International Journal of Scientific & Engineering Research, Volume 5, Issue 12, December-2014
ISSN 2229-5518

Strength and Permeability Characteristics of Selected Laterite Stabilized Using Powermax Cement

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ABSTRACT

Laterite soil samples classified as A-2-6(1), A-6(5) and A-6(12) by grouping according to AASHTO that are considered not suitable for use as pavement base course were stabilized using a new brand of Portland cement called Powermax. In this research, Powermax cement was mixed with the lateritic soils respectively at varying proportion by weight of 6%, 8% and 10% whilst their respective Unconfined Compressive Strength (UCS), Coefficient of Permeability k, Optimum Moisture Content (OMC), Maximum Dry Density (MDD) and California Bearing Ratio (CBR) were evaluated in the laboratory. The results of the unconfined compressive tests show that the value of compressive stress of the stabilized lateritic soil materials increases as Powermax cement proportion increases from 6% through 8% to 10% for both uncured and cured specimens of A-2-6(1), A-6(5) and A-6(12) soil samples. Also, the value of k of the stabilized lateritic soil-cement mixture moved from good state of 10^{-6} mm/sec at 6% to poor state of 10^{-7} at 8% and 10%. At 10 % stabilized lateritic soil-cement mixture considered optimum, the OMC values are 15.8%, 15.5% and 15% whilst the respective MDD are 1912 kg/m³, 1864 kg/m³ and 1831 kg/m³ for the corresponding soil group of A-2-6(1), A-6(5) and A-6(12). Also, the values of the unsoaked CBR for the aforementioned soil groups at optimum are 133%, 100.75% and 90.75% respectively while values of the soaked CBR are 199.25%, 165.5% and 131.25% respectively for 10% stabilized lateritic soil-cement mixture. It is significant from the results that when Powermax cement is used to stabilize the three lateritic soil samples, their strengths increased in the multiple of 16, 12 and 10 respectively when compared to the CBR of the natural soil while the coefficient of permeability has decreased from 10^{-5} mm/sec to 10^{-7} mm/sec.

KEYWORDS: Density, Design, Moisture, Optimum, Soaked, Unsoaked

1. INTRODUCTION

Lateritic soil in its natural state is not always suitable as base course for highway pavement design. However, its stabilization can bring improvement of the shear and compressive strengths while also reducing coefficient of permeability values. Stabilization of soil is one of the most reliable and practical ways to economically increase its strength, reducing permeability, as well as to limit water absorption, control soil erosion and settlement in order to meet related engineering design standards and to be suitable for pavement construction (Salahudeen and Akiije, 2014), (Aminaton, et al., 2013) and (Eisazadeh, et al., 2013). Permeability is a measure of the ease with which fluids especially water, oil and gas flow through a porous material; oftentimes a rock or unconsolidated material.

According to Chambers (2007), erosion is the removal of the land surface or pavement material by weathering, corrasion, corrosion, and transportation under the influence of gravity, wind or running water. Weathering is a process of disintegration and decomposition in rock minerals as a consequence of exposure to the atmosphere and to the action of frost, rain and isolation. Corrasion is erosion by the work of vertical or lateral cutting performed by a river by virtue of the abrasive power of its load. Corrosion is erosion by chemical process. Seepage is the process by which a liquid leaks through a porous substance. Settlement is the subsidence of highway pavement due to consolidation of the foundation soil.

Garber (2010) claimed that soil stabilization is the treatment of natural soil to improve its engineering properties either by mechanical or chemical methods. Mechanical stabilization is the blending of different grades of soils to obtain a required grade while chemical stabilization is the blending of the natural soil with chemical agents. Portland cement, asphalt binders, and lime are the most commonly used binding agents. Binder is a component employed in the mix of carbon products, organic brake linings, sintered metals, tar macadam to impact cohesion to the body to be formed.

