THE INTERNATIONAL JOURNAL OF SCIENCE & TECHNOLEDGE

Strength Characteristics of Lateritic Soil Stabilized with Terrasil

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Abstract:
This paper presented the strength characteristics of lateritic soil stabilized with chemical stabilization using Terrasil,two samples, A and B were collected from two different borehole locations from a site. The effects of Terrasil on the engineering properties of the samples were investigated by conducting series of laboratory tests on the samples, the tests include consistency/index property tests, standard Protor test, Unconfined Compression Strength test (UCS), and California Bearing Ratio (CBR) test before and after mixing with 2%, 4%, 6%, 8% and 10 % of Terrasil. The Samples were classified as A-6(4) and A-7-6(7) soils for sample A and B respectively on mixing with Terrasil,an increase in UCS from 200kPa at 0% additive to 351 kPa at 4% additive. Results of the CBR test on soil sample 'A' shows an increase in strength from its natural value of 11.5% to 34.9%, at 4% of the additive; sample 'B' increased from 8.8% to a maximum value of 28.6% at 6% of Terrasil. The test results show that treated samples A and B have CBR values greater than 20% and can therefore be used as "sub-base type 2" material in road construction.

Keywords: *Stabilization, terrasil, unconfined compression test, California bearing ratio*

1. Introduction

More often than not, soils do not have the desired geotechnical properties for constructing structures upon them. The alternatives available to a Civil Engineer therefore are to: bypass the weak soil (*e.g.*, use of piles), remove the weak soil and replace with one with a higher bearing capacity (*e.g.,* removal of peat at a site and replacement with selected suitable material), or treat the soil to improve its properties. Depending on the circumstances, the last approach may be the most economical solution to the problem. The method of treating the soil to improve its properties is termed 'soil stabilization' (Venkatramaiah,2006). Soil stabilization may be classified based on the treatment given to soil, on additives used, or on the process involved to improve the soil.Stabilization may be achieved with or without the use of additives.Thus there is mechanical stabilization, chemical stabilization, stabilization by grouting, stabilization by geotextiles and fabrics among others.

Sharma (2016)categorizes stabilizers into three groups: traditional stabilizers (cement, bitumen etc.), waste products stabilizers (fly ash, phosphor-gypsum, etc.) and chemical stabilizers (potassium compounds, polymer, ammonium chlorides etc.). Cement has been used with great success to stabilize naturally unsuitable soils, but the chemical conditions of some of the soils can inhibit the normal hardening of cement or lead ultimately toloss of durability or high construction cost for thehighly plastic clay soils(Amu *et al.,*2005). Bituminous stabilization is also usedfor road surfacing all over the world, but has itsown disadvantage in terms of energy loss during heating, it's dependent on machines to ensure maximum production and quality and negative effect on the environment and human exposed tothe hazardous emissions produced in the industry. In chemical stabilization of soil depends mainly on chemical reactions between stabilizer and soil minerals to achieve the desired effect. Chemical stabilization is achieved by mixing appropriate percentages of chemical such as Sodium Silicate, Calcium Chloride, Terrasil etc. (Ola,2013). The most common application of soil stabilization is the strengthening of the soil components of highway and airfield pavements. Urbanization and development in Nigeria have led to an increase in construction activities and have necessitated the provision of infrastructure projects such as highways, railways, air strips, buildings etc. These projects require good quality soil materials in massive quantities. In urban areas, soil with desirable geotechnical properties from borrow pit, which, more often than not, has to be hauled from a long distance is not easily available(Oluyemi-Ayibiowu and Ola,2015).

Nearly all lateritic soils are rusty red because of iron oxides. They develop by intensive and long-lasting weathering of the underlying parent rock. Lateritic soils cover about one third of the earth's continental land area with the majority of that in the land areas between the tropics of cancer and Capricorn(Thagesen,1996).However, not all lateritic soils are expansive, laterite is rich in silica, aluminum and iron formed in wet and hot tropical areas. But these soils are deficient in potash, phosphoric acid, lime and nitrogen. Silica leached away due to heavy rainfall and becomes hard when exposed to atmosphere.

