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Characterization of Soil A-6(11) Stabilized Using Three Different Types of Nigerian Produced Portland Cement Independently

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Abstract **- In this paper, two different types of normal 42.5N and one rapid 42.5R Portland cements that are being produced in Nigeria have been used to stabilize soil A-6(11) and characterized for optimization purpose. The three Portland cement are tagged 42.5Np, 42.5Ns and 42.5Rx for the purpose of clarity and identification. The natural laterite soil was obtained from a borrow pit at Abule-Ijoko in Ogun State of Nigeria. Material composition tests showed that the major components in the cements 42.5Np, 42.5Ns and 42.5Rx are CaO, SiO_2 and Al_2O_3 while that of the soil are SiO_2 and Al_2O_3. Laboratory experiments employed on the laterite included soil classification for highway purposes and also its stabilization at 2%, 4%, 6%, 8%, 10%, 12% and 14% using the three types of cement individually. Other laboratory experiments performed individually included optimum moisture content (OMC), maximum dry density (MDD), California Bearing Ratio (CBR), unconfined compressive strength (UCS) and permeability upon the natural and the stabilized soil. The classification results showed that the percent passing sieves 4.750 mm, 2.000 mm, 0.425 mm and 0.075 mm respectively by grain size analysis of A-6(11) are 100%, 98%, 71% and 56%. The respective results of the liquid limit, plastic limit and plasticity index for soil A-6(11) are 40, 20 and 20. The OMC of the soil specimen at natural and at the increasing cement stabilization of same are reducing while the related MDD are increasing. At natural state and for the strategic percent increase of cement content for the soil specimen, both unsoaked and soaked CBR, uncured and cured UCS values are increasing while the permeability amounts are reducing. The significance of this study is that for each type of stabilization at 2% cement content the unconfined compressive strength satisfied subbase requirement whilst at 4% of same satisfied maximum and minimum standard requirements respectively for subbase and road base. The justification for this study is that at 6% cement content of stabilization, the three different types of cement satisfied possible design values of cured UCS for road base economically in spite soil being A-6(11) clayey soil.**

Keywords: Laterite; Borrow; Subbase; Base; Highway; Nigeria

1. INTRODUCTION

Oftentimes different cement types' with equal content in percentages of stabilized soil sample individually to attain specified strength for stable subbase or road base is not the same. Akiije [1] experimented in the laboratory upon optimizing 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 as to their pertinent stabilization for highway subbase. It was concluded that 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.

Achampong et al.[2] reported that cement stabilization mechanism is mainly controlled by hydrolysis and hydration which affect physical properties of soil-cement including soil type (particle size distribution, grain shape, mineralogy); proportion of soil; cementation material; water content; quantity of cement; degree of mixing; time of curing; and density of the of the compacted mixture. Here hydration means addition of water and cement while hydrolysis is the reaction process of both.

Khan [3] considered cement stabilization into two categories which are normal soil-cement and plastic soil-cement. He claimed that normal soil-cement consists of 5% to 14% cement content by volume and with sufficient water used for hydration and workability requirement whilst ample to produce a material that is hard, durable weather resistant, strong and used for stabilizing sandy and other low plasticity soils. Khan [3] also stated that the plastic soil-cement consists of 5% to 14% of cement by volume with more water to have wet consistency similar to that of plastering mortar at the time of placement which are useful for water proof lining for canals, reservoirs and protection for steep slopes against water erosion.

Husna [4] considered the possible initial estimated cement requirements for various soils using the Unified System and proclaimed initial estimated cement content percent dry weight for highway subbase and base stabilization as in Table 1. Also, Das [5] identified symbols in use by the Unified System for soils description as in Table 2.

Table 1: Possible Initial Estimated Cement Content Percent Dry Weight for Soil Stabilization

S/No	Unified System Soil Classification	Possible Initial Estimated Cement Content Percent Dry Weight for Soil Stabilization
1	GW, SW	5
2	GP, GM-GC, GW-GM, SW-SC, SW-SM	6
3	GC, GM, GP-GC, GP-GM, GM-GC, SC, SM, SP-SC, SP-SM, SM-SC, SP	7
4	CL, ML, MH	9
5	CH	11

Husna [4]

Table 2: The Unified System symbols and descriptions for Soil identification

Symbol	G	S	M	C	O	Pt	H	L	W	P
Description	Gravel	Sand	Silt	Clay	Organic silts and clay	Pt and highly organic soils	High plasticity	Low plasticity	Well graded	Poorly graded

Das [5]

This research considered individual laboratory tests upon strength, durability and permeability characteristics of a selected soil sample at natural state and when stabilized with three different types of Portland cements tagged 42.5Np, 42.5Ns and 42.5Rx individually. Specifically, the objectives are to:

i. Determine the specific chemical and metallic composition properties of the three Portland cement as well as a laterite soil individually in the laboratory; Determine the 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 selected disturbed natural soil sample in the laboratory;
ii. Determine moisture-density relationship, California Bearing Ratio (CBR), unconfined compressive strength (UCS) and permeability characteristics of the laterite soil sample when stabilized with three different types of Portland cements tagged 42.5Np, 42.5Ns and 42.5Rx individually at percentages of 2%, 4% , 6%, 8%, 10%, 12% and 14% in proportion by weight in the laboratory; and
iii. Compare and contrast at optimum of the results of moisture-density relationship, California Bearing Ratio (CBR), unconfined compressive strength and permeability of the soil sample as evaluated in the laboratory by using Portland cements tagged 42.5Np, 42.5Ns and 42.5Rx as stabilizer individually in accordance to standard specification requirements for highway subbase and base.