According to Wright and Dickson (2004), Portland cement is the usual binder for concrete and it is named for its resemblance when set to Portland stone haven been invented by Joseph Aspdin in 1828. Asphalt is one of the various bituminous substances which may be: (i) of natural occurrence in oil-bearing strata from which the volatiles have evaporated; (ii) a residue in petroleum distillation; (iii) a mixture of asphalt bitumen, granite chippings and sand or powdered limestone. Lime is a substance produced by heating limestone to 825°C or more, as a result of which the carbonic acid and moisture are driven off.

Also, according to Wright and Dixon (2004), soil stabilization type that is popularly increasing in recent years involves the incorporation of Portland cement in amounts that generally varieties from 7 to 14 percent by volume of the compacted mixture with naturally occurring or artificially created soils or soil-aggregate mixtures. Liu et al. (2011) claimed that traditional stabilizers such as Portland cement and lime are more common in use compared to non-traditional stabilizers such as enzymes, liquid polymers, resins, acids, silicates, and lignin by-products. According to Latifi et al. (2013), the liquid TX-85 and the powder SH-85 are chemical additive non-traditional stabilizers.

ASTM C150 (2012), specified eight types of Portland cement: type I, type IA, type II, type IIA, type III, type IIIA, type IV, and type V. All the eight types of Portland cement have the following chemical composition: aluminium oxide, ferric oxide, magnesium oxide, sulphur trioxide, tricalcium silicate, dicalcium silicate, tricalcium aluminate, and tetracalcium aluminoferrite. Wright and Dickson (2004) claimed that types I, II and III, are frequently in use for highway pavement construction.

The aim of this research therefore is to consider strength and permeability characteristics of three selected laterite soil samples classified as A-2-6(1), A-6(5) and A-6(12) by grouping according to AASHTO M 145 (2012) when stabilized. For the materials are considered not suitable for use at the natural state as pavement base course according to Akiije (2014). Specifically, the objectives include the followings.

1. To carry out laboratory experiments using Powermax cement as stabilizer upon the three selected laterite soil samples classified as A-2-6(1), A-6(5) and A-6(12).
2. To stabilize the three laterite soil samples involving the addition of 6%, 8% and 10% of Powermax cement in proportion by weight respectively.
3. To obtain the required engineering properties of the three lateritic soil samples while determining their suitability for use as pavement base course.
4. To compare and contrast at optimum of the results of unconfined compressive strength, permeability, moisture-density relationship and California Bearing Ratio (CBR) of the three lateritic soil samples as evaluated in the laboratory by using Powermax cement as stabilizer.

Significantly, to consider the effect of Powermax cement that is new in the market as a stabilizing soils material. Considerably, to evaluate the strength induced and permeability reduction proffered by Powermax cement upon the selected lateritic soil samples. Thereby depicting a model portraying the withstanding strength and state of permeability expected of the selected lateritic soils when used as pavement base course at optimum design traffic load.

2. MATERIALS AND METHODOLOGY

Powermax used in this study as lateritic soil stabilizer is a standard or normal Portland cement termed type I intended for use in general concrete construction. The cement was produced at a cement factory owned by Lafarge Cement WAPCO Nigeria PLC in Ewekoro, Ogun State of Nigeria. Lafarge (2012) claimed that Powermax cement could be purchased in 30 tons bulk tanker, 2 tons jumbo bag and 50 kg bag. The 50 kg bag pack was used in this study. The disturbed laterite soil samples at three locations used in this investigation have being classified in groups according to AASHTO M 145 (2012) as A-2-6(1), A-6(5) and A-6(12). The three lateritic soil samples were collected respectively from three towns Papalanto, Ofada and Shagamu borrow pits in Ogun State of Nigeria. Their respective optimum moisture contents were 14.8%, 17%, and 17.8% while in soaked situation the CBR values were 19.3%, 13.45% and 5.8% according to (Akiije, 2014).

