atterberg limits test carried out include the liquid limit, plastic limit and the shrinkage limit. The liquid limit (LL) of a soil is the moisture content, expressed as a percentage of the weight of the oven-dried soil, at a boundary between the liquid and plastic states of consistency. The apparatus used for the test are Cassagrande apparatus, 0.425mm sieve, spatula, grooving tool, water bottle, weighing balance, moisture content can and a flat glass plate for mixing.

The plastic limit (PL) of a soil is the moisture content of a soil expressed as a percentage of the weight of the oven-dry soil at the boundary between the plastic and semi-solid states of consistency. It is the moisture content at which a soil will just begin to crumble when rolled into a diameter of 3mm. The apparatus used include 0.425mm sieve, spatula, water bottle, weighing balance, moisture content can and a flat glass plate for mixing. The plasticity index (PI) of a soil is the numerical difference between its liquid limit and its plastic limit.

The shrinkage limit is defined as the maximum moisture content at which further loss of moisture does not cause a decrease in volume of the soil. The shrinkage limit apparatus used include the shrinkage mould, a spatula and a meter rule. Some of the sample that remained during the liquid limit test was used for the shrinkage limit test.
The compaction test was performed on the lateritic soil in its natural form, and thereafter on the lateritic soil with the addition of stabilizers in the form of cement and the beach sand ranging from 2.5% to 15% by weight of the lateritic soil sample. The apparatus used include a cylindrical compaction mould, 2.5kg rammer, spatula, analogue weighing balance, moisture content cans and a tray.

The California bearing ratio (CBR) test is a penetration test designed for the evaluation of sub-grade strengths in which the load required to cause the penetration of a plunger at constant rate is measured. The test was carried out on the lateritic soil sample both in its natural form and after the addition of the stabilizers. The basic apparatus needed for this test include the CBR machine, the CBR mould, spatula, 4.5kg rammer, filter paper used for the soaked CBR test and a tray for mixing [22].

4. Analysis and Discussion of Results

The natural moisture content, specific gravity, particle size distribution and the Atterberg limits tests were carried out to classify the lateritic soil while the compaction, and the California bearing ratio tests were carried out to assess the effects of beach sand and cement on the lateritic soil.

4.1. Natural Moisture Content test

The natural moisture content obtained for the lateritic soil used in this research was 22.75% which shows that the sample contains appreciable amount of moisture while that of the beach sand was 0.16%. The results of the natural moisture content test are as presented in Tables 1(a) and (b).

Table 1(a): Natural Moisture Content Determination for Lateritic Soil.

S/N	**DESCRIPTION** (weight in grammes)	**SAMPLE**		
		A	**B**	**C**
1.	Weight of Can (W_1)	43.9	41.1	44.7
2.	Weight of Can (W_1) + Wet Sample (W_2)	120.2	106.5	117.1
3.	Weight of Can (W_1) + Dried Sample (W_3)	105.9	94.5	103.7
CALCULATION:				
1.	Weight of Dry Sample (W_4) = $W_3 – W_2$	62.0	53.4	59.0
2.	Weight of Moisture (W_5) = W_2 - W_3	14. 3	12.0	13.4

3.	Moisture Content (M_c) = (W_5/W_4) * 100%	23.06	22.47	22.71
4.	Average Moisture Content	**22.75%**		

Table 1(b): Natural Moisture Content Determination for Beach Sand

S/N	DESCRIPTION (weight in grammes)	SAMPLE		
		A	B	C
1.	Weight of Can (W_1)	45.8	46.9	46.0
2.	Weight of Can (W_1) + Wet Sample (W_2)	174.5	173.9	183.6
3.	Weight of Can (W_1) + Dried Sample (W_3)	174.3	173.7	183.4
CALCULATION:				
1.	Weight of Dry Sample (W_4) = $W_3 – W_2$	128.5	126.8	137.4
2.	Weight of Moisture (W_5) = W_2 - W_3	0.2	0.2	0.2
3.	Moisture Content (M_c) = (W_5/W_4) * 100%	0.16	0.16	0.15
4.	Average Moisture Content	**0.16%**		

4.2. Specific Gravity test

The specific gravity obtained for the lateritic soil was 2.61 while that for the beach sand was 2.56. The results are as presented in Tables 2 (a) and (b).

