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Characterisation of Selected Individually Stabilized Soils for Highway Subbase using Powermax Cement at 6% Maximum

Isaac Akiije
Department of Civil and Environmental Engineering,
Faculty of Engineering,
University of Lagos, Akoka, Yaba,
Lagos, Nigeria

***Abstract*: The purpose of this research work is upon optimising the characteristics of A-1-b(0) stone fragments gravely sandy soil, A-2-7(0) clayey gravely sandy, A-4(3) silty soil and A-5(10) silty soil individually using Powermax Portland cement of grade 42.5N upon their pertinent stabilization for highway subbase. All the materials obtained originated from Southwest part of Nigeria and laboratory experiments employed included the soil classification for highway purposes and their individual cement stabilization tests at 1%, 2%, 3%, 4%, 5% and 6% respectively. Tests carried out included optimum moisture content (OMC), maximum dry density (MDD), California Bearing Ratio (CBR), unconfined compressive strength (UCS) and permeability. The results show that the percent passing sieves 2.0 mm, 0.425 mm and 0.075 mm respectively by grain size analysis of A-1-b(0) are 29%, 13% and 3%; for A-2-7(0) are 85%, 48% and 35%; for A-4(3) are 99%, 71% and 57%; and also for A-5(10) are 92%, 76% and 65%. The results of the coefficient of uniformity and coverture respectively for soil A-1-b(0) are 21 and 3. The results also show that liquid limit, plastic limit and plasticity index respectively for soil A-2-7(0) are 45, 33 and 12; for A-4(3) are 40, 33 and 7; and for A-5(10) are 43, 33 and 10. The OMC of the four soil specimens at natural and at the increasing cement stabilization of same are reducing while the related MDD are increasing. At natural state and for the increasing cement content of the four soil specimens, both unsoaked and soaked CBR, uncured and UCS are increasing while the permeability values are reducing. The chemical composition tests of grades 42.5N Portland cements revealed that C_3S is 44.82% and C_2S is 29.95% and these features made the cement normal. The significance of this study is of the four soils experimented upon only the stabilized A-1-a(0) with Powermax cement stabilization attained UCS value of 840 kN/m² at 6% that satisfied the minimum strength requirement of 750 kN/m² for highway subbase. The justification for this study is that the newly produced 42.5N cement economically stabilized A-1-a(0) soil and its use for the other soils experimented upon should be discouraged to prevent premature failure of highway.**

Keywords: Inquiry; Cemented; Amounts; Specimen; Cost-Effective; Choice.

1. INTRODUCTION

The percentage composition of a stabilized soil in a cement stabilization process paradigm for the engineering properties improvement of highway pavement subbase materials varied Salahudeen and Akiije [1], Rashid et al. [2]. This is actually based upon the type of soil samples in order to meet standard specification requirements considered for subbase. Soil stabilization makes the soil more stable due to the reduction in the compressibility, permeability and increase in compression together with shear strengths hence leading to its increase in the bearing capacity. For possible stabilization of soils, the Garber and Hoel [3] reported that the cement percentage by weight for soil A-1 is ranging from 3% to 8%; for soil A-2 is ranging from 5% to 9%; for soils A-4 and A-5 is ranging from 7% to 12% and; for A-6 and A-7 is ranging from 9% to 16%. FMT-W [4] claimed that cemented soil for highway pavement subbase 7 day unconfined compressive strength UCS value should range from 0.75 N/mm² to 1500 N/mm².

Chaudhary [5] claimed that the various method of stabilization includes mechanical or granular, cement, lime, bitumen and geo-textiles. Cement stabilization is considered in this research which involved the pulverization of the soil followed by the mixing of same with appropriate cement and water to form soil-cement. Soil-cement formed in place is later compacted by compacting machine and with cement hydration process strength is developed so that it becomes a hard and durable structural material. Chaudhary [5] also claimed that the factors affecting soil-cement are; type of soil, quality of cement, quality of water, admixture, mixing, compaction and curing. As to the type of soil, granular materials with sufficient fines requires lesser cement than those with deficiency in fines that required more cement but also fall under suitable materials. For quality of cement, its requirement depends upon the gradation for well graded soil requires about 5% cement content whereas uniform and poorly graded soil will require about 9% cement content.

Also, non-plastic silts require about 10% cement content and plastic clayey soil may need about 13% cement content. Potable water is the most desirable and when used it must be sufficient enough for compaction at optimum moisture content, cement hydration and for good workability. It is pertinent to note that the addition of admixtures such as lime, calcium chloride, fly ash, sodium carbonate and sodium sulphate reduces the cement requirement. Also, the soil-cement ingredients are to be thoroughly mixed in order to produce a more stable subbase otherwise a non-homogeneous weak layer would be constructed that would not be stable for compaction.

Alhassan and Mustapha [6] researched upon the effect of rice husk ash on cement stabilized laterite soil classified as an

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A-7-6 clayey soil by AASHTO standard. The experiments involved stabilization of the clayey soil samples with 2% to 8% amount of cement by weight of the dry soil at interval of 2% and addition of Rice Husk Ash (RHA) quantity from 2% to 8% on each specified cement content. At 7 days cured UCS there was increase in each of the specimen strength up to 6% RHA partial replacement after which the strength values declined as the percentages of RHA increases. Based upon their results and since A-7-6 laterite soil is a clayey soil and at maximum of 6% RHA partial replacement with cement subjected the stabilized soil material to an unsuitable subbase highway pavement, hence the RHA used should be considered as a retarder based upon the Garber and Hoel (2010) report.

Akiije [7] carried out a research on strength, durability and permeability characteristics of A-2-6(1) silty gravely soil; A-6(5) clayey soil and A-6(12) clayey soil while stabilizing them using Powermax cement. From the results obtained it was shown that the results of the 7 days cured unconfined compressive tests upon specimens show that the value of the unconfined compressive stress of the stabilized lateritic soil materials increases as Powermax cement proportion increases from 6% through 8% to 10% whilst the permeability decreases. The research had also shown that Powermax Portland cement is a binder to soil material but could not be able to make both silty and clayey soils to attain the required minimum strength requirement for subbase at 10% cement content of stabilization. This result is in conformity with the requirement as declared by Garber and Hoel (2010) claiming 12% minimum cement content is required for both silty and clayey soils stabilization. However, the use of 12% minimum cement content may not be economical.

Gadzama and James [8] investigated the comparative response of A-2-4 silty gravely sandy soil and A-2-6 clayey gravely sandy soil when stabilized with Portland cement for unconfined compressive strength test. The results showed that cement stabilized A-2-4 silty gravely sandy soil satisfied the 7 days cured UCS minimum strength requirement at 2% cement content whereas A-2-6 clayey gravely sandy soil satisfied same at 4%. Although, the brand name of the Portland cement used was not mentioned, it could be noted that both cement satisfied the required 7 days cured UCS minimum strength requirement below 5% cement content needed for gravely soils for highway subbase stabilized soil according to the Garber and Hoel [3].

