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STRENGTH IMPROVEMENT OF LATERITE SOIL MIXED WITH HYDRATED LIME AND UNTREATED TEXTILE EFFLUENT AS AN ADMIXTURE FOR PAVEMENT CONSTRUCTION

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Abstract

This paper present a laboratory study to investigate the viability of utilizing textile effluent as an admixture on the strength characteristics of lime treated laterite soil. The soil used for this investigation is classified as A-7-6(12) in accordance with AASHTO soil classification system and CL in accordance with USCS. This group of soils is typically very poor for engineering use. Hydrated lime/textile effluent (TE) blend in stepped content of 0, 2, 4, 6 and 8% lime with 0, 25, 50, 75 and 100% TE concentration each by dry weight of soil was used to treat the soil. Compaction was carried out using British Standard Light (BSL) and the three criteria for the evaluation of strength (i.e. UCS, CBR and Durability) were considered. The UCS values of specimens treated with 6% lime/100% TE, 8% lime/ 25% TE and 4% lime/ 75% TE concentration increased from 335, 400 and 573kN/m^2 for the natural soil to 670.63, 991.00 and 1531.91kN/m^2 when cured for 7, 14 and 28 days respectively. The CBR values of 12.68 and 5.76% of the natural soil for unsoaked and soaked conditions increased to peak values of 56.68 and 49.71% at 6% lime/ 50% TE treatment, while the durability in terms of resistance to loss in strength increased from 9.36% for the natural soil to 71.77%. The strength and durability values also increased with curing ages, thus indicating that the blend has the potentials for time-dependent increase in strength due to utilization of this Industrial waste and will help reduce the quantity of lime required for construction purposes.

Keywords: California bearing ratio, Durability, Hydrated Lime, Laterite Soil,Textile Effluent Unconfined Compressive Strength.

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1.0 INTRODUCTION

Laterite is a highly weathered natural material, formed by concentrations of hydrated iron and aluminum oxides.This concentration can also occur due to residue accumulation or due to solution, movement and chemical precipitation. Laterite is found in tropical and subtropical regions of the world and deposits have been identified in six major regions of the world: Africa, India, Southeast Asia, Australia, Central and South America (CIRIA, 1988). Laterite formation occurs under weathering systems that give rise to the late method, the important characteristic of which is the decomposition of iron-aluminium-silicate minerals and the deposition of sesquioxides in the surface cut to form material ranges known to engineers and builders. (Gidigasu, 1976).

In Nigeria, laterite is employed as a road material and it forms the subgrade of most tropical roads, it's also used as sub-base and base for low cost roads that carry low to medium traffic. Furthermore, in rural areas of Nigeria, the soil is employed as a building material for the moulding of blocks and plaster works. Most Nigerian laterites are composed predominantly of Kaolinite clay minerals with some quartz. (Gidigasu, 1976). In some cases, they contain swelling clay mineral type like vermiculite, hydrated halloysite and montmorrilolite (Ola,1974). When laterite contains swelling clay mineral type, they are referred to as "problem laterite", reason being that they have the reputation of being problematic in construction (Gidigasu,1976). Generally, if laterite doesn't meet the planning and engineering requirements, they are meant for either modification or stabilization or a combination of both to enhance their engineering properties using additives.

Lime is one among the traditional stabilizers or additives that's best and widely utilized in engineering applications. Lime stabilization is similar to that of cement and produces similar results. Stabilization of soil using lime creates a highly alkaline environment which enhances the pozzolanic reaction and promotes the formation of calcium aluminate hydrate and calcium silicate hydrate, which bind the soil particles together. The addition of hydrated lime tends to reduce the swelling potential, Atterberg limits, maximum dry density of the soil, while the optimum water content and shear strength increases (Sherwood, 1993; Bell, 1996; Amer *et al.*, 2005; Ramesh and Mamatha, 2010; Basma and Tuncer, 1991). On the other hand, the production of any calcium-based material like lime involves the calcination of carbonate. This calcination process occurs at very high temperatures and the process is liable for a substantial percentage of CO_2 emission additionally to high energy consumption (Birchal *et al.*, 2000; Shand, 2006).

Overtime, conventional stabilizers like cement and lime are the most used stabilizing agents for improving soil properties. Due to the sharp rise in energy costs during the 1970s, the price of these materials has increase substantially (Neville, 2000). Hence, the over-reliance on the use of those commercially produced soil-improving additives has maintained the financial value of building stabilized roads, while also increasing the emission of CO2, a greenhouse gas that is harmful to the environment and is one of the causes of environmental pollution and global warming. (Aboubakar *et al.*, 2013; Kolovos *et al.*, 2013; Justice, 2005). In this regard, attempts are made by numerous researchers to seek out suitable and eco-friendly ways towards economic utilization of both agricultural and industrial wastes for engineering purposes in order to minimise their safe disposal and as well preserve the natural resources.

Textile effluent is an industrial wastewater of the textile mill. Effluents from this mill is one among the foremost chemically intensive industries of the world and a serious polluter of water (Ntuli *et al*., 2009, Shivam *et al*., 2015). The textile mill consumes large quantities of water (200m^3/tonne of product) and generate significant volumes of effluent (~90% of consumed water) (Verma *et al*., 2012). This wastewater is produced in large volume in many parts of the planet, including Nigeria. It emits a wide sort of pollutants arising from the chemicals and insoluble substances from all stages within the processes of textile production. The chemicals utilized by textile mills all depends on the nature and type of raw materials used and the final Fabric expected (Aslam *et al*., 2004). Therefore, the use of untreated textile effluent as an admixture in soil stabilization which can enhance the strength properties of soil and reduce the cost of stabilization process and the impact of the textile mill effluent is been evaluated.

2.0 REVIEW OF RELATED LITERATURE

From literature, numerous researchers have undertaken studies on the use of Textile effluent on the stabilization of different type of soils**.** Sani *et al*. (2021) have presented the effect of untreated textile effluent on some geotechnical properties of hydrated lime treated lateritic soil. They have carried out tests to determine the specific gravity, Atterberg limits and compaction test using different efforts. Their results inferred that the textile effluent showed positive effect on the properties of the lime treated soil. Narasimha and Indiramma (2009) have reported the effect of textile mill effluent on some geotechnical properties of expansive soil. From their work, they considered moisture-density relation, plasticity, swelling and strength characteristics such as California bearing ratio and Unconfined compressive strength values. The results of their study revealed that using textile effluent increased the stability of the soil mass (strength).

