Journal of Earth Science and Engineering 8 (2018) 66-74
doi: 10.17265/2159-581X/2018.02.000

Soil Stabilization Using Bitumen Emulsion and Cement Combination as Additive

AYININUOLA Gbenga Matthew and ABIDOYE Shola Paul

Department of Civil Engineering, University of Ibadan, Ibadan 200284, Nigeria

Abstract: This study examined effect of stabilising lateritic soil with combination of bitumen emulsion and cement. Soil samples were obtained from borrow pits located in Kwali Area Council in Abuja. Three percentages of additives were considered: 4%, 6% and 8%. The bitumen emulsion and cement contents were combined in percentages: 100:0, 75:25, 50:50, 25:75 and 0:100 to form five additives. The stabilized soils and unstabilized soils (control) geotechnical properties such as Unconfined Compressive Strength (UCS) test and California Bearing Ration (CBR) test were determined. The UCS and CBR for soil samples A and B were 0.46 MPa and 19.6%, 0.95 MPa and 22.6%, respectively. The CBR of soil A at 4% additives of mix proportions 100%/0%, 75%/25%, 50%/50%, 25%/75% and 0%/100% were 49.1%, 68.8%, 140.5%, 172.1% and 218.5%, respectively. The corresponding values for UCS were 0.64, 0.66, 1.21, 1.27 and 1.33. While for 8% additives the CBR for soil B were 78.4%, 88.4%, 180.5%, 224.2%, 288.1% and UCS were 0.48, 0.68, 1.50, 2.16 and 2.45, respectively. It was observed that both the UCS and CBR values increased as the cement component increased for both soil samples. Stabilising laterite with mixture of bitumen emulsion and cement improved the strength of the soil.

Key words: Stabilization, unconfined compressive strength test, California bearing ratio, moisture contents, bitumen emulsion.

1. Introduction

Stabilization is a process of improving subsoil engineering properties prior to construction. This can be accomplished in several ways such as preloading of the grounds application of high energy impacts, use of sand drains and sand filters, prefabricated wick drains, and chemical additives [1]. On the other hand, laterite describes no material with reasonable constant properties. To those in the temperate countries, it could be described as a red friable clay surface. To those in the hilly tropical countries, it could be described as a very hard homogenous vesicular massive clinker—like materials with a framework of red hydrated ferric oxides of vesicular infill of soft aluminium oxides of yellowish color and in less hilly country, it could exist as a very hard, or soft coarse angular red. Lateritic soils as a group rather than well-defined materials are most commonly found in a leached soils of humid tropics. Laterite is a surface formation in hot and wet tropical areas which is enriched in iron and aluminium and develops by intensive and long lasting weathering of the underlying parent rock [2]. These varied properties have brought limitations to their use on some construction sites. Many of these Limitations have been overcome by the addition of stabilising agents to improve their properties or by various other means of soil improvement. Some of the stabilization methods include the use of cement, lime, fly ash and bitumen depending on the type of soil and site condition [3].

Portland cement has been used with great success to stabilize natural soil because almost all soils respond to treatment with cement. However, the chemical conditions of some soils which can inhibit the normal hardening of cement or lead ultimately to loss of durability or high construction cost for the highly plastic soils have limited their use. Bituminous stabilization is also being in use for construction purposes all over the world, and so is hydrated lime.

Corresponding author: AYININUOLA Gbenga Matthew, associate professor, research fields: geotechnical engineering.

Hydrated lime in its own case increases soil strength primarily by pozzolanic action with the formation of cementation materials especially in granular materials or lean clays [4, 5].

Bituminous stabilization is generally achieved using asphalt cement, cutback asphalt, or asphalt emulsions. The type of bitumen to be used depends on soil to be stabilized, method of construction, and weather conditions. In frost areas, the use of tar as a binder should be avoided because of its high temperature susceptibility. Asphalts are affected to a lesser extent by temperature changes, but a grade of asphalt suitable to the prevailing climate should be selected. As a general rule, the most satisfactory results are obtained when the most viscous liquid asphalt that can be readily mixed into the soil is used. For higher quality mixes in which a central plant is used, viscosity-grade asphalt cements should be used. Much bituminous Stabilization is performed in place with the bitumen being applied directly on the soil or soil-aggregate system and the mixing and compaction operations being conducted immediately thereafter. For this type of construction, liquid asphalts, i.e., cutbacks and emulsions are used. Emulsions are preferred over cutbacks because of energy constraints and pollution control efforts [6].