This research aims at considering individual laboratory tests upon strength, durability and permeability characteristics of four selected soil samples at natural and at the Powermax Portland cement stabilized conditions. Specifically, the objectives are to:

i. Determine in the laboratory the specific chemical and metallic composition properties of the Powermax Portland cement as well as the four soils investigated 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 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 Powermax cement separately at percentages of 1%, 2% , 3%, 4%, 5% and 6% in proportion by weight; and
iv. Compare and contrast at optimum of the results of moisture-density relationship, California Bearing Ratio (CBR), unconfined compressive strength and permeability of the four soil samples as evaluated in the laboratory by using Powermax Portland cement as a stabilizer in accordance to standard specification requirements for highway pavement.

The main scope of work in this study is the laboratory experiments on each of the four types of soils obtaining from four different borrows pits whilst at natural and when stabilized with Powermax Portland cement individually. Also, classification of the four soils individually at natural states according to both AASHTO standard specifications and Unified System. More so, the determination of the percentages at which each stabilized soil will attain the strength and durability at a standard specified level of subbase for highway pavement. This study proffered information while using Powermax Portland cement as a stabilizer in the production of highway pavement subbase while stabilizing individually the selected four soils. The justification for this project research is that Powermax Portland cement is not readily available in the Nigeria market and to order same from the factory for its large quantity for subbase stabilization economically the suitability must be firstly established.

2. MATERIALS AND METHODOLOGY

Powermax Portland cement has been used in this study as a stabilizer for four different types of soils individually that include A-1-b(0) stone fragments gravely sandy soil, A-2-7(0) clayey gravely sandy, A-4(3) silty soil and A-5(10) silty soil. The cement used may be purchased by factory ordering system in a number of 30 tons bulk tankers; a number of trailers carrying many 2 tons per jumbo bag; and a number of 30 tons trailers carrying the cement in several of 50 kg per bag. The 50 kg bag pack type was used in this study and obtaining same was based upon attachment to a merchant in order to collect the number of bags used. The Powermax Portland cement Type I used in this research is a product of Lafarge Cement WAPCO Nigeria PLC a subsidiary of LafargeHolcim. The Powermax cement used was produced at Lafarge cement factory at Ewekoro, a town in Ogun State of Nigeria. Powermax Portland cement somewhat newly manufactured in Nigeria is of grade 42.5N as claimed by International Cement Review Newsroom ICRN [9]. Lafarge West African Portland Company WAPCO newly launched Powermax Cement as a top grade quality cement of 42.5N strength to energies infrastructural development of roads, bridges and high-rise buildings as compared to other cement in the market which are neither flexible nor open to other uses International Cement Review. ICRN [9] claimed that

WAPCO cements are manufactured in conformity to AASHTO Designation M85 [10] and could only be successfully used with materials which are not contaminated with silt, clay or organic materials.

For this research work, soil materials were collected from four different locations in southwest part of Nigeria. The locations of the four borrow pits are Ilesa in Osun State, Ondo in Ondo State, Matogun and Ijoko in Ogun 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 specific chemical, metallic, and compound parameters of the cement and the four selected soils were determined in the laboratory by performing the X-Ray Diffraction test and Atomic Absorption Spectroscopy (AAS) test.

The wet sieve analysis test was carried out in accordance to AASHTO T 88 [11] upon each soil. The liquid limit test on each soil was performed according to AASHTO T 89 [12] while tests to determine same for plasticity limit and plasticity index were carried out by AASHTO T 90 [13]. Each soil relative density test was conducted according to AASHTO T 100 [14]. Additional work done included the determination of group index of each soil according to AASHTO M 145 [15].

Clean, clear and drinkable water found in the laboratory of the department of Civil and Environmental Engineering, Faculty of Engineering, University of Lagos was used for the soil stabilization. The moisture-density relationship of each soil at natural state and when stabilized with cement were conducted according to AASHTO T 99 [16].

Stabilization of the A-1-b(0), A-2-7(0), A-4(3) and A-5(10) soils were carried out individually based upon optimum moisture content values and cement at percentages of 1%, 2%, 3%, 4% , 5% and 6%. At natural state and for each specimen cement stabilized soil for a defined percentage individually, optimum moisture content, maximum dry density, California Bearing Ratio (CBR), unconfined compressive strength (UCS) and permeability test were carried out. Each California Bearing Ratio (CBR) test was carried out in accordance to AASHTO T 193 [17], each specimen of the unconfined compressive strength (UCS) test was determined according to AASHTO T 208 [18] and also each permeability test was carried out with reference to ASTM D7664 [19].

3. ANALYSIS OF RESULTS AND DISCUSSIONS

The results and discussions of laboratory tests conducted in this study using Powermax Portland cement of grade 42.5N as a stabilizer are upon the optimal suitability of the four different types of individual soils of A-1-b(0) stone fragments gravely sandy soil, A-2-7(0) clayey gravely sandy soil, A-4(3) silty soil and A-5(10) silty soil for highway pavement. The results of the cement chemical, metallic, physico and compound composition as well as the relevant properties of the four soil samples at natural state as assessed in the laboratory and characterized are presented. The results on the four soils individually at natural state included Atterberg limits, wet grain sieve analysis and their classifications. Also presented are the results of the four natural soils and as at when stabilized with Powermax Portland cement individually which include moisture-density relationship, California Bearing Ratio, unconfined compression and permeability. Tables and graphs are used in presenting the results of the analysis of the cement samples, the four natural soils in their disturbed states individually and when they are stabilized with cement independently. Discussions of the natural and stabilized soils by laboratory experiments are compared with relevant standard specification requirements for the optimization of highway pavement design and construction.

3.1. Properties of the Powermax Portland cement grade 42.5N examined

Considering Table 1, the percentages of chemical composition of Powermax 42.5N Portland cement for Calcium oxide, Silicon dioxide and Ferric oxide complied with the standard specification favourably. Also, the ratio of CaO to SiO_2 that is not less than 2 makes it suitable for use as a binder in stabilization process. Although, Al_2O_3 is found to be higher than the maximum standard requirement, this makes it a possible advantage for attaining formation of tricalcium silicate and dicalcium silicate at lower temperature. More so, SO_3 is found to be lower in value than the standard specification which eliminates a significant undue expansion of the stabilized soils.

