Durability Characteristics of Lateritic Subgrade Treated with Iron Ore Tailings and Lime Exposed to Moisture Fluctuations

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Abstract

This research evaluated the durability of lateritic subgrade treated with Iron Ore Tailings (IOT) and lime exposed to moisture variations. Representative sample of the subgrade was treated with 0, 5, 10, 15, and 20% IOT and optimal lime percent (6.2%) determined through Eades and Grim pH test. Preliminary tests such as particles size distribution, Atterberg limits and compaction were conducted to characterize the mixtures while Unconfined Compressive Strength (UCS) and CBR-swell tests were carried out to access durability of the soil mixtures. Addition of lime to the soil increased the liquid limit to 45% from 36% obtained in natural soil. Similarly, the plastic limit of the lime-treated sample increased from 16 to 26% with reduced plasticity index. While the natural soil exhibited CBR of 3 and 75% for soaked and unsoaked specimens respectively, the value increased and peaked at 11 and 118% with addition of lime and 15% IOT. Durability of the soil improved with addition of IOT and lime. 15% IOT and lime treated soil recorded the best results with UCS of 240 kN/m2 and 200% Relative Volumetric Stability (RVS), which is a measure of strength loss of a soil. Similarly, swell value of 0% was recorded when the lime-IOT samples were subjected to CBR-Swell test. This shows that the lime-IOT treated samples are less vulnerable to moisture condition normally prevalent in the pavement subgrades.

Keywords: Iron Ore Tailings, Lateritic subgrade, Lime, Pavement durability

Introduction

Road transport is considered to be most patronized among other modes of transportation in developing countries such as Nigeria. This is largely owed to its large coverage, door-to-door service and affordability. It is estimated that road transport is responsible for about ninety percent (90%) of the national passenger and haulage services and provides the sole access to the rural areas (Adedeji *et al.*, 2014). However, efficiency of this highly-patronized mode of transportation is hampered as a result of incessant pavement failures resulting from materials of poor durability, poor workmanship, abuse by users and adverse environmental effect. Most of our roads, especially in rural areas, where the largest of our population resides are in very bad shape (Chidolue *et al.*, 2013). Adedeji *et al.* (2013) observed that most of our rural roads cannot be safely traveled at a speed exceeding 25-30 miles per hour.

Highway Engineers are often concerned with durability of road pavement especially when subgrades with volumetric instability are involved. For soil materials to be effective as pavement subgrades, it is essential for it to satisfy standard durability conditions especially in tropical regions where moisture conditions severely alternate (Andrew, 2008; Rushikesh, 2011; Amadi, 2014; Laura *et al.*, 2016).

Additives used in soil modification have been classified into two subgroups; reactive additives such as lime and self-cementing such as Portland cement, slag modified Portland cement and fly ash. Reactive additives chemically react with the clay content of the soil to produce desirable changes in the soil's engineering properties. Plasticity, workability, shrinkage-swell potential and strength of fine-grained soils can generally be improved with addition of lime. Demand for much more durable and, at the same time economic road structures have increased over time. This consequently resulted in the need for improved properties of pavement and subgrade materials. Such substances that could greatly enhance pavement and subgrade soil are cement, bituminous materials, lime, fly ash and alkali (Athanasapoulou and Kollarous, 2011).

According to Amadi (2014), it is essential to constantly improve the quality, strength and durability of roads. Bituminous roads have proven to be effective over time but has often been affected by temperature, rainfall, traffic load and land base which causes failures ranging from cracks, potholes and rutting. Sometimes, failures occur in the pavement materials or subgrade. Such failures can be curtailed by the use of additives like Recron-3S, Fly ash and lime which can be mixed with soil in various proportion (Nwadiogbu and Salahadeen, 2014).

Tests conducted by Elinwa and Maichibi (2014), tests conducted on mixture of Iron Ore Tailings (IOT) and Ordinary Portland Cement in accordance with British Standard Specification indicates pozzolanic activity of seventy-five (75%) percent. Vickrant *et al.* (2015) as well as Sofilic *et al.* (2015) stated that IOT can be a vital construction material if properly applied to specific needs. The menace of environmental degradation resulting from surface disposal of tailings waste will also be easily checked in so doing.

Francis (2015) concluded in his work on characterization and application of Iron Ore Tailings as building and construction materials that: the use of IOT in production of geopolymer bricks could yield products with compressive strength of as high as 50.35MPa and cost reduction of over thirty-six (36%) when compared to the use of traditional aggregates for production of similar products.

In this study, emphasis has been placed on the effectiveness of Iron Ore Tailings (IOT) and lime in curtailing the adverse effects of moisture on pavement subgrade.

Materials and Methods

Materials

Lateritic soil was obtained from a borrow pit in Minna, Niger state. The soil is reddish with little granular particles having more fines in the sampled mass. Presence of moisture in the soil was evident mainly due to the prevailing wet season. The present study evaluates the durability characteristics of the poor-quality lateritic subgrade treated with IOT and lime in an area where variation in moisture intensity is of serious concern.

Iron Ore Tailings (IOT); dark-colored sand-like iron ore waste generated upon removal of Iron concentrate was obtained from the National Iron Mining Company of Nigeria in Itakpe, Kogi State, Nigeria. The particle size ranges from fines of less than 75µm to small-sized sand-like particles of about 5mm.

