International Journal of Science, Technology and Society
2016; 4(6): 89-98
http://www.sciencepublishinggroup.com/j/ijsts
doi: 10.11648/j.ijsts.20160406.12
ISSN: 2330-7412 (Print); ISSN: 2330-7420 (Online)

Strength Characterization of Stabilized A-5(10), A-7-5(16), A-4(3) and A-2-7(1) Laterite Soils Individually Using Supaset Cement

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To cite this article:

Isaac Akiije. Strength Characterization of Stabilized A-5(10), A-7-5(16), A-4(3) and A-2-7(1) Laterite Soils Individually Using Supaset Cement. *International Journal of Science, Technology and Society*. Vol. 4, No. 6, 2016, pp. 89-98. doi: 10.11648/j.ijsts.20160406.12

Received: September 4, 2016; **Accepted**: September 13, 2016; **Published**: October 28, 2016

Abstract: The purpose of this research work is on the strength characterization of the Supaset Portland cement stabilized with laterite soil materials from four different borrow pits locations within Southwest part of Nigeria and the level of their usefulness for highway pavement subbase and basecourse. The four laterite soils after laboratory experiments are classified as A-5(10) silty soil; A-7-5(16) clayey soil; A-4(3) silty soil and A-2-7(1) clayey gravely sandy soil respectively. Stabilization of each laterite soil with the cement at percentages of 0% through 14% at the interval of 2% shows that with the increase in cement content during stabilization process the optimum moisture content of each soil specimen is reducing while the related maximum dry density is increasing. Furthermore, while considering at natural and stabilized states, both unsoaked and soaked California Bearing Ratio, uncured and unconfined compression strengths values of the tested specimens are increasing with increase in cement content with soil A-4(3) having the highest value while soil A-5(10), A-2-7(1) and A-7-5(16) values followed respectively. The coefficient of permeability of each soil specimen stabilized was reducing as the cement content was increasing. The chemical composition tests on Supaset Portland cement revealed CaO and SiO_2 are the major components while for those of soils are SiO_2 and Al_2O_3. The significance of this study is that although A-5(10) and A-4(3) silty soils stabilized by Supaset Portland cement of grade 32.5R attained the 750 kN/m^2 minimum standard strength requirement for subbase, A-7-5(16) and A-2-7(1) clayey soils did not satisfy same. The justification for this research is that Supaset Portland cement is an economical and valuable material to stabilize silty soils but not cost-effective for the stabilization of clayey soils for highway pavement in order to prevent its incessant and premature failure.

Keywords: Research, Stabilization, Coefficients, Sample, Optimization, Scope

1. Introduction

Strength improvement of different types of laterite soils by chemical stabilization methodology using the same stabilizing agent such as Portland cement varies in percentages composition when used for the development of highway pavement in order to meet standard specification requirements considered for subbase and basecourse Akiije [1], Akiije [2], Rashid et al. [3].

Supaset Portland cement is relatively new in Nigeria and it is being considered as a stabilizer in this study for four different types of laterite soils individually. Supaset Portland cement is manufactured in Nigeria to meet the identifiable needs of customers in the building and construction sectors of which block makers in the precast and concrete business have been identified as the main target for this product International Cement Review Newsroom (ICRN) [4]. According to Marotta [5], cement is a material that reacts chemically with water by a process called hydration to form a stone like mass and it was patented by an English mason named Joseph Aspdin in 1824 who named his product Portland cement.

Xiaohong et al. [6] claimed that a laterite profile usually exhibits the surface soil zone, the completely weathered zone, the moderately weathered zone, and the bedrock zone. They further claimed that the completely weathered zone may account for over 90% of the total thickness of a laterite profile though may be divided into the red weathered bed and the yellow weathered bed according to the weathering degree and colour. Their additional claim is that red weathered bed is located in the upper part of the weathering zone that may be of 3 m to 5 m thickness. However, Bayewu et al. [7] acknowledged the significance and the necessity to take proper cognizance and characteristic of engineering and behaviour of residual soils properties such as grain size distribution, plastic index, California Bearing Ratio (CBR), unconfined compressive strength (UCS) and dry density to a level of adequate understanding. Using the natural laterite soil as subgrade highway foundation and improving the strength of the imported lateritic materials as subbase and basecourse by means of stabilization is common in most part of tropical regions for road strength, stability, durability and permeability reduction.

Akiije [1], Akiije [2], conducted experimental studies of laterite cement mixture as pavement basecourse material and found out that the Ordinary Portland Cement (Type I) could be effectively used to stabilize some laterite soils. He also noted that engineering properties of laterite soils such as strength, durability and permeability at natural and when improved by cement stabilization trend can be determined by UCS, CBR and permeability tests.