Faustinus *et al*. (2023) in their investigation aimed at evaluating the impact of different compaction efforts on the strength behavior of Hydrated lime treated laterite soil admixed with untreated textile mill effluent. Some laboratory tests such as California bearing ratio (CBR), Unconfined compressive strength (UCS) and Durability assessment using different compaction efforts, namely; British Standard Light (BSL), West African Standard (WAS) and British Standard Heavy (BSH). They found that there are potentials of using textile effluent for improvement of the strength properties of deficient soils. Thus, from their findings, the combination of 6% lime/50% TE and 8% lime/50% TE suggest it will really improve the stabilization of soils to be used as a sub-base material.

Narasimha and Chittaranjan (2012) have evaluated three types of effluent, namely; Textile, Tannery and Battery effluents on the moisture-density relation, California bearing ratio, Unconfined compression strength and Triaxial shear strength of expansive black clay soil. From their findings, they concluded that the optimum moisture content (OMC) and the maximum dry density (MDD) increased and decreased when the soil was treated with textile and battery effluents respectively. But, on utilizing the tannery effluent the OMC and MDD decreased and increased respectively. Owing to these, the strength characteristics of all test values were enhanced by the different effluents.

Shehzad *et al*. (2015) have studied the variation of different effluent concentration on some index and engineering properties of plastic clay. As a result of step increment in concentration of 0, 5, 10 and 20% of the effluents, the liquid limit, angle of internal friction and cohesion decreased, while the compressibility and void ratio increased respectively. Shivaraju *et al*. (2017) have used acidic effluent from a silk dyeing industry to evaluate its effect on the strength characteristics and moisture-density relationship of expansive black cotton soil. The acidic effluent was observed to marginally improves the maximum dry density (MDD) and Unconfined compressive strength (UCS) value to optimal strength values at 60% concentration, while the optimum moisture content (OMC) decreased.

Mallikarjuna *et al*. (2008) examined the influence of spent orange dye effluent obtained from a textile mill on the properties of clayey soil. In their study, a series of laboratory tests such as Potential of hydrogen; pH, Atterberg limits, coefficient of consolidation and X-ray diffraction were carried out at varying curing periods. From their findings, they discovered the effluent and its constituents induced cementitious/bonding and flocculation to the soil resulting in improved engineering properties. The liquid limit, plastic limit and coefficient of consolidation with no swelling pressure increases, while the pH and plasticity index decreases. X-ray diffraction studies reveals that the clay mineral present in the soil reacted with the effluent which lead to formation of new unidentified amorphous chemical substances which positively enhanced the properties of the clayey soil.

Chetan (2017) carried out an investigation on the effect of an industrial textile effluent on both laterite and expansive soils. The tests carried out and analysed are Atterberg limits, compaction and unconfined compression strength. Based on the results obtained, it can be concluded that the liquid limit, plastic limit and maximum dry density of the laterite and expansive soils increased and decreased, respectively with increase in effluent concentration. He also found that with increase in the concentration of the effluent, the unconfined compression strength values of both soils increased. While the optimum moisture content of the laterite and expansive soils decreased and increased, respectively with the addition of the effluent.

3.0 MATERIALS AND METHODS

3.1 Materials

3.1.1 Soil

The soil used for this study is laterite soil and was obtained by method of disturbed sampling from a lateritic soil formation located in Shika, Zaria, Kaduna state, Nigeria (Latitude $11^0 15'$ N and longitude $7^0\ 45'$ E). The soil sample was collected at depths between 1.5 and 2.0 m corresponding to the B – horizon usually characterized by accumulation of material leached from the overlying A - horizon. The samples were collected in large bags while a sizeable quantity was collected and sealed airtight in a polythene bag in order to obtain the natural moisture content immediately upon returning to the laboratory. The soil bags were then transported to the Department of Civil Engineering Geotechnics Research Laboratory, Nigerian Defence Academy, Kaduna, Nigeria; thereafter,the soil samples were air-dried and pulverizing to obtain particles passing BS No. 4 Sieve (4.75 mm aperture). The oxide composition of the soil was determined using the method of Energy Dispersive X – Ray Florescence and is shown in Table 1.

3.1.2 Lime

The lime used for the study is hydrated lime and was purchased from a chemical shop at Bayyajidda street, Kaduna central market, Kaduna. Nigeria. The oxide composition of the hydrated lime was determined at the National Steel Raw Materials and Exploration Agency (NSRMEA), Malali, Kaduna, by method of Energy Dispersive X – Ray Florescence.

3.1.3 Textile Effluent

The Textile effluent was obtained from African Textile manufacturers limited located at Challawa industrial estate. The Mill lies between latitude 11^{o} 53$'$ N and longitude 8^{o} 28$'$ E, in Kumbosto local government area of Kano state, Nigeria. The effluent was obtained fresh into dry, clean rubber containers after all textile production processes are complete from the outfall of the effluent discharge pipe. The chemical and physical characteristics of the effluent were determined at National Water Resources Institute (NWRI), Mando, Kaduna. The Effluent characteristics are shown in Tables 2 and 3.

3.2 Methods

The laboratory tests conducted on the natural and stabilized soils include, Particle size distribution, Specific gravity, Atterberg limits, Compaction, California bearing ratio (CBR), Unconfined compressive strength (UCS) for 7, 14 and 28 days curing periods and Durability. The tests were carried out in accordance with BS 1377 (1990) and BS 1924 (1990) for the natural and treated soil respectively. The California bearing ratio (CBR) tests were also conducted as recommended by Nigerian General Specifications for Road and Bridges (1997) with a CBR value of 180% to be attained in the laboratory for cement stabilized materials to be constructed by the mix-in-place method. The UCS and CBR tests were prepared at optimum moisture content (OMC) and compacted with British Standard light (BSL) effort. The resistance to loss in strength was determined as a ratio of the UCS of specimens cured for 7 days under controlled conditions, which were subsequently immersed in water for another 7 days to the UCS of specimens cured for 14 days.