Quick lime manufactured in whitish hard lumps form was obtained from a commercial supplier in Kaduna, Nigeria. The lime was pulverized to finer particles passing sieve No.40.

Methods

Preliminary tests such as natural moisture content and Atterberg limit tests were conducted in accordance with BS 1377 (1990) as well as Mittal and Shukla (1999).

California Bearing Ratio (CBR)

The CBR principle involves determination of relationship between force and penetration when a cylindrical plunger of standard cross-sectional area is made to penetrate a compacted or undisturbed soil mass at a given rate. The ratio of penetration force to standard force, expressed as a percentage, is termed California Bearing Ratio (CBR).

The apparatus are cylindrical metal mould, sample extruder, 4.5kg rammer, measuring cylinder, sample tray and the California Bearing Ratio testing machine.

The mould was assembled with its base plate and collar fitted to the mould. Six kilogram of the soil sample was weighed and water equivalent to the OMC was added and mix thoroughly.–The soil was then compacted in the mould in five layers with each layer receiving evenly distributed fifty-six blows. (BS 1377, 1990; Braja, 2010).

The compacted sample was placed on the CBR testing machine to record the readings for both ends of the specimen.

Optimum Lime Determination

The test is one the simplest but most reliable means of determining quantity of lime required for soil stabilization. Eades and Grim (1966), have established that most soils will require between 2 and 5 percent lime for optimum lime effect. Different soils possess distinctive optimum lime required for it to assume full pozzolanic potentials, that is: optimum reaction with soil.

To conduct the test, the target soil sample is air-dried and passed through sieve 0.425mm. 20g of the sieved soil is measured and added mixed with 150ml of distilled water in plastic bottles with screw tops. The prepared slurry was mixed with the trial proportions of Lime; 2, 3, 4, 5 and 6%. The bottles are agitated for thirty seconds (30s) every ten minutes for the first one hour (1hr). After one hour of consistent agitation, part the slurry is transferred into a plastic biker to take pH reading. The pH was recorded for each of the samples with various lime contents. From Eades and Grim (1966) test, the least percentage of lime that recorded pH of 12.40 or 2.30 is the optimum lime required to stabilize the soil.

Durability tests

The durability tests was carried out using Relative Volumetric Stability (RVS) and CBR-swell test.

Relative Volumetric Stability (RVS)

The unconfined compressive strength (UCS) test is the standard and most widely adopted test used to characterize stabilized soils and has been found to be a competent indicator of the durability of soils. (Amadi, 2014)

The loss of strength on immersion test was conducted according to the procedure described in the BS 1377, (1990).

5, 10, 15 and 20% of IOT and optimum lime were mixed with the soil to yield uniform mixtures; the mixtures are then compacted with British Standard Light (BSL) compaction effort. A cylinder-shaped mold with 38mm diameter and 76mm length was then driven through the compacted soil mixture to extract the required shape of specimen with the aforementioned dimensions for UCS test. The samples were sealed in polythene and air-cured for fourteen days at room temperature (20°C) after which they were immersed in water for another fourteen (14) days. Another set of identical specimens were prepared and air-cured for 28. At the end of 28 days curing, (14 days' air and 14 days' immersion in water for the treated samples and 28 days' air-curing for the control specimen), the cured specimens were tested in a load frame at a strain rate of 1.25mm/min (BS 1377, 1990).

Loss of strength was computed according to the relation

$$\Delta q = \left(\frac{q_{u-soaked}}{q_{u-control}}\right) x100 \geq 80 \qquad (1)$$

where Δq is the relative volumetric stability (RVS) which is measure of strength loss of soaked UCS sample to that of unsoaked sample, expressed in %; which should be equal or greater than eighty percent for a material to be deemed durable.

$q_{u\text{-soaked}}$ is UCS of immersed samples, $q_{u\text{-control}}$ UCS of control sample (BS1377; part 7, 1990; Amadi, 2014).

CBR-swell test

In regular CBR test, mixture of the soil and IOT treated with lime was compacted at optimum moisture (OMC) using 4.50kg rammer with 56 blows on 5 layers. The compacted samples were cured for seven (7) days. The first three (3) days of air-curing while the specimen will be fully immersed (soaked) in water for the remaining four days prior to testing (BS 1377, 1990; Amadi, 2014)

In swell test, the specimens were soaked for twenty-eight (28) days (longer than specified for regular CBR) after which swell values were measured using Vernier caliper.

Result and Discussion

Lateritic soil

From the particle size distribution curve for the soil (Fig. 1); 80.35% passed sieve no. 40 (size 0.425mm). 39.98% passed through sieve no. 200 (size 0.075mm); being fines content, above 35% maximum specified for granular materials in AASHTO classification chart (AASHTO, 1986). With 36% liquid limit and 16% plastic limit; the soil can be classified as type A-6 of AASHTO soil classification chart.