The aim of this research therefore is to consider through laboratory individual tests strength, durability and permeability characteristics of the four selected laterite soil samples at natural and cement stabilized states. Specifically, the objectives are to:

i. Determine in the laboratory the specific chemical and metallic composition properties of the cement as well as the four laterite soils used individually;
ii. Determine in the laboratory specific gravity, wet sieve analysis, liquid limit, plasticity limit, plasticity index, group index, moisture-density relationship, California Bearing Ratio (CBR), unconfined compressive strength (UCS) and permeability characteristics of the four disturbed natural laterite soils samples separately;
iii. Determine in the laboratory moisture-density relationship, California Bearing Ratio (CBR), unconfined compressive strength (UCS) and permeability characteristics of the four laterite soil samples when stabilized with Supaset cement separately at percentages of 2%, 4%, 6%, 8%, 10% and 14% in proportion by weight; and
iv. Compare and contrast at optimum of the results of unconfined compressive strength, permeability, moisture-density relationship and California Bearing Ratio (CBR) of the four laterite soil samples as evaluated in the laboratory by using Supaset Portland cement as stabilizer in accordance to standard specification requirements for highway pavement subbase and basecourse.

The main scope of work in this study therefore includes obtaining four types of laterite soils from four different borrows pits and test each one of them at natural and when stabilized with Supaset Portland cement individually. Also to classify the four laterite soils individually at natural states according to the required AASHTO standard specifications. More so to determine the percentages at which each stabilized laterite soil will attain the strength and durability at a standard specified level of subbase and basecourse for highway pavement.

The significance of this study is in the information it proffered while using Supaset Portland cement as a stabilizer in the production of subbase or basecourse in highway pavement construction in spite of it being specifically manufactured for the production of sandcrete blocks and rigid pavement maintenance.

The justification for this project research is that since Supaset Portland cement is readily available in Nigeria attaining the strength and durability required by standard specification requirements economically is affordable.

2. Materials and Methodology

Supaset Portland cement is used in this study as a stabilizer for four different types of laterite soils individually. The cement could be purchased in 30 tons bulk tanker, 2 tons jumbo bag and 50 kg bag. The 50 kg bag pack type was used in this study. The Supaset Portland cement Type I used in this research is a product of Lafarge Cement WAPCO Nigeria PLC a subsidiary of Lafarge Holcim. One of the factories for the production of the cement is in Ewekoro, a town in Ogun State of Nigeria. Supaset Portland cement somewhat newly manufactured in Nigeria is of grade 32.5R being claimed by ICRN [5] to achieve a strength of > 32 N/mm^2 at 28 day under standard test conditions and fast early strength development for it > 20 N/mm^2 at 2 days of it concrete production. ICRN [5] claimed that Supaset cement is manufactured in conformity to AASHTO Designation M85 [8] and could only be successfully used with materials which are not contaminated with silt, clay or organic materials. The specific chemical, metallic, and compound parameters of the cement were determined in the laboratory by performing the X-Ray Diffraction test and Atomic Absorption Spectroscopy (AAS) test.

Four laterite soil materials were collected from four different locations in southwest part of Nigeria. The locations of the four borrow pits are Matogun in Ogun State, Akoka in Lagos State, Ijoko in Ogun State and Ore in Ondo State. The four different laterite soil samples used were air dried and tested in the laboratory individually in order to determine their chemical composition, metallic components, engineering properties and classification for highway purposes. The liquid limit test on each soil was performed according to AASHTO T 89 [9] while tests to determine same for plasticity limit and plasticity index were carried out by AASHTO T 90 [10]. Each soil relative density test was conducted according to AASHTO T 100 [11] while wet sieve analysis test was carried out in accordance to AASHTO T 88 [12]. Group index of each soil was determined according to AASHTO M 145 [13]. Also, the specific chemical and metallic composition properties of the four laterite soils individually were determined in the laboratory by performing the X-Ray Diffraction test and Atomic Absorption Spectroscopy (AAS) test.

Tap water found in the laboratory of the Department of Civil and Environmental Engineering, Faculty of Engineering, University of Lagos is clean, clear, and drinkable was used for the soil stabilization.

Stabilization of each of the four soil samples was carried out individually based upon optimum moisture content and cement at percentages of 2%, 4%, 6%, 8%, 10% and 14% for California Bearing Ratio (CBR), unconfined compressive strength (UCS) and permeability tests. The moisture-density relationship of each soil at natural state and when stabilized with cement were conducted according to AASHTO T 99 [14] while their respective California Bearing Ratio (CBR) was carried out in accordance to AASHTO T 193 [15]. The unconfined compressive strength (UCS) tests for each soil at natural state and when stabilized with cement were also determined according to AASHTO T 208 [16]. Similarly, the permeability tests to define the four respective soils hydraulic conductivity at both natural and the cement stabilization were carried out with reference to ASTM D7664 [17].

3. Analysis of Results and Discussions

The results and discussions of laboratory tests conducted on the Supaset Portland cement of grade 32.5R as a stabilizer for four different types of laterite soils classified as A-5(10) silty soil; A-7-5(16) clayey soil; A-4(3) silty soil and A-2-7(1) clayey gravely sandy soil individually for highway pavement design are presented in this section.

The results of the cement chemical, metallic, physico and compound composition as well as the relevant properties of the four laterite samples at natural state as assessed in the laboratory and characterized are presented. The results on the four laterite soils individually at natural state included Atterberg limits, wet grain sieve analysis and their classifications. Also presented are the results of the four natural laterite soils and as at when stabilized with Supaset Portland cement individually which include relative density, bulk density, dry density, unconfined compression, moisture-density relationship, California Bearing Ratio and permeability. Tables and graphs are used in presenting the results of the analysis of the samples of cement, the four natural laterite soils used and when they are stabilized with cement independently. Discussions of the natural and stabilized laterite soils by laboratory experiments are compared with relevant standard specification requirements for the optimization of subbase and basecourse for highway pavement.