For this research, samples of soil-cement mixtures of A-2-6(1), A-6(5) and A-6(12) at cement contents by weight of soil of 6%, 8% and 10% for each soil group based upon soil-cement mixture limits of Table 1 as suggested by Garber and Hoel (2010). Goswami and Mahanta (2007) claimed that earlier laboratory investigations into laterite soils indicated that oven drying of same at natural state significantly changes their plasticity and compaction properties.

Table 1: Normal Range of Cement Requirements for Soils

S/No	AASHTO Soil Group	Cement (percentage by weight of soil)	Cement (kilograms per cubic meter of compacted soil cement)
1	A-2-6	5 - 9	110 - 140
2	A-6	9 - 15	140 - 210

Source: Garber and Hoel, 2010

In this study, the three laterite soil samples of which 100 percent of same passed the 4.75-mm (No. 4) sieve were air-dried and pulverized by being broken down until all materials passed through 2 mm sieve. In the laboratory tests, the Powermax was mixed with the lateritic soils to form laterite soil-cement mixture for the purpose of stabilization. Lateritic soil-cement mixture was respectively done at varying Powermax cement contents of 6%, 8% and 10% and their respective unconfined compressive strength, permeability, moisture-density relationship and California Bearing Ratio (CBR) were evaluated in the laboratory. In order to carry out each test, samples of materials already grouped as A-2-6(1), A-6(5) and A-6(12) were air-dried and pulverized with the required amount of water by initially increasing the optimum moisture content (OMC) of the natural soil by 2%.

Unconfined compressive strength, q_u of the stabilized cohesive soils with Powermax cement was determined out on each of the soil sample classified as A-2-6(1), A-6(5) and A-6(12) in accordance to ASTM D2166M (2013).

Three specimens of the stabilized laterite soil-cement mixture were prepared by extracting and trimming to100 mm length and 50 mm diameter from a sampling tube for each cement content of 6%, 8% and 10%.

For the original sample area A_0 with its total deformation at failure as ε, the final cross-sectional area of the sample A_f is defined in equation 1.

$$A_f = \frac{A_0}{1-\varepsilon} \tag{1}$$

The unconfined compressive strength, q_u for load at failure P_f is defined in equation 2.

$$q_u = \frac{P_f}{A_f} \tag{2}$$

The undrained shear strength c that is also considered as cohesion for each sample test was determined as half of the unconfined compressive strength at which the angle of shearing resistance was assumed zero is defined in equation 3.

$$c = \frac{1}{2} q_u \tag{3}$$

During each permeability test a stabilized laterite soil-cement mixture was contained in a cylinder mould between porous plates with length 12.3 cm and of area 0.283 cm^3. The coefficient of permeability k was calculated by the following equation.

$$k = \left[\frac{2.3aL}{A(t_1 - t_2)} \log \frac{H_1}{H_2} \right] \tag{4}$$

In the above equation, L is the sample length and A is the cross sectional area of the sample respectively. The cross sectional area of the burette is a, while H_1 and H_2 are the initial and final heights above the constant head chamber with their respective measured time as t_1 and t_2 respectively. Variable or falling head permeability test performed here was carried out according to ASTM D7664 (2010).

Compaction tests were performed in the laboratory on the three stabilized laterite soil-cement mixture sample by the standard Proctor test AASHTO T 99 (2010). The methodology involved using a mould with 102 mm diameter which has a volume of 944 cm^3, a hammer weighing 2.5 kg having a striking face of 51 mm in diameter and a 3000 kg of the lateritic dry soil sample that passes No.4 (4.75 mm) sieve. The stabilized laterite soil-cement mixture sample was mixed with water and placed in three layers of about equal thickness and each layer is subjected to 25 blows from the hammer by falling freely through a distance of 305 mm in the mould. The compacted sample with the mould was measured and after which part of it was taken about the centre to oven dry for the purpose of determining the water content. Repeated operation continued by addition of more water in sequence of increment of 2% until the density decreases.

