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Effect of 'Ionic Soil Stabilizer 2500'on the Properties of Black Cotton Soil

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Authors' contributions

This work was carried out in collaboration between two authors. Author LFO designed the study, collected samples from the field and performed the laboratory tests, and produced a draft of the manuscript. Author HMA checked the data for validity and carried out the analyses of the study. Author HMA further managed the literature searches. Both authors read and approved the final manuscript.

Research Article

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ABSTRACT

This study was carried out to establish the effect of "Ionic Soil Stabilizer 2500" (ISS 2500) on black cotton soil. Samples were collected along Dikwa–Gamboru Ngala road in North-East Nigeria. Initial results indicated that the black cotton soil could be expansive with over 60% passing the number 200 sieve size. The ISS stabilizer is 100% organic and is derived from combined organic Sulphur and buffered acids that are combined as bi-sulphates. The ISS stabilizer dosages of 0%, 1ml, 2ml, and 3ml were mixed with 6000g weight of black cotton soil and tests were carried out to determine if improvement in properties would occur. For the pH tests carried out, there were increases in the acidity of the samples with increase in ISS content. Similarly, the redox potential showed consistent increase in value with increase in ISS content. However, the plasticity index which was expected to decrease in view of the increases in the redox potential, and the electrical conductivity decreased instead. The CBR test was conducted in accordance with energy levels using British light compaction method. Consequently, the CBR values increased marginally but below the specifications for soil-cement stabilization for road base materials. The ISS stabilizer has not produced a consistent set of results for inferences to be made on its effectiveness in improving the properties of black cotton soils to road base standards. Further tests are required on the long term effects of the stabiliser on black cotton soils.

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1. INTRODUCTION

The behavior of expansive soils is uncertain when subjected to moisture changes. This present considerable challenge in their utilization for infrastructural development. The strength properties of these soils change according to the amount of water contained in the voids of the soils. The movement of water into and out of the soil voids induces severe swell-shrink behaviour causing stress levels which could result to damages to facilities placed on them. Highway facilities in particular stretch over considerable distances traversing diverse soil formations. The chances of encountering expansive soils are therefore high with highway facilities. Expansive soil behaviour is generally attributed to clay soils, and are characterized by excessive compression, dispersive behavior, collapsing behavior, low shear strength, high swell potential, and frost susceptibility [1]. They are therefore not suitable for use without improvement of their properties.

The smectite mineral contained in soils such as black cotton soils is found in many parts of the world especially in arid and semi-arid parts of the world. In Nigeria they are available in the vast watersheds of the Chad Basin brought about by the accumulation of alluvial deposits over several decades. Due to the seasonal variation in the moisture content of black cotton soil engineering infrastructure built on the soil experience severe stresses which may eventually lead to failure. Road construction over an extensive area of black cotton soil such as that in the Chad basin generally poses operational, maintenance and construction challenges due to factors such as the high volume changes, severe cracking when dry, low bearing value when wet, lack of drainage and scarcity of suitable construction materials. Location of projects in this area therefore calls for careful evaluation of material properties to avert premature failure.

One difficulty encountered in the handling of clay soils in construction is the problem of pulverization. They are difficult to work with and stabilization methods when applied to the soil are inefficient in agglomerating the soil particles and reducing their void moistures content and therefore do not achieve substantial improvement in strength properties.

Recently, proprietary chemical additives are being marketed in Nigeria as capable of achieving high strength gains in cohesive soils. However, no known tests, whether field trials or laboratory programs have been carried out to determine the efficacy of these chemical stabilizers in the Nigerian environment. The aim of this paper therefore is to determine the efficiency of “ISS 2500” chemical stabilizer in the improvement of the strength of black cotton soil obtained from the failed sections of Maiduguri-Gamboru Ngala highway in northeast Nigeria. This is with a view of comparing the results with cement stabilized soil mixes.

2. LITERATURE REVIEW

Black cotton soil is an expansive soil which swells or shrinks excessively due to changes in moisture content and has an appreciable plasticity in the clay fraction. It is dark gray to black in colour. Soils with a high content of clay usually over 50 percent; in which montmorillonite is the principal clay mineral are commonly expansive [2]. The Lake Chad Basin is known to be the only location having extensive lacustrine deposits of black clayey soils in Africa [3]. Conditions which favour the formation of black cotton soils include evaporation exceeding precipitation, poor leaching, alkaline conditions, retention of magnesium and calcium in the soil. The parent material is basic igneous rocks such as basalt, made up of calcium-rich feldspars and dark minerals which are inapt and easily weathered [4].