3.1. Properties of Supaset Portland Cement Grade 32.5R Used

Table 1 is showing the results in percentages of the chemical composition of the Supaset Portland cement grade 32.5R used. Considering the percentages of chemical compositions results of the cement we have Calcium Oxide CaO, Silica SiO_2, Alumina Al_2O_3 and Magnesium Oxide MgO as the four major oxide compounds. It is shown in Table 1 that CaO and SiO_2 present in Supaset Portland cement complied with the specification requirements for being more than 80% whilst Al_2O_3 and MgO composition that sum up to 6% do not conform to the standard. Nevertheless, the satisfactory level exhibited upon the compliance of oxide compounds identified in the Supaset Portland cement used has adequate efficiency as shown in this research work in the production of stabilized soils. Also, Table 1 depicts the chemical composition of the four laterite soils used and it is found that there are two major compounds which are SiO_2 and Al_2O_3 of varying percentages from 74% to 92%. However, the two clayey soils are having higher values of SiO_2, Al_2O_3 and loss of ignition than silty soils.

Table 2 is showing the compound composition properties of 32.5R Portland cement used. Although tricalcium silicate C_3S present in the cement has a higher percentage than standard specification thus consequently indicating a more rapid hardening along with early initial setting and early strength. Also, dicalcium silicate C_2S having a lower value than specification can contribute to fast hardening of the stabilized soils while tricalcium aluminate C_3A that complied with the standard specification will also contribute to strength development in the first few days. Since tetracalcium aluminoferrite C_4AF amount is lower than standard specification and does not also contribute to strength development, early strengthening of the stabilized soil could not be jeopardized.

In Table 3 it is found that metallic components are present at very low values and the presence of chlorine makes the materials healthy wise safe. Although Pb is present in the materials but it is at very low percentage value that could not be injurious to health. The pH value of each material is not of acidic while the Al value of cement is lower than those of the laterite soils. It is worthy of note that Fe and Zn contents are higher in gravel clayey sandy soil than the other three soil materials.

Table 1. *Chemical composition of laterite soils used.*

S/N	PARAMETER (%)	Supaset Portland Cement	A-5 (10) silty soil	A-7-5 (16) clayey soil	A-4 (3) silty soil	A-2-7 (1) clayey gravely sandy soil
1	SiO_2	20.350	45.700	52.560	44.240	63.110
2	Na_2O	0.640	0.058	0.034	0.0460	0.058
3	K_2O	0.390	0.050	0.060	0.042	0.042
4	CaO	63.740	0.050	0.002	0.030	1.620
5	MgO	2.040	0.030	1.460	0.020	0.85
6	BaO	0	0	0	0	0
7	PbO	0	0	0	0	0
8	MnO	0	0.010	0.0170	0.008	0.004

S/N	PARAMETER (%)	Supaset Portland Cement	A-5 (10) silty soil	A-7-5 (16) clayey soil	A-4 (3) silty soil	A-2-7 (1) clayey gravely sandy soil
9	Al_2O_3	4.480	32.560	40.70	30.350	32.790
11	Fe_2O_3	0.910	0.140	0.010	0.054	0.028
12	SO_3	1.140	0	0.003	0	0
13	$Ca(OH)_2$	0.500	0	0	0	0
14	SO_4^{2-} (mg/kg)	1299.030	102.000	24.750	108.000	139.000
15	Fibre	0	0	0	0	0

Table 2. *Compound composition of 32.5R Portland cement used.*

S/N	Supaset Portland Cement Compound Composition	Compound Composition %	Standard Min-Max %	Remarks
1	C_3S	70.110	40-63	Not Complied
2	C_2S	5.540	9-31	Not Complied
3	C_3A	10.330	6-14	Complied
4	C_4AF	2.770	5-13	Not Complied

Table 3. *Metallic and other components of 32.5R Portland cement and laterite soils used.*

No	PARAMETERS	Supaset Portland cement	A-5 (10) silty soil	A-7-5 (16) clayey soil	A-4 (3) silty soil	A-2-7 (1) clayey gravely sandy soil
1	Cd (mg/kg)	0.005	0	0.020	0	0
2	Cu (mg/kg)	0.400	0	0.310	0	0
3	Mn (mg/kg)	0.140	0	0.160	0	0.030
4	Ni (mg/kg)	0.020	0	0.030	0	0.0
5	Pb (mg/kg)	0.160	0	0.110	0	0.0
6	Fe (mg/kg)	0.390	0.043	0.500	0.038	0.020
7	Zn (mg/kg)	0.020	0	0.300	0	0
8	Al (mg/kg)	3.180	15.890	21.550	16.070	17.340
9	pH	11.130	8.870	9.950	8.590	7.320
10	SO_4^{2-} (mg/kg)	1299.030	102.000	24.750	108.000	139.000
11	Organic Carbon (%)	0.150	0.180	0.250	0.180	0.230
12	LOI (%)	1.080	0.005	0.730	0.006	0.360
13	Cl (mg/kg)	137.260	234.000	79.210	267.000	360.000
14	Insoluble Residue, IR	0.050	0	0	0	0

3.2. Classification of the Laterite Soils for Highway Purposes

The results of the individual four different laterite soils in their disturbed natural states are stated in Table 4. The A-5(10) silty soil is a highly elastic laterite material as indicated by its high liquid limit. Also, the soil has the highest value of silt-clay materials when compared with the other three laterite soils. However, the group index value indicates that it has average strength reliability when compared in its group for highway purposes.