The main scope of work in this study is the laboratory experiments on laterite soil sample from a borrow pit at Abule-Ijoko in Ogun State of Nigeria and using the three different types of cements individually to stabilize it. Also, classification of the soil stabilized at the natural state according to both America Association of State Highway and Transportation Officials AASHTO, and Unified System standard specifications. More so, the determination of the percentages at which each stabilized soil will attain the strength and durability at a standard specified level for highway pavement subbase and base. This study therefore also proffered information while using each of the selected three different types of Portland cement individually as stabilizer on the chosen soil in the production of highway pavement subbase and base.

2. MATERIALS AND METHODS

The disturbed laterite soil sample used in this research work was collected from Abule-Ijoko borrow pit in Ogun State of Nigeria for the purpose of stabilizing it with three different types of grade 42.5 Portland cement independently. The three different types of Portland cement are tagged for the purpose of this research 42.5Np, 42.5Ns and 42.5Rx. The cements were bought in bags of 50 kg each and tested in the laboratory in accordance to AASHTO T 85 [6]. Water in the laboratory of the department of Civil and Environmental Engineering found drinkable, free from oil, acid and alkali was used for the stabilization of the laterite soil.

The laterite soil sample used was air dried in the laboratory and the cement in pack were free from moisture before they were subjected to engineering properties tests and classification for highway purposes. Some specific chemical, metallic, and compound parameters of the three brands of cements and the dried laterite soil used 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 on the soil sample in accordance to AASHTO T 88 [7]. The liquid limit test on the soil sample was performed according to AASHTO T 89 [8] while AASHTO T 90 [9] standard methodologies were employed upon same to determine plasticity limit and plasticity index values. The soil sample relative density test was conducted according to AASHTO T 100 [10]. Also, the determination of group index of the soil sample was carried out according to AASHTO M 145 [11].

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The moisture-density relationship of the soil sample at the natural state and when stabilized with cement was conducted according to AASHTO T 99 [12]. Stabilization of the laterite soil sample was also carried out based upon optimum moisture content values and cement at percentages of 2%, 4%, 6%, 8%, 10%, 12% and 14%. At natural state and for the cement stabilized soil specimen 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 upon natural and when stabilized was carried out in accordance to AASHTO T 193 [13]. Also, each specimen of the natural and when stabilized with cement unconfined compressive strength (UCS) test was determined according to AASHTO T 208 [14]. The permeability of each test upon natural and stabilized was carried out with reference to ASTM D7664 [15].

3. ANALYSIS OF RESULTS AND DISCUSSIONS

The results and discussions of laboratory tests conducted in this study using the three different types of Portland cement that are tagged 42.5Np, 42.5Ns and 42.5Rx individually whilst stabilizing the soil A-6(11) are presented. The purpose is for the possible production of subbase and or base course for highway pavement upon improving the strength of the soil. It also includes defining the optimum suitable stabilizing material among the three Portland cements used. The results of the soil sample tests at natural state included Atterberg limits, wet grain sieve analysis and their classifications. Also presented are the results of the tests upon the natural soil specimen and as at when stabilized with cements tagged 42.5Np 42.5Ns and 42.5Rx individually which included moisture-density relationship, California Bearing Ratio, unconfined compression and permeability. Tables and graphs are used in presenting the results of the analysis of the three different types of cement samples, the natural soil in its disturbed state and when stabilized with same cements individually. Discussions of the natural and stabilized soils by laboratory experiments are compared with relevant standard specification requirements for the optimization of subbase and base for highway pavement design and construction.

3.1. Properties of the Portland cements tagged 42.5Np 42.5Ns and 42.5Rx defined

Considering Table 1, the percentages of chemical composition of Portland cements tagged 42.5Np, 42.5Ns and 42.5Rx values for calcium oxide and silicon dioxide both complied with the standard specification favourably. Also, the values of aluminium oxide in cement 42.5Np and 42.5Rx complied with the standard specification favourably but Portland cement 42.5Ns does not conform. Also, the ratio of CaO to SiO_2 that is not less than 2 makes the three Portland cements suitable for use as a binder in the stabilization process. While the amount of Al_2O_3 present in 42.5Np and 42.5Rx complied with the standard specification but same for 42.5Ns did not comply. The implication is that Al_2O_3 present in 42.5Np or 42.5Rx Portland cement with higher value will act faster at gaining strength than that in 42.5Ns. The amount of SO_3 present in each of 42.5Np, 42.5Ns and42.5Rx is less than the standard requirement for Portland cement hence this is showing the possibly that its purpose as a retarder has to be adequately monitored. The amount of MgO and Na_2O in the two cements complied with the standard specification thereby ensuring normal hydration and this prevents the cause of alkali reaction in the stabilized soil. The specific gravities of the cements 42.5Np 42.5Ns and 42.5Rx are 3.15, 3.15, 3.15 respectively.

Table 2 is showing that the values of tricalcium silicate and dicalcium silicate of 42.5Np Portland cement are within the standard specification requirements. On the other hand, tricalcium silicate value of 42.5Ns and 42.5Rx Portland cement is higher while dicalcium silicate is lower than the standard specification requirements. The values of tricalcium aluminate C_3A of the three cements are within the standard specification requirements. On the other hand, the values of tetracalcium aluminoferrite C_4AF of the three cements are lower than the minimum standard specification requirements.