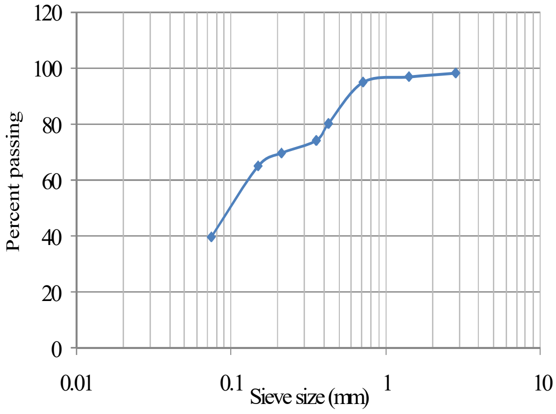

Fig. 1 Particle size distribution curve for the lateritic Soil

Iron Ore Tailings

From the particle size distribution curve for the IOT (Fig. 2); 40.66% passed sieve no. 40 (size 0.425mm). 10.52% passed through sieve no. 200 (size 0.075mm); below 35% maximum specified for granular materials in AASHTO classification chart. IOT consists of stones fragments, gravel and sandy particles just as Group A-3 soil is characterized in AASHTO flow chart.

Fig. 2 Particle size distribution curve for the IOT

Optimum Lime Content Determination Test Results

From the lime-pH curve in Fig. 3, the least percentage of lime that yield maximum pH of 12.41 is 6.2% and is therefore adopted as the optimum lime for the lateritic soil. From the curve, the pH increased up to 12.4 and leveled off at 6.2% lime content before the curve assumed a slight downward trend.

This indicated that the soil – lime reaction of the tested soil mixture increased with addition of more lime up to 6.2% beyond which no additional lime to the soil will result in higher reaction. This is below the optimum lime for lateritic clay investigated by Amadi and Okeiyi (2017).