The California Bearing Ratio tests were performed in the laboratory on the stabilized laterite soil-cement mixture sample by applying AASHTO T 193 (2000) methodology after the standard Proctor test. At optimum moisture content, each stabilized laterite soil-cement mixture sample was compacted in a mould of 152 mm diameter and 127 mm high and was put in place for four days with surcharge weight in place. Removing the sample from the water it was allowed to drain for a period of 15 min. The same surcharge was imposed on the sample and immediately subjected to penetration by forcing a 19.4 cm^2 plunger at the rate of 1.25 mm/min into the sample to a depth of 2.5 mm. The total loads corresponding to penetrations of 2.5, 5.0, 7.5, 10, and 12.5 cm were recorded.

3. RESULTS

Tables 2 and 3 show the results of unconfined compression tests of both uncured and cured lateritic soil samples classified as A-2-6(1), A-6(5) and A-6(12) when stabilized with Powermax cement at variations of 6%, 8% and 10% proportions. In the two tables, values of unconfined compression strength, strain, stress/strain relationship and shear strength are depicted. Figures 1 and 2 also show the results of unconfined compression tests of both uncured and cured lateritic soil samples stabilized with Powermax cement at optimum of 10%.

Powermax cement at 6%, 8% and 10% proportions of lateritic soil samples classified as A-2-6(1), A-6(5) and A-6(12) permeability tests values are in Table 3. Figure 3 is vividly showing the permeability coefficient variations of the stabilized lateritic soil samples. Figure 4 shows the variations of OMC of the lateritic soil samples in relationship to Powermax cement content increment as stabilizer. Figure 5 shows the variations of MDD in relationship to Powermax cement content increment when used to stabilize the soil samples. Figures 6 and 7 respectively show the variations of CBR for both unsoaked and soaked specimen lateritic soil samples with Powermax cement as stabilizer in 6%, 8% and 10% proportions.

Table 2: Unconfined Compression Uncured Samples

Cement Percent	Soil Group	Unconfined Compression Strength	Strain	Stress/ Strain	Shear Strength
6% Powermax cement stabilization	A-2-6(1)	195	2.6	75.000	97.500
	A-6(5)	152	2.6	58.462	76.000
	A-6(12)	128	2.6	49.231	64.000
8% Powermax cement stabilization	A-2-6(1)	225	2.8	80.357	112.500
	A-6(5)	205	2.8	73.214	102.500
	A-6(12)	125	2.2	56.818	62.500
10% Powermax cement stabilization	A-2-6(1)	265	2.8	94.643	132.500
	A-6(5)	230	2.8	82.143	115.000
	A-6(12)	140	2.1	66.667	70.000

Table 3: Unconfined Compression Cured Samples

Cement Percent	Soil Group	Unconfined Compression Strength	Strain	Stress/ Strain	Shear Strength
6% Powermax cement stabilization	A-2-6(1)	470	2.6	180.769	235.000
	A-6(5)	380	2.6	146.154	190.000
	A-6(12)	223	2.6	85.769	111.500
8% Powermax cement stabilization	A-2-6(1)	540	2.8	192.857	270.000
	A-6(5)	520	2.8	185.714	260.000
	A-6(12)	430	2.8	153.571	215.000
10% Powermax cement stabilization	A-2-6(1)	700	2.8	250.000	350.000
	A-6(5)	680	2.8	242.857	340.000
	A-6(12)	580	2.8	207.143	290.000