Table 2 is showing that tricalcium silicate and dicalcium silicate complied with the standard specification which means that hydration of the Powermax 42.5N Portland cement is satisfactory for when mixed with water would provide of desirable stabilized soils with preferred strength and durability characteristics. Aluminium oxide and ferric oxide that were produced due to presence of alumina and iron in order to reduce the processing temperature in the production of Powermax Portland cement is suitable for energy savings and effective material cost. It should be noted that aluminium oxide present complied with standard specification although it is at the extreme high side while it is also noted that ferric oxide amount is only at a close value to the minimum requirement.

Table 1: Typical Constituents of the Powermax 42.5N Portland cement examined

S/N	Powermax Portland Cement Compound Composition	Cement Chemists Notation, CCN	Chemical composition %	Standard Min-Max %	Remarks
1	Calcium oxide, CaO	C	63.82	60.6-66.3	Complied
2	Silicon dioxide, SiO_2	S	22.210	18.7-22.0	Complied
3	Aluminium oxide, Al_2O_3	A	6.080	4.7-6.3	Complied
4	Ferric oxide, Fe_2O_3	F	1.240	1.6-4.4	Complied

Table 2: Compound composition of the Powermax 42.5N Portland cement examined

S/N	Powermax Portland Cement Compound Composition	Compound Composition %	Standard Min-Max %	Remarks
1	Tricalcium silicate C_3S	44.82	40-63	Complied
2	Dicalcium silicate C_2S	29.95	9-31	Complied
3	Tricalcium aluminate C_3A	14.00	6-14	Complied
4	Tetracalcium aluminoferrite C_4AF	3.77	5-13	Not Complied

3.2. Properties and classification of the four soils examined for highway purposes

The results of the properties and classification of the individual four different types of soil in their disturbed natural states are defined in Table 3 and Figure 1 by AASHTO soil classification system as A-1-b(0) stone fragments gravely sandy soil, A-2-7(0) gravely sandy with plastic clayey soil, A-4(3) nonplastic silty soil and A-5(10) highly elastic silty soil. These four soils have also been described individually as shown in Table 3 by Unified soil classification system as SW, CL, ML and ML. Of the four types of soil treated individually as shown in Table 3, A-1-b(0) has the lowest values of moisture content, void ratio, porosity, degree of saturation, plastic limit, liquid limit, plasticity index and percent passing sieve 0.075 mm. It could also be seen that A-1-b(0) soil has the values obtained for both bulk and dry densities being respectively the highest among the soils experimented. On the other hand, A-5(10) has the highest values for void ratio, porosity, liquid limit, plasticity index and percent passing sieve 0.075 mm.

The graphical representation in Figure 1as grain-size distribution curves shows the results of the sieve analysis of the soil A-1-b(0) and the wet sieve analysis of soils A-2-7(0), A-4(3) and A-5(10) after the individual laboratory experiments. Soil A-1-b(0) is of a well graded coarse sandy soil with a good distribution of particles from medium and fine gravel through coarse and fine sand to silt. It could also be seen that 50% coarse fraction of the soil retained on No. 4 sieve and only 4% of the soil passed through No. 200 sieve. The result of the A-1-b(0) soil coefficient of uniformity Cu is 21 whilst greater than 6 and for its coefficient of curvature Cc as 2 for being less than 3 described the soil to be stone fragments gravely sandy soil. For soil A-2-7(0), it is a granular material of fine grained soil for 68% of the soil passed through No. 200 sieve with only 7% coarse fraction of same retained on No. 4 sieve and for PI of 12 being greater than 7 is an indication that it is an inorganic low plasticity clay CL soil. In lieu of soil A-4(3), it is a fine-grained soil for 56% of the soil passed through No. 200 sieve with 100% of the soil passed through No. 4 sieve and for PI of 7 and liquid limit LL being 40 is an indication that it is an inorganic low plasticity silty soil ML. Also for A-5(10) soil, it is a fine-grained soil for 65% of the soil passed through No. 200 sieve with 100% of the soil passed through No. 4 sieve and for PI of 10 and liquid limit LL being 43 is an indication that it is an inorganic low plasticity silty soil ML. However, based upon the results of the properties of the four types of soils as stated and the values of plasticity index for the four soils, A-1-b(0) exhibited the possible best suitable material for highway pavement purposes followed by A-4(3) then A-5(10) and lastly A-2-7(0).

3.3. Material compositions of the Powermax 42.5N Portland cement and the four types of soils examined

Table 4 is showing the results in percentages of the chemical composition of the Powermax Portland cement grade 42.5N, A-1-b(0) coarse sandy soil, A-2-7(0) gravely sandy with plastic clayey soil, A-4(3) nonplastic silty soil and A-5(10) highly elastic silty soil. As shown in Table 4, the percentage value of the silica SiO_2 of the cement is lower than those of the four soils examined while soil A-1-b(0) has the highest value. However, the value of calcium oxide, CaO of cement is far higher than those of the three types of soils. Also, the percentage values of aluminium oxide, Al_2O_3 of each of the four soil samples are similar but they are very high when compared with that of the cement studied. Although the value of Ferric oxide Fe_2O_3 is very small when compared with the main typical constituents of cement but it could be seen that it is a large amount when compared with the four types of the soils studied. Moreover, the value of the silica SiO_2 of the cement is lower than those of four soils which they all have similar amount. There is a small amount of sulphate SO_3 value in cement whereas the constituent is not present in any of the four types of soil scrutinized.

As shown in Table 5 it could be seen that the metallic components Cu, Mn, Fe and Zn values in mg/kg are highly present in A-1-b(0) coarse sandy soil when compared to Powermax Portland cement grade 42.5N as well as laterite soils A-2-7(0), A-4(3) and A-5(10). Similarly, the percentage of organic carbon and loss of ignition is very high in A-1-b(0) soil when compared to other soil materials and the cement used. The logarithmic index for hydrogen ion concentration in the materials aqueous solution, pH is higher than 7 for Powermax Portland cement grade 42.5N together with silty soils which are A-4(3) and A-5(10) being them alkaline. However, the pH of A-1-b(0) coarse sandy soil and A-2-7(0) is 7 and being neutral. The presence of Pb in A-1-b(0) coarse sandy soil is at very low percentage value that could not be injurious to health.