Table 2(a): Specific Gravity for the Lateritic Soil.

S/N	DESCRIPTION (weight in grammes)	SAMPLE		
		A	B	C
1.	Weight of glass jar (m_1)	295.3	268.4	260.0
2.	Weight of glass jar (m_1) + 50G of dry soil (m_2)	345. 3	318.4	310.0
3.	Weight of glass jar (m_1) + soil + Water (m_3)	643.9	621. 3	617.6
4.	Weight of glass jar (m_1) + Water (m_4)	613.0	590.7	586.7
CALCULATION:				
1.	Specific gravity $G_S = \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_2)}$	2.62	2.58	2.62
2.	Average G_S	**2.61**		

Table 2(b): Specific Gravity for Beach Sand.

S/N	DESCRIPTION (weight in grammes)	SAMPLE		
		A	B	C
1.	Weight of glass jar (m_1)	295.3	310.8	259.8
2.	Weight of glass jar (m_1) + 50G of dry soil (m_2)	345. 3	360.9	309.8
3.	Weight of glass jar (m_1) + soil + Water (m_3)	644.0	646.2	617.1
4.	Weight of glass jar (m_1) + Water (m_4)	613.1	616.0	586.7
CALCULATION:				
1.	Specific gravity $G_S = \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_2)}$	2.62	2.52	2.55
2.	Average G_S	**2.56**		

4.3. Particle Size Distribution

Table 3 shows a breakdown of the particle size distribution analysis of the lateritic soil with the corresponding percentages retained on and passing through each of the sieves. Figure 4.1 shows the particle size distribution curve for the lateritic soil sample (as percent finer by weight) with the particle size increasing from left to right on the horizontal axis. The weight of the soil sample used for the experiment was 500g.

Table 3: Particle Size Distribution Analysis of the Lateritic Soil

S/N	APERTURE SIZE	MASS RETAINED (g)	PERCENTAGE RETAINED (%)	MASS PASSING(g)	PERCENTAGE PASSING (%)
1	2.36mm	49.8	9.96	450.2	90.04
2	1.70mm	2.1	0.42	448.1	89.62
3	1.18mm	15.4	3.08	432.7	86.54
4	600µm	23.5	4.70	409.2	81.84
5	500µm	23.6	4.72	385.6	77.12
6	425µm	1.9	0.38	383.7	76.74
7	212µm	35.7	7.14	348.0	69.60
8	150µm	7.0	1.40	341.0	68.20
9	75µm	7.3	1.46	333.7	66.74
10	RECEIVER	334.7	66.94	0	0