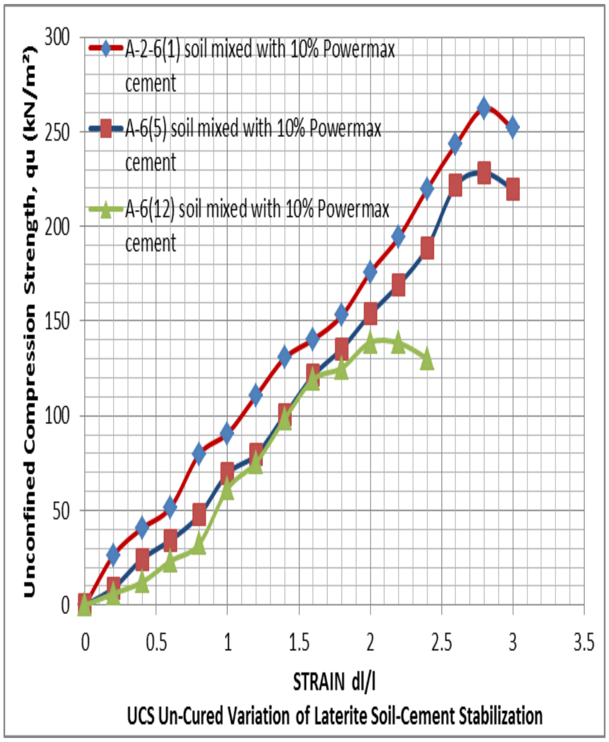

Figure 1: UCS Uncured at 10% Powermax Cement

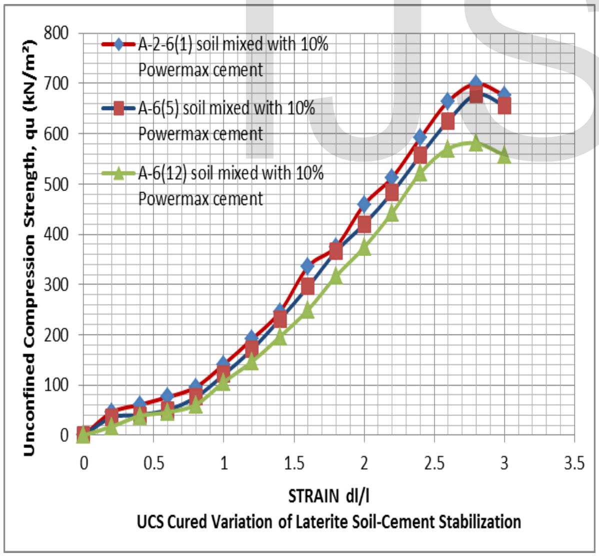

Figure 2: UCS Cured at 10% Powermax Cement

Table 4: Permeability Values of Stabilized Lateritic Soils

	A-2-6(1)	A-6(5)	A-6(12)
6% Cement	1.77354E-06	2.62E-06	3.39E-06
8% Cement	3.49775E-07	6.47823E-07	8.35E-07
10% Cement	1.22E-07	5.74043E-07	7.39E-07