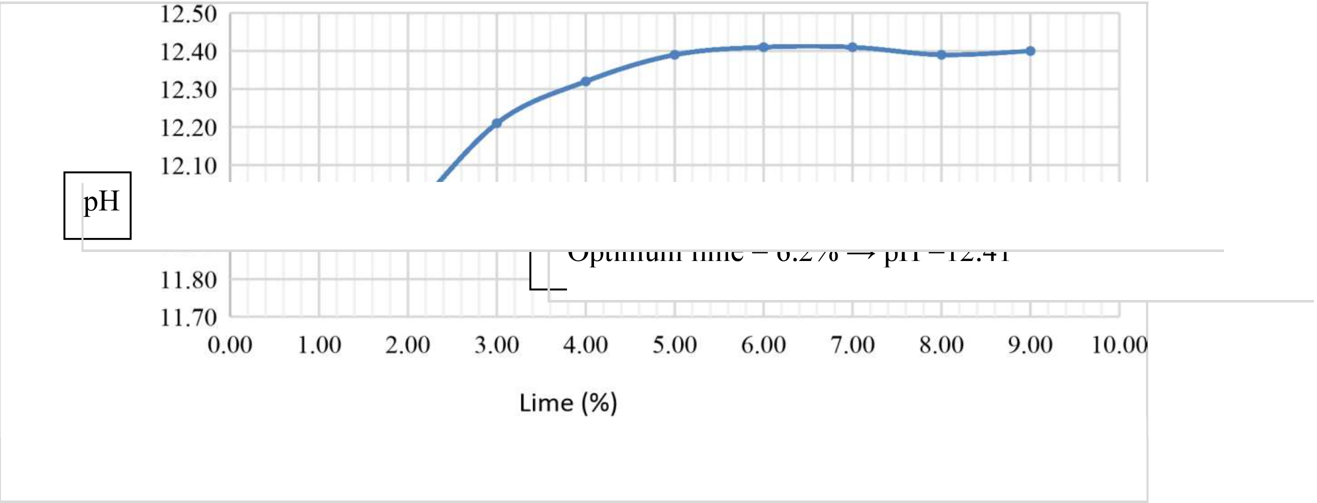

Fig. 3: Optimum Lime Content Tests Results

Atterberg limits test results

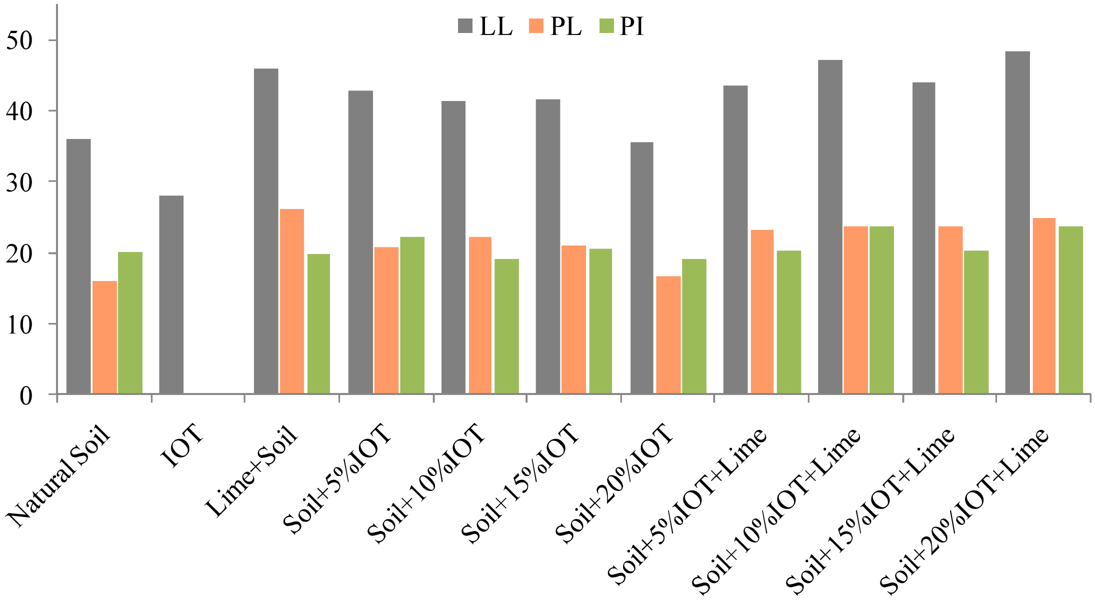

Fig. 4 Variation in Atterberg limits of soil, IOT and lime

The Atterberg limits of the natural soil, IOT and lime mixtures are presented in Fig 4. Both liquid limit and plastic limit of the soil increased with addition of lime. The LL increased to 45% from about 36% obtained in natural soil. Similarly, PL of the lime-treated specimen increased from 16 to 26 % with reduced plasticity index (PI) of soil mixtures. The reduction in plasticity of soil with addition of lime corroborates the results recorded by Ankit *et al.* (2013) that lime reduces plasticity of soil. The consistency is further enhanced by the non-plastic nature of IOT. From the particle size distribution curve (Fig 1) and Atterberg limits results (Fig. 4), the soil can be classified as A-6 subgroup of the AASHTO classification system (AASHTO, 1986). This implies that the material is within the fair to poor subgade geomaterials for road pavement construction (Nigerian General Specifications, 1997).

Results of Unconfined Compressive Strength Tests (UCS)

The idealized fluctuation of moisture was achieved by immersion of some prepared specimens in water while allowing some similar specimens to cure under natural dry condition for the same duration of time prior to testing.

From Fig 5, durability of the untreated soil was reduced upon soaking from 94 kN/m^2 to 30 kN/m^2. This illustrates the vulnerability of the soil once intruded by moisture.

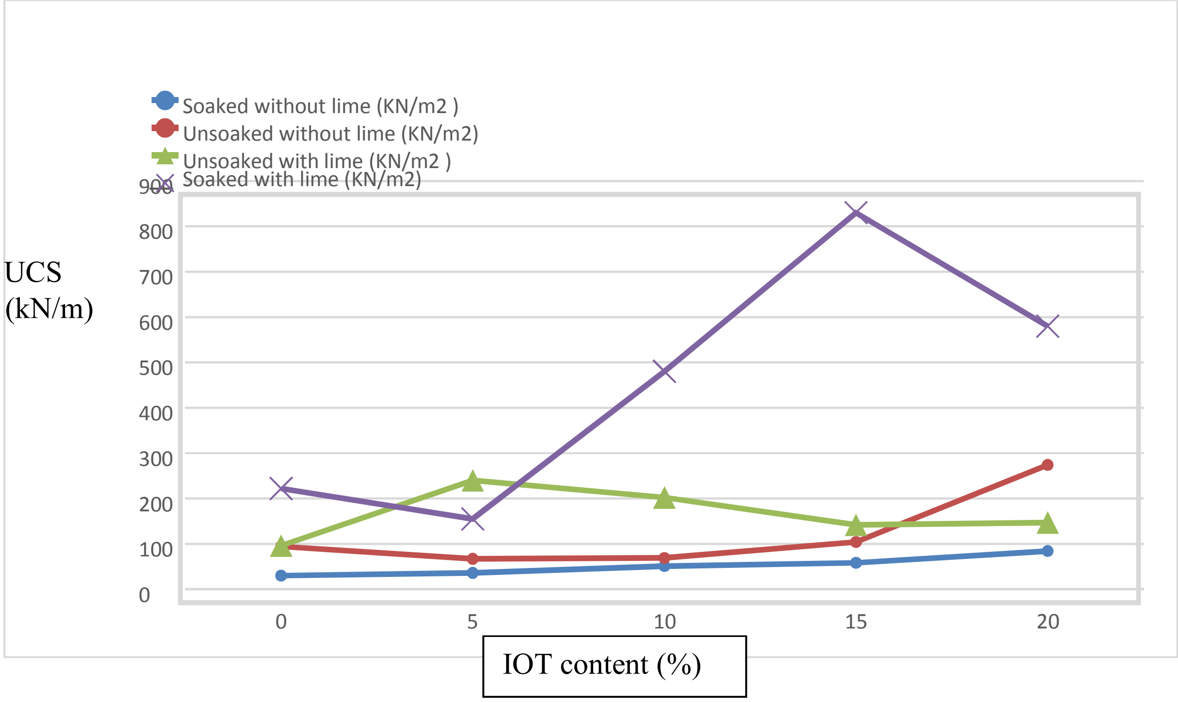

Fig. 5 Variation in UCS of specimens of soil with IOT + Lime

Lime-treated specimens

There is a good improvement in strength upon addition of lime to the soil; increasing its UCS from 30kN/m^2 to 147kN/m^2.Further improvement with addition of lime was however achieved with soaking: raising the UCS to 222 kN/m^2 representing over 7 folds increase. This corroborates the findings of Umar and Elinwa (2015).