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Table 3: Properties of the three types of soil materials examined

S/N	Properties	A-1-b(0)	A-2-7(0)	A-4(3)	A-5(10)
1	Moisture Content (%)	11.724	24.665	18.027	14.960
2	Bulk Density (Mg/m³)	2.159	2.094	1.972	2.024
3	Dry Density (Mg/ m³)	1.933	1.78	1.671	1.627
4	Specific Gravity (Gs)	2.769	2.7	2.800	2.780
5	Void Ratio e	0.433	0.514	0.676	0.709
6	Porosity n, %	0.302	0.339	0.403	0.415
7	Degree of Saturation Sr, %	0.750	0.915	0.995	0.933
8	Liquid Limit (PL)	-	45	40.000	43.000
9	Plastic Limit (LL)	-	33	33.000	33.000
10	Plasticity Index (PI)	-	12	7.000	10.000
11	Percent Passing 0.075 mm	3	35	57	65
12	Percent Passing 0.425 mm	13.14	48	71	76
13	Coefficient of uniformity, Cu	21	-	-	-
14	Coefficient of Coverture	2	-	-	-
15	Group Index	0	0	3	10
16	AASHTO Soil Classification	A-1-b(0)	A-2-7(0)	A-4(3)	A-5(10)
17	AASHTO Soil Description	Stone fragments gravely sandy soil	Gravely sandy with plastic clayey soil	Nonplastic silty soil	Highly elastic silty soil
18	Unified System Soil Classification	SW	CL	ML	ML
19	Unified System Soil Description	Well graded sand	Low plasticity clay	Low plasticity silty soil	Low plasticity silty soil

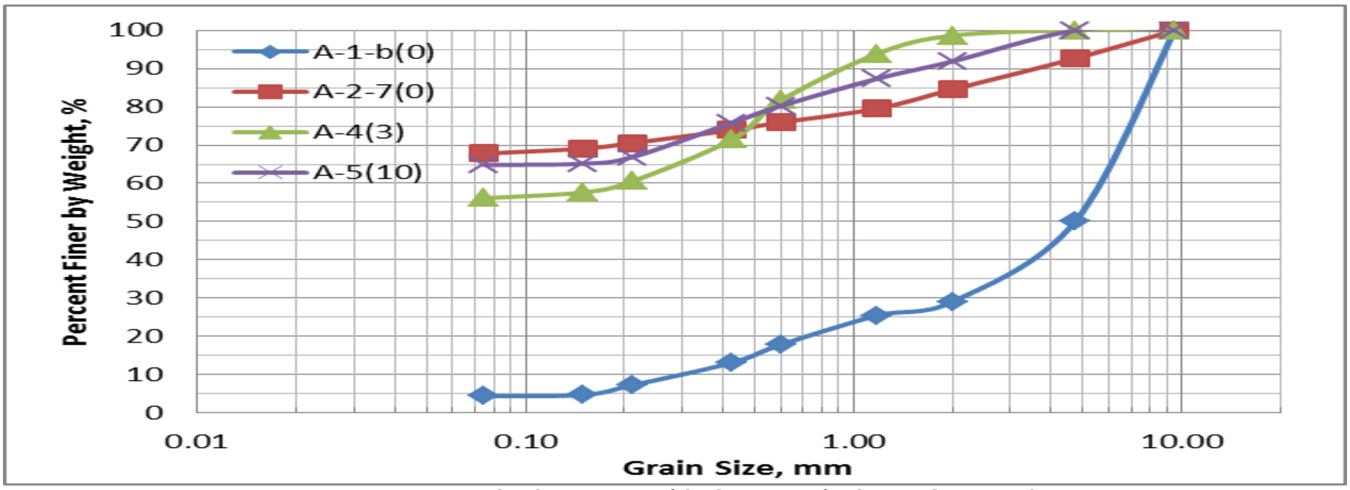

Figure 1: Grain-size distribution curves of the three types of soil materials examined

Table 4: Chemical composition of the Powermax 42.5N Portland cement and soils examined

S/N	PARAMETER (%)	Powermax Portland Cement	A-1-b(0)	A-2-7(0)	A-4(3) silty soil	A-5(10) silty soil
1	SiO_2	22.210	44.62	63.1	44.240	45.700
2	Na_2O	0.500	0.690	0.051	0.0460	0.058
3	K_2O	0.300	0.482	0.044	0.042	0.050
4	CaO	63.820	0.181	1.66	0.030	0.050
5	MgO	2.750	0.05	0.571	0.020	0.030
6	BaO	0.002	0	0	0	0
7	PbO	0	0	0	0	0
8	MnO	0	0.016	0.05	0.008	0.010
9	Al_2O_3	6.080	35.2	34.02	30.350	32.560
11	Fe_2O_3	1.240	0.12	0.053	0.054	0.140
12	SO_3	1.230	0	0.001	0	0
13	$Ca(OH)_2$	0.270	0		0	0

Table 5: Metallic and other components of the Powermax 42.5N Portland cement and the three soils examined

S/N	Parameters	Powermax Portland cement	A-1-b(0)	A-2-7(0)	A-4(3) silty soil	A-5(10) silty soil
1	Cd (mg/kg)	0	0	0	0	0
2	Cu(mg/kg)	0.001	2.610	0	0	0
3	Mn (mg/kg)	0.002	1.720	0.030	0	0
4	Ni (mg/kg)	0	0	0.0	0	0
5	Pb (mg/kg)	0	0.040	0.0	0	0
6	Fe (mg/kg)	0.012	28.900	0.020	0.038	0.043
7	Zn (mg/kg)	0.000	4.570	0	0	0
8	Al (mg/kg)	17.06	0	17.340	16.070	15.890
9	Cl^- (mg/kg)	640	410	360.000	267.000	234.000
10	$SO_4{}^2$ (mg/kg)	640	139.000	112	108.000	102.000
11	Organic Carbon (%)	0.7	2.160	0.230	0.180	0.180
12	LOI (%)	0.026	8.050	0.360	0.006	0.005
13	pH	12.1	6.90	7.320	8.590	8.870

3.4. Moisture-Density Relationships of the four Soils individually for Highway Purposes

Table 6 is showing specifically the results for the optimum moisture content OMC and maximum dry density MDD of the four soils individually at natural state and when they are stabilized at 6% of Powermax Portland cement. It is obviously seen in the table that the optimum moisture content value of soil A-1-b(0) at natural state is lower than when it was stabilized at 6% Powermax Portland cement whereas the MDD at natural state is lower than when it was stabilized at 6% cement. Considering the soils A-4(3) and A-5(10), the former soil has lower optimum moisture content and higher maximum dry density than the later at natural state as well as at 6% Powermax Cement Stabilization. It is vividly shown that the MDD at 6% Powermax Cement Stabilization of soil A-1-b(0) is higher than that of each value of soils A-4(3) and A-5(10) at 6%. Figure 2 is showing the results of the optimum moisture content for the four different soils individually in their natural disturbed states and when it has been stabilized with Powermax cement for highway purposes at interval of 1% up to 6%. The graph of each soil displayed is showing a decrease in optimum moisture content as the percentage of cement content is increasing for all the soils A-1-b(0), A-2-7(0), A-4(3) and A-5(10). Also, Figure 3 is showing the results of the variations of the maximum dry density for the four different soils individually in their natural disturbed states and when stabilized with Powermax Portland cement for highway purposes. The graph of each soil displayed an increasing maximum dry density values as the percentage of cement content is increasing.