3.2. Properties and classification of the soil sample defined for highway purposes

The results of the properties and classification of the soil sample experimented upon in its disturbed natural states are defined in Table 3 and Figure 1. It could be seen in Table 3 that more than 50% of the soil sample passed through the 0.075 sieve. Considering the soil sample description, it is silt-clay material based upon AASHTO soil Classification while by the Unified Systems, it is a fine-grained soil. Further classification method were also based upon liquid limit, plastic limit, plasticity index, percent passing sieves 4.750 mm, 2.000 m, 0.425 mm and 0.075 mm together with the soil group index and symbol. However, by AASHTO soil classification system, the sample is by group symbol A-6(11) and described as plastic clayey soil. Also, by Unified Systems soil classification the sample is by group symbol CL and described as clay of low plasticity.

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Table 1: Typical Constituents of the three Portland cements examined

S/N	Portland Cement Chemical Composition	Cement Chemists Notation, (CCN)	42.5Np Chemical composition %	42.5Ns Chemical composition %	42.5Nx Chemical composition %	Standard Min-Max %	Remarks
1	Calcium oxide, CaO	C	63.82	63.74	64.25	60.6-66.3	All the cements complied.
2	Silicon dioxide, SiO_2	S	21.22	20.35	19.16	18.7-22.0	All the cements complied.
3	Aluminium oxide, Al_2O_3	A	6.08	4.48	4.92	4.7-6.3	42.5Np and 42.5Nx complied, 42.5Ns does not comply.
4	Ferric oxide, Fe_2O_3	F	1.24	0.91	0.75	1.6-4.4	All the cements do not comply.
5	Sulphate, SO_3	$\bar{S}$	1.23	1.14	1.02	1.8-4.6	All the cements do not comply.
6	Magnesium Oxide MgO	M	2.75	2.04	2.17	0.7-4.2	All the cements comply.
7	Sodium Oxide Na_2O	S	0.5	0.64	0.40	0.11-1.2	All the cements comply.
8	Lime Saturation Factor	LSF	0.399	0.768	0.578	0.85-0.95	All the cements do not comply.
9	Insoluble Residue	IR	0.94	0.62	0.44	3-5	All the cements do not comply.

Table 2: Compound composition of the three Portland cements examined

S/N	Portland Cement Compound Composition	42.5Np Compound Composition %	42.5Ns Compound Composition %	42.5Nx Compound Composition %	Standard Min-Max %	Remarks by Portland Cement Type I
1	Tricalcium silicate C_3S	44.82	70.11	78.83	40-63	42.5Np complied, but 42.5Ns and 42.5Rxdo not comply.
2	Dicalcium silicate C_2S	29.95	5.54	4.45	9-31	42.5Np complied, but 42.5Ns and 42.5Rx do not comply.
3	Tricalcium aluminate C_3A	14.00	10.33	11.77	6-14	All the cements complied.
4	Tetracalcium aluminoferrite C_4AF	3.77	2.77	2.28	5-13	All the cements do not comply.

Table 3: Properties and classification of the laterite soil sample examined

S/N	Properties	A-6(11)	S/N	Properties	A-6(11)
1	Moisture Content (%)	18.027	11	Percent Passing 0.075 mm	56
2	Bulk Density (Mg/m³)	1.972	12	Percent Passing 0.425 mm	71
3	Dry Density (Mg/ m³)	1.671	13	Percent Passing 2.000 mm	98.00
4	Specific Gravity (Gs)	2.800	14	Percent Passing 4.750 mm	100
5	Void Ratio e	0.676	15	Group Index	11
6	Porosity n, %	0.403	16	AASHTO Soil Group Symbol	A-6(11)
7	Degree of Saturation Sr, %	0.995	17	AASHTO Soil Description	Plastic Clayey Soil
8	Liquid Limit (PL)	40	18	Unified System Soil Group Symbol	CL
9	Plastic Limit (LL)	20	19	Unified System Soil Description	Clay of Low Plasticity
10	Plasticity Index (PI)	20			

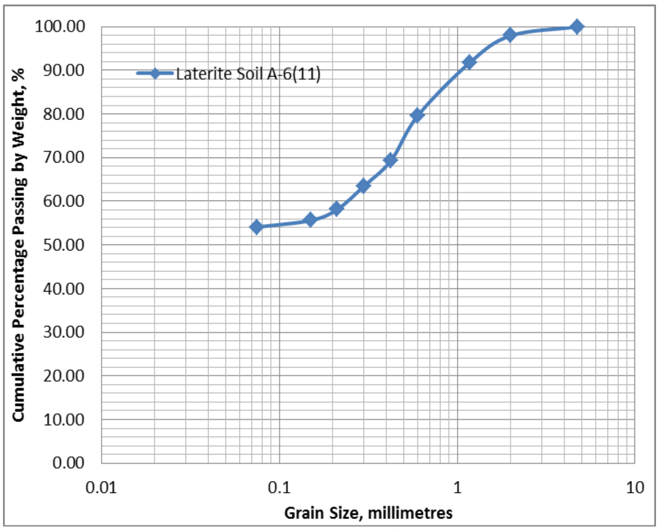

Figure 1: Grain-size distribution curve of the soil material examined

3.3. Material compositions of the three Portland cements and the laterite soil defined

Table 4 is showing the results in percentages of the chemical composition of the three Portland cement tagged 42.5Np, 42.5Ns and 42.5Rx together with A-6(11) plastic clayey soil. While the values of SiO_2 for the three Portland cements in percentages are comparable the value of same for the laterite soil is dissimilar. Although the values of Na_2O, K_2O and $Ca(OH)_2$ are less than 1% and are similar for the three Portland cements, yet they are incomparable and greater than those obtained for the laterite soil. CaO is having the largest percentage value of the chemical composition for each of the three Portland cement but for the soil its amount is nearly of zero percentage. While MgO, Fe_2O_3 and SO_3 have somewhat lower values in the three Portland cements yet they are somewhat far bigger in comparison to same in the laterite soil. The value of Al_2O_3 in the soil is of the second largest chemical composition and is averagely six times greater than each of same in each of the three Portland cements. The values of BaO, PbO and MnO in the three Portland cements ranged from 0% to 0.002% while same for soil range from 0.02% to 0.3%.