Stabilization of lateritic soils using different additives is a usual practice as it becomes uneconomical to replace the foundation material with good quality soils (Wright-Fox, *et al,* 1993). The process of selecting the appropriate additives involves the study of the soil type and properties, the design intent for stabilizing the material, the required strength and durability of the product, initial cost/cost savings and environmental consideration (Aderinola and Nnochiri, 2017). According to Sharma (2016), the rate of development of strength is higher in chemicals compared to other methods of stabilization and advantage of chemical stabilization over other stabilization is that the setting and curing time can be controlled. However it may prove sometimes to be more expensive than other methods of stabilization. Against this background therefore, this study assesses the influence and suitability or otherwise of Terrasil; a nanochemical on the natural engineering properties of lateritic soils. Terrasil

Terrasil is a nanotechnology based material made of 100% organo-silane molecules. It is an organosilane compound which when added to soil, forms hydrophobic (oily) layers on the surface of the soil and clay particles. This make soil particles water insensitive and can be compacted to a better particle interlock state by equipment and traffic forces (Prakash and Sridharan,2004).Terrasil is highly soluble in water and stable to heat and ultra-violet rays . Results of earlier research on the use of Terrasil to stabilize soils of virtually all types have shown that the substance renders the treated soils highly water repellant; with improved cohesion and adhesion values and maintains breathability of the soil layer without altering their the soil colour(Sharma, 2016).The bonding process starts within 3 hours of the initial application and completeafter about 72 hours after application of Terrasil, it becomes a permanent part of each soil molecule and willnot separate or leach into groundwater

Terrasilis Pale yellow liquid with specific gravity 1.01. It contains Hydroxyalkyl-alkoxyalkylsilyl, Benzyl alcohol and Ethylene glycol. Terrasil is water soluble compound which forms form water clear solution. After application of Terrasil, it becomes a permanent part of each soil molecule and will not separate or leach into groundwater.The technical specifications and properties as well as the composition of Terrasil are summarized respectively in Table 1 and Table 2.

Property	Description
Appearance	Pale Yellow Liquid
Solid Content	68±2%
Viscosity at 250C	20-100cps
Specific gravity	1.01
Solubility	Forms water clear solution
Flash Point Flammable	12ºC
Terrasil : Water	1: 200ml(Maximum)

Table 1: Technical Specifications of Terrasil
Source: Zydex Industries Ltd (2018)

Chemical Compound	Value in Range (%)
Hydroxyalkyl-alkoxy-alkylsilyl	65 –70 %
Benzyl alcohol	25 –27 %
Ethylene glycol	3 –5 %

Table 2: Chemical Composition of Terrasil
Source: Zydex Industries Ltd (2018)

The reaction of Terrasil and soil leads to permanent nanosiliconization of the surfaces by converting the water loving silanol groups to water repellent siloxane bonds. The siloxane is non-leachable as it chemically binds to surfaces permanently. Terrasil unique chemical structure makes it water soluble. Terrasil, when added to soil, forms Si-O-Si bonded nano-siliconize surfaces and converting water loving Silanol groups to water repellent Alkyl Siloxane groups in soil. Once applied, it works to bond with the soil's silica and oxygen molecules. This chemical reaction makes the soil about 98% water resistant.

2. Material and Methods

2.1. The Study Area

The study area lies inlatitudes 7̊ 18′ 03″ N to 7̊ 18′ 06″ N and Longitudes 5̊ 08′ 02″ E to 5̊ 08′ 05″ E. Two samples, A and B of lateritic soils were collected within this location from a site proposed for the construction of an indoor sports hall at the Obanla campus of the Federal University of Technology, Akure, Nigeria. Figure 1 shows the study area.

Figure 1: A Street Map of the Federal University of Technology, Akure, Showing Sample Locations (Source: Google Maps)

2.2. Material

Terrasil is a commercially available chemical stabilizer in concentrated liquid form. It is mixed with water in maximum of 1ml of Terrasil to 200ml of water proportions so as not to weaken the potency of the additive before addingit to the soil specimen. Figure 2 shows Terrasil in bottles.