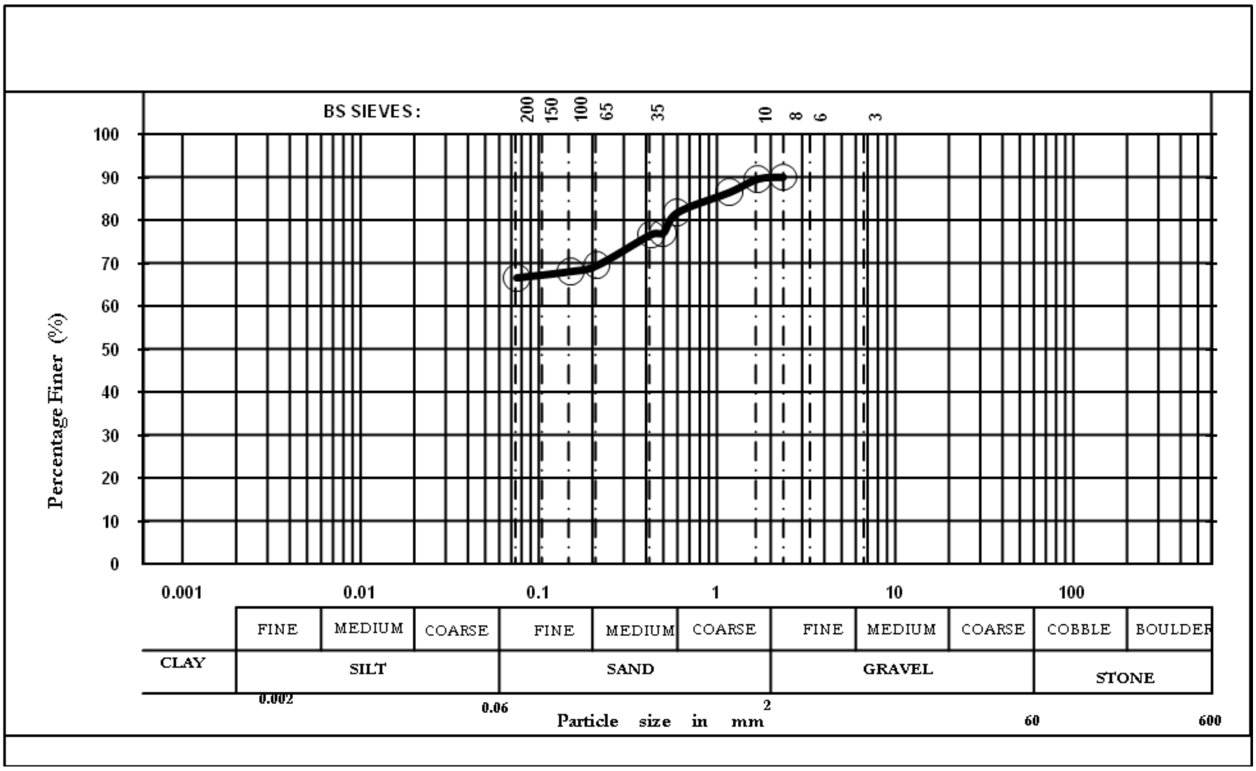

Figure 3. Particle Size distribution curve for tested lateritic soil.

4.4 Atterberg's Limits test

The results of the Atterberg's limits test are summarized in table 4. The liquid and plastic limits of the soil sample were 41.1% and 28.8% respectively from which the plasticity index obtained was 12.3%. The group index (GI) was calculated as 5.37 and the shrinkage limit obtained was 11%.

Table 4: Determination of the Liquid and Plastic Limit of the Lateritic Soil

Type of Test	LIQUID LIMIT					PLASTIC LIMIT		SHRINKAGE LIMIT
Container No.	A	B	C	D	E	A	B	Original Length = 14cm
No. of Blows	47	37	24	18	9	-	-	
Wt. of Container (g)	33.7	39.7	46.2	45.8	44.8	46.8	34.4	
Wt. of Container +Wet Soil (g)	39.2	43.8	50.4	51.6	50.5	50.3	37.6	
Wt. of Container + Dry Soil (g)	37.7	42.7	49.2	49.9	48.6	49.5	36.9	Final Length = 12.5cm
Wt. of Moisture (g)	1.5	1.1	1.2	1.7	1.9	0.8	0.7	
Wt. of Dry soil (g)	4.0	3.0	3.0	4.1	3.8	2.7	2.5	
Moisture Content (%)	37.5	36.7	40.0	41.5	50.0	29.6	28	
	LL = 41.1%					**PL = 28.8%**		**SL = 11%**

4.5 Chemical Test on the Beach Sand Soil Sample

Table 5 shows the percentages of oxides present in the beach sand soil sample as obtained from the chemical test in which silicon dioxide (SiO_2) has the highest percentage. The soil sample also contained 8.1% of radioactive elements.

Table 5: Percentages of Oxides in the Beach Sand Soil Sample

Oxide	SiO_2	K_2O	CaO	MnO	Fe_2O_3	CuO	ZrO_2	PdO	Eu_2O_3	HfO_2
Conc. Unit	59%	0.4%	5.1%	0.3%	8.4%	2.1%	3.8%	13%	3%	5.1%

4.6 Compaction Test

The compaction test was carried out on the lateritic soil to which was added beach sand and Portland cement in percentages varying from 0 to 15%. Table 4.6 shows the results of the compaction test which indicates that the maximum dry density (MDD) of the lateritic soil decreases on the addition of 2.5% beach sand by weight of the soil and thereafter increases up to 10% addition, decreases again at 12.5% addition and thereafter experiences an increase at 15% addition.