Black cotton soils are soft and highly compressible, and have unacceptable consistency indices, low strength, and high impermeability. These undesirable properties make them unfitting for use in infrastructural development projects; hence they have to be stabilized. However, though clay soil materials have poor engineering behaviour and are generally inappropriate for construction purposes they are used beneficially as barriers in containment of contaminants as an integral part of environmental protection strategy and as buffer materials for waste disposal. This application of expansive soils is due to the possession of a remarkable swelling due to water intrusion and therefore restriction of the water and contaminant migration through them [5].

Stabilization makes it possible for soils to support themselves and other imposed loads. In the case of black cotton soils, stabilization could be achieved by means of chemical additives. This is because pulverization is difficult to achieve with black cotton soils and chemical additives facilitates flocculation making densification possible; the main essence of stabilization. Stabilization of clay (black cotton) soils must improve the swell potential for strength gain to be attained. However, the swell potential is associated with increased plasticity indices and higher cation exchange capacity [6] and [7]. The cation exchange capacity (CEC) of soils containing montmorillonite mineral (black cotton soil) is mainly due to the presence of sodium ions (Na^{++}), Potassium ions (K^{++}), Magnesium ions (Mg^{++}) and Calcium ions (Ca^{++}). This creates additional water affinity for clay soils leading to high swell potential. Hence the lower the CEC the more the strength gain [8]. Most studies on montmorillonite clay focuses on the index, physical and chemical properties while strength properties are often ignored due to the low strength of clay soils when in contact with water.

Ionic Soil Stabilizer (ISS2500) is a water soluble chemical used in the construction of all types of road utilizing in-situ materials. It is 100% organic and is derived from combined organic Sulphur and buffered acids that are combined as bi-sulphates [9]. Stabilization with ISS2500 improves the physical and mechanical characteristics of marginal soils [10]. Treatment with ISS releases the adsorbed water from the clay soil particles, minimizing the voids and allowing the particles to be compacted to much greater densities thereby increasing the shear strength and bearing capacity of the layer. The treatment is permanent and the compacted layer has a high density and high load bearing capacity and is unaffected by extreme climatic conditions [9]. ISS2500 could be applied to road base, sub-base and sub-grade materials. The fine particles of the clays and silts, due to their mineralogical composition have an excess of negative ions (anions) and therefore attract positive ions (cations) of water, making this water adhere to them to form pellicular water [9]. ISS2500 has enormous cationic exchange capacity [10]. When small quantities of *ISS2500* are added to water, they activate the hydrogen ions (H^+) and hydroxyl ions (OH); ionizing the water which then vigorously exchanges its electrical charges with the soil particles forcing the pellicular water to break its electrochemical bond with the soil particles to become free water which can then drain from the soil through gravity or evaporation.

3. MATERIALS AND METHODS

The disturbed samples were collected from three different locations along Maiduguri–Gamboru Ngala road at latitude 12º19'24.06" and longitude 14º09'16.81. The conditions of the road are shown in Fig. 1. The three locations belong to the same Sahel region of Nigeria which is a semi-arid region with long periods of dry weather and short spells of wet weather. These areas lie in the Chad basin that was formed in the late tertiary period of geological history and in which was deposited a series of clays and sands during the Paleocene and Pleistocene periods. The general topography is flat and the vegetation is of the savannah type with considerable tree growth diminishing towards Lake Chad. The soils consist of medium to fine sands, silty fine sands and clays with deposits of coarse to medium sands [3].

Soil sampling was carried out by removing the topsoil, digging test pits at three locations, between 400mm and 1500mm depth and collecting 12 soil samples from each pit, taking natural moisture content using the speedy tester, properly labeling and conveying to the laboratory for testing.

Fig.1. Condition of Dikwa-Gomboru Road

3.1 Laboratory Test Program

A laboratory testing program was designed to determine the Geotechnical and physicochemical properties of the soil samples. The tests conducted on the samples included grain size distribution, soil classification, Atterberg limits, optimum moisture content, maximum dry density, specific gravity and CBR tests, all in conformity with the relevant Nigerian standards [11]. The tests on the soil samples included pH, redox potential and electrical conductivity. The pH measurement was performed in accordance with standard test method [12] using a Hanna bench-top pH meter. The particle charge test for the chemical stabilizers was carried out by introducing low direct current into the chemicals by immersing a cathode and an anode into it. Besides, chemical content tests on the stabilizers were carried out by titrimetry, gravimetry (density and weight) or calorimetry methods and the contents were reported mainly in mg/liter of the chemical, following the guidelines and standards for environmental pollution control in Nigeria [13]. The sample preparation processes were all in accordance with the Nigerian standard methods [11].