The A-7-5(16) clayey soil is an inorganic laterite material as indicated by its high liquid limit, moderate plasticity index, highly elastic with considerable volume change. The group index of A-7-5(16) clayey soil is showing that it is not of high strength when compared in its group for highway purposes. A-7-5(16) soil will have high volume change between wet and dry states for having high liquid limits characteristic that is elastic leading to a high volume change.

The A-4(3) silty soil is moderately plastic silty soil with low plastic limit value. The results have shown that the soil has the lowest plasticity index. The group index is showing that it has respectively high strength when compared in its group for highway purposes.

The A-2-7(1) gravely clayey and sand soil is of granular material that contains plastic clay having the characteristics a high volume change between wet and dry states, and clay subject to a high volume change. Its group index is showing that it is of high strength when compared in its group for highway purposes.

The values of plasticity index PI of both A-5(10) and A-4(3) being less than 10 is an indication that they are suitable for cement stabilization. However, since the PI value of A-4(3) is lower than that of A-5(10) is a hint that the former will have higher strength and durability than the later. The values of plasticity index PI of both A-7-5(16) and A-2-7(1) being greater than 10 and less than 20 is a signal that they are doubtfully suitable for cement stabilization. Likewise, with A-2-7(1) having a lower value of plasticity index than that of A-7-5(16) is a hint that the former will have higher strength and durability than the later.

The results of wet sieve analysis of the individual four laterite soils researched upon in this study are plotted on semilogarithmic graph as grain–size distribution curves as shown in Figure 1.

Table 4. *Basic and engineering properties of the four selected laterite soils for highway purposes.*

S/N	Properties	A-5 (10) silty soil	A-7-5 (16) clayey soil	A-4 (3) silty soil	A-2-7 (1) clayey gravely sandy soil
1	Bulk Density (Mg/m^3)	2.024	2.083	1.972	2.094
2	Dry Density (Mg/ m^3)	1.627	1.697	1.671	1.784
3	Specific Gravity (Gs)	2.780	2.800	2.800	2.700
4	Void Ratio e	0.709	0.654	0.676	0.514
5	Porosity n, %	0.415	0.395	0.403	0.339
6	Degree of Saturation Sr, %	0.933	0.989	0.995	0.915
7	Plastic Limit (LL)	33.447	33.333	33.055	33.194
8	Liquid Limit (PL)	43.000	48.000	40.000	44.800
9	Plasticity Index (PI)	9.553	14.670	6.945	11.606
10	Percent Passing 0.075 mm	71.520	43.920	55.900	34.500
11	AASHTO Soil Classification	A-5(10)	A-7-5(16)	A-4(3)	A-2-7(1)
12	Soils Description	Silty soil	Clayey soil	Silty Soil	Clayey gravelly sandy soil

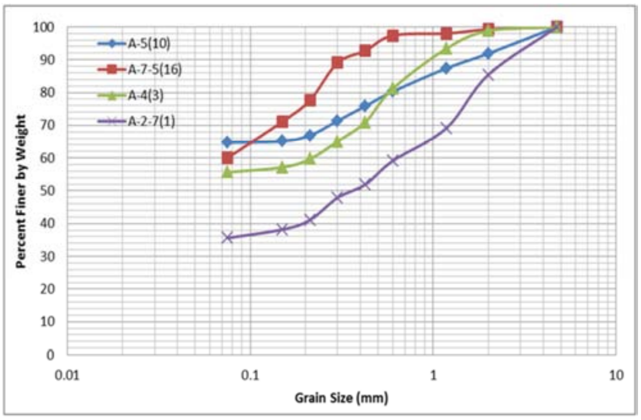

Figure 1. *The four selected laterite soils grain size distribution curves for highway purposes.*

3.3. Moisture-Density Relationships of the Laterite Soils for Highway Purposes

Table 5 is showing specifically the results for the optimum moisture content and maximum dry density of the four laterite soils individually at natural state and when they are stabilized at maximum of 14% of Supaset Portland cement. It is obviously seen in the table that the optimum moisture content value of each soil at natural state is higher than when they are stabilized at 14% Supaset Portland cement independently. Also in table, the maximum dry density value of each soil at natural state is lower than that of their stabilization at 14% Supaset Portland cement independently.

Figure 2 is showing in general the results of the optimum moisture content for the individual four different laterite soils in their natural disturbed states and when it has been cement stabilized for highway purposes. The figure vividly shows the variation of optimum moisture content of the four laterite soils individually at natural state and at when stabilized with Supaset Portland cement. The graph of each soil displayed a decrease in optimum moisture content as the percentage of cement content is increasing. It is worthy of note that laterite soil A-2-7(1) with the highest optimum moisture content at natural state has the lowest OMC when stabilized with 14% Supaset cement while comparing with other soils when similarly evaluated. On the other hand, laterite soil A-4(3) that has the lowest OMC is having same at highest value when stabilized with 14% Supaset cement while comparing with other soils when similarly evaluated.