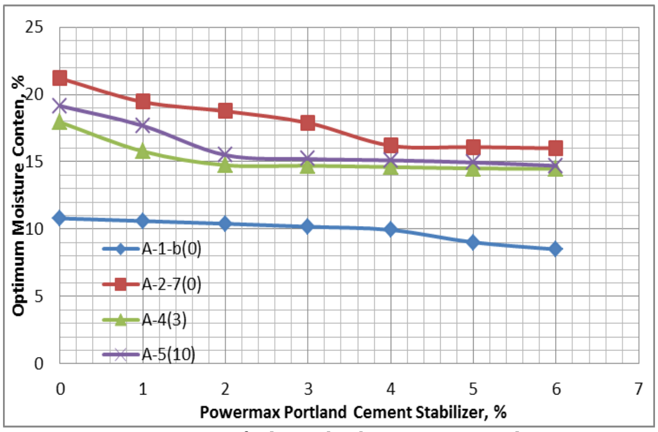

Figure 2: Curves of relationship between OMC and cement percent increase of the stabilized soils individually

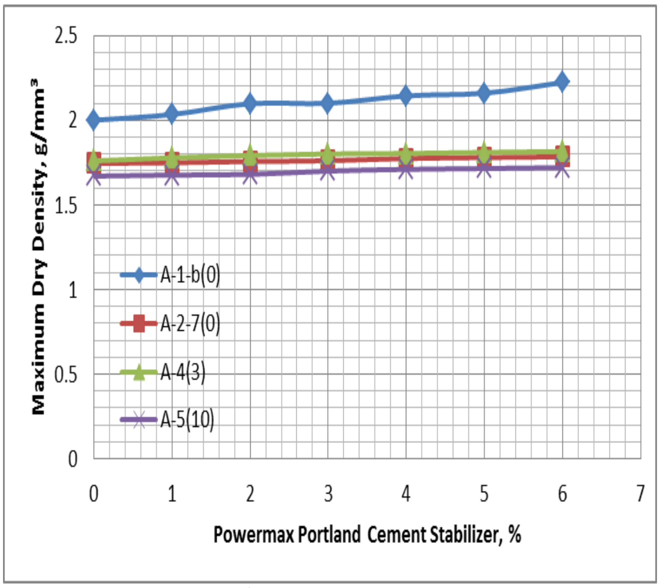

Figure 3: Curves of relationship between MDD and cement percent increase of the stabilized soils individually

Table 6: Moisture Density Relationship of the soils at natural and cement stabilized states

Label	Moisture Density Relationship	Soil Classification			
		A-1-b(0)	A-2-7(0)	A-4(3)	A-5(10)
Natural Soil	Optimum Moisture Content %	8.200	10.00	17.940	19.150
	Maximum Dry Density g/cm³	2.158	1.774	1.760	1.670
6% Powermax Cement Stabilization	Optimum Moisture Content %	10.000	16.20	14.390	14.51
	Maximum Dry Density g/cm³	2.248	1.948	1.821	1.710

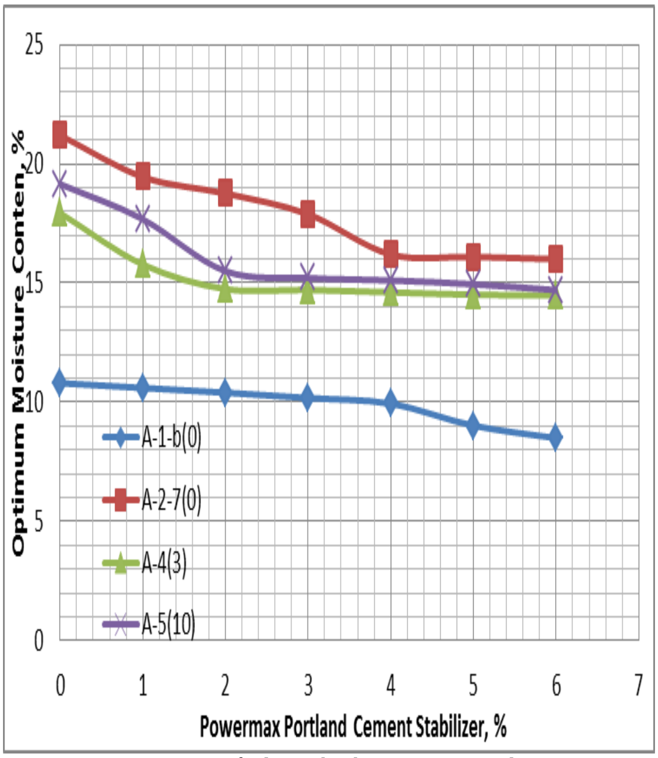

Figure 2: Curves of relationship between OMC and cement percent increase of the stabilized soils individually.

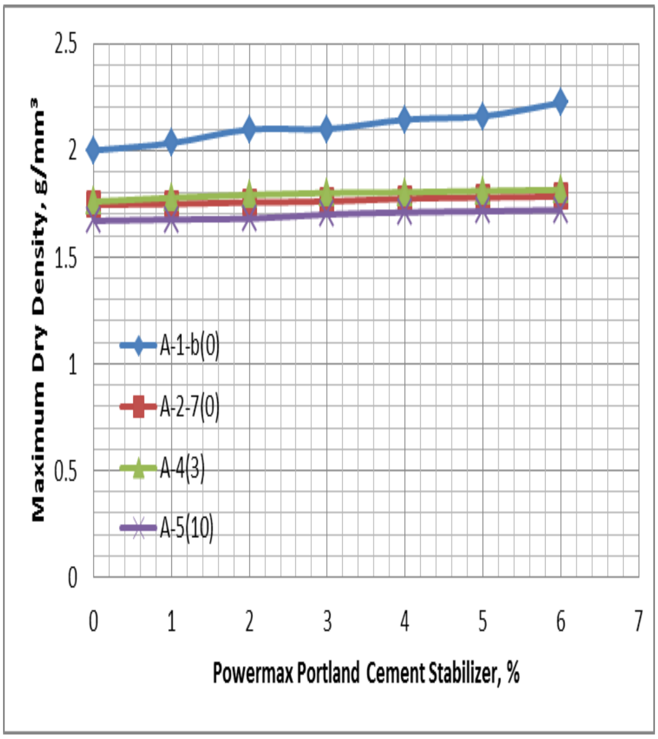

Figure 3: Curves of relationship between MDD and cement percent increase of the stabilized soils individually.