3.2 Soil Stabilization Designs

Stabilization design was carried out to determine relative increase in strength achieved by the stabilized soils as the quantity of the proprietary ISS stabilizer was increased. The strength parameter measured is the California Bearing Ratio (CBR), tested after wrapping in a polythene bag and curing for seven (7) days. In carrying out the stabilization designs, pre-determined doses of the chemical were diluted with water to achieve the optimum moisture content. Also 6,000g of each soil sample was required to be compacted to the optimum moisture content (OMC) for the CBR test to be run on them. In determining the range of quantities of chemicals to dose to each 6,000g untreated soil, the claim of the marketers of ISS 2500 was used as a guide. Road Technologies [9] claim that only 0.04 liters of the ISS 2500 was needed to fully stabilize a square meter of soil, 100mm thick. Compaction test was conducted to determine the initial optimum moisture content (OMC) and maximum dry density (MDD) with zero Ionic Soil Stabilizer (ISS) additive. The average OMC obtained from this experiment was used to mix the soil samples with the addition of various quantities of ISS solution, while the MDD results from the preliminary compaction test were used in the determination of ISS dosage. Dosages of 0ml, 1ml, 2ml, and 3ml were then used and mixed with the samples accordingly. Samples of the soils are shown in Fig. 2 and the CBR test in Fig. 3.

Fig. 2. Samples of the black cotton soils

Fig. 3. CBR test in progress

4. RESULTS AND DISCUSSIONS

The results of the physico-chemical tests conducted on the soil samples are shown in Table 1. The soils are cohesive in nature with over 60% passing the number 200 sieve size. The average natural moisture content of the soil was found to be 8.6% suggesting that the soil may have undergone several cycles of shrink-swell. The classification of the soil according AASHTO classification is A-7-6 [2] indicating that the soil could be lacking in some qualities to be suitable for use as a road building material. The soil in its natural form is basic in pH value and has poor conductivity but has a substantial electrical conductivity.

The behaviour of the Atterberg limit parameters with respect to increment in percentage ISS content is shown in Fig. 4 for liquid limit and Fig.5 for plastic limit. In the case of liquid limit there are increases in the liquid limit as the stabilizer content increases. The average liquid limit value for all samples at zero stabilizer content is 40.62 while the values for the 1ml, 2ml and 3ml stabilizer contents are respectively 41.32, 44.06 and 44.37. Similarly, the plastic limit increases with increase in stabilizer content except for 3ml stabilizer content at which the plastic liquid drops below the zero stabilizer content value for trial pit 3 samples. There is no consistent trend for the plastic limit changes. For instance whereas the plastic limit increases for trial pits 1 and 2 samples, the reverse is the case for trial pit 3 for stabilizer content of 1ml. The overall average plastic limit value for zero stabilizer content for the three trial pits are 23.26. At 1ml, 2ml and 3ml stabiliser contents the average values are 24.62, 22.33 and 24.16 respectively. The plasticity index and linear shrinkage changes with an increase in stabilizer content and these results are shown in Fig.6 and 7 respectively. For the plasticity index (PI) variation with stabilizer content, all the increments were higher than the zero stabilizer content indicating increases in PI with a corresponding increase in stabilizer content.

Table 1. Physico-chemical characteristics of the soils

Properties/samples stabilizer content	**Samples**			
	0%	**1%**	**2%**	**3%**
Description	Dark gray to black clay			
Gravel	0.00	-	-	-
Coarse sand	0.00	-	-	-
Fine sand	35.44	-	-	-
Silt/clay	64.56	-	-	-
Specific Gravity	2.25	-	-	-
Nat. Moisture Content, %	8.60	-	-	-
Optimum Moisture Content, %	12.17	-	-	-
Maximum Dry Density [Mg/m^3]	1.79	1.86	1.80	1.80
Soaked CBR, % (7days)	37.47	41.40	46.77	50.27
% Passing BS sieve No 19 mm	100	-	-	-
% Passing BS sieve No 7	100	-	-	-
% Passing BS sieve No 36	100	-	-	-
% Passing BS sieve No 200	63.21	-	-	-
Liquid Limit, %	40.62	41.32	44.06	44.37
Plastic Limit, %	23.26	24.62	22.33	24.16
Plasticity Index, %	17.36	16.70	21.73	20.21
Linear Shrinkage	14.30	12.97	12.73	12.63
pH	9.88	5.70	4.48	4.12
Redox Potential	15	115	189	211
Electrical Conductivity	119.30	168.50	367.50	912.00
AASHTO	A-7-6[2]			