Figure 2: Commercially Available Terrasil Nano-Chemical in Bottles

lateritic soil sample were collected at depths of 0.7m-1.0m from 2 different pits: A and B. Preliminary tests; classification and strength tests were conducted on each sample so as to assess their geotechnical index and engineering properties. These tests served as the control tests whose results were used to compare the subsequent tests on the Terrasil-treated soil specimen. In preparing the soil for treatment with Terrasil, Terrasil was first mixed with water to form a Terrasil: water solution in a 1:100ratio before adding to the soil the solution was added in varied amounts to each of the two lateritic soil samples: A and B weighing 3000g each. The percentage of the additive by dry mass of the lateritic soil samples used were 2%, 4%, 6%, 8%, and 10% at 2% intervals. The mixture was then air-dried for 3 days so as to allow a complete reaction of Terassil with the soil, after which tests strength tests were conducted. All laboratory tests in this project were conducted according to BS 1377 standards specifications: Soils for Civil Engineering Purposes (1990)

3. Results and Discussion

3.1. Sieve Analysis of Untreated Samples

Figure 3 presents the Results of the Sieve and Hydrometer Analysis of the soil samples. Soil sample 'A' is classified as A-6(4) soil based on AASHTO method. Results of classification tests on Sample B reveals that, it comprises more fines (silt and clay-sized particles) than sample A and it is classified as an A-7-6(7).Using the Unified Soil Classification System (USCS), both samples, 'A' and 'B' are classified as Clayey soil (CL). The results of the classification tests on the lateritic soil sample A and B are based on particles size greater than or equal to 75µ in line with the American Association of State highway and Transportation Officials (AASHTO) requirements. Sample A comprises particle sizes of 0.4% gravel, 54.98 %sand 44.56% fines fractions. Soil sample B comprises particle sizes of 0% gravel, 49.7 %sand 50.2% fines fractions.

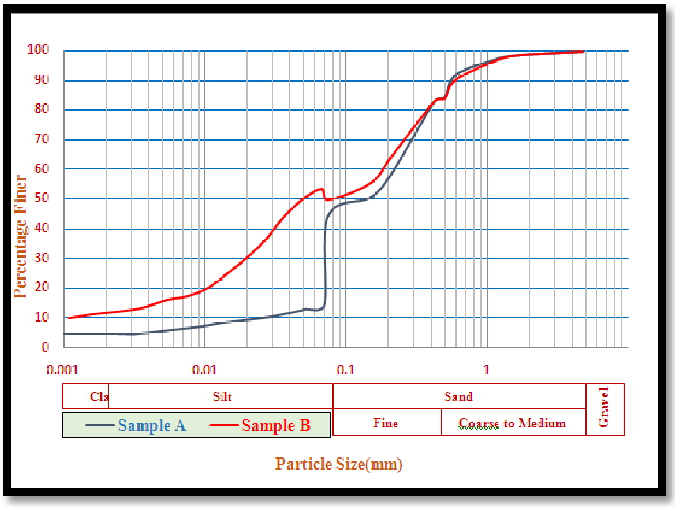

Figure 3: Particle Distribution Curve of Soil Samples a and b

3.2. Atterberg Limits Properties of Soil Samples Treated and Untreated with Terrasil

Figures 4 and 5 present the results of plasticity index tests carried out on the samples, Results of Atterberg Limits tests carried out on the treated soil samples show that the plasticity Indices of both samples decreased with increase in amounts of Terrasil. Sample A at 0% of Terrasil recorded 21% plasticity index and reduced to 16% at 6% addition terrasil to the lateritic soil, whereas, the plastic index of Sample B reduced from 15% at 0% addition of Terrasil to 12% at 6% addition of Terrasil, although an increment in plasticity index occurred at 8% terrasil addition. Sample A recorded linear shrinkage of 11% at 0% level of Terrasil and reduced significantly to 5% at 10% addition of Terrasil and Sample B, linear shrinkage reduced from 12% at 0% Terrasil to 7% at 10% Terrasil addition (Figure 5). The liquid limit exhibited in sample A is 42% at 0% addition of Terrasil and slightly reduced at 6% addition of Terrasil to 41%. Sample B exhibited highest value of liquid limit at 8% addition of Terrasil.