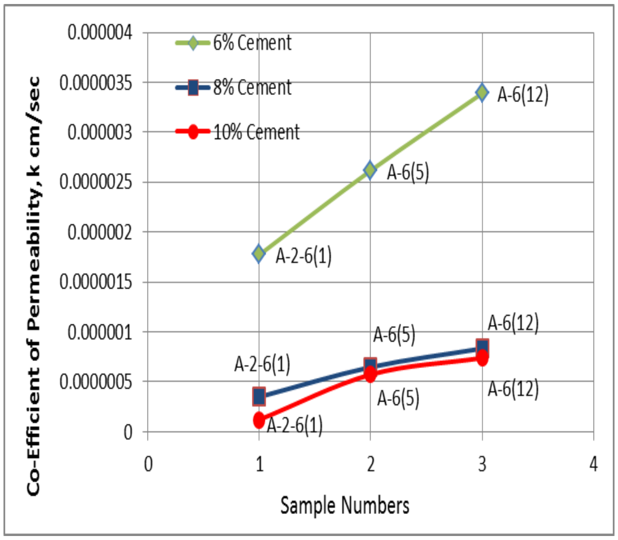

Figure 3: Co-Efficient of Permeability Variations

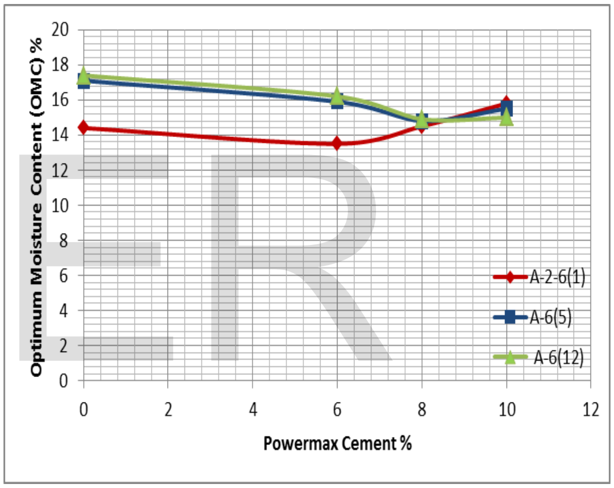

Figure 4: Variations of OMC and Powermax Content

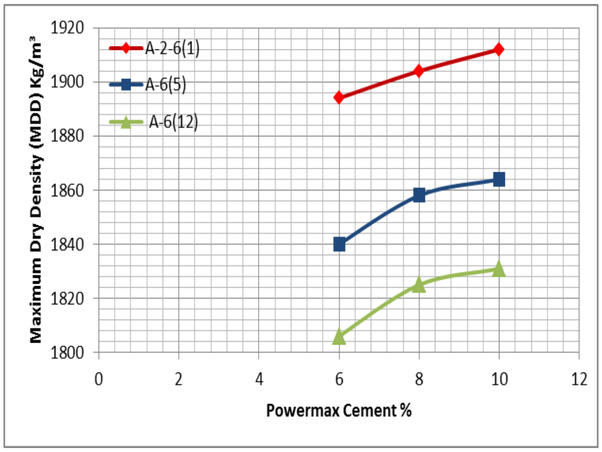

Figure 5: Variations of MDD and Powermax Content

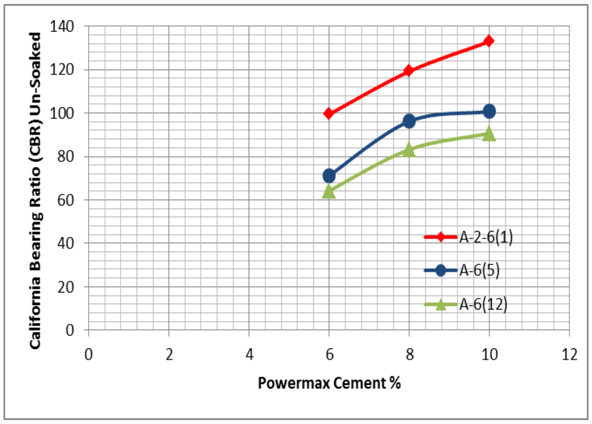

Figure 6: Variations of CBR Unsoaked and Powermax Content

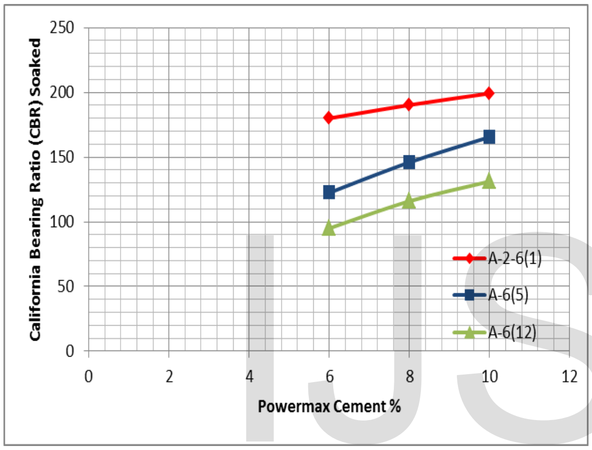

Figure 7: Variations of CBR Soaked and Powermax Content

4. DISCUSSION

Unconfined compression strength of both uncured and cured stabilized lateritic soil samples classified as A-2-6(1), A-6(5) and A-6(12) increases as the percentage of the Powermax cement used increases from 6% through 8% to 10%. It has been obviously shown in Table 2 that the unconfined compression strength for the uncured soil sample group A-2-6(1) increases from 195 kN/m^2 through 225 kN/m^2 to 265 kN/m^2. Also, the uncured soil sample group A-6(5) increases from 152 kN/m^2 through 205 kN/m^2 to 230 kN/m^2. Likewise, the uncured soil sample group A-6(12) increases from 128 kN/m^2 through 125 kN/m^2 to 140 kN/m^2.

In Table 3 the unconfined compression strength for the cured soil sample group A-2-6(1) increases from 470 kN/m^2 through 540 kN/m^2 to 700 kN/m^2. Similarly, the cured soil sample group A-6(5) increases from 380 kN/m^2 through 520 kN/m^2 to 680 kN/m^2. Correspondingly, the cured soil sample group A-6(12) increases from 223 kN/m^2 through 430 kN/m^2 to 580 kN/m^2. It could be seen critically that in Table 3 the unconfined compression strength for the cured soil samples for 7 days for groups A-2-6(1), A-6(5) and A-6(12) is of higher value than the uncured soil samples from Table 2.

For the 10% Powermax cement stabilization of A-2-6(1), A-6(5) and A-6(12) materials, the value of each lateritic soil sample strain is 2.8 and whilst the stress/strain relationships are 250 kN/m^2, 243 kN/m^2 and 207 kN/m^2. The values of stress/strain relationship for A-2-6(1) and A-6(5) as in Table 3 at 10% cement stabilization are very close. For this reason, it is possible to use A-6(5) soil material where it is readily available for economic reasons than better lateritic soil A-2-6(1) even though they are not in the same soil group based upon standard specification for classification of soils and soil-aggregate mixtures for highway construction purposes AASHTO M 145 (2012).