For the three trial pits the average plasticity index values at zero, 1ml, 2ml and 3ml stabiliser contents are 17.4, 17.11, 21.72 and 20.22 respectively. It could be inferred that there is no consistent change in plasticity index with increase in stabilizer content. The linear shrinkage value decreased for samples taken from trial pits 2 and 3 at 1ml stabilizer content. However, the linear shrinkage value increased for samples from trial pit 1 at 1ml content. The overall average values across the trial pits at zero content, 1ml, 2ml and 3ml are 14.30, 12.97, 12.73 and 12.62 respectively indicating consistent decreases as the stabilizer content increased.

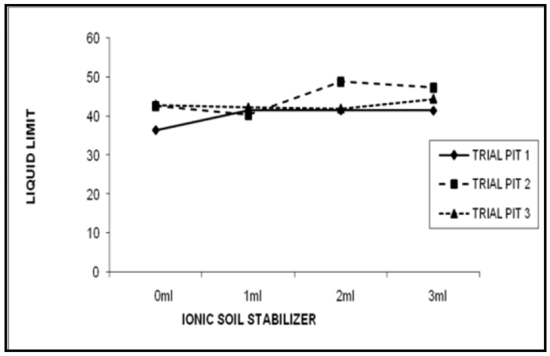

Fig. 4. Liquid limit properties with stabilizer content

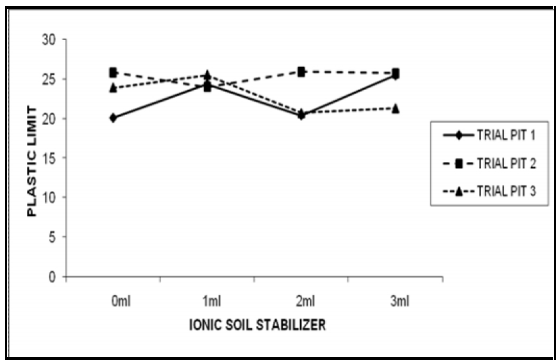

Fig. 5. Plastic limit properties with stabilizer content

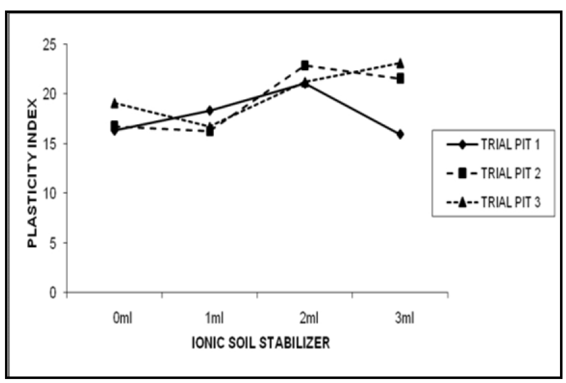

Fig. 6. Plasticity index properties with stabilizer content

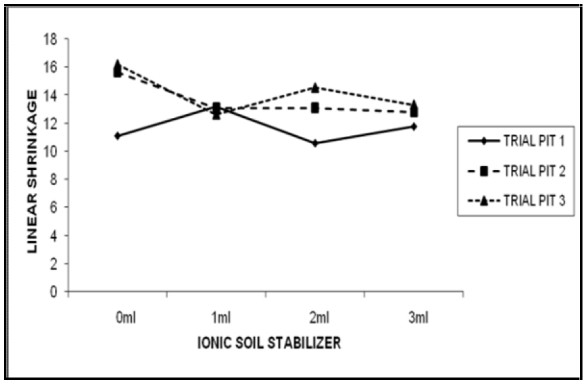

Fig. 7. Linear shrinkage properties with stabilizer content

The pH-value trends with stabilizer content are shown in Fig.8 while the redox potential of the soil samples is shown in Fig.9. The pH decreased as the stabilizer content increased whereas the trend was reversed in the case for redox potential. This means the samples are becoming easily ionized in acidic medium. It was observed from the pH results that black cotton soil is alkaline in nature (Table 1) with average pH value of 9.88. Soil with a high pH value is deficient in cations [14] and this enhances the water molecules to be held by the soil particles in their natural states. The pH value of black cotton soil turns acidic as ISS is added and increases in acidity as the ISS content is increased.