IOT-treated specimens

The UCS mixtures increased with increasing percentage of IOT from 30 kN/m^2 to 36.1 kN/m^2, 51kN/m^2, 58kN/m^2 and 84kN/m^2 for 5, 10, 15 and 20% IOT respectively, for the soaked samples. Similar unsoaked specimens however exhibited decrease in UCS to 67 kN/m^2 and 69kN/m^2 for 5% and 10% IOT treatment respectively from the 94 kN/m^2 of the unsoaked soil sample while 15% and 20% IOT yielded 104 kN/m^2 and 274 kN/m^2 respectively. This shows that significant quantity of IOT can improve the UCS of the soil (Yisa and Sani, 2014; Samadou, 2015). .

IOT-and-lime-treated samples

Addition of lime to IOT-treated soil samples enhanced the soil UCS with increasing IOT up to 15% and 20% IOT when the improvement began to decrease. Lime-treated soil with 5%, 10% 15% and 20% IOT yielded 96 kN/m^2, 240 kN/m^2, 202.2 kN/m^2 and 142 k/m^2 respectively. The improvement could be attributed to reduced water-soil interaction resulting from quick flocculation due to exchange of soil cations with Ca^{++} from lime (Anathasopoulou and Kollarus, 2011). Lime-treated soil with 5%, 10% 15% and 20% IOT yielded 96 kN/m^2, 240 kN/m^2, 202.2 kN/m^2 and 142 k/m^2 respectively. Decrease in UCS value is not unconnected to enhanced bulk volume of the constituent sample which diminished pozzolanic effect of the lime by increasing material-lime ratio (Anathasopoulou and Kollarus, 2011). Meanwhile, unsoaked sample of soil containing 20% IOT exhibited better strength of 274 kN/m above all unsoaked samples of lime and IOT- treated soils.

Soaked samples of lime and IOT-treated soils demonstrated superior attributes in terms strength gain; recording 155 kN/m^2, 480 kN/m^2, 830 kN/m^2 and 580 kN/m^2 for 5, 10, 15 and 20% respectively. At 15%, the soil UCS is about 27 times the value of the untreated soil. This result corroborates the conclusions of the United States National Lime Association (2004) that; lime enhances soil strength by a factor of over twenty (20).

Relative Volumetric Stability (RVS) of the Soil mixtures

Influence of Lime

From Fig. 6, Relative Volumetric Stability (RVS), a measure of strength loss of a soil sample compared to the untreated specimens (Δq in equation 1) improved with addition of lime to the soil: from 39.91 to 151.02% for untreated specimens and lime-treated soil samples respectively. All soil mixtures recorded significant improvement in RVS upon addition of lime. RVS of 162, 200, 410.5 and 408.5% were recorded for 5, 10, 15 and 20% IOT with lime. This progressive improvement has to do with the ability of lime to enhance cohesion of particles in the presence of abundant moisture through exchange of soil cations with Ca^{++} from lime (Anathasopoulou and Kollarus, 2011; Obeta, and Njoku, 2016)

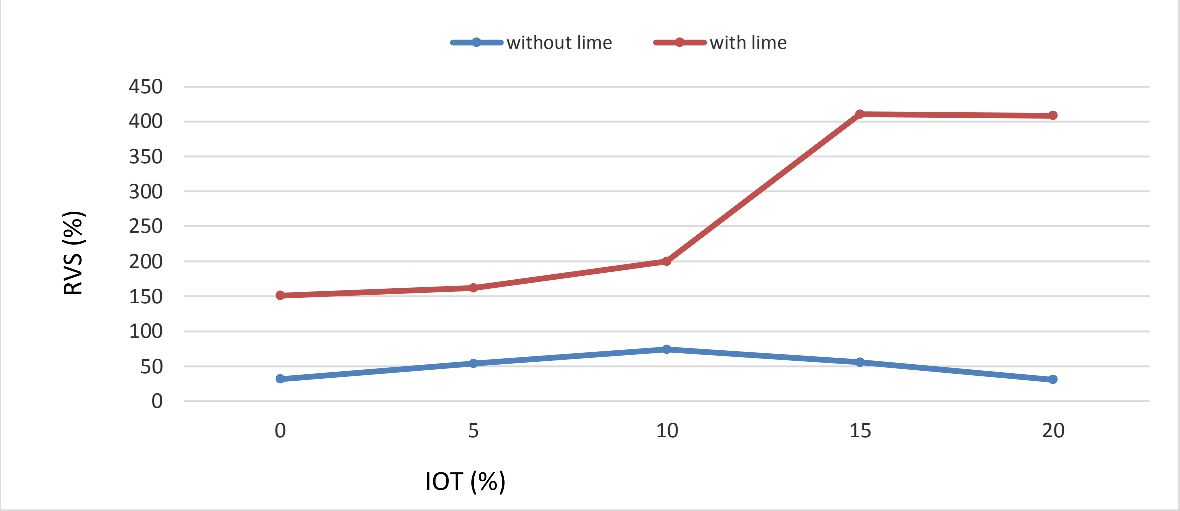

Fig. 6. Variation in RVS of Soil mixtures with IOT and lime

The improvement in RVS diminished with addition of IOT only to the mixture. Though

IOT-treated samples recorded RVS enhancement upon initial addition of IOT from 39.91 to 54% with 5% IOT and 74% for 10% IOT while a decrease was observed at 15% IOT recording 55.77% RVS and further declined at 20% IOT to 31%.

Influence of Lime and IOT

All lime-treated samples have experienced improvement in major durability indices; however, Fifteen percent (15%) IOT and lime treated sample was found to be the most durable. This is because of its significant performance with and without moisture (soaked and unsoaked) exhibiting an RVS of 410% (Yisa and Sani, 2014; Obeta and Njoku, 2016; Amadi and Okeiyi, 2017).