3.2.1 Unconfined compression Strength Test

The unconfined compression strength (UCS) was determined following the procedure outlined in British Standards 1377 and 1924 (BSI 1990). The UCS was evaluated as :

$$UCS=\frac{\text{Load at failure}}{\text{Cross sectional area}} \qquad (1)$$

3.2.2 California Bearing ratio

The test was carried out in accordance with BSI 1377 and 1924 (1990) for the natural and treated soils. The specimens were cured for a period of 6 days and after the sixth day the specimens were submerged in portable water for 24 hours before testing as specified by Nigerian General specifications for Road and Bridges (1997). The CBR was calculated as:

$$CBR=\frac{\text{Measured load}}{\text{Standard load}}x100 \qquad (2)$$

3.2.3 Durability

The durability is a measure of the resistance to loss in strength. The durability assessment of the Soil-lime-TE treated soil used in this study is proposed by (Ola,1983). It is the ratio of unconfined compression strength (UCS) of specimen wax-cured for 7 days, and then de-waxed upper and lowest cross section of specimen to allow for water absorption in water tank for another 7 days to the UCS of specimen wax-cured for 14 days (Ola, 1983; Osinubi, 2006). The resistance to loss in strength was calculated as:

Resistance to loss in strength =

$$\frac{\text{UCS (7 days cured+7 days soaked)}}{\text{UCS (14 days cured)}} X\, 100 \quad (3)$$

4.1.1 Properties of the Natural Laterite soil

The results of the index properties of the natural soil used is summarized in Table 4. The soil is classified as A-7-6 (12) according to AASHTO soil classification system (AASHTO, 1996) as well as CL soil in the Unified Soil Classification System, USCS (ASTM, 1992). The virgin soil is adjudged to be clay of low plasticity that is poor to be used for construction purposes. Its particle size distribution curve is shown in figure 1.

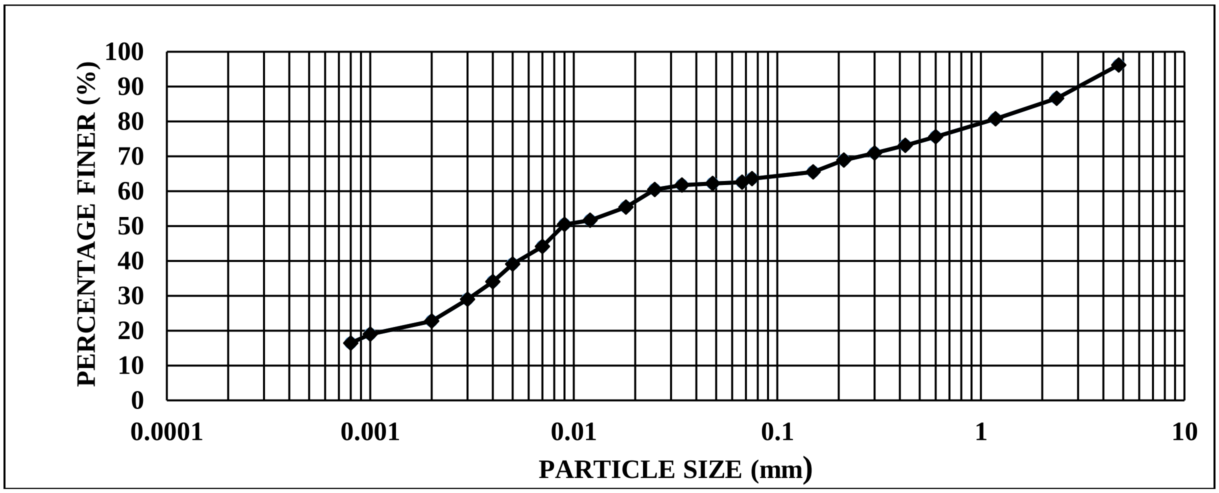

Figure 1: Particle size distribution curve of the natural laterite soil

Table 1: Oxide Composition of Natural soil and Hydrated Lime

ELEMENTAL OXIDE	COMPOSITION (%).	
	Natural soil	Hydrated Lime
SiO_2	41.05	3.61
AL_2O_3	24.16	4.57
Fe_2O_3	10.16	0.25
Cao	0.23	48.32
MgO	0.21	2.27
SO_3	1.04	0.01
Na_2O	1.37	1.22
K_2O	0.34	2.00
TiO_2	0.39	0.09
P_2O_5	1.32	0.20
MO_2O_5	0.02	0.01
Rb_2O_5	0.27	0.01
PbO	0.01	ND
Cr_2O_3	0.02	0.01
MnO	ND	0.01
LOI	19.35	37.02

Table 2: Chemical Characteristics of Textile Effluent

PARAMETER	CONCENTRATION MEASURED (mg/l)	MAXIMUM PERMISSIBLE LEVELS FOR DRINKING WATER QUALITY	
		WHO	NSDWQ
Nickel ; Ni	4.975	0.07	0.02
Chromium; Cr	7.040	0.05	0.05
Cadmium; Cd	0.162	0.003	0.003
Lead ; Pb^+	1.204	0.01	0.01
Magnesium ; Mg	2.667	0.20	0.20
Sodium ; Na^+	3393	50	200
Calcium ; Ca^+	21.79	200	200
Potassium ; K^+	179.03	120	110
Zinc ; Zn	0.100	4	3
Copper ; Cu	0.311	2	1
Iron ; Fe^{2+}	10.30	0.30	0.30
Chloride ; Cl^-	190	200	250

Sulphate ; SO_4^{2}	90	250	100

Table 3: Physical Characteristics of Textile Effluent

PARAMETER	CONCENTRATION MEASURED	MAXIMUM PERMISSIBLE LEVELS FOR DRINKING WATER QUALITY	
		WHO	NSDWQ
pH	12.80	6.5-8.5	6.5-8.5
Colour (Hazen)	6.0	15	15
Turbidity (NTU)	210	5	5
Total dissolved solids (mg/l)	2950	500	500
Total Alkalinity (mg/l)	2230	500	-
Total suspended solids (mg/l)	1260	30	-
Biochemical oxygen demand	35	5	10
Chemical oxygen demand	1100	40	100
Electrical conductivity (µs/cm)	6010	1000	1000
Dissovled oxygen	110	< 8	100
Specific gravity	1.001	-	-