Figure 3 is showing the results of the maximum dry density for the individual four different laterite soils in their natural disturbed states and when stabilized for highway purposes. The figure vividly shows the variation of maximum dry density of the four laterite soils individually at natural state and at when stabilized with Supaset Portland cement. The graph of each soil displayed an increasing maximum dry density values as the percentage of cement content is increasing. Although laterite soil A-2-7(1) is not having the same MDD at natural state with laterite soil A-5(10) but at the cement stabilization of 14% they both have the same MDD.

Table 5. *Natural laterite soils and 14% cement stabilization of same compared for optimum moisture content and maximum dry density.*

Label	Soil Classification	A-5 (10)	A-7-5 (16)	A-4 (3)	A-2-7 (1)
Natural Soil	Optimum Moisture Content	19.150	17.800	17.940	21.200
	Maximum Dry Density	1.670	1.578	1.690	1.645
14% Supaset Cement Stabilization	Optimum Moisture Content	12.080	11.560	14.010	10.000
	Maximum Dry Density	1.780	1.760	1.797	1.780

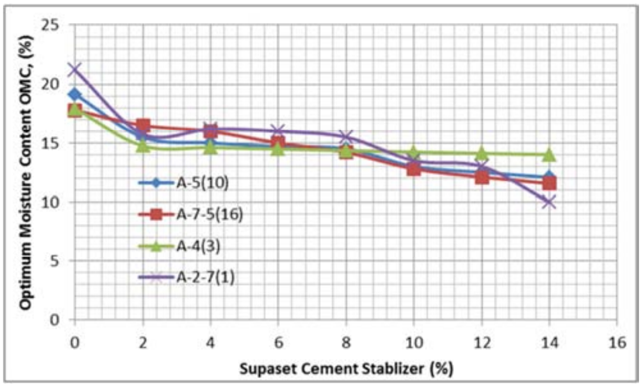

Figure 2. Curves of relationship between OMC and cement percent increase of the stabilized laterite soils individually.

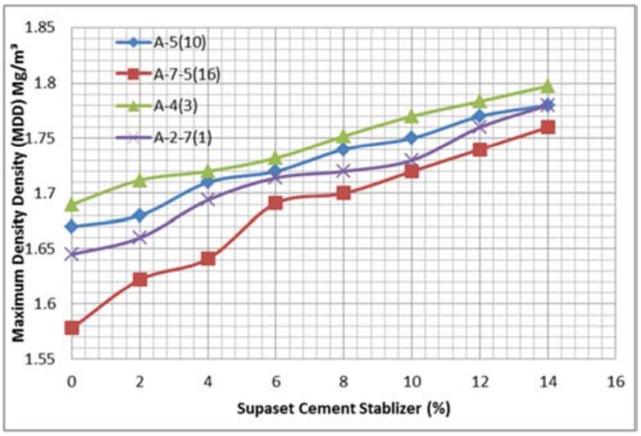

Figure 3. Curves of relationship between MDD and cement percent increase of the stabilized laterite soils individually.

3.4. Unsoaked and Soaked CBR Relationships of the Laterite Soils for Highway Purposes

Table 6 is showing specifically the results for the unsoaked and soaked California Bearing Ratio of the four individual laterite soils at natural state and when stabilized at maximum of 14% with Supaset Portland cement. It is worthy of note that subbase natural material is to have satisfactory soaked CBR value between 30% and 50% while soaked CBR value for basecourse natural material is be between 50% and 80%. However, as shown in Table 6 none of the materials at natural state satisfied the said conditions to be suitable for a proposed highway subbase and basecourse. Correspondingly, it is obviously seen in the table that the unsoaked CBR value of each soil at natural state is lower than when they are stabilized at 14% Supaset Portland cement independently. Also in the table, the soaked CBR value of each soil at natural state is lower than that of 14% Supaset Portland cement stabilization independently. Obviously it is also seen in Table 6 that the soils have been individually improved in strength and durability for attaining higher soaked CBR values upon 14% Supaset cement stabilization

Figure 4 and Figure 5 present respectively the unsoaked and soaked CBR curves of the four laterite soils individually at natural and stabilized conditions. The four laterite soil materials were from four different borrow pits for use as subbase or basecourse. Both A-4(3) and A-5(10) that are silty soils have higher values of unsoaked and soaked CBR values when compared to the clayey soils A-2-7(1) and A-7-5(16) similarly at natural state as well as at when stabilized with Supaset Portland cement.

Table 7 is showing percentages at which satisfactory CBR values were attained by the four individual cement stabilized soils up to 14% maximum for highway design of subbase and basecourse materials. A-4(3) silty soil attained required standard specification for 80% unsoaked CBR value at the lowest level than the other three soils for highway subbase and it is the only stabilized soil that satisfactorily attained the 180% unsoaked CBR value for road basecourse. Upon the soaked CBR values both A-5(10) silty soil and A-4(3) silty soil attained required standard specification for 80% unsoaked CBR value at lower level than the other two soils for highway subbase and only these two stabilized soils satisfactorily attained the 180% soaked CBR value for road basecourse. It should be noted that soaked CBR values upon natural soil are normally used for the design of subgrade for highway pavement construction.