As shown in Table 5 it could be seen that the metallic components Cd, Cu, Mn, Ni, Pb, Fe and Zn values in mg/kg for the three types of cement and soil are found to be 0% or less than 0.51%. It is pertinent to note that the values of Al for all the cements and soil are comparable but it only similarly for Cl present in the cements and not so for the soil sample. Also, sulphate values for the cements are comparable but greater than that of the soil sample. The organic carbon percent value is similar in the three cements but greater than that of the soil. Loss of ignition values for the three cements and for the soil is similar and this is also alike for insoluble residue values of same. The pH value for each the three cements and soil is of alkalinity. Insoluble residue values for the three cements and the soil sample are of comparable values. The conductivity of the three types of cement and the soil sample is of dissimilar values. Fibre is not present in any of the three types of cement and the soil sample.

3.4. Moisture-Density relationships of the natural and cement stabilized A-6(11) laterite soil for highway purposes defined

Figure 2 is showing specifically the graphical representation of results for the optimum moisture content OMC and cement percentages of the A-6(11) laterite soil and when stabilized with the three types of cements individually. It is obviously seen in the graph that the optimum moisture content value obtained for the stabilized soil A-6(11) is reducing gradually from the natural state as the stabilization cement percentage is increasing at interval 2% through 14% for each of the individual three types of cement 42.5Np, 42.5Ns and 42.5Rx. Also, Figure 3 is showing specifically the graphical representation of results for the maximum dry density MDD and cement percentages of the A-6(11) laterite soil and when stabilized with three types of cements individually. It is obviously seen in the graph that the MDD value obtained for the stabilized soil A-6(11) is increasing gradually from that of the natural state as the stabilization cement percentage is increasing at interval 2% through 14% for each of the individual three types of cement 42.5Np, 42.5Ns and 42.5Rx. The line graph of cement stabilized soil for each optimum moisture content by cement percentages of the A-6(11) laterite soil decreased similarly. Also the line graph of cement stabilized soil for each maximum dry density by cement percentages of the A-6(11) laterite soil increased similarly.

3.5. Unsoaked and soaked CBR relationships of the natural and cement stabilized A-6(11) laterite soil for highway purposes defined

Figure 4 and Figure 5 are respectively showing graphically the results of the unsoaked and soaked California Bearing Ratio CBR values of the A-6(11) laterite soil at natural and when stabilized individually with the three types of cement samples used in this research work. It is obviously seen in the figures that the unsoaked and soaked CBR values obtained for soil A-6(11) at natural state as well as when stabilized individually are increasing at the interval corresponding to 2% through 14% for each of the three types of the cements used which are 42.5Np, 42.5Ns and 42.5Rx. It is pertinent to note that the unsoaked and soaked CBR values of soil A-6(11) stabilized with cement tagged 42.5Np is having the highest values while considering the three line graphs followed by specimen worked with cements 42.5Ns and 42.5Rx respectively.

Table 6 is showing percentages at which satisfactory CBR values were attained when soil was improved through laboratory stabilization using the three types of Portland cements individually. Under the unsoaked condition, the three types of cements adequately attained 80% CBR value as subbase at 6% cement content. However, it is cement tagged 42.5Np that satisfactorily attained 180% CBR value as base at 12% of same whilst both 42.5Ns and 42.5Nx attained it at 14% of cement contents in the unsoaked CBR condition. The cement tagged 42.5Np satisfactorily attained 80% CBR value as base at 2% of cement content of stabilization while both 42.5Ns and 42.5Nx attained same at 4% of cement contents in the soaked CBR condition. Also, in the soaked condition, the three types of cements adequately attained 180% CBR value as base at 12% cement content that can be expensive.

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Table 4: Chemical compositions of the three Portland cements and the laterite soil defined

S/N	PARAMETER (%)	42.5Np Portland Cement	42.5Ns Portland Cement	42.5Rx Portland Cement	A-6(11) Laterite Soil
1	Silicon Dioxide, SiO_2	22.210	20.350	19.16	44.240
2	Sodium oxide, Na_2O	0.500	0.640	0.40	0.046
3	Potassium Oxide, K_2O	0.300	0.390	0.35	0.042
4	Calcium oxide, CaO	63.820	63.740	64.25	0.030
5	Magnesium oxide, MgO	2.750	2.040	2.17	0.020
6	Barium Oxide, BaO	0.002	0.001	0.00	0.020
7	Lead oxide, PbO	0.000	0.000	0.00	0.310
8	MnO	0.000	0.000	0.00	0.007
9	Al_2O_3	6.080	4.480	4.92	30.350
10	Fe_2O_3	1.240	1.010	0.75	0.054
11	SO_3	1.230	1.140	1.02	0.003
12	$Ca(OH)_2$	0.270	0.500	0.41	0.110