Table 4: Physical properties of the natural soil used for the study

PROPERTY	QUANTITY/DESCRITION
Percentage passing BS sieve No. 200 (%)	64.00
Natural moisture content (%)	16.70
Liquid limit (LL) (%)	47.00
Plastic limit (PL) (%)	27.30
Plasticity index (PI) (%)	19.70
Linear shrinkage (LS) (%)	11.43
Specific gravity	2.66
AASHTO classification	A-7-6
USCS	CL
Group index (GI)	12
pH	7.65
CEC (Cmol/kg)	0.56
Maximum dry density (MDD) (mg/m^3)	1.68
Optimum moisture content (OMC) (%)	20.20
Unconfined Compressive Strength (kN/m^2)	335.25
California Bearing Ratio (Unsoaked) (%)	12.68
California Bearing Ratio (24 hours soaking) (%)	5.76
Color	Light Brown
Dominant clay mineral	Kaolinite

4.1.2 Unconfined compressive strength

The variation of unconfined compressive strength (UCS) with textile effluent (TE) concentration for laterite soil – lime mixtures are shown in Figures 2 - 4 for 7, 14 and 28 days curing periods, respectively. Generally, the strength of the laterite soil increased with higher lime content/ textile effluent concentration blend and curing period. Thereafter, with increment in TE the UCS values decreased. The increase in UCS or (the gain in strength) is due to the formation of cementitious products, such as calcium silicates hydrate (CSH), calcium aluminate hydrate (CAH) and micro fabric changes which are responsible for strength development (Ingles and Metcalf, 1972; Jones and Holt, 1973; Osinubi *et al.*, 2011 and Negi *et al.*, 2013). Peak UCS values were recorded from 335, 400 and 537kN/m^2 for the natural soil to 670.63, 991 and 1531.91kN/m^2 for treatment with 6%L/100% TE, 8%L/25% TE and 4%L/75% when cured for 7, 14 and 28 days respectively. However, the subsequent decrease in UCS could be probably because of insufficient water needed to bring the pozzolanic reaction to completion. Although, the UCS values increased with higher curing period but fell short of the 7 days UCS value of 1720kN/m^2 specified by (TRRL, 1977) as criterion for adequate stabilization using Ordinary Portland Cement for a stabilized base course. The strength of 991 and 1531.91kN/m^2 at 14 and 28 days however, showed that the strength development of Lime/TE treated soil is a slow process and a longer period is required to attain the required strength.

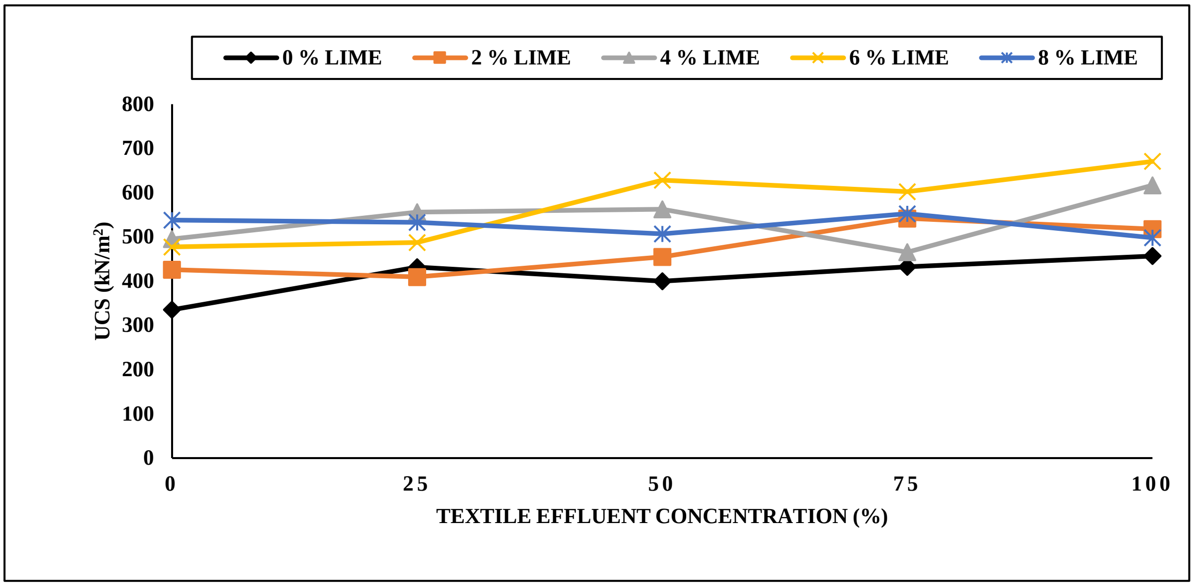

Figure 2: Variation of Unconfined compressive strength (7 days curing period) of soil-lime mixtures with textile effluent concentration