Inferior quality materials can be made to resist excessive deformation and deflection by applying soil stabilization or modification techniques [7]. Soil stabilization and soil modification are both related to improvement of the soil properties so that they suit a particular purpose. Soil modification often refers to soil improvements that happen during or shortly after mixing. Modified soils are those whose consistency, gradation, and/or swelling properties are improved to the desired extent and strength is increased to a certain extent [8]. Soil stabilization is broadly classified into four types, namely: thermal, electrical, mechanical, and chemical. Chemical stabilizers are most widely used in road construction industry and broadly classified into three groups, namely: Traditional stabilizers, non-traditional stabilizers, and by-product stabilizers [9].

Laterite is a group of highly weathered soils formed by the concentration of hydrated oxides of iron and aluminum [10]. Soils under this classification are characterized by forming hard, impenetrable and often irreversible pans when dried [11]. Laterites and lateritic soils form a group comprising a wide variety of red, brown, and yellow, fine-grained residual soils of light texture as well as nodular gravels and cemented soils [12, 13] named laterites based on hardening, such as “ferric” for iron-rich cemented crusts, “alcrete” or bauxite for aluminum-rich cemented crusts, “calcrete” for calcium carbonate-rich crusts, and “silcrete” for silica rich cemented crusts. Other definitions have been based on the ratios of silica (SiO_2) to sesquioxides ($Fe_2O_3 + Al_2O_3$). In laterites the ratios are less than 1.33. Those between 1.33 and 2.0 are indicative of laterite soils, and those greater than 2.0 are indicative of non-lateritic soils [14].

Most laterites are encountered in an already hardened state. When the laterite is exposed to air or dried out by lowering the groundwater table, irreversible hardening occurs, producing a material suitable for use as a building or road stone. The lateritic soils behave more like fine grained sands, gravels, and soft rocks. The laterite typically has a porous or vesicular appearance which may be self-hardening when exposed to drying; or if they are not self-hardening, they may contain appreciable amounts of hardened laterite rock or laterite gravel. The behavior of laterite soils in pavement structure has been found to depend mainly on their particle-size characteristics, the nature and strength of the gravel particles, the degree to which the soils have been compacted, as well as the traffic and environmental conditions [15].

It was found that stabilized soils have beneficial engineering properties and could potentially be used more often, though additional field use and testing should be carried out for proper scientific procedures

[16]. Furthermore, during an experimental study of the shear strength of the stabilized soil, duration of failure of each specimen being tested was observed to increase with increase in stabilizers. Also shear stress at which failure occurred reduced and most of the soil sample mixture increased in shear strength [7]. Stabilization of soil is employed when it is more economical to overcome a deficiency in a readily available material than to bring in one that fully complies with the requirements of specification for the soil [16]. It has been regarded as a last resort for upgrading substandard materials where no economic alternative is available. A continual reference to economy here denotes a careful consideration of all costs that would be incurred by importation (not readily available) of a compliant soil and comparing this to the cost of improving the properties of an unstable but readily available soil.

Ref. [17] described some terms commonly applied in chemical stabilization of soil especially with Portland cement, lime and asphalt. All agents for stabilization have particular soil material to which when they are applied would produce the required properties. Cement stabilization involves three processes: cement hydration; cation exchange reaction and pozzolanic reaction carbonation [18]. Cement hydration is a chemical reaction between cement and water to produce calcium hydroxide or hydrated lime ($Ca(OH)_2$). The soil and cement reaction involves replacement of divalent calcium (Ca^{2+}), adsorption of $Ca(OH)_2$ and cementation at inter-particle contacts by the tobermorite gel. Calcium silicate, the chief constituent of the Portland cement produces lime ($Ca(OH)_2$) and tobermorite gel which are responsible for strength increase in the treated soil.

Bituminous soil stabilization refers to a process by which a controlled amount of bituminous material is thoroughly mixed with an existing soil material to form a stable base or wearing course. Bitumen increases the cohesive and load bearing capacity of the soil and renders it resistant to the action of water. Stabilization of soil with bitumen differs greatly from cement stabilization. The basic mechanism involved in bitumen stabilization is a water proofing phenomenon. Soil particles are coated with bitumen that prevents or slows the penetration of water [19].