Table 5: Metallic and other components of the three Portland cements and the laterite soil defined

S/N	PARAMETER	42.5Np Portland Cement	42.5Ns Portland Cement	42.5Rx Portland Cement	A-6(11) Laterite Soil
1	Cadmium, Cd (mg/kg)	0.000	0.000	0.000	0.000
2	Copper , Cu(mg/kg)	0.001	0.000	0.002	0.000
3	Manganese, Mn (mg/kg)	0.002	0.140	0.005	0.000
4	Nickel, Ni (mg/kg)	0.000	0.020	0.000	0.000
5	Lead, Pb (mg/kg)	0.000	0.000	0.000	0.000
6	Iron, Fe (mg/kg)	0.012	0.508	0.036	0.038
7	Zinc, Zn (mg/kg)	0.000	0.020	0.003	0.12
8	Aluminium, Al (mg/kg)	17.060	12.09	17.95	16.07
9	Chloride, Cl (mg/kg)	640.000	720.00	700.00	225.000
14	Sulphate, SO_4^{2-} (mg/kg)	4.700	4.060	4.500	1.500
10	Organic Carbon (%)	0.700	0.720	0.840	0.180
11	LOI (%)	0.003	0.007	0.005	0.006
12	Insoluble Residue, IR(%)	0.620	0.500	0.440	0.500
13	pH	12.100	12.300	12.300	8.879
14	Conductivity μScm^{-1}	640.00	460.000	250.00	0.000
15	Fibre	0.000	0.000	0.000	0.000

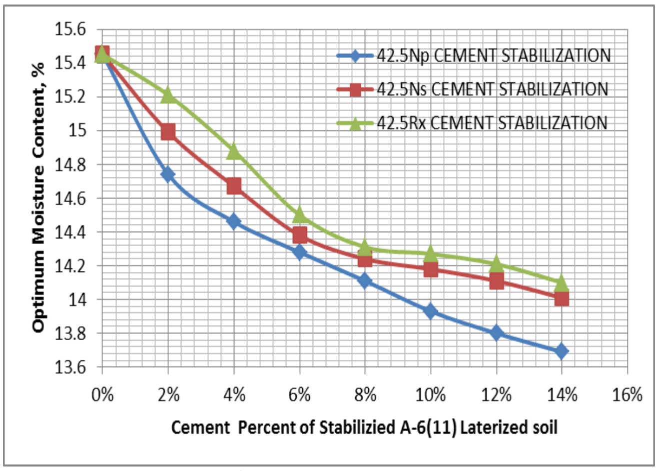

Figure 2: Curves of relationship between OMC and cement percent increase of the stabilized soils individually

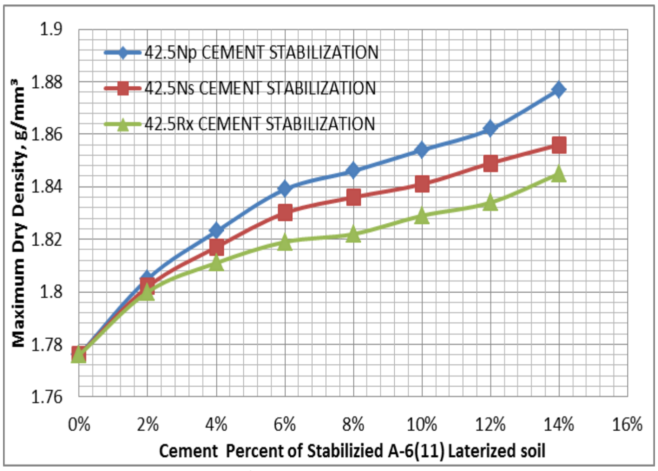

Figure 3: Curves of relationship between MDD and cement percent increase of the stabilized soils individually

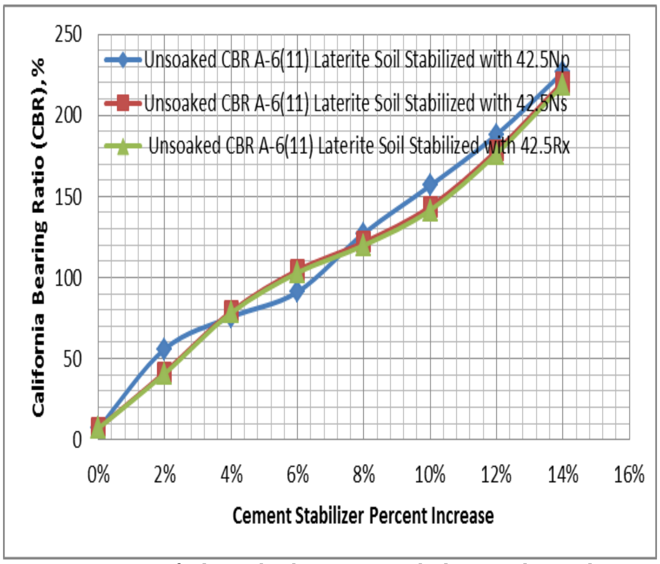

Figure 4: Curves of relationship between unsoaked CBR values and cement percent increase of the stabilized laterite soils individually