Based upon the permeability values of stabilized lateritic soils of Table 4, it is obvious that the coefficient values related to A-2-6(1), A-6(5) and A-6(12) materials at 6% of Powermax cement are of the order of 10^{-6} while those of 8% and 10% are of the order 10^{-7}. These values are showing that the stabilized materials with Powermax cement at 8% and 10% are of permeability at poorer level than that at 6%. However, Figure 3 is showing vividly that the permeability of stabilized lateritic soil samples of A-2-6(1), A-6(5) and A-6(12) with Powermax cement is poorer at 10% than that of 8%. This fact makes the stabilization of lateritic soil samples of A-2-6(1), A-6(5) and A-6(12) with Powermax cement at 10 % content optimum.

It is obviously shown in Figure 4 that OMC values of the lateritic soils A-6(5) and A-6(12) decreased from 15.9% to 14.8% and 16.2% to 14.9% respectively as Powermax cement increased from 6% to 8% of stabilization. On the other hand, OMC value of the lateritic soils A-2-6(1) increased from 13.5% to 14.5% as Powermax cement increased from 6% to 8% of stabilization. However, the three stabilized lateritic soil materials of groups A-2-6(1), A-6(5) and A-6(12) with Powermax cement increased differently in OMC values from 8% to 10% of stabilization. This is obvious in Figure 4 as A-2-6(1) has the highest OMC value with decreasing values followed by A-6(5) and the A-6(12) respectively. At the maximum cement content of 10% the optimum moisture content of the three stabilized lateritic soil materials of groups A-2-6(1), A-6(5) and A-6(12) are 15.8%, 15.5%, and 15% respectively.

The maximum dry density (MDD) for each of the soil samples A-2-6(1), A-6(5) and A-6(12) increases as the Powermax cement content in it increases from 6% through 8% and 10% as shown Figure 5. For the 10% optimum Powermax cement content stabilization, the values of MDD for soil samples A-2-6(1), A-6(5) and, A-6(12) are 1912 kg/m³, 1864 kg/m³ and 1831 kg/m³ respectively.