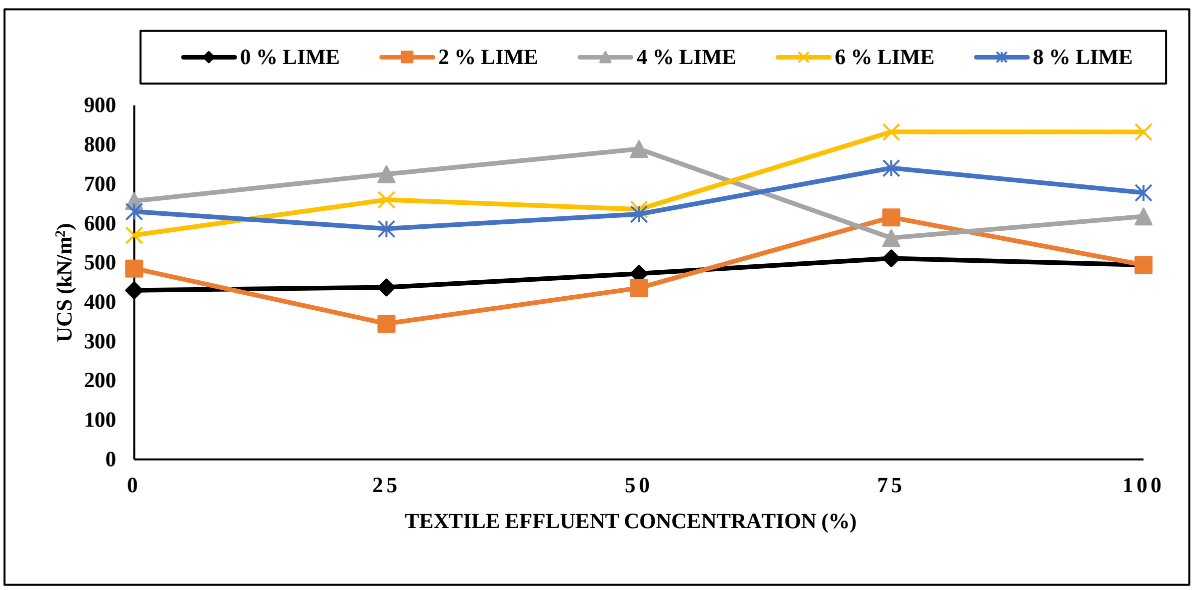

Figure 3: Variation of Unconfined compressive strength (14 days curing period) of soil-lime mixtures with textile effluent concentration

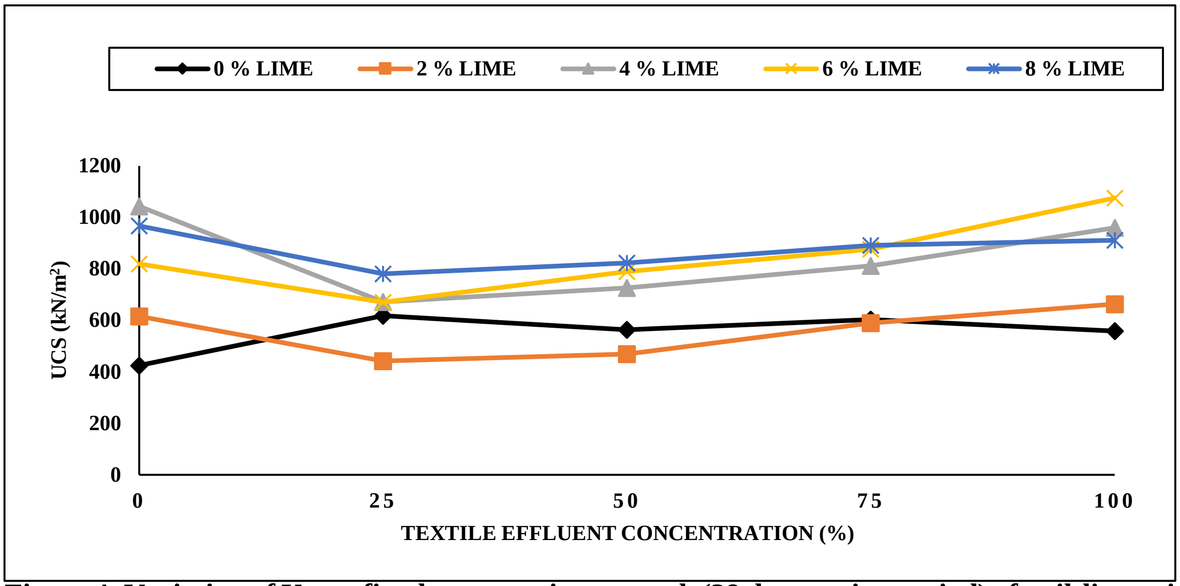

Figure 4: Variation of Unconfined compressive strength (28 days curing period) of soil-lime mixtures with textile effluent concentration

.1.3 California bearing ratio

The California bearing ratio (CBR) value of a soil/stabilized soil is an important parameter used to indicate its strength and bearing capacity for base and subbase in pavement structure. Lime stabilized soils are often used for the construction of these pavement layers and also for embankment. The CBR is therefore a familiar test used to evaluate the strength of soils for these applications. The results presented in Figures 5 and 6 shows the variation of unsoaked and soaked California bearing ratio (CBR) of laterite soil lime with textile effluent concentration. The CBR values of the natural soil is 12.68 and 5.76% for unsoaked and soaked conditions, respectively. The unsoaked CBR value increased to a peak value of 56.68% at 6% lime/50% TE and progressively decreased to 50.38% at 8% lime/100% TE. For the soaked condition, CBR value increased to a maximum value of 49.71% at 6% lime/50% TE concentration and linearly decreased to a CBR value of 40.75% at 8% lime/100% TE concentration.

The reason for the improvement in the strength for the unsoaked condition was due to adequate amount of calcium from admixing lime with effluent for the formation of calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH) which are the major compounds responsible for strength gain (Faustinus *et al.*, 2023; Amadi and Okeiyi, 2017; Nnochiri and Aderinlewo, 2016; Khemissa and Mahamedi, 2014; Koteswara *et al.*, 2012). The lower values of soaked CBR recorded in comparison to the unsoaked CBR values were due to the ingress of water into the specimen that reduced their strength. The Nigerian General Specification for Roads and Bridges (1997) specifies that a CBR value of 180% should be attained in the laboratory for cement stabilized material to be constructed by the mix-in-place method, while it did not state the value for lime treated soil. Usually, a minimum CBR value of 60 to 80% is required for Bases course and from 20 to 30% for Sub-bases course when both are compacted at optimum moisture content and 100% intermediate/West African Standard (Gidigasu and Dogbey, 1980; Gidigasu,1982;

Osinubi, 2001). However, the minimum conventional CBR values for lime treated soils of 40, 80 and 100% (Standard Proctor or British Standard light) for sub-base, base (lightly trafficked roads) and base (heavy trafficked roads) respectively, were adopted by (Osinubi, 2006) to evaluate the strength of soil lime mixtures. Based on the criteria adopted for lime treated soil it can be inferred that at 6 % lime/ 50 % TE treatment, the soil lime-TE mixture can be used for sub-base course of lightly trafficked road when compacted with British Standard light (BSL) effort.