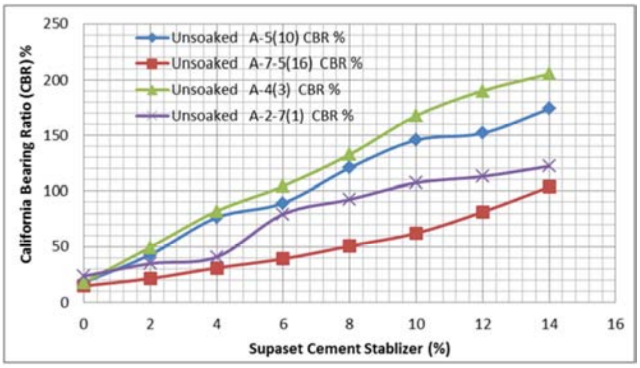

Figure 4. Curves of relationship between unsoaked CBR values and cement percent increase of the stabilized laterite soils individually.

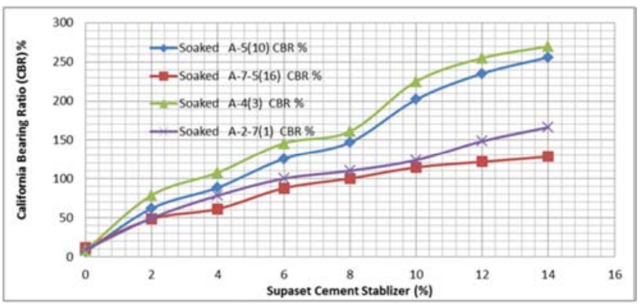

Figure 5. Curves of relationship between soaked CBR values and cement percent increase of the stabilized laterite soils individually.

Table 6. *Natural laterite soils and 14% cement stabilization of same compared for unsoaked and soaked CBR values.*

LABEL	SOIL CLASSIFICATION	A-5(10)	A-7-5(16)	A-4(3)	A-2-7(1)
NATURAL SOIL	Unsoaked CBR values, %	17.800	14.750	17.800	23.500
	Soaked CBR values, %	6.900	9.100	8.640	9.500
14% SUPASET CEMENT STABILIZATION	Unsoaked CBR values, %	174.000	103.750	205.400	122.250
	Soaked CBR values, %	255.750	128.410	269.680	166.250

Table 7. *Highway subbase and basecourse satisfactory CBR values attained by the individual stabilized cement soils up to 14% maximum.*

	Unsoaked CBR		Soaked CBR	
	Supaset Portland cement percentage that attained 80% CBR value as stabilized subbase	**Supaset Portland cement percentage that attained 180% CBR value as stabilized basecourse**	**Supaset Portland cement percentage that attained 80% CBR value as stabilized subbase**	**Supaset Portland cement percentage that attained 180% CBR value as stabilized basecourse**
A-5(10) Silty Soil	6%	Not Attainable	4%	10%
A-7-5(16) Clayey Soil	12%	Not Attainable	6%	Not Attainable
A-4(3) Silty Soil	4%	14%	4%	10%
A-2-7(1) Clayey Soil	8%	Not Attainable	6%	Not Attainable

3.5. Individual Unconfined Compressive Strength of the Four Laterite Soils for Highway Purposes

Table 8 is showing explicitly the results for the uncured and cured unconfined compression strength of the four individual laterite soils at natural state and when stabilized at maximum of 14% with Supaset Portland cement. The uncured unconfined compression strength values of all the four laterite soils samples at natural states are closely related but which is not so for cured unconfined compression strength values.

Considering uncured unconfined compression strength values when stabilized at maximum of 14% with Supaset Portland cement, only the two silty soils have comparable values while on the other hand the two clayey soils on their own are related based upon incomparable values. On the other hand, cured unconfined compression strength values of the stabilized soils at maximum of 14% with Supaset Portland cement resulted to the two silty soils only having similarly values which are greater than the values of the two clayey soils that are of incompatible values.

Figure 6 and Figure 7 present respectively the uncured and cured UCS curves of the four laterite soils individually at natural and cement stabilization from 2% to 14% at interval of 2%. As vividly seen in the two figures, both A-5(10) and A-4(3) that are silty soils have higher values of uncured and cured UCS values when compared to the clayey soils A-7-5(16) and A-2-7(1).

It is worthy of note that subbase is to have cemented soil 7 day cured UCS value between 750 kN/m^2 and 1500 kN/m^2 while basecourse is to have cemented soil 7 day cured UCS value between 1500 kN/m^2 and 3000 kN/m^2. As shown in Table 9 specifically, only cemented soils A-5(10) and A-4(3) satisfied the required minimum 7 day cured UCS requirements to be suitable for highway subbase at stabilized cement contents of 8% and 6% respectively. However as seen in Table 9, only cemented soils A-4(3) satisfied the required minimum 7 day cured UCS requirements to be suitable for highway basecourse at stabilized cement contents of 12%. On the other hand, it could also be seen in Table 9 that only soil A-4(3) satisfied the required maximum 7 day cured UCS requirements to be suitable for highway subbase at stabilized cement contents of 12%. It is worthy of note that none of the four cement stabilized soils to 14% individually satisfy the required maximum 7 day cured UCS requirements to be suitable for highway basecourse.