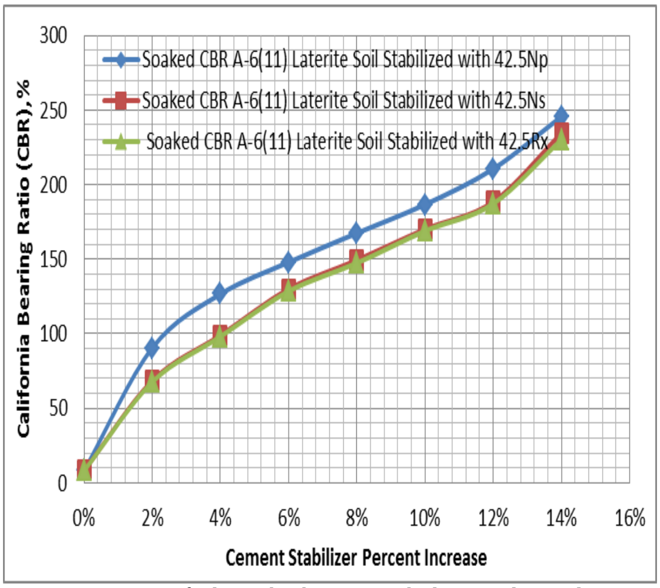

Figure 5: Curves of relationship between soaked CBR values and cement percent increase of the stabilized soils individually

Table 6: Highway subbase and base satisfactory level of unsoaked and soaked CBR value attained by the individual stabilized cement soil employing the three types of cements.

	Unsoaked CBR		Soaked CBR	
	Percentage at which A-6(11) Laterite Soil stabilized with Portland cement attained 80% CBR value as subbase	Percentage at which A-6(11) Laterite Soil stabilized with Portland cement attained 180% CBR value as base	Percentage at which A-6(11) Laterite Soil stabilized with Portland cement attained 80% CBR value as subbase	Percentage at which A-6(11) Laterite Soil stabilized with Portland cement attained 180% CBR value as base
Portland Cement 42.5Np	6%	12%	2%	12%
Portland Cement 42.5Ns	6%	14%	4%	12%
Portland Cement 42.5Rx	6%	14%	4%	12%

3.6. Uncured and cure UCS relationships of the natural and cement stabilized A-6(11) laterite soil for highway purposes

Figure 6 and Figure 7 present respectively the uncured and cured unconfined compressive strength UCS curves of the natural soil A-6(11) and when stabilized with three types of Portland cements tagged 42.5Np, 42.5Ns and 42.5Rx individually. The stabilization of the soil A-6(11) sample was done with the three types of Portland cement individually from 2% to 14% at interval of 2% of cement content. As vividly seen in the two figures, each line graph is representing the A-6(11) soil sample being stabilized with a Portland cement and they behave similarly but with different rate of strength development. While considering Figure 6 the line graphs for soil A-6(11) when stabilized with Portland cements tagged 42.5Np, 42.5Ns and 42.5Rx individually are of gradient of higher rate from 0% cement stabilization to 2% of same than from 2% to 14%. Whereas while considering Figure 7 the line graphs for soil A-6(11) when stabilized with Portland cements tagged 42.5Np, 42.5Ns and 42.5Rx individually are of gradient of higher rate from 0% cement stabilization to 6% of same than from 6% to 14%. Since the UCS values for cured samples are higher than those of the uncured samples respectively at 2% and 6%, the use of cured UCS graphs are to be appropriately adopted for highway pavement design.

Table 7 is showing explicitly the results for the cured unconfined compression strength of the soil A-6(11) when stabilized with the Portland cement tagged in this research work as 42.5Np, 42.5Ns and 42.5Rx. The minimum UCS value standard required for highway pavement subbase is 750 kN/m^2 and the all three types of cement used adequately satisfied same at 2% cement content of stabilization. Also, at individual 4% cement content stabilization with the soil A-6(11), UCS value of 1500 kN/m^2 was attained that is suitable for maximum standard requirement for highway pavement subbase and minimum standard value requirement for highway pavement base. As in Table 7, only the Portland cement tagged 42.5Np attained maximum standard value requirement of 3000 kN/m^2 for highway pavement base out of the three types of cements used although it is of high value. Based upon the developmental strength trend as exhibited in Figure 7, the cement content in percentage that gives 2500 kN/m^2 would be advantageously necessary for use as highway pavement base. This is exhibited in Table 8 of which Portland cement tagged 42.5Np successfully satisfied highway pavement base design value of 2500 kN/m^2 at 6%

cement content but 42.5Ns and 42.5Rx satisfied same at 8% cement content of the stabilized A-6(11) laterite soil.

3.7. Individual permeability value of the stabilized A-6(11) laterite soil for highway purposes defined

Figure 8 is depicting the comparison of the permeability results of the A-6(11) laterite soil sample at natural state as well as at when the soil samples were stabilized by 42.5Np, 42.5Ns and 42.5Rx Portland cement individually. The A-6(11) laterite soil was individually stabilized with the three cements individually at an interval variation of 2% increment up to 14%. Each stabilized A-6(11) laterite soil for the permeability tests of the three types of cements 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% at which they all have similar permeability values.

Table 10 is showing critically the results of the permeability tests of A-6(11) laterite soil sample when compacted at its natural state as well as at when its samples were stabilized individually by 42.5Np, 42.5Ns and 42.5Rx Portland cement at interval of 2% and up to 8% upon optimal economy of pavement development. It is shown in the table that the permeability values at 0%, 2% and 4% of cement content stabilization of the soil sample individually are the same. On the other hand, it could be seen that the permeability values of 6% and 8% cement content stabilization of the soil sample individually that are also the same.