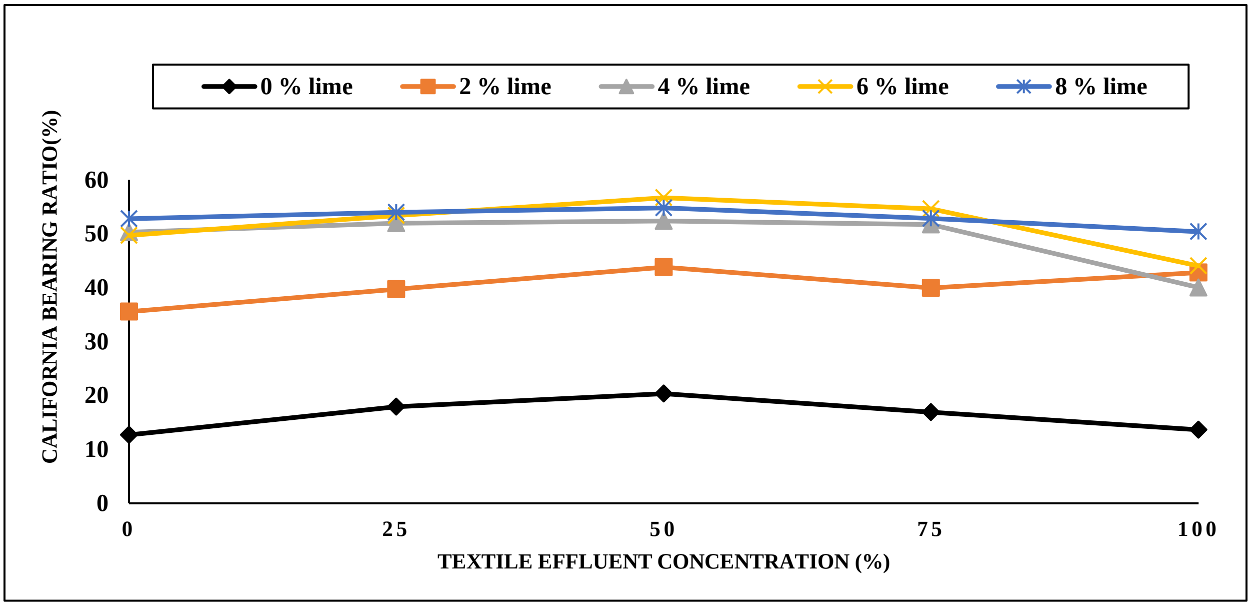

Figure 5: Variation of California bearing ratio (Unsoaked condition) of soil-lime mixtures with textile effluent concentration

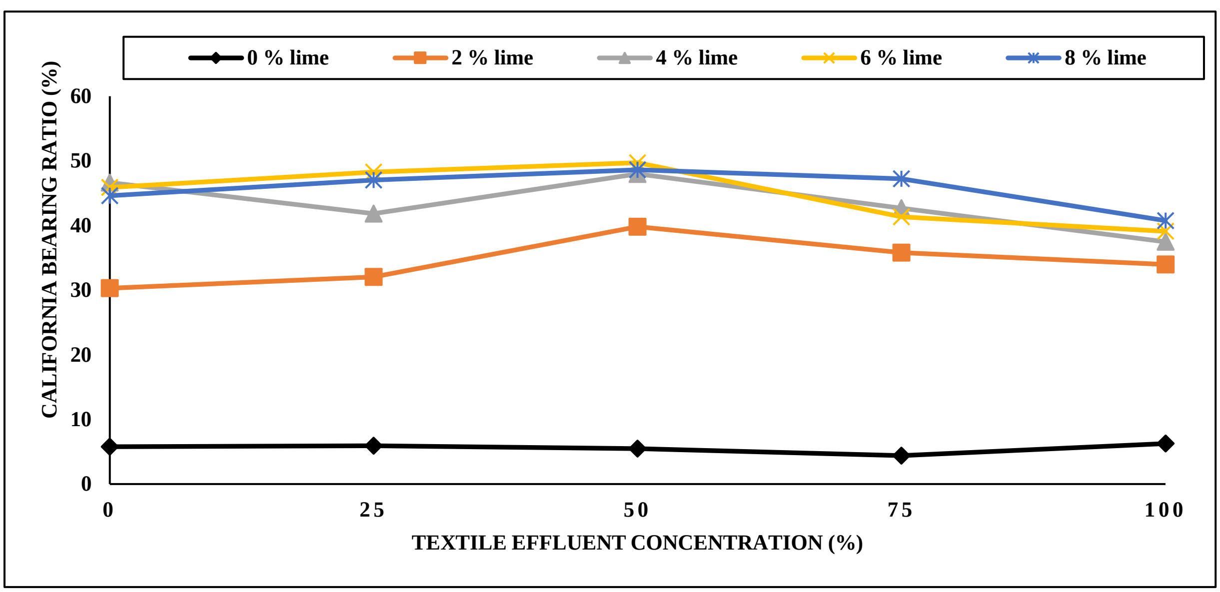

Figure 6: Variation of California bearing ratio (Soaked condition) of soil-lime mixtures with textile effluent concentration

4.1.4 Durability

The variation of resistance to loss in strength of the soil-lime mixture with textile effluent concentration is shown in figure 7. It was proposed by (Ola, 1983), that an allowable 20% loss in strength (i.e. 80% resistance to loss in strength) should be recommended for a specimen cured for 7 days and immersed in water for 4 days. However, specimens for this study were exposed to a harsher condition of 7 days soaking periods and not 4 days (Ola, 1983). The resistance to loss in strength for the laterite soil initially increased with increment in textile effluent at 25% effluent and thereafter decreased, but with further increase in the concentration of effluent there was an increase from the natural soil value of 9.36% to a peak value of 71.77% (i.e. 28.23% loss in strength) at 8% lime/100% TE concentration. The recorded loss in strength was more than the maximum 20% allowable loss in strength. The peak resistance to loss in strength of the treated soil is low compared to the allowable value, but considering the harsher condition these specimens were subjected to, the treated soil could be use as a Sub-base course material.