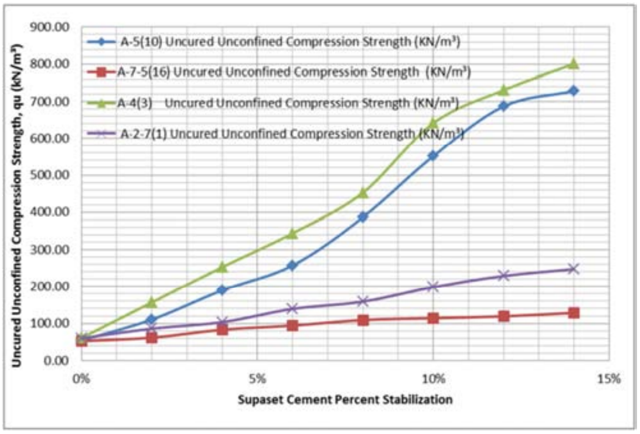

Figure 6. *Curves of relationship between uncured UCS values and cement percent increase of the stabilized laterite soils individually.*

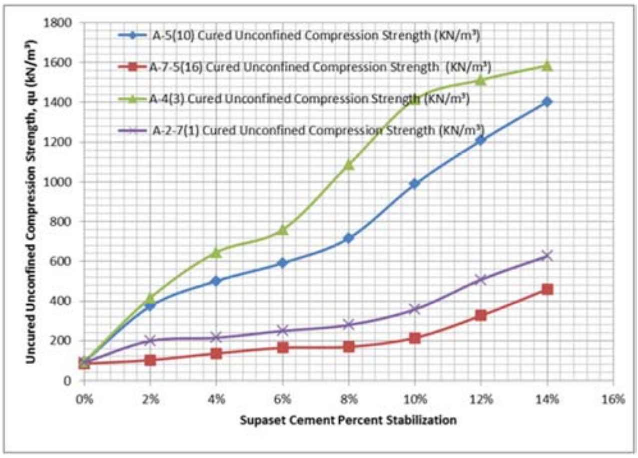

Figure 7. *Curves of relationship between cured UCS values and cement percent increase of the stabilized laterite soils individually.*

Table 8. *Natural laterite soils and 14% cement stabilization of same compared for cured and uncured UCS values.*

	Uncured Unconfined Compression Strength (KN/m²)		Cured Unconfined Compression Strength (KN/m²)	
	0%	**14%**	**0%**	**14%**
A-5(10) Silty Soil	54.090	728.350	94.250	1402.560
A-7-5(16) Clayey Soil	52.210	128.710	84.660	459.490
A-4(3) Silty Soil	60.640	800.980	103.640	1584.950
A-2-7(1) Clayey Soil	59.880	247.390	89.640	626.440

Table 9. *Optimization of cement stabilization for UCS standard requirements for highway subbase and basecourse specification at 14% maximum.*

	Minimum Requirements at 7 Day Cured UCS		Maximum Requirements at 7 Day Cured UCS	
	Supaset Portland Cement percentage to attained 750 kN/m² for Subbase	**Supaset Portland Cement percentage to attained 1500 kN/m² for Basecourse**	**Supaset Portland Cement percentage to attained 1500 kN/m² for Subbase**	**Supaset Portland Cement percentage to attained 3000 kN/m² for Basecourse**
A-5(10) Silty Soil	8%	Not Attainable	Not Attainable	Not Attainable
A-7-5(16) Clayey Soil	Not Attainable	Not Attainable	Not Attainable	Not Attainable
A-4(3) Silty Soil	6%	12%	12%	Not Attainable
A-2-7(1) Clayey Soil	Not Attainable	Not Attainable	Not Attainable	Not Attainable

3.6. Individual Permeability Value of the Four Laterite Soils for Highway Purposes

Table 10 is showing plainly the results of the permeability tests of the four individual laterite soils at natural state and by cement stabilization at maximum of 14% with Supaset Portland cement. Permeability test results at natural states show that all the soils A-5(10), A-7-5(16), A-4(3) and A-2-7(1) behave similarly and the similarity was also exhibited upon being stabilized at cement content of 14%.

Figure 8 is depicting the comparison of the permeability results of the four laterite soils individually at natural state as well as at when each soil was stabilized by Supaset Portland cement at an interval variation of 2% increment up to 14%. All the laterite soil samples A-5(10), A-7-5(16), A-4(3) and A-2-7(1) behave similarly by decreasing in permeability values as the cement content is increasing. This behaviour of decrease in permeability continued as the cement content is increasing up to 14% when they all have similar permeability values.