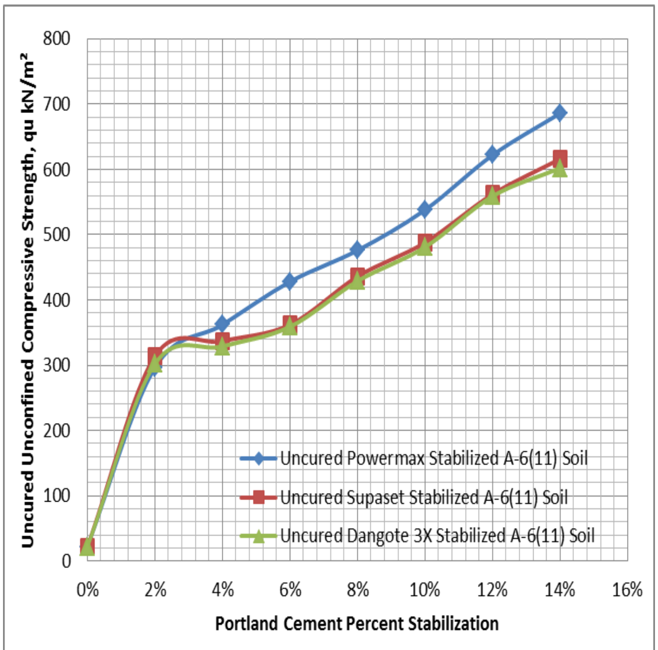

Figure 6: Curves of relationship between uncured UCS values and cement percent increase of the stabilized laterite soils individually

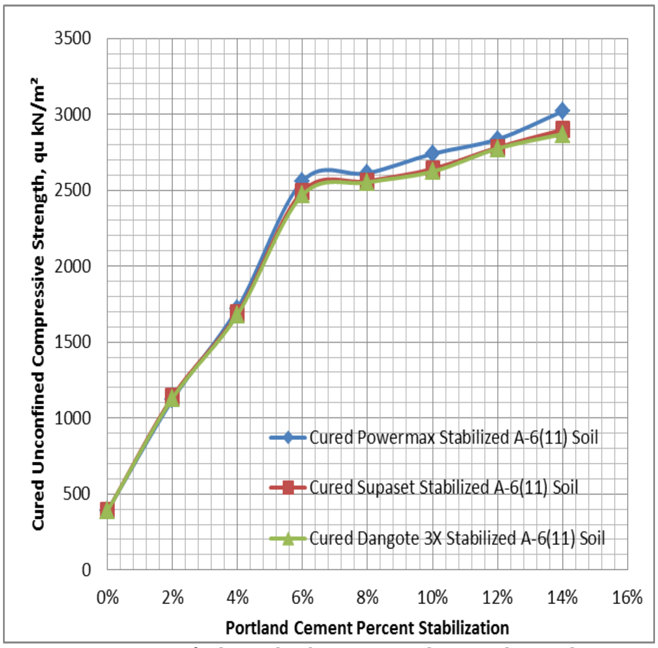

Figure 7: Curves of relationship between cured UCS values and cement percent increase of the stabilized laterite soil individually

Table 7: Highway subbase and basecourse satisfactory level of UCS in percentage value attained by the individual cement stabilized A-6(11) laterite soil

LABEL	Percentage at which A-6(11) Laterite Soil Stabilized with Portland Cement at 7 Day Cured UCS			
	Considering 750 kN/m ^{2} minimum standard value requirement for highway pavement subbase	Considering 1500 kN/m ^{2} maximum standard value requirement for highway pavement subbase	Considering 1500 kN/m ^{2} minimum standard value requirement for highway pavement base	Considering 3000 kN/m ^{2} maximum standard value requirement for highway pavement base
Portland Cement 42.5Np	2%	4%	4%	14%
Portland Cement 42.5Ns	2%	4%	4%	Not attainable
Portland Cement 42.5Rx	2%	4%	4%	Not attainable

Table 8: Design values considered for highway subbase and basecourse at satisfactory level of UCS in percentage value attained by the individual cement stabilized A-6(11) laterite soil

	Cement Percent of Stabilization at attainment	A-6(11) Laterite Soil Stabilized with 42.5Np Cured UCS Values selected kN/m ^{2}	A-6(11) Laterite Soil Stabilized with 42.5Ns Cured UCS Values selected kN/m ^{2}	A-6(11) Laterite Soil Stabilized with 42.5Rx Cured UCS Values selected kN/m ^{2}
Minimum Standard value for Subbase (750 kN/m ^{2})	2%	1120	1140	1130
Maximum Standard value for Subbase and minimum value for base (1500 kN/m ^{2})	4%	1722	1690	1680
Maximum design value for base considered at 2500 kN/m ^{2}	6%	2560	2492	2469
	8%	2612	2560	2552

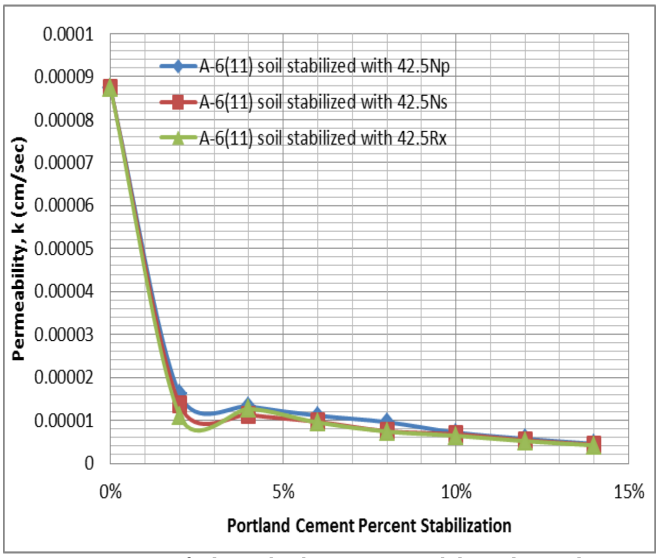

Figure 8: Curves of relationship between permeability values and cement percent increase of the stabilized soil individually