3.5. Unsoaked and soaked CBR relationships of the laterite soils for highway purposes

Figure 4 and Figure 5 present respectively the unsoaked and soaked CBR curves of the soils A-1-b(0), A-2-7(0), A-4(3) and A-5(10) individually at natural and when stabilized with Powermax Portland cement. The four laterite soil materials were from four different borrow pits for use as subbase or base. For the four soils, as the percentages of cement increase CBR values also increased both at unsoaked and soaked conditions. It is pertinent to note that the CBR value of soil A-2-7(0) is higher than those of soils A-4(3) and A-5(10) at natural state but at 1% of cement stabilization the CBR value of the later is higher than same. Also, it could be seen that at 2% of cement stabilization the CBR value of A-5(10) is also higher than that of the A-2-7(0) for the unsoaked conditions. The stated phenomenal could be attributed to the fact of soil A-2-7(0) being a clayey soil of which cement will not be performing as a good binder.

Table 7 is showing specifically the results for the unsoaked and soaked California Bearing Ratio of the four individual soils at natural state and when stabilized at maximum of 6% with Powermax Portland cement. It is worthy of note that subbase natural material is to have satisfactory soaked CBR value between 30% and 50%. However, as shown in Table 7 none of the materials at natural state satisfied the said conditions to be suitable for a proposed highway subbase. Apparently it is noticeable in Table 7 that the soils have been individually improved in strength and durability for attaining higher soaked CBR values upon 6% Powermax cement stabilization however, it is obviously seen in the table that the unsoaked and soaked CBR values of each soil at natural state are lower than when they are stabilized at 6% Powermax Portland cement independently.

Table 8 is showing percentages at which satisfactory CBR values were attained by the four individual cement stabilized soils up to 6% maximum for highway design of subbase and base materials. A-1-b(0) and A-4(3) soils attained required standard specification for 80% unsoaked CBR value and are both satisfactorily good materials for highway subbase at 5% Powermax Portland cement stabilization. However, soils A-2-7(0) and A-5(10) could not attain the required standard specification of 80% unsoaked CBR value for both to satisfactorily serve as good materials for highway subbase at maximum use of 6% Powermax Portland cement stabilization. The unsoaked CBR of soils A-1-b(0), A-2-7(0), A-4(3)and A-5(10) could not also attain the required standard specification of 180% unsoaked CBR value for both to satisfactorily serve as good materials for highway base at maximum use of 6% Powermax Portland cement stabilization. The soaked CBR of soils A-1-b(0), A-2-7(0), A-4(3)and A-5(10) soils attained required standard specification for 180% soaked CBR value and are all satisfactorily good materials for highway subbase at respective percentages Powermax Portland cement stabilization as shown in Table 8. On the facet of stabilization of the soaked CBR values of Powermax Portland cement, only soil A-1b(0) attained 180% CBR value at 6% cement stabilization for highway base of the four soils under the same conditions .

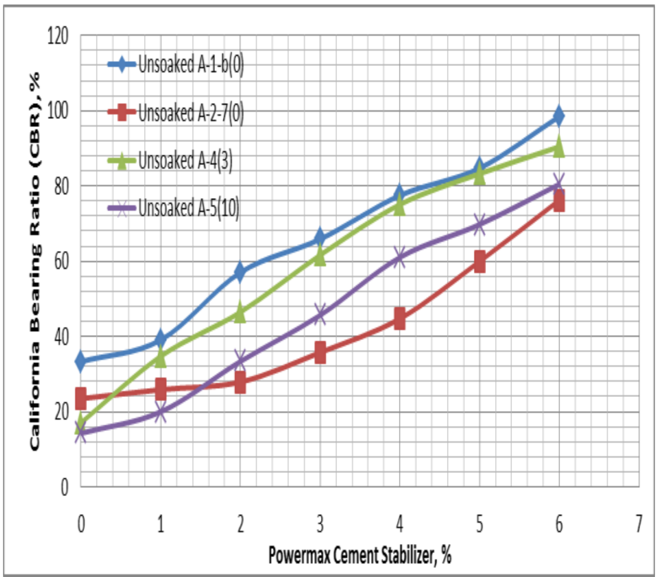

Figure 4: Curves of relationship between unsoaked CBR values and cement percent increase of the stabilized laterite soils individually

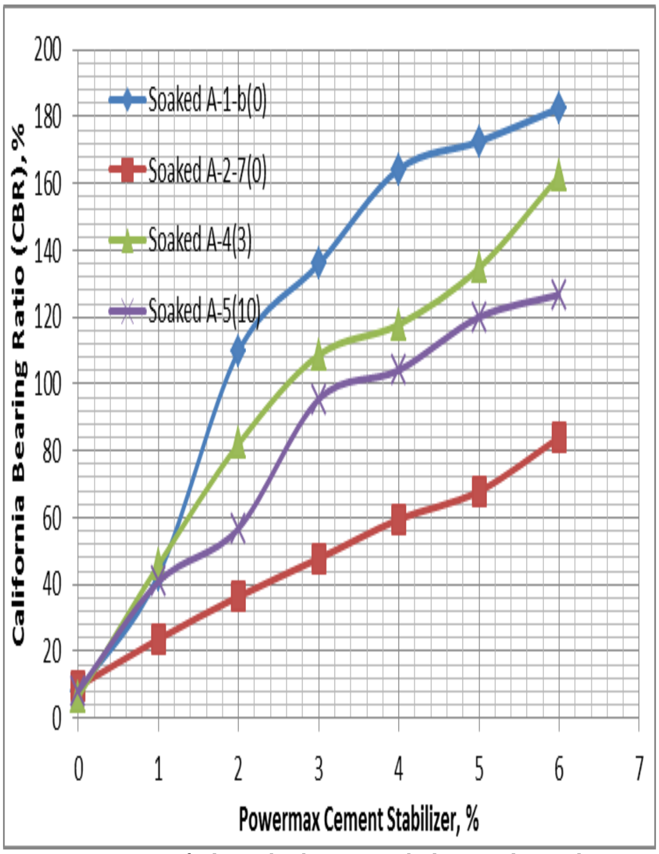

Figure 5: Curves of relationship between soaked CBR values and cement percent increase of the stabilized soils individual

Table 7: Natural laterite soils and 6% cement stabilization of same compared for unsoaked and soaked CBR values

Label	Soil Classification	A-1-b(0)	A-2-7(0)	A-4(3)	A-5(10)
Natural Soil	Unsoaked CBR values, %	33.333	23.500	17.100	14.300
	Soaked CBR values, %	8.000	9.500	6.360	8.110
6% Powermax Cement Stabilization	Unsoaked CBR values, %	98.500	76.250	90.450	80.500
	Soaked CBR values, %	182.500	84.000	162.300	126.700