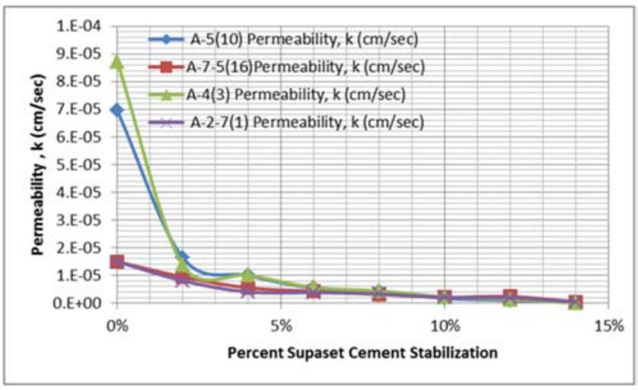

Figure 8. *Curves of relationship between permeability values and cement percent increase of the stabilized laterite soils individually.*

Table 10. *Natural laterite soils and 14% cement stabilization of same compared for permeability values.*

Label	A-5(10), k (cm/sec)	A-7-5(16), k (cm/sec)	A-4(3), k (cm/sec)	A-2-7(1), k (cm/sec)
0%	10^{-5}	10^{-5}	10^{-5}	10^{-5}
14%	10^{-7}	10^{-7}	10^{-7}	10^{-7}

4. Conclusions and Recommendations

Four different laterite soil samples have been characterized and as well classified as A-5(10), A-7-5(16), A-4(3) and A-2-7(1). Each soil was stabilized with Supaset Portland cement and their usefulness discussed in relationship to highway pavement.

4.1. Conclusions

The followings are the conclusions proffered in the course of the laboratory experiments and results of the natural and Supaset Portland cement stabilization of the four selected laterite soils individually.

a. Elephant Supaset cement used is a made in Nigeria normal grade 32.5R Portland Cement and its conformity to ASTM, AASHTO and British relevant standard specification requirements for its chemical and potential compound compositions is satisfactory.
b. Supaset Portland cement made in Nigeria has been successfully utilized to stabilize A-5(10) and A-4(3) silty laterite soils.
c. A-5(10) silty laterite soil is one of the samples subjected to laboratory experiments and it was found that its plasticity index PI is 9.55 which is less than 10 making it a useful material for cement stabilization. Soaked CBR values of 80% and 180% for subbase and basecourse were attained at 4% and 10% cement stabilization correspondingly. Whereas for the same soil

only subbase strength was attained at the minimum requirements strength of 750 kN/m^2 at 7 day cured UCS for highway subbase development at 8% cement stabilization.

d. A-7-5(16) clayey laterite soil is another sample subjected to laboratory experiments and it was found that its plasticity index PI is 14.67 which is greater than 10 and this makes it not a useful material for cement stabilization. Soaked CBR values of 80% and 180% for subbase and basecourse were not attained even as at the maximum of 14% cement stabilization. Similarly, for the same soil, subbase strength minimum requirements strength of 750 kN/m^2 at 7 day cured UCS for highway subbase development at 14% cement stabilization was not attained at all.

e. A-4(3) silty laterite soil sample was also subjected to laboratory experiments and it was found that its plasticity index PI is 6.945 which is less than 10 makes it a useful material for cement stabilization. Soaked CBR values of 80% and 180% for subbase and basecourse were attained at 4% and 10% cement amount of stabilization correspondingly. For the same soil, highway subbase strength was attained at the minimum and maximum requirements strength of 750 kN/m^2 and 1500 kN/m^2 at 7 day cured UCS at 6% and 12% cement stabilization respectively. However, it is only the minimum requirements strength of 1500 kN/m^2 at 7 day cured UCS for highway subbase development that was attained at its 12% cement stabilization.

f. A-2-7(1) gravely clayey and sandy laterite soil is also a sample subjected to laboratory experiments and it was found that its plasticity index PI is 11.606 which is greater than 10 makes it not a useful material for cement stabilization. Only soaked CBR values of 80% for subbase was attained at 6% cement stabilization. Whereas, for the same soil, subbase strength minimum requirements strength of 750 kN/m^2 at 7 day cured UCS for highway subbase development at 14% cement stabilization was not attained at all.

g. Only the satisfactory percentages values of the Supaset Portland cement stabilization for both subbase and basecourse based upon UCS are at the acceptable values of permeability.

4.2. Recommendations

The followings are the recommendations proffered in the course of the laboratory experiments and results of the natural and Supaset Portland cement stabilization of the four selected laterite soils individually.

a. As exhibited in this research among the four types of soils stabilized, Supaset Portland cement that is made in Nigeria is recommended for the stabilization of silty laterite soils and not clayey soils to prevent premature failure of the highway pavement in the country.

b. Considering the results of CBR and UCS values of the four laterite soils investigated in this study, it is the results of the UCS that should be considered for cement stabilized soils and not that of CBR values for satisfactory strength, durability and permeability of cemented subbase and basecourse highway pavement design and construction.

c. A-7-5(16) and A-2-7(1) clayey soils stabilized with Supaset Portland cement individually shouldn't be adopted for subbase of highway pavement rather it is better to consider A-5(10) and A-4(3) silty soils for same.

d. Further work upon the stabilization of A-1 and A-3 stone fragments, fine gravel and sand as well as other A-2 classified silty soils, using Supaset Portland cement is highly recommended for highway pavement premature failure prevention.

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