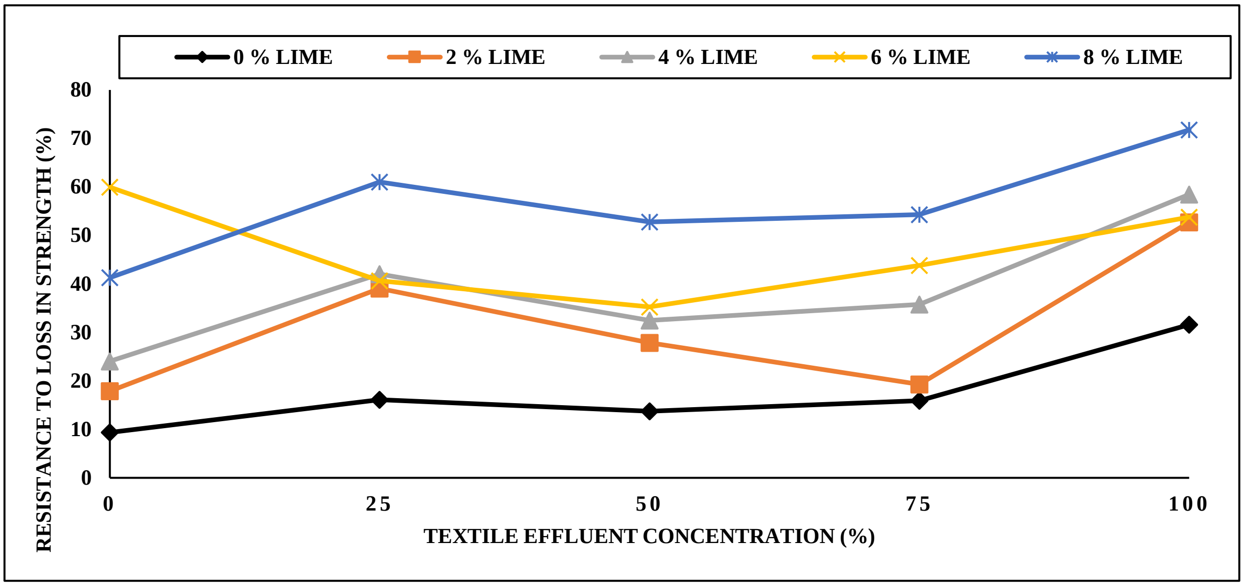

Figure 7: Variation of resistance to loss in strength of laterite soil-lime mixtures with textile effluent concentration

5.0 CONCLUSION

The ever increasing cost of construction materials in Nigeria and other developing countries has created the need for research into locally, eco-friendly, accessible materials and also on how to convert waste to wealth. This work evaluated the strength improvement of laterite soil mixed with hydrated lime and untreated textile effluent (TE) which is considered a textile mill waste water for use in construction and soil improvement. The strength properties of the lime stabilized matrix (California bearing ratio, Unconfined compressive strength and Durability) all increased with increment in the textile effluent concentration. So, using textile effluent as an admixture in soil stabilization will produce highly positive outcomes in terms of using lime in the stabilization of deficient soils, solving the problems posed by the disposal of industrial effluents. In view of the foregoing, textile effluent showed and confirmed to be a good admixture in soil stabilization with hydrated lime. Based on the results, it is recommended that treatment with a combination of between 2% lime/50% TE and 6% lime/50% TE concentration could be used for treatment of the laterite soil to achieve a sub-base material when compacted with British Standard light (BSL) compaction effort.

REFERENCES

CIRIA (1988). 'Laterite in roads pavements'. Construction Industry Research and Information Association, Special Puplication, No. 47, 71.

Gidigasu, M. D. (1976): "*Laterite Soil Engineering-Pedogenesis and Engineering Principles- Developments in Geotechnical Engineering."* Elsevier ScientificPublishing Company, Amsterdam, 9: 554.

Ola, S. A. (1974)."Need for estimated cement requirement for stabilizing lateritic soil." J. Transport Div., ASCE, Vol. 17, No 8, 379-388.

Sherwood P.T. (1993). "Soil stabilization with cement and lime". State-of the- art review. Transport Research Laboratory, London: Her Majesty's Stationery Office, 67, 54-61.

Bell F.G.(1996)."Lime stabilization of clay minerals and soils".Engineering Geology,42, 223- 237.

Amer A. A., A.W. Hago, Hilal A.(2005) ."Effect of lime, cement and Sarooj on the swelling potential of an expansive soil from Oman". Building and Environment, 40, 681–687.

Ramesh H.N. and Mamatha H.V. (2010) ." Compaction and strength behavior of lime-coir fiber treated Black Cotton soil". Applied Clay Science, 17(4), 73–75.

Basma A.A., Tuncer E.R. (1991): "Effect of lime on volume change and compressibility of expansive clays". Transportation Research Board, Washington DC,TRR No.1296, 54 – 61.

Birchal, V.S.S., Rocha, S.D.F. and Ciminelli, V.S.T (2000). The effect of magnesite calcination conditions on magnesia hydration. Miner. Eng., 13(14 -15), 1629 – 1633.

Shand, M.A., (2006). The Chemistry and Technology of Magnesia. Wiley – Interscience, New York.

Neville, A.M. (2000). Properties of Concrete'' 4th ed (low-price ed.). Pearson Education Asia publication Ltd, Kuala LUMPUR, Lumpur, Malaysia.

Aboubakar, M.A., Ganjian, E., Pouya, H., Akashi, A. (2013). A study on the effect of the addition of thermally treated Libyan natural pozzolan has on the mechanical properties of ordinary Portland cement mortar. *International journal of Science and Technology*. Vol.3, No. 1, 79 – 84.

Kolovos, K.G., Asteris, P.G., Cotsovos, D.M., Badogiannis, E., Tsivilis, S. (2013). Mechanical properties of soilcrete mixtures modified with metakaolin. *Construction and Building Materials*. Vol.47, 1026 – 1036. https://doi.org/10.1016/ j.conbuildman.2013.06.008.

Justice, J.M. (2005). Evaluation of metakaolin for use as supplementary cementitious. An *Unpublished MSc thesis*. School of Material Science and Engineering, Georgia Institute of Technology.