California Bearing Ratio (CBR)

The natural soil exhibited CBR values of 3.38 and 75.44% for soaked and unsoaked samples respectively. This indicates that the soil sample's CBR value decreased by a factor of 22 when subjected to standard soaking condition (Fig. 7). IOT on its own exhibited CBR values of 8.77 and 17.94% for soaked and unsoaked samples of its specimens respectively. The low CBR value for IOT is related to its index properties, characterized with no plasticity and therefore devoid of cohesion between its particles (Francis *et al*., 2013). CBR value of IOT decreased by a factor of two, this is because moisture has less influence on its compacted mass compared to the soil sample whose CBR decreased by a factor of 22. This is because of the nature of particles of materials that made up IOT being reasonably incompressible (Francis, 2015), hence passage of water through its sample has minimal effect on it compared to sample of soil that has expansion tendency upon exposure to moisture (Adedayo and Modupe, 2012; Salour, 2015).

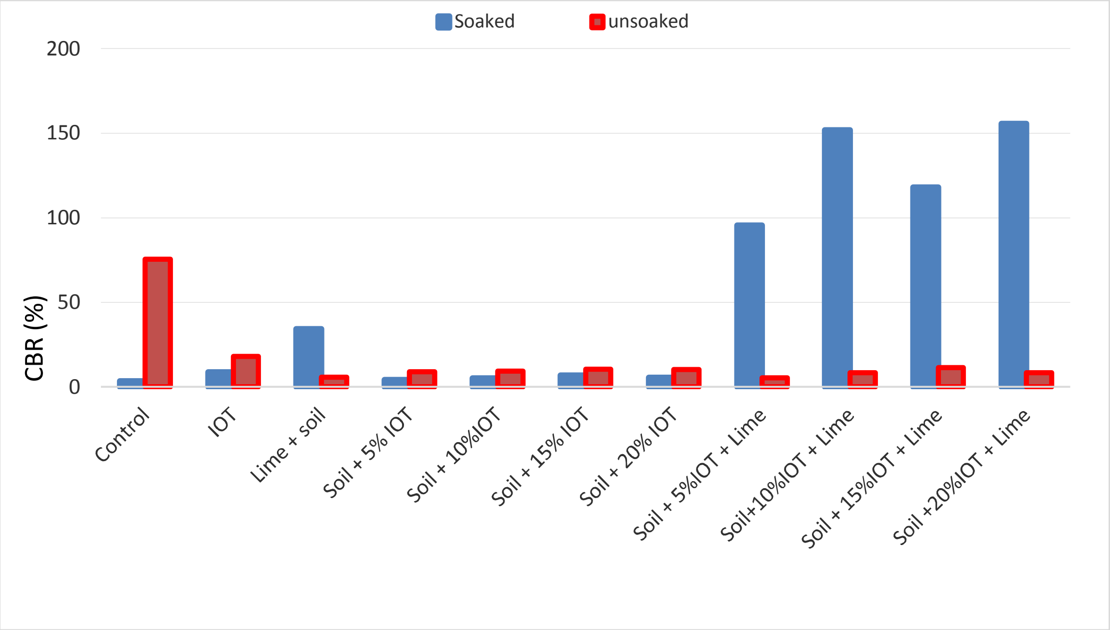

Fig. 7: Variation in CBR values of the soil treated with IOT and Lime

CBR-swell Test Result

Fig. 8 shows the results of CBR-swell of the soil mixtures. The natural soil showed significant swelling tendency. Soaked sample of only IOT could not withstand soaking and dissolves in short period due to its poor plasticity. In the conduct of regular California Bearing Ratio (CBR) test, sampled soil is compacted at optimum moisture (OMC) using British Standard Light (BSL) compaction effort and then sealed in polyethene and cured for seven (7) days. The first three (3) days was air-cured, while the specimen was fully immersed (soaked) in water for the remaining four days prior to testing (BS 1377, 1990; Amadi, 2014).

Addition of lime to all samples completely curtailed swelling even as sample strength gets enhanced with observable volumetric stability. It is worth noting that, lime has proven to be adequate in curtailing swelling by reducing sample permeability to moisture as suggested by Ratnasiri (2004).