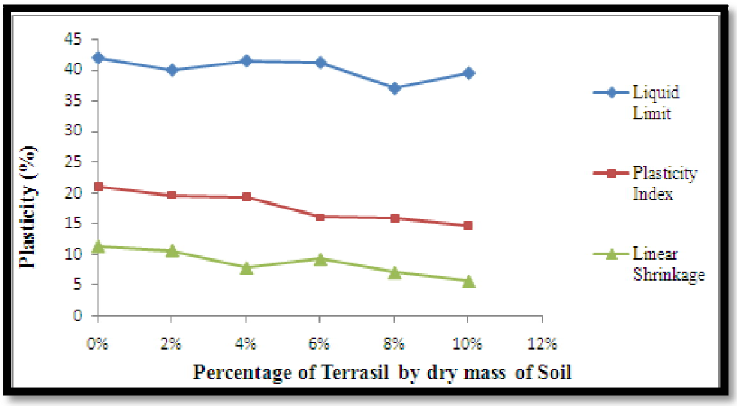

Figure 4: Atterberg Limits against Percentage of Terrasil In Soil Sample A

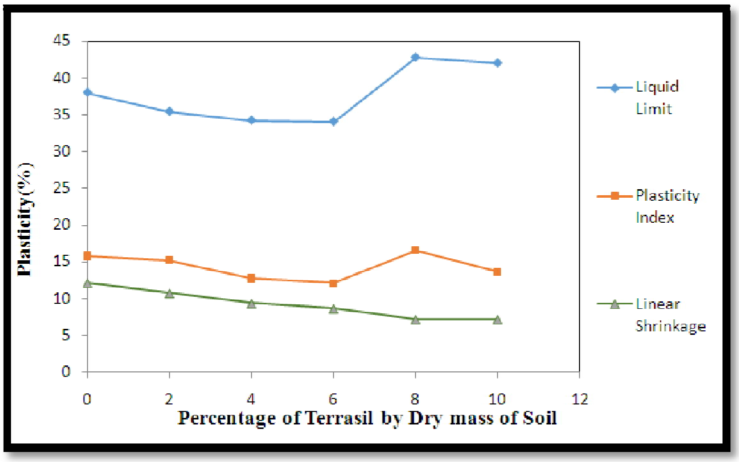

Figure 5: Atterberg Limits against Percentage of Terrasil in Soil Sample B

3.3. Compaction Characteristics of Untreated and Treated Lateritic Soil Samples

Table 3 summaries compaction Characteristics of Lateritic Soil treated with Terrasil. On increasing the percentage of Terrasil in the soil samples, a marked increase in MDD (Maximum Dry Density) and OMC (Optimum Moisture Content) was observed up to 4% of the additive. For sample A, MDD increased from 1842kg/m^{3}to 1900kg/m^{3}at 4% of the additiveand OMC decreased from 17.46% to 13.98%. Sample B recorded an MDD of 1880kg/m^3 at OMC of 17.78% at 4% additive; from its initial value at 1871kg/m^3 and OMC of 15.61%. Reduction in MDD followed further increase in the amount of the addition of Terrasil. The decrease in value of maximum drydensity could be attributed to the formation of new chemical product betweensoil mineral and Terrasil as reaction advanced. The variation of Maximum Dry Density of the treated soil with increase in percentage of Terrasil is shown in Figures 6. Also, Figure 7and Figure 8 are the compaction curves for sample A and B respectively with 2%, 4%, 6%, 8%, and 10% Terrasil.

Lateritic Soil (%)	*Terrasil(%)*	*Optimum Moisture Content(%)*	*Maximum Dry Density(kg/m^3)*	*Optimum Moisture Content(%)*	*Maximum Dry Density(kg/m^3)*
		Sample A		*Sample B*	
100	0	17.46	1842	15.61	1871
98	2	14.5	1845	18.04	1876
96	4	13.98	1900	17.78	1880
94	6	17	1882	17	1848
92	8	13	1860	18.4	1820
90	10	17.18	1802	17.4	1765