Ntuli, F., Omoregbe, I., Kuipa, P., Muzenda, E., Belaid, M. (2009). Characterization of effluent from textile wet finishing operations. WCECS 1

Shivam, L., Garima, G., Snehel, S. and Surbi, H. (2015). " Textile waste water – A thread to Jodhpur." International Journal of Engineering Research and Technology (IJERT), Vol. 3. Issue 23.

Verma A.K, Dash R.R., Bhunia P. (2012). A review on chemical coagulation/ flocculation technologies for removal of color from textile wastewater, Journal of Environmental management, 93, 154- 168.

Aslam, M.M., Baig, M.A., Hassan, I., Qazi, I.A., Malik, M., Saeed, H., (2004). Textile wastewater characterization and reduction of its COD and BOD by oxidation, *EJEAF CHE.*, 3, 804-811.

Sani, J.E., Faustinus, B., Munta, S. and Ijimdiya, T.S. (2021). "Effect of Untreated Textile Effluent on some Geotechnical properties of Lime treated Lateritic Soil." Taraba Journal of Engineering and Technology (TAJET) 2 (1), 29 – 36.

Narasimha, R. A.V and Indiramma, P., (2009). Effect of textile effluent on the geotechnical properties of black cotton soil. Proceedings of Indian Geotechnical conference, Guntur, India. IGC, 308-311.

Faustinus, B., Sani, J.E., Omolara, K.K. and Ijimdiya, T.S. (2023). "Influence of compactive effort on the strength characteristics of lime treated laterite soil mixed with untreated textile effluent". Nigerian Journal of Technology (NIJOTECH). Vol. 42. No. 2, June, 199 – 208.

Narasimha, R. A. V and Chittaranjan, M. (2012). ''Effect of certain industrial effluent on the compaction characteristics of expansive soil."International Journal of engineering inventions, Vol.1, issue 7, 22-28.

Shehzad, A., Khan, A.H., Rehman, Z.U. (2015). "Characteristics of low plastic clay contaminated by industrial effluents." *Int/J Adv Struc. Geotech. Eng.* 04, 138 – 147.

Shivaraju,R., Ravishankar, B.V. Nanda, H.S., Sivapulliah, P.V. and Krishna, K.V.M. (2017). "Effect of Acidic dyeing effluent on the compaction and strength behavior of expansive black cotton soil." International Journal for Research in Engineering Application and Management. Vol.3. Issue 9, 23 - 29.

Mallikarjuna, R.,Tirumala, R. and Reddy, B (2008). "On interaction of a clayey soil with textile dye waste." Electronic Journal of Geotechnical Engineering (EJGE), Vol. 13.

Chethan, K. (2017). "The effect of industrial effluent interaction with both laterite soil and expansive soil." International Journal of advance research and development. Vol. 2, issue 3.

B.S. 1377 (1990)."Methods of testing soil for civil engineering purposes". British Standards Institute, London.

B.S. 1924 (1990). "Methods of testing for stabilized soils." British Standards Institute, London.

Nigerian General Specifications (1997): Roads and Bridges. Federal Ministry of Works and Housing Headquaters, Abuja, Nigeria.

Ola, S. A. (1983)."The geotechnical properties of laterites of North Eastern Nigeria." Ola, S., Ed., *Tropical Soils of Nigeriain Engineering Practice,* Balkema, Rotterdam, 178 - 260.

Osinubi, K.J. (2006)," Influence of compactive efforts on lime-slag treated tropical black clay." Journal of Materials in Civil Engineering, ASCE, Vol. 18(2), 175 – 181.

AASHTO (1996). Standard Specification for Transportation Materials and Method of Sampling and Testing. 14th Edition, American Association of State Highway and Transportation Officials, Washington, D.C.

ASTM (1992) *Annual Book of Standards*, Vol. 08. American Society for Testing and Materials, Philadelphia.

Ingles, O.G and Metcalf, J.B. (1972). Soil stabilization - Principles and Practice. Butterworths, Sydney.

Jones, D.E and Holtz, J. (1973). "Expansive soils the hidden disaster" Civil Engineering, ASCE, Vol.43, 54.

Osinubi, K. J, Oyelakin, M. A and Eberemu, A. O. (2011). Improvement of Black Cotton Soil with Ordinary Portland Cement – Locust Bean Waste Ash blend. Electronic Journal of Geotechnical Engineering. 16: 619 – 627.

Negi, A.S., Faizan, M., Siddharth, D. P. and Singh, R. (2013). Soil Stabilization Using Lime.

TRRL (1977)."A guide to the structural design of bitumen surfaced roads in tropical and sub-tropical countries." *Transport and Road Research Laboratory, Road Note 31*, H. M. S. O., London.

Amadi, A.A. and Okeyi, A. (2017). ' Use of quick and hydrated Lime in stabilization of laterite soil: Comparative analysis of laboratory data.*" International journal of GeoEngineering,* TGS. 8(3), 1 – 13.

Nnochiri, E.S. and Aderinlewo, O.O. (2016). "Geotechnical properties of lateritic soil stabilized with periwinkle shell ash construction." International Journal of Advanced Engineering, Management and Science, 2(5), 484 – 487.

Khemissa, M. and Mahamedi, A. (2014). "Cement and Lime mixture stabilization of an expansive over consolidated clay." Applied Clay Science, 95, 104-110.

Koteswara, R., Anusha, M., Pranav, P. and Venkatesh, G. (2012). "A Laboratory study on stabilization of Marine Clay using Sawdust Ash and Lime". *International journal of Engineering science.* 2,(4), 851 – 862.

Gidigasu, M.D. and Dogby, J.L.K. (1980). "Geotechnical characteristics of Laterized decomposed rocks for pavement construction in dry sub-humid environment", Proc. 6th Southeast Asian Conf. on Soil Engrg. Taipei, Vol.1, 492 – 506.

Gidigasu, M. D. (1982)."Importance of material selection, construction control and field performance studies in developing acceptance specification for laterite paving gravels". Solos and Rocha, Rio de Janeiro, Brazil. Vol. 5 NO 1, 27 – 35.

Osinubi, K.J. (2001). "Influence of compaction energy levels and Delays on cement-treated soil.'' NSE Technical Transactions. Vol. 36, No. 4., 1 – 13.