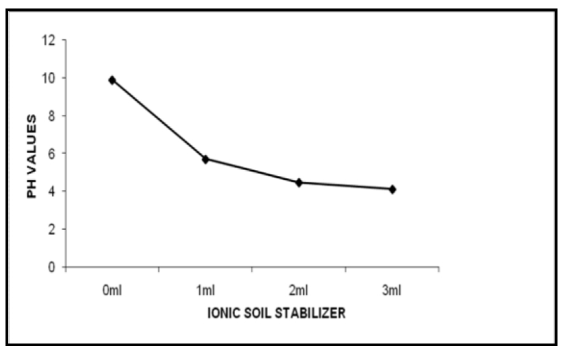

Fig. 8. pH-Value with stabiliser content

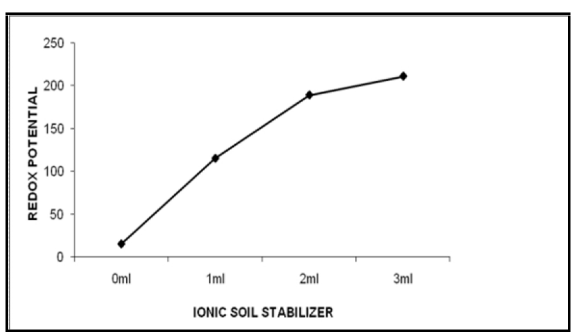

Fig. 9. Redox potential with stabiliser content

Electrical Conductivity increases for every addition of ISS as depicted in Fig.10. Electrical conductivity is a measurement of the dissolved materials in an aqueous solution or the measure of the swiftness of movement of electrons. The ISS system of stabilization has to do with ionizing and exchange of electrical charges. The fine particles of black cotton soils due to their mineralogical composition have an excess of negative ions (anions) and therefore attract positive ions (cations) of water, making this water adhere to them to form pellicle water. But it was observed from the results of the redox potential and electrical conductivity that ISS has an enormous potential ionic exchange capacity [10]. When small quantities of ISS were added to water they activate the ions H+ and (OH) - ionizing the water which then vigorously exchanges its electrical charges with the soil particles as evident in the increment of redox potential and electrical conductivity with the addition of ISS.

The effect of the stabilizer on maximum dry density (MDD) is shown in Fig.11 and that of CBR in Fig.12. The maximum dry density increases suddenly upon addition of ISS stabilizer and decreases gradually to a lower value at 3ml ISS content addition. However, the MDD increment at 3ml ISS content is higher than the corresponding value at zero ISS content. Addition of 1, 2 and 3ml of ISS increased the CBR values by 11%, 25% and 34% respectively. Within the ISS content utilized, none of the samples tested was able to achieve 80% unsoaked CBR which is the specification for base course materials [11].