Table 3: Compaction Characteristics of Lateritic Soil Treated with Terrasil

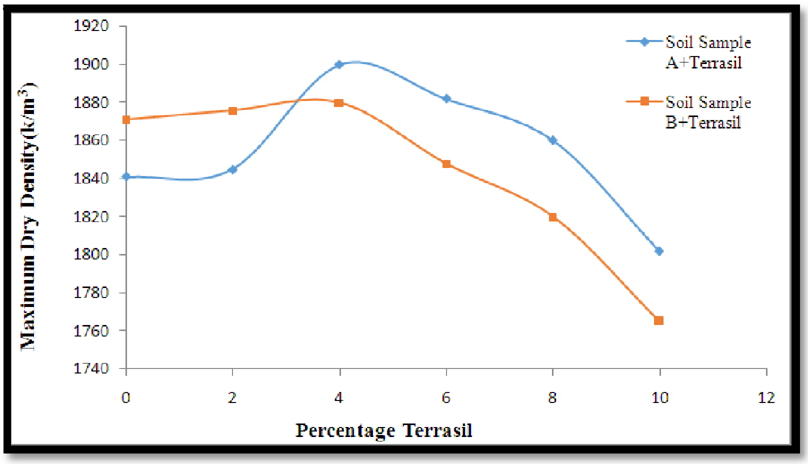

Figure 6: Variation of MDD with Increase in Terrasil on Soil

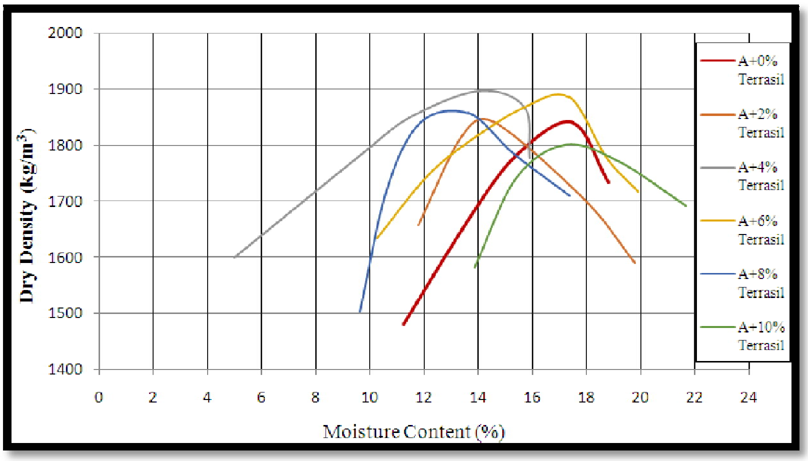

Figure 7: Compaction Curves for Terrasil-Treated Soil Sample A

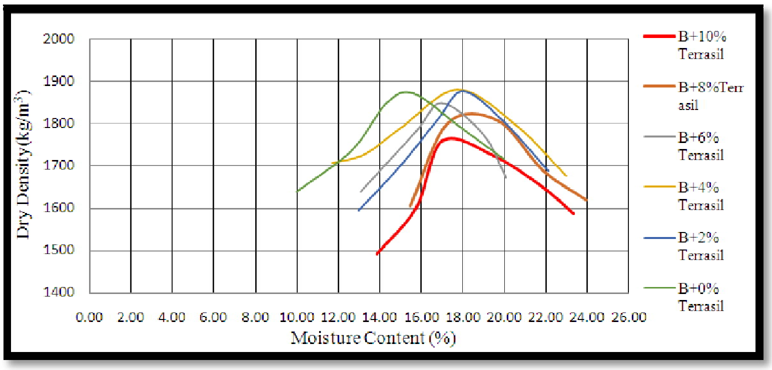

Figure 8: Compaction Curves for Terrasil-Treated Soil Sample B

3.3. Unconfined Compression Strength (UCS) of Treated Soil Samples

The results of the Unconfined Compression Test conducted on the treated samples are summarized in Table 4, For Sample A, an increase in the percentage of Terrasil in soil sample shows an increase in strength, from 200kPa at 0% additive to 351kPa at 4% additive. Further increase in additive from 6% exhibited a decrease in the values of UCS. UCS test on treated sample B also increased with increase in additive up to 4% and decreased in strength on further increase in the proportion of the additive in the soil sample. This decrease in strength could be as a result of chemical reaction taking place between the additive and soil minerals. The variation of UCS of the treated soil with increase in percentage of Terrasil is displayed in Figure 9.