The California Bearing Ratio (CBR) of both unsoaked and soaked soil samples A-2-6(1), A-6(5) and A-6(12) increased as the Powermax cement content is increasing from 6% through 8% and 10%. For the 10% maximum Powermax cement content mixture the values of CBR for the unsoaked specimens are at optimum of stabilization at 133%, 100.75% and 90.75% for soil samples A-2-6(1), A-6(5) and, A-6(12) respectively. Also, for the 10% maximum Powermax cement content mixture the values of CBR for the soaked specimens are at optimum of stabilization at 199.25%, 165.5% and 131.25% for soil samples A-2-6(1), A-6(5) and, A-6(12) respectively. According to Akiije (2014) the values of CBR in percentages of these natural lateritic soils were 31.5, 19.55 and 13.106 in unsoaked condition while in soaked situation the values were 19.3, 13.45 and 5.8. More so, it could be claimed in this research that the rate of increasing strength of lateritic soils by Powermax is higher for clayey soils than silty or clayey sandy soils.

5. CONCLUSIONS AND RECOMMENDATIONS

Based upon the laboratory experiments carried out by investigating the strength and permeability of lateritic soil samples classified as A-2-6(1), A-6(5) and A-6(12) when stabilized with Powermax cement, the following are the accomplished conclusions and able recommendations.

1. Powermax which is a new Portland cement product by LAFARGE WAPCO in Nigeria has been identified in this research as a stabilizer of natural lateritic soils for it improved the materials of groups A-2-6(1), A-6(5) and A-6(12) in strength and decreased their permeability potential.
2. At 10% Powermax cement used in this research, A-2-6(1) lateritic soil material is at its upper boundary condition of cement requirement (see Table 1) for stabilization with unconfined compressive strength (UCS) optimum value of 700 kN/m² at strain value of 2.8. Whereas A-6(5) lateritic soil material is at its lower boundary condition cement requirement with closer UCS value of 680 kN/m² at the same strain value of 2.8.
3. The permeability potential of the materials of groups A-2-6(1), A-6(5) and A-6(12) decreased as Powermax cement content increases from 6% through 8% to 10% with coefficient values of 10^{-6} through 10^{-7} to 10^{-7} respectively. Although at 8% to 10% coefficient values of permeability are the same but Figure 3 has vividly shown that the poorer permeability is that of 10% Powermax cement stabilization.
4. A-2-6(1), A-6(5) and A-6(12) lateritic soils when stabilized with Powermax cement, the optimum moisture content of each material increased as the stabilizer increased from 8% to 10%. OMC value of A-2-6(1) is the highest while OMC of A-6(5) is higher than that of A-6(12) which is attributable to heat of hydration and higher gaining of strength.
5. The values of maximum dry density increased as percentages of Powermax cement increased from 6% through 8% to 10% for A-2-6(1), A-6(5) and A-6(12) lateritic soil materials. Although the increment for each soil sample is similarly in values of MDD obtained, at each percent of Powermax cement stabilization the A-2-6(1) are at the highest level while those of the A-6(5) are higher than that of A-6(12) as exhibited in Figure 5.
6. For unsoaked and soaked California bearing ratio (CBR), similar trend values were obtained when Powermax cement was used as stabilizer for A-2-6(1), A-6(5) and A-6(12) lateritic soil materials as exhibited in Figure 6 and Figure 7. There were tremendous higher CBR values of soaked specimens compared to the unsoaked. This is a credible improvement proffered by Powermax as a stabilizer while materials are under wet conditions.
7. Powermax which is a Portland cement has been used as a stabilizing agent upon soil groups A-2-6(1), A-6(5) and A-6(12) lateritic materials resulting to their improvement in strength potential and reduction in permeability power leading to their suitability for basecourse material in pavement construction. The use of Powermax Portland cement is hereby recommended as a

lateritic soil stabilizer particularly where found economical and environmentally friendly.

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