Table 8: Highway subbase and basecourse satisfactory level of CBR value attained by the individual stabilized cement soils up to 6% maximum

	Unsoaked CBR		Soaked CBR	
	Powermax Portland cement percentage that attained 80% CBR value as stabilized subbase	Powermax Portland cement percentage that attained 180% CBR value as stabilized basecourse	Powermax Portland cement percentage that attained 80% CBR value as stabilized subbase	Powermax Portland cement percentage that attained 180% CBR value as stabilized basecourse
A-1-b(0)	5%	Not Attainable	2%	6%
A-2-7(0) Clayey Soil	Not Attainable	Not Attainable	6%	Not Attainable
A-4(3) Silty Soil	5%	Not Attainable	2%	Not Attainable
A-5(10) Silty Soil	Not Attainable	Not Attainable	3%	Not Attainable

3.6. Individual unconfined compressive strength of the four laterite soils for highway purposes

Figure 6 and Figure 7 present respectively the uncured and cured UCS curves of the soils A-1-b(0), A-2-7(0), A-4(3) and A-5(10) individually at natural and when stabilized with Powermax Portland cement from 1% to 6% at interval of 1%. As vividly seen in the graph, four figures of which each one is representing a particular soil behave similarly but with different rate of strength development. While considering Figures 6 and 7, both A-4(3) and A-5(10) that are silty soils have similar line shape of uncured and cured UCS when compared to the soil A-1-b(0) stone fragments gravely sandy soil and A-2-7(0) gravely sandy with plastic clayey soil. However, the line shape of A-1-b(0) UCS of the two figures for uncured and cured unconfined compressive strength are at

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the higher level than those of A-4(3) and A-5(10) and whilst line shape for soil A-2-7(0) is at the lowest level.

Table 8 is showing explicitly the results for the uncured and cured unconfined compression strength of the soils A-1-b(0), A-2-7(0), A-4(3) and A-5(10) individually at natural state and when stabilized at maximum of 6% with Powermax Portland cement. The uncured unconfined compression strength values of A-4(3) and A-5(10) silty soils samples at natural states are closely related similarly so for cured unconfined compression strength values. It pertinent to note that soil A-1-b(0) values of uncured and cured UCS at natural disturbed state are higher than those the other three soils while soil A-2-7(0) values of same has the least values. Considering uncured and cured unconfined compression strength values when stabilized at maximum of 6% with Powermax Portland cement, only the two silty soils have comparable values while on the other hand soil A-1-b(0) has higher values for same and soil A-2-7(0) has lower values respectively.

By standard specification for highway subbase is to have cement stabilized soil 7 day cured UCS value between 750 kN/m^2 and 1500 kN/m^2 while its base is to have cemented soil of 7 day cured UCS value between 1500 kN/m^2 and 3000 kN/m^2. It is obviously seen in Table 9 that only soil A-1-b(0) stone fragments gravely sandy soil that has 839.921 kN/m^2 is the only stabilized soil that is suitable for highway subbase. It is worthy of note that of the other three types of soil A-2-7(0), A-4(3) and A-5(10) none of them with cement stabilization up to 6% individually satisfy the required 7 day cured UCS requirements to be suitable for highway subbase.

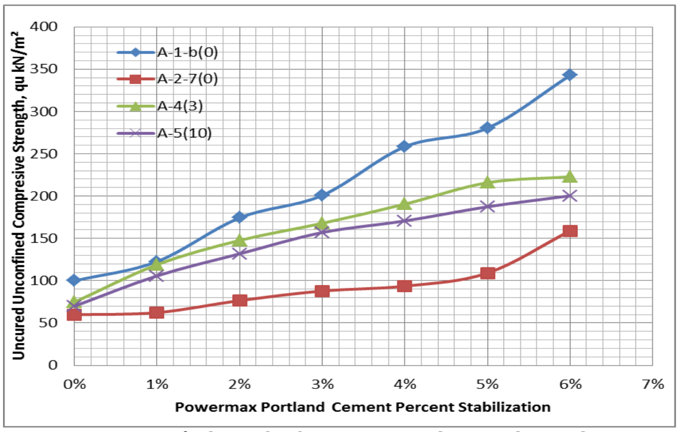

Figure 6: Curves of relationship between uncured UCS values and cement percent increase of the stabilized laterite soils individually

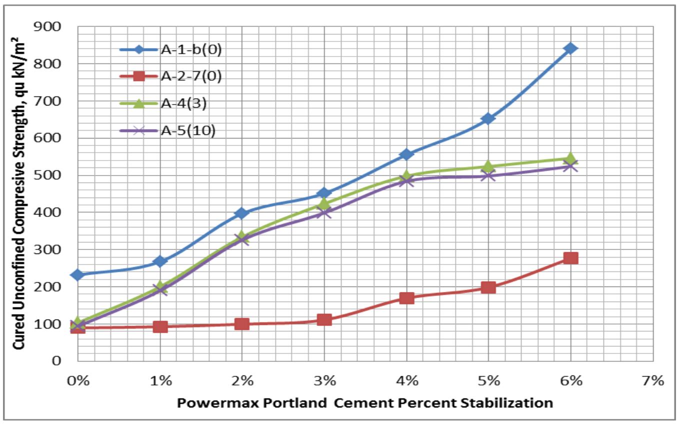

Figure 7: Curves of relationship between cured UCS values and cement percent increase of the stabilized laterite soils individually

Table 8: Natural soils and 6% cement stabilization of same individually compared for cured and uncured UCS values

Label	Uncured Unconfined compressive strength (kN/m²)		Cured Unconfined compressive strength (kN/m²)	
	0%	6%	0%	6%
A-1-b(0) stone fragments gravely sandy soil	99.922	342.742	231.964	839.921
A-2-7(0) clayey gravely sandy	59.880	159.046	89.641	276.67
A-4(3) silty soil	74.640	222.900	103.640	545.950
A-5(10) silty soil	69.860	200.400	94.250	523.950

Table 9: Optimization of cement stabilization for UCS standard requirements for highway subbase and base specification at 6% maximum

Label	Minimum Requirements at 7 Day Cured UCS		Maximum Requirements at7 Day Cured UCS	
	750 kN/m^2 for Subbase	1500 kN/m^2 for Base	1500 kN/m^2 for Subbase	3000 kN/m^2 for Base
A-1-b(0) stone fragments gravely sandy soil	Attainable at 6%	Not Attainable Up to 6%	Not Attainable Up to 6%	Not Attainable Up to 6%
A-2-7(0) clayey gravely sandy	Not Attainable Up to 6%	Not Attainable Up to 6%	Not Attainable Up to 6%	Not Attainable Up to 6%
A-4(3) silty soil	Not Attainable Up to 6%	Not Attainable Up to 6%	Not Attainable Up to 6%	Not Attainable Up to 6%
A-5(10) silty soil	Not Attainable Up to 6%	Not Attainable Up to 6%	Not Attainable Up to 6%	Not Attainable Up to 6%

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3.7. Individual permeability value of the four laterite soils for highway purposes

Figure 8 is depicting the comparison of the permeability results of the four soils individually at natural state as well as at when each soil was stabilized by Powermax Portland cement at an interval variation of 1% increment up to 6%. All the soils samples A-1-b(0), A-2-7(0), A-4(3) and A-5(10) 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 6 % when they all have similar permeability values.