Lateritic Soil (%)	Terrasil(%)	UCS (kPa)	Shear Strength((kPa)	Strain(%)	UCS (kPa)	Shear Strength(kPa)	Strain(%)
			Sample A			Sample B	
100	0	200	100	3.33	240	120	1.1
98	2	230	115	8.67	243.88	121.94	8
96	4	351	175.5	4.67	258	129	3
94	6	254.48	127.24	4	223	111.5	7.8
92	8	202	101	2.43	174.84	87.42	1.07
90	10	178.58	89.29	9.33	124.59	62.3	6

Table 4: Unconfined Compression Strength of Lateritic Soil Treated wth Terrasil

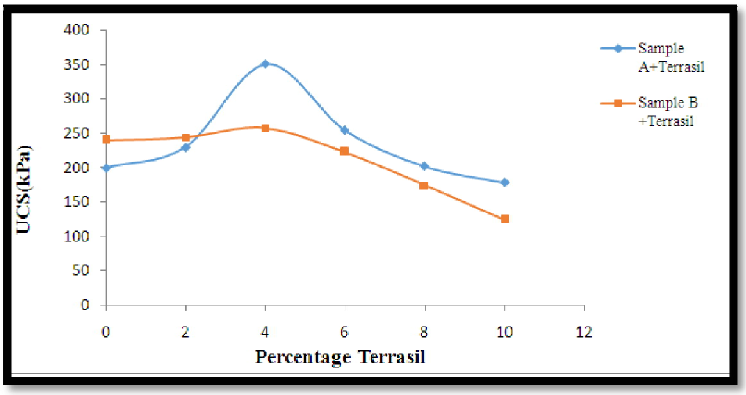

Figure 9: Variation of UCS with Increase in Terrasil on Soil Sample A and B

3.4. California Bearing Ratio (CBR) of the Treated Soil Samples

The CBR test was conducted on Terrasil-treated and un-soaked lateritic soil samples A and B to evaluate the force per unit are a required to penetrate the treated soil mass with standard circular piston at the rate of 1.25 mm/min. Results of the CBR test soil Sample A showed an increase in strength from its natural value of 11.5% to 34.9%. at 4% of the additive, Sample 'B' increased from 8.8% to a maximum value of 28.6% at 6% of Terrasil. A decrease in CBR was observed on further additions of the additive beyond 4% for soil Sample A and 6% for sample B. These decreases in strengths could be attributed to the reaction of the substance with soil. The results are summarized in Table 5. The variation of CBR with percentage increase in amount of additive in the soil samples A and B is shown in Figure 10. The Federal Ministry of Works standard specification states that the "sub-base type 2"material shall have a minimum CBR of 20% and the "sub base type 1" material shall have a minimum CBR of 30%(NBBR,1983).The test results show that treated samples A and B have CBR values greater than 20% and up to 30% and can therefore be used as "sub-base type 1 and 2" material in road construction and consequently, they are also suitable as subgrade materials. However, both treated samples have CBR less than 80%, they are therefore not suitable for use as road base materials

Soil Treated with Terrasil		California Bearing Ratio(CBR)%	
Lateritic Soil (%)	Terrasil (%)	Sample A	Sample B
100	0	11.5	8.8
98	2	19.8	15.3
96	4	34.9	31.7
94	6	32.2	28.6
92	8	25.9	22.7
90	10	24.8	20.9