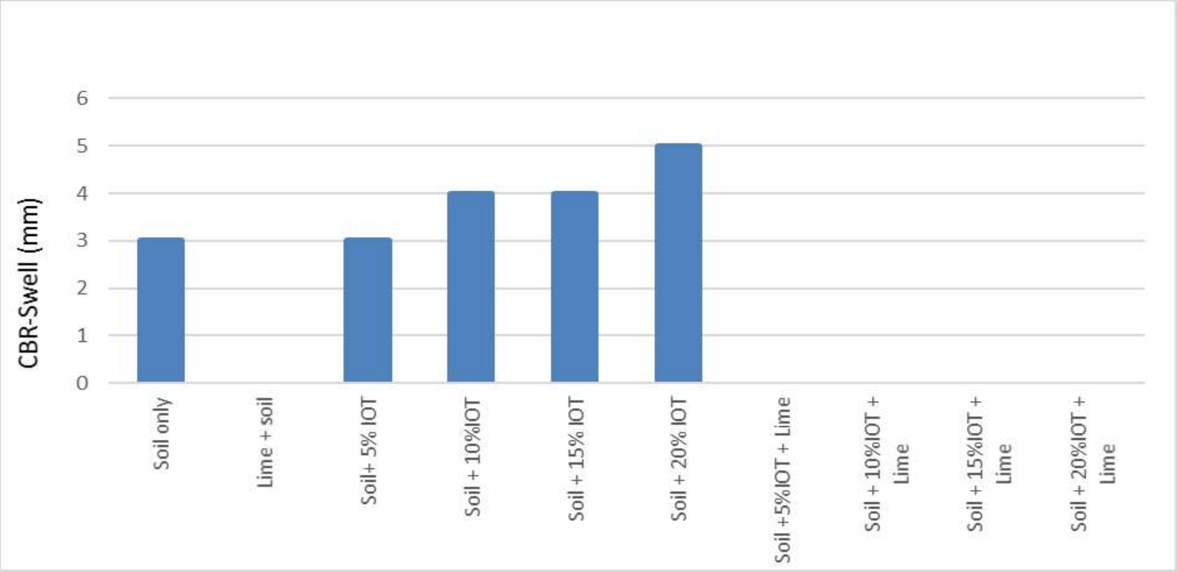

Fig. 8: CBR-swell test results of the soil mixtures

Addition of lime to all samples completely curtailed swelling even as specimen strength gets enhanced with observable volumetric stability. It is worth noting that, lime has proven to be adequate in curtailing swelling by reducing sample permeability to moisture as suggested by Rasnatari, (2004). This is because all samples treated with lime recorded no swell including sample of soil treated with lime only. This is as swelling continue to increase with increase in IOT with 3, 4, 4, and 5mm swell values for 5, 10, 15 and 20% IOT respectively in the absence of lime while all samples treated with lime recorded no swell. The zero swell in lime-treated samples could be attributed to reduced water-soil interaction resulting from quick flocculation due to exchange of soil cations with Ca^{++} from lime (Anathasopoulou and Kollarus, 2011).

Conclusions

The present study evaluates the durability characteristics of poor-quality lateritic subgrade treated with IOT and lime.

Preliminary tests conducted on the sample of the subgrade soil indicated that the soil is of A-6 subgroup using AASHTO classification chart. The soil exhibited unsatisfactory durability indices in swell test and Unconfined Compressive strength test (UCS). The properties however, improved with addition of IOT and Lime to a reasonable extent despite the fact that most soil mixtures did not perform satisfactorily under varying conditions. IOT alone could not satisfactorily enhance durability of the soil, especially when exposed to moisture (soaking). It however demonstrated high durability tendencies with the addition of lime. The strength of all lime-and-IOT-treated samples, as in CBR and UCS tests have significantly improved with soaking. Meanwhile, most of the indicated unsoaked lime-treated samples exhibited unsatisfactory improvement except the sample treated with 15% IOT and lime. Considering the requirements of 80% minimum CBR and 80% Relative Volumetric Stability (RVS), 15% IOT and Lime-treated sample appears to be the best, having attained a CBR of 117% and Relative volumetric stability (RVS) of 410%. This result corroborates the 15% optimum IOT reported by Umar and Elinwa (2015).

As the swelling of soil is curtailed with addition of IOT and Lime, water percolation through its exposed surfaces is reduced. This minimizes the negative effects of moisture incursion into the soil

References

AASHTO (1986). *Standard Specifications for Transport Materials and Methods of Sampling and Testing*. 14th Edition, American Association of State Highway and Transport Officials (AASHTO), Washington, D.C

Adedayo, S.M.; Modupe, A.O (2012) Machinal properties of Iron Ore Tailings Filled Polypropylene Composites, *Journal of material and material characterization and Engineering11,671678* http://www.SciRP.org/journal/jmmce

Adedeji, O.A.; Olafiaji, E.M.; Omole, F. K.; Olanibi, J. A. and Yusuff, L. (2014). An Assessment of the Impact of Road Transport on Rural Development: A Case Study of Obokun Local Government Area of Osun State, Nigeria. British Journal of Environmental Sciences, Vol. 2, No.1, 34-48. www.ea.journals.org

Amadi, A. A. (2014). Enhancing durability of quarry fines modified black cotton soil subgrade with cement kiln dust stabilization: *Transportation Geotechnics* Vol. 1, No. 1, 55-61. www.elsevier.com

Amadi, A. A and Okeiyi A. (2017), Use of Quick and Hydrated Lime in Stabilization of Lateritic Soil: Comparative analysis of Laboratory Data: *International Journal of Geo-Engineering DOI 10.1186/s40703-017-0041-3*

Athanasopoulou, A. and Kollaros, G. (2011). Use of additives to improve the Engineering Properties of Swelling soils in Thrace, Northern Greece. WIT Transactions in Engineering Sciences, Vol. 72, 327-338.

Andrew, D. (2008). Water in Road Structures; Movement, Drainage and Effects *Nottingham Transportation Engineering Center, University of Nottingham, UK.* Vol. 5, 11-12.

Ankit, S.N, Mohammed F., Devavish P. S, Rehanjot S. (2013). Soil Stabilization using Lime; *International Journal of Innovative Research in Science, Engineering and Technology. Vol2 Issue 2 ISSN: 2319-8753*

Braja, M. D. (2010). Principles of Geotechnical Engineering (7th Edith), PWS, USA. ISBN-13:978-0-495—41130-7.