Table 6: Results of Compaction Test on the Lateritic Soil with the Stabilizing Agents

Percentage Addition (%)	Lateritic soil + Beach Sand		Lateritic soil + Cement	
	Maximum Dry Density (kg/m^3)	Optimum Moisture Content (%)	Maximum Dry Density (kg/m^3)	Optimum Moisture Content (%)
0	1698	21	1698	21
2.5	1650	19	1650	16
5	1682	19	1544	18
7.5	1720	18.9	1650	18.6
10	1740	18.6	1670	18.8
12.5	1728	19.3	1714	19
15	1745	18	1668	19.1

4.7 California Bearing Ratio (CBR) Test

Table 7 shows the results of the California Bearing ratio tests (both soaked and unsoaked) on the lateritic soil stabilizes with beach sand and Portland cement. The results show that the CBR (soaked) increases from 4.53% for that of the control sample to 5.96 at 15% beach sand addition while the CBR (unsoaked) increases from 3.46% for the control sample to 34.85% at 15% beach sand addition.

Table 7: Results of California Bearing Ratio Test on the Lateritic Soil with the Stabilizing Agents

Percentage Addition (%)	Lateritic soil + Beach Sand		Lateritic soil + Cement	
	SOAKED (%)	UNSOAKED (%)	SOAKED (%)	UNSOAKED (%)
0	4.53	3.46	4.53	3.46
2.5	4.77	6.83	17.17	14. 31
5	5.25	9.66	31.00	15. 38
7.5	5. 37	10.14	39.94	16.81
10	5.75	11.57	48.89	20.27
12.5	5.93	29.52	58.92	30.95
15	5.96	34.85	90.21	60.5

4.8 Discussion

The chemical test results on the beach sand show that it contains 59% of SiO_2 indicating that it is a pozzolana. A pozzolana is a siliceous material which by itself does not possess cementitious properties but will in finely divided form and in the presence of water react with calcium hydroxide, $Ca(OH)_2$, to form cementitious compounds [23].

The compaction test results show that higher values of maximum dry densities were obtained for the lateritic soil containing the beach sand as compared to that containing cement. This can be attributed to the cementing property of the beach sand since it contains SiO_2.

The unsoaked CBR test results show that the values continued to increase as both the cement and beach sand content were increased. This is due to the fact that cement has a very high flexural strength which translates to the high strength of the soil-cement mix. In the case of the soil-beach sand mix, the beach sand acts as a pozzolana (siliceous material) which reacts with calcium hydroxide in the presence of water at room temperature to form insoluble calcium silicate hydrate compound which possesses cementitious properties that strengthen the soil.

The soaked CBR test results show that only the cement additive has very noticeable positive effect on the CBR of the soil with its highest value at 90.21% which is a sharp contrast to the CBR value of the natural soil at 3.46%. In this case, the beach sand produces barely noticeable positive changes in the CBR of the soil. It appears that the beach sand loses its strength under soaked conditions.

5. Conclusion

Based on the results obtained in this study, it has been shown that the addition of beach sand to the lateritic soil influenced the properties of the soil positively. The compaction and the California bearing ratio tests indicate that the dry densities as well as the CBR's of the lateritic soil experienced the greatest increase at 15% addition of beach sand. In the case of the CBR, the values continued to increase with corresponding increase in the beach sand content. This maybe as a result of the accumulation of SiO_2 and Fe_2O_3 in the beach sand which reacted with the lateritic soil to induce the stabilization process.

6. Recommendations

It is recommended that further research should be carried out to determine the effects of the radioactive elements contained in the beach sand on human beings when used as a soil stabilizer. Further research should also be carried out to determine the optimum amount of the beach sand needed for effective lateritic soil stabilization. This apparently seems to have a value beyond 15% beach sand content. The effect of the beach sand on other kinds of soils such as clay should be investigated to determine whether similar results will be obtained which will help to establish it as an all-round or general soil stabilizer.

References

[1] Alexander LT, Cady JG. Genesis and Hardening of Laterite in Soils. *USDA Tech. Bull.* No. 1282, 1962.

[2] Gidigasu MD. Mode of Formation and Geotechnical Characteristics of Laterite Materials of Ghana in Relation to Soil Forming Factors. *Engineering Geology*, Vol. 6, pp. 79-150, 1972.