Table 5: California Bearing Ratio (CBR) of Lateritic Soil Treated with Terrasil

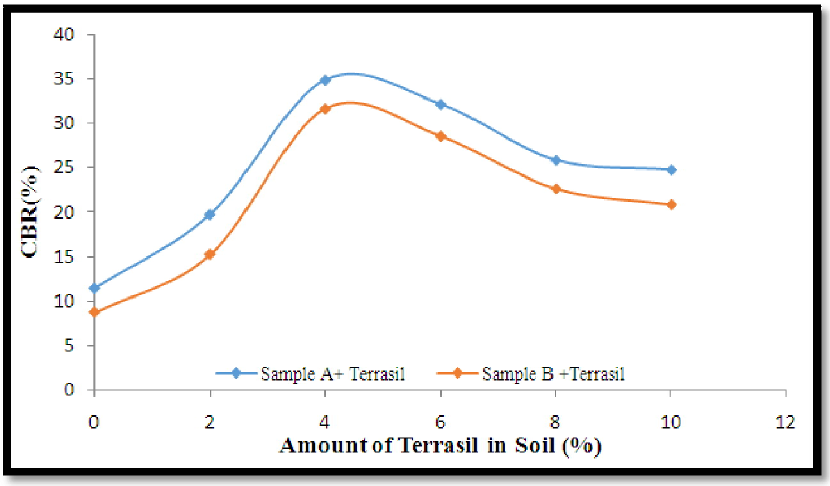

Figure 10: CBR against Percentage of Additive in Soil

4. Conclusions

Results of the CBR test soil sample A showed an increase in strength from its natural value of 11.5% to 34.9%. at 4% of the additive; sample 'B' increased from 8.8% to a maximum value of 28.6% at 6% of Terrasil. A decrease in CBR was observed on further additions of the additive beyond 4%. for soil sample 'A' and 6% for sample B. These decreases in strengths could be attributed to the reaction of the substance with soil.The test results shows that treated samples A and B have CBR values greater than 20% and can therefore be used as "sub-base type 2" material in road construction and consequently, they are also suitable as subgrade materials. However, both treated samples have CBR less than 80%, they are therefore, not suitable for use as road base materials. Treated sample B meets the requirements to be used as a 'sub-base type 2'This study has shown that treatment of lateritic soil with Terrasil improves the engineering properties of the tested soils by reducing their plasticity, and shrinkage characteristics and increasing their unconfined compression strength and shear strength. with this stabilizer, some of the unsuitable widely available soil materials could be improved and used for major construction works.

5. References

i. Aderinola,O.S.,and Nnochiri,E.S.(2017) 'Stabilizing Lateritic Soil Using Terrasil Solution',Selected Science Publications(SSP) -Journal Of Civil Engineering Vol. 12, Issue 1.pp 19-28

ii. Amu, O. O., Fajobi, A.B. and Afekhuai, S.O. (2005) "Stabilizing Potential of Cement and Fly Ash Mixture on Expansive Clay Soil," Journal of AppliedSciences, 5(9), 1669-1673

iii. British Standard 1377 (1990) Methods of Test for Soils for Civil Engineering Purposes, British Standards Institution, London.

iv. Lekha, B.M., Goutham, S. and Shankar, A.U.R (2015) "Evaluation of Lateritic Soil. Stabilized with Are canut Coir for Low Volume Pavement" Journal of Transportation Geotechnies, vol. 2, pp 20-29

v. Nigerian Building and Road Research Institute, NBRRI (1983). 'Engineering Properties of Black Cotton Soils of Nigeria and Related Pavement Design', NBRRI research paper 1,Nigerian Building and Road Research Institute, Lagos, Nigeria.

vi. Ola, S.A. (2013).Essentials of Geotechnical Engineering. University Press Pls.:Ibadan,471p

vii. Ola, S.A.(1978).The Geology and Engineering Properties of The Black Cotton Soils of North- EasternNigeria: Engineering Geology. Elsevier Scientific Publishing Company: Amsterdam

viii. Oluyemi-Ayibiowu, B.D and Ola,S.A.(2015) 'Stabilization Of Black Cotton Soils From North- Eastern Nigeria With Sodium Silicate' International Journal of Scientific Research and Innovative Technology. Vol. 2 No. 6 pp 190-203

ix. Prakash, K., Sridharan. (2004). Free Swell Ratio and Clay Mineralogy of Fine grained Soils. Geotech.Test. Journal. Vol. 27(2), 220-225

x. Sharma,V.(2016) Stabilization Of Black Cotton Soil Using Terrasil(Published Master's Thesis).National Institute Of Technology, Kurukshetra, India.

xi. Thagesen, B. (1996). Tropical rocks and soils: Highway and traffic engineering in the Utilization of Waste Materials for the Construction of Roads in Black Cotton Soil Areas,'High way Research Bulletin, 36, 1-11.

xii. Venkatramaiah, C.(2006). Geotechnical Engineering. New Age International (P), Ltd: New Delhi. 947p

xiii. Wright-Fox, R., Macfarlane, J.G. and Bibbens, R.F. (1993).Alternate Chemical Soil Stabilizer: Minor Research Report. 3rd Edition. Caltrans Publisher: London

xiv. Zydex Industries Ltd (2015). Water Resistant Bases For Paved Gravel/Soil Roads. Retrieved from:www.zydexindustries.com[accessed 20 March 2018]