Table 10 is showing plainly the results of the permeability tests of the four individual soils, A-1-b(0) stone fragments gravely sandy soil, A-2-7(0) clayey gravely sandy, A-4(3) silty soil and A-5(10) silty soil at natural state and by cement stabilization at maximum of 6% with Powermax Portland cement. Permeability test results at natural states show that all the soils behave similarly and the similarity was also exhibited upon being stabilized at cement content up to 6%.

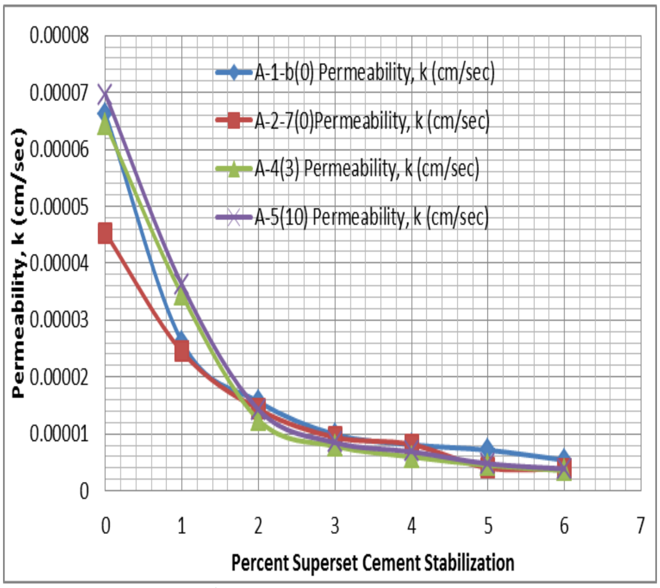

Figure 8: Curves of relationship between permeability values and cement percent increase of the stabilized selected four soils individually

Table 10: Permeability values of the four natural soils and at 6% of cement stabilization individually compared

Label	A-1-b(0), k (cm/sec)	A-2-7(0), k (cm/sec)	A-4(3), k (cm/sec)	A-5(10), k (cm/sec)
0%	10^{-5}	10^{-5}	10^{-5}	10^{-5}
6%	10^{-6}	10^{-6}	10^{-6}	10^{-6}

4. CONCLUSIONS AND RECOMMENDATIONS

Four different soil samples have been characterized and as well classified as of A-1-b(0) stone fragments gravely sandy soil, A-2-7(0) clayey gravely sandy soil, A-4(3) silty soil and A-5(10) silty soil according to AASHTO classification and respectively described according to Unified System Soil Classification Well graded sand SW, Low plasticity clay CL, Low plasticity silty soil ML and Low plasticity silty soil. Each soil was individually stabilized with Powermax Portland cement and their usefulness discussed in relationship to subbase for highway pavement.

4.1. Conclusions

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

i. Powermax Portland cement used is a made in Nigeria of normal grade 42.5N that satisfactorily conforms to ASTM, AASHTO and British relevant standard specification requirements for its chemical and potential compound compositions.

ii. Powermax Portland cement made in Nigeria has been successfully utilized to stabilize soils A-1-b(0), A-2-7(0), A-4(3) and A-5(10) soils for CBR and UCS values increased while the permeability values decreased as the cement content increased from 1% to 6% at the 1% increment.

iii. A-1-b(0) stone fragments gravely sandy soil sample subjected to laboratory experiments in this research is found to have 3% passing sieve 0.075 mm, 13% passing 0.424 mm, the coefficient of uniformity Cu value is 21 while coefficient of curvature Cc is 2 and which forms suitable subbase material for highway pavement cement stabilization. The soil soaked CBR values of 80% and 180% for subbase and basecourse could only be attained using 2% and 6% cement stabilization correspondingly. Whereas for this 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 6% cement stabilization.

iv. A-2-7(0) clayey gravely sandy soil sample subjected to laboratory experiments in this study has plasticity index PI of 12 which is greater than 10 and this makes it not a useful material for cement stabilization. Soaked CBR values of 80% for subbase was only attained at 6% cement stabilization. However, for this same soil, subbase strength minimum requirements strength that is 750 kN/m^2 at 7 day cured UCS for highway subbase development at 6% cement stabilization was not attained at all.

v. A-4(3) silty soil sample was also subjected to laboratory experiments and it was found that its plasticity index PI is 7 which is less than 10 makes it a useful material for cement stabilization. However, only soaked CBR values of 80% for subbase was attained at 2% cement amount of stabilization. However, for this same soil, subbase strength minimum requirements strength that is 750 kN/m^2 at 7 day cured UCS for highway subbase development at 6% cement stabilization was not attained at all.

vi. A-5(10) silty soil sample subjected to laboratory experiments in this study has plasticity index PI of 10 which is greater that makes it not a useful material for cement stabilization. However, only soaked CBR values of 80% for subbase was attained at 3% cement amount of stabilization. For this same soil, subbase strength minimum requirements strength that is 750 kN/m² at 7 day cured UCS for highway subbase development at 6% cement stabilization could not be attained.

vii. Interestingly, the soils experimented that are grouped as A-1-b(0), A-2-7(0), A-4(3) and A-5(10) are of similar permeability values of k at natural state with 10^{-5} and has 10^{-6} for 6% of cement stabilization.

4.2. Recommendations

The followings are the recommendations proffered in the course of the laboratory experiments upon the four selected soils that are individually stabilized with Powermax Portland cement.

i. As exhibited in this research among the four types of soils stabilized, Powermax Portland cement that is made in Nigeria is recommended for the stabilization of A-1-b(0) stone fragments gravely sandy soil and not for A-2-7(0) clayey gravely sandy soil, A-4(3) silty soil and A-5(10) silty soil in other to prevent premature failure of the highway pavement in the country.

ii. Considering the results of PI, CBR and UCS values of the four soils investigated in this study while stabilizing with Powermax Portland cement, it is the results of the UCS that should be considered for cement stabilized soils and not that of PI and CBR values for satisfactory strength, durability and permeability of cemented subbase highway pavement design and construction.

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