[3] Amu OO, Ogunniyi SA, Oladeji OO. Geotechnical Properties of Lateritic Soil Stabilized with Sugarcane Straw Ash. *American Journal of Scientific and Industrial Research*, Vol. 2, No. 2, pp. 323-331, 2011.

[4] Onyelowe KC. Cement Stabilized Akwuete Lateritic Soil and Use of Basse Ash as Admixture. *International Journal of Science and Engineering Investigations*, Vol. 1, No. 2, pp. 16-20, 2012

[5] Bhattacharja S, Bhatty JI, Todres HA. Stabilization of Clay Soils by Portland Cement or Lime - A Critical Review of Literature. *Portland Cement Association*, Skokie, *IL*, 2003.

[6] Kolias S, Kasselouri-Rigopoulou V, Karahalios A. Stabilization of Clayey Soils with High Calcium Flyash and Cement. *Cement and Concrete Composites*, Vol. 27, pp. 301-313, 2005.

[7] Consoli NC, Prietto PDM, Ulbrich LA. Influence of Fiber and Cement Addition on Behaviour of Sandy Soil. *Journal of Geotechnical and Geoenvironmental Engineering*, ASCE, Vol. 124, No. 12, pp. 1211-1214, 1998.

[8] Sariosseiri F, Muhunthan B. Effect of Cement Treatment on Geotechnical Properties of Some Washington State Soils. *Engineering Geology*, Vol. 104, No. 2, pp. 119-125, 2009

[9] Szendefy J. *Impact of Soil Stabilization with Lime*. Proceedings of the 18th International Conference on Soil Mechanics and Geotechnical Engineering, Paris, 2013

[10] Onyelowe KC, Okafor FO. A Comparative Review of Soil Modification Methods. *ARPN Journal of Earth Sciences*, Vol. 1, No. 2, pp. 36-41, 2012.

[11] Ola SA. *Tropical Soils of Nigeria in Engineering Practices.* Rotterdam: Balkema publishers; 1983.

[12] Ingles OG, Metcalf JB. *Soil Stabilization Principles and Practice*. Boston: Butterworth Publishers; 1992.

[13] Al-Khafaji AW, Andersland OB. *Geotechnical Engineering and Soil Testing*. New York: Sounder College Publishing; 1992.

[14] Gray DH. Optimizing Soil Compaction and other Strategies. *Erosion Control*, Vol. 9, No. 6, pp. 34-41, 2003.

[15] Bowles JE. *Engineering properties of soils and their measurement.* 4th Edition, pp. 78-89. London: McGraw- Hill Int.; 1992.

[16] Makusa GP. *Soil Stabilization Methods and Materials in Engineering Practice*. A State of the art review in the Department of Civil, Environmental and Natural Resources Engineering, Lulea University of Technology, Lulea, Sweden, 2012.

[17] Ola SA. Geotechnical Properties and Behaviour of some Stabilized Nigerian lateritic Soils. *Journal of Engineering Geology and Hydrogeology,* Vol. 11, No. 2, pp. 145-160, 1978

[18] Baghini MS, Ismail A, Kheradmand B, Hafezi MH, Almansob RA. The Potentials of Portland Cement and Bitumen Emulsion Mixture on Soil Stabilization in Road Base Construction. *Jurnal Teknologi*, Vol. 65, No. 2, pp. 67-72, 2013.

[19] Jawad IT, Taha MR, Majeed ZH, Khan TA. Soil Stabilization Using Lime: Advantages, Disadvantages and Proposing a Potential Alternative. Research Journal of Applied Sciences, Engineering and Technology, Vol. 8, No. 4, pp. 510-520, 2014.

[20] Bell FG. *Engineering Treatment of Soils.* 1st Edition. London: E &FN Spon; 1993

[21] Chiques GM. *Spectral Characterization of Sandy Beaches in Western Portion of Puerto Rico*. University of Puerto Rico, Department of Geology, Mayaguez Campus, 2005.

[22] BS1377. Methods of Test for Soils for Civil Engineering Purposes. Part 4. London: British Standard Institute; 1990.

[23] Kadyali LR, Lal NB. *Principles and Practices of Highway Engineering.* 5th Edition. Delhi: Khanna Publishers; 2008.