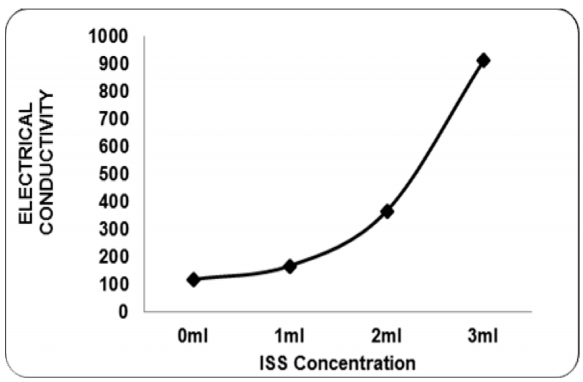

Fig.10. Electrical conductivity against ISS content

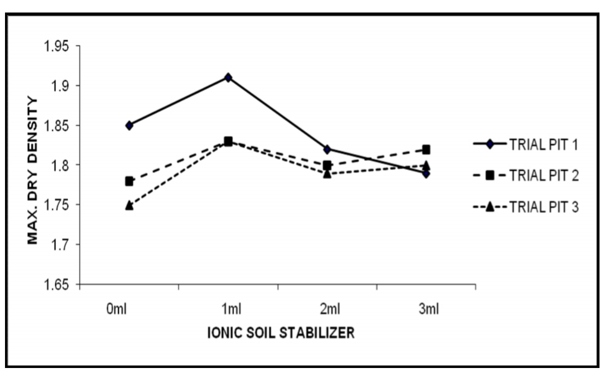

Fig.11. Maximum dry density against stabiliser content

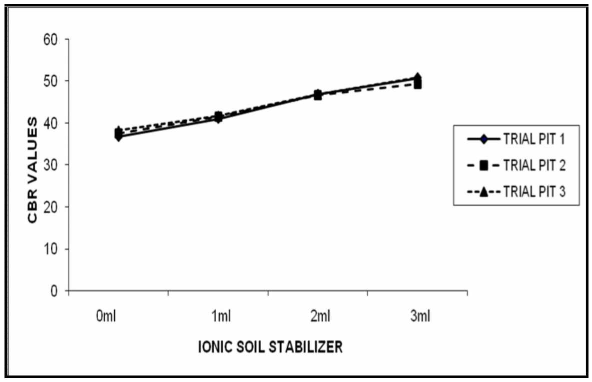

Fig.12. CBR against stabiliser content

5. CONCLUSIONS

From the results of tests conducted and discussed above, the following conclusions are made:

The ISS stabilizer mixed with black cotton soil turns the alkaline soil into an acidic medium thereby increasing the chances of ionization of the water in the voids of the soils and enhancing the cation exchange with cations contained in the soil.

The improvement of the properties of the black cotton soil falls below the specifications required of a material for road base construction. CBR increased by 9.5% for 1ml ISS content, by 24.8% for 2ml ISS content and by 34.2 with the addition of ISS dosage of 3ml. The CBR at zero ISS content was 37.7%. The plasticity index at zero ISS content was 17.36% and increased to 20.21% at 3ml ISS content.

Both the increases in redox potential and electrical conductivity recorded was expected to cause greater ionization and cation exchange capacity but did not translate into consistent increase in the strength and engineering properties of the black cotton soil.

Stabilized black cotton soil with ISS could be used for fill and sub base materials in road construction. An optimum dosage of 1.5ml of ISS dosage could be used to stabilize the sub base material. 1ml of ISS dosage could be used in treating the black cotton soil to make it useful for fill materials in road construction.

Further tests can also be made to clarify the erratic behaviour of the black cotton soil with ISS as found in this study.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1 Abdullah WS, Al-Abadi AM. Cationic-Electrokinetic Improvement of an Expansive Soil. Applied Clay Science. 2010;47:343-350.
2 Ayodele I. Research on Expansive Black Tropical Clay Areas of Maiduguri – Gamboru-Wulgo Road in Borno State of Nigeria. Technical Report on Road Design and Construction Unpublished; 1979.
3 Ola SA. The Geology and Geotechnical Properties of the Black Cotton Soils of North-Eastern Nigeria. Engineering Geology. 1978;12:375-391.
4 Balogun LA. Black Cotton Soils. Seminar Paper Presentation, Faculty of Engineering, University of Lagos, Nigeria; 1985.
5 Arya AL, Yasrobi SS. A Micro-Mechanical Approach to Swelling Behaviour of Unsaturated Expansiv Clays under Controlled Drainage Conditions. Applied Clay Science. 2009;45:8-19.
6 Fateme Y, Yasrobi SS. Effect of Cyclic Wetting and Drying on Swelling Behaviour of Polymers-Stabilised Expansive Clays. Applied Clay Science. 2009;50:461-468.
7 Guney Y, Sari D, Cetin M, Tuncan M. “Impact of Cyclic Wetting-Drying on Swelling Behaviour of Lime-Stabilised Soil”. Building and Environment Journal. 2007;42:681-688.
8 Zeynal AE, Resat UA. Simple Test And Predictive Models For Assessing Swell Potential Of Ankara (Turkey) Clay. Engineering Geology. 2003;67:331-352.
9 Road Materials Stabilizers. Technical Report on ISS2500, Road Material Stablizers (Pty) Ltd. (1990), Johannesburg, Republic of South Africa; 1990.
10 Alhassan HM, Chukwuma IM. The Efficacy of Sulphonated Petroleum Products in the Stabilization of Marginal Lateritic Soils. International Journal of Emerging Technology and Advanced Engineeringt. 2013;2(12):14-23.
11 FMWH. General Specifications For Roads And Bridges. Federal Ministry Of Works and Housing, Nigeria. 1997;4
12 ASTM Annual Book of ASTM Standards. Standard Test Method for pH Soils. ASTM Publication, Philadelphia, USA; 2000.
13 FEPA. Guidelines and Specifications for Environmental Pollution Control. Federal Environmental Protection Agency, Nigeria; 1991.
14 Basha EA, Hashim R, et al. Stabilization of Residual Soil with Rice Husk and Cement. Construction and Building Materials. 2005;19:448-453.

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