Table 9: Permeability values and cement percent increase of the stabilized soil individually optimally

Cement Percent	A-6(11) soil stabilized with 42.5Np, k (cm/sec)	A-6(11) soil stabilized with 42.5Ns, k (cm/sec)	A-6(11) soil stabilized with 42.5Rx, k (cm/sec)
0%	10^{-5}	10^{-5}	10^{-5}
2%	10^{-5}	10^{-5}	10^{-5}
4%	10^{-5}	10^{-5}	10^{-5}
6%	10^{-6}	10^{-6}	10^{-6}
8%	10^{-6}	10^{-6}	10^{-6}

4. CONCLUSIONS AND RECOMMENDATIONS

Laterite soil sample at natural state experimented upon has been characterized and as well as classified according to AASHTO and Unified System classification systems as A-6(11) clayey soil and CL low plasticity clay soil respectively. Three different types of Portland cement tagged 42.5Np, 42.5Ns and 42.5Rx for the purpose of this research have been used individually to stabilize the soil sample while creating subbase or base for highway pavement.

4.1. Conclusions

The followings conclusions are considered in the course of the laboratory experiments and results of the natural soil stabilized individually with the three different types of Portland cement tagged 42.5Np, 42.5Ns and 42.5Rx.

i. Considering the chemical composition of the three types of Portland cement used tagged 42.5Np and 42.5Rx complied with ASTM C 150, AASHTO M 85 and British relevant standard specification than that of 42.5Ns.

ii. Also, considering the potential compound composition of the three types of cement used, Portland cement tagged 42.5Np complied with ASTM C 150, AASHTO M 85 and British relevant standard specification than those marked 42.5Ns and 42.5Rx.

iii. More than 56% of the A-6(11) clayey soil experimented upon passed through the 0.075mm sieve and the plasticity index PI of same is 20 whilst usually considered not suitable for stabilization process. However, its stabilization using selected three types of Portland cement separately has been made possible at low value of cement content upon the use of the three types of newly Nigerian produced cements.

iv. The soaked and unsoaked CBR values of the A-6(11) clayey soil are 16% and 54% respectively. The soaked CBR value of 16% is an indication that the soil could not be suitable for highway subbase purpose. Hence, the soil was subjected to cement stabilization using Portland cement tagged 42.5Np, 42.5Np and 42.5Rx.

v. The values of the soaked CBR results proclaimed usefulness of the A-6(11) clayey soil highway pavement when stabilized individually with cements tagged 42.5Np, 42.5Ns and 42.5Rx. In the process of the cement stabilization, using the three types of cement individually, CBR minimum standard value of 80% was attained for subbase at 2% cement content of 42.5Np but it was at 4% while using 42.5Np and 42.5Rx cements. Also, at 4% cement content of stabilization cement tagged 42.5Np made CBR value of 100% of the soil stabilization, whereas it was at 6%

cement content that 42.5Ns and 42.5Rx could achieve same.

vi. The values of the cured UCS results proclaimed usefulness of the A-6(11) clayey soil when stabilized individually with cements tagged 42.5Np, 42.5Ns and 42.5Rx. In the process of the cement stabilization, using the three types of cement individually, UCS minimum standard value of 750 kN/m ^{2} was attained for subbase at 2% cement content.

vii. Also, UCS maximum standard value for subbase and minimum standard value for base that is 1500 kN/m ^{2} was reached at 4% cement content. While, maximum design value for base considered at UCS value of 2500 kN/m ^{2} was attained at 6% cement content for 42.5Np whereas it was at 8% cement content for 42.5Ns and 42.5Rx to attain it.

viii. Remarkably, the soil experimented that is grouped as A-6(11) clayey soil has permeability values of k at natural state and at 2% cement content stabilization as 10^{-5} and has 10^{-6} for each of the 6% and 8% cement stabilization.

4.2. Recommendations

The followings are the recommendations proffered in the course of the laboratory experiments upon stabilizing A-6(11) clayey soil with cements tagged 42.5Np, 42.5Ns and 42.5Rx individually for the purpose of optimization of stabilized subbase and base for highway pavement.

i. As exhibited in this research the three newly produced cements tagged 42.5Np, 42.5Ns and 42.5Rx in Nigeria have potential to stabilize certain clayey soils such as A-6(11) clayey soil of which when used at 2% to 4% cement content it adequately satisfied subbase for highway pavement.

ii. It is also advisable not to exceed using 6% cement content while stabilizing A-6(11) clayey soil for road base as exhibited in Figure 7 while using independently the three types of Portland cement produced in Nigeria as used in this research work.

iii. Endorsement at 6% cement content stabilization of soil A-6(11) clayey soil individually, using 42.5Np has the highest value of UCS of 2560 kN/m ^{2} and it is the most preferable followed by 42.5Ns of 2492 kN/m ^{2} and lastly by 42.5Rx of 2469 kN/m ^{2} .

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