BS 1377-1, (1990) Methods of tests for soils for civil engineering purposes. British Standard institutions, London.

Chidolue, C. A.; NNwajuaku, A. I.; Okwonkwo, V.O. (2013). Rehabilitation of Onitsha-Enugu Dual Carriageway in Anambra State, Nigeria: Lessons Learned.

Nigerian Journal of Technology (NIJOTECH), Vol. 32, No. 3, 393-402.

Eades, J. L. and Grim, R. E. (1966). A quick test to determine lime requirements for lime stabilisation. Highways Research Record 139, Highways Research Board, Washington.

Elinwa, A.U. and Maichibi, J.E (2014), Evaluation of the iron ore tailings from Itakpe in Nigeria as concrete material. Journal of Advances in Materials, Vol. 3, No. 4, 27-33. doi: 10.11648/j.am.20140304.12 ISSN: 2327-2503. pISSN: 2327-252X

Francis, A; Reginald, A. A.; Fred, B. (2013) Effect of Lime on Plasticity, Compaction and Compressive Strength Characteristics of Synthetic Low Cohessive (CL) and High Cohessive (CH) clayey soils, *International Journal of Science and Engineering Research, Volume 4, Issue II, ISSN 2229-5518*

Francis, A.K. (2015). Characterization and application of iron ore tailings in building and construction projects, Thesis presented in fulfilment of the requirement for the degree of philosophy, school of Engineering, Faculty of Health, Engineering and Science, Edith Cowan University. http:///ro.ecu.edu.au/thesis/1623

Laura, Z.; Algirdas, M.; Rita, K.; Gediminas, G. and Igoris, K. (2016). Temperature and Moisture Variation in Pavement Structure of the Test Road, *Transportation Research Procedia* 14 (2016) 778-786, 6th Transport Research Arena.

Mittal, S. and Shukla, J. P. (1999) Soil Testing for Engineers: Khana publishers (ISBN NO: 81-7409-065-7)

Nigerian General Specification for Roads and Bridges (1997). Federal Ministry of Works and Housing, Abuja.

Nwadiogbu, P.C and Salahdeen, A. B (2014). Potentials of Lime on Modified Lateritic Soil Using Locust Bean Waste Ash as Admixture, *Journal of Mechanical and Civil Engineering (ISOR-JMCE)* Vol. II issue I, 69-73.

Obeta, I. N and Njoku, J. E (2016). Durability of Flexible Pavements: A Case Study of South-Eastern Nigeria. *Nigerian Journal of Technology (NIJOTECH),* Vol., 35, No. 2, 297-305

Ratnasiri, R. (2004): Control of Moisture During Construction of Road Pavements, *State Development and Construction Corporation, Road Development Authority, Northern Region, Sri Lanka,* 1-9

Rushikesh, P.D, Umriga, F.S and Zala, L.B (2011) Pavement deterioration: A Case Study on National Highway 8b Section Rajkot-Bamanbore (Gujarat state, India) *Conference on Recent Trends in Engineering & Technology; Birla Vishvakarma Mahavidyalaya Engineering College, Gujarat: India,* Vol. 6, No.11, 117-184.

Salour, F. (2015). Moisture Influence on Structural behavior of Pavements; Field and Laboratory Investigations, *Doctoral Thesis, KTH Royal Institute of Technology, School of Architecture and the Built*

Environment, Department of Transport Sciences, Division of Highway and Railway Engineering, 14-21.

Segun, M. A and Modupe, A. O (2012). Mechanical properties of Iron Ore Tailings filled polypropylene composites, *Journal of minerals and material characterization and Engineering, 11, 671-678*

Samadou, J. (2015). Stabilization of Black Cotton Soil with Iron Ore Tailings*, A Thesis Presented In Partial Fulfilment of the Requirements for The Award of Masters of Science in Civil Engineering, Faculty of Engineering, Ahmadu Bello University, Zaria, Nigeria*

Sofilic, U.; Sofilic, T. and Brnardic (2015); The significance of Iron and Steel slag as by-product for utilization in road construction.*12th International Foundrymen Conference, Sustainable Development in Foundry Materials and Technologies, Opatija, Crotia.* 419-431.

Umar S. Y and Elinwa A. U, (2015). Effects of Iron Ore Tailings (IOT) and Lime on Engineering Properties of Problem Laterite: *Journal of Raw Material Research,*Vol 2, No. 1, 1-5, ISSN: 2536-6440

US National Lime Association, (2004) Lime the versatile chemical, *Mineral data Publishing, Handbook of Mineralogy.*

Vikrant, S.; Kshitija, K.; Mujahed, S.; Mahesh, K.; Mahendra, C. and Sagar, S. (2015). Use of Iron Ore Tailings as Construction Materials. *International Journal of Conceptions on Mechanical and Civil Engineering* Vol. 3, Issue. 2, ISSN: 2357 – 276, 113-119.

Yisa, G. L. and Sani, J. E (2014). Reliability Estimate of Strength Characteristic of Iron Ore Tailings Stabilized Lateritic Soil for Road Pavement Sub-Base Material, Electronic Journal of Geotechnical Engineering (EJGE), Vol. 19 (2014), Bound. S, P4180-4192