Most bituminous soil stabilization has been performed with asphalt cement, cutback asphalt, and asphalt emulsions. Soils that can be stabilized effectively with bituminous materials usually contain less than 30 percent passing the No. 200 sieve and have a PI less than 10. Soils classified by the USCS as SW, SP, SW-SM, SP-SM, SW-SC, SP-SC, SM, SC, SM-SC, GW, GP, SW-GM, SP-GM, SW-GC, GP-GC, GM, GC, and GM-GC can be effectively stabilized with bituminous materials, provided the above-mentioned gradation and plasticity requirements are met [19]. There are two major types of bitumen emulsion: Cationic bitumen emulsion and Anionic bitumen emulsion. The cationic emulsifiers are generally based on long hydrocarbon nitrogen compound, such as alkyl amines. The alkyl amines are powerful surface active compounds with great influence on the surface tension. Anionic bitumen emulsion is normally based on fatty acids. A fatty acid molecule consists of a long hydrocarbons chain and terminates with carboxyl group. The emulsifier solution is prepared by reaction the anionic emulsifier with sodium hydroxide. This reaction is called saponification. Chemical substances that can enter in the natural reactions of the soil and control the moisture getting to the clay particles, therefore converting the clay fraction to permanent cement that holds the mass of aggregate together. The chemical stabilizer in order to perform well must provide strong and soluble cations that can exchange with the weaker clay cations to remove the water from the clay lattice, resulting in a soil mass with higher density and permanent structural change [20].

2. Materials

Two borrow pits were located at Kwali Area Council of Abuja, North Central Nigeria, with a distance of about 1 km apart. The top soil of the borrow pit was removed before excavating to depth of about 1.2 m (Fig. 1). At this depth, enough samples were taken from the two borrow pits in bags, labeled for identification purpose and transported to the laboratory in Abuja. At the laboratory, the samples were air-dried, stock pilled separately and covered with polythene materials to prevent moisture ingression. Enough quantity of bitumen emulsion was procured and also six bags of ordinary Portland cement. The bitumen emulsion and cement contents were combined in percentages: 100:0, 75:25, 50:50, 25:75 and 0:100 to form five additives. Three percentages of additives were considered: 4%, 6% and 8%. The additives and soil were mixed manually on flat surface. Various tests

Fig. 1 Taking measurement during sample collection.

Fig. 2 Soil in mould for compaction and CBR tests.

Fig. 3 Compacted specimens for UCS test.

Fig. 4 Specimen for UCS in compression machine.

such as particle size distribution, compaction and Atterberg limits were carried out on the unstabilized soils A and B. The stabilized soils and unstabilized soils (control) geotechnical properties such as Unconfined Compressive Strength (UCS) test and California Bearing Ration (CBR) test were determined as shown in Figs. 2 to 4. All the tests were carried out in accordance with Ref. [21].

3. Results and Discussion

The two soil samples A and B were classified in accordance with the Unified Soil Classification System (USCS). The parameters used were the soils grading curves, Liquid Limits, Plastic Limits and

Plasticity Index. Soli sample A, R_{200} (percentage retained by sieve No. 200 i.e. 0.075 mm) was 75.5%. This value was greater than 50%, thus coarse grained soil. Also, R_4 (percentage retained by sieve No.4) was 40.3% which was greater than $0.5R_{200}$, indicating that the soil was gravelly soil with plasticity index (PI) of 8% and liquid limit (LL) of 34.4%. The soil was clayey gravel, gravel-sand-clay mixture (GC). Similarly, for sample B, R_{200} was 79.4%, which was greater than 50%, thus coarse grained soil. Also, R_4 was 48.6% which was greater than $0.5R_{200}$, indicating that the soil is gravelly soil with PI of 9% and LL of 32%, the soil was also clayey gravel, gravel-sand-clay mixture (GC). Figs. 5 and 6 showed the grading curves for soil samples A and B, respectively.

Prior to CBR text, compaction test was carried out and the results were utilized to prepared soil samples for CBR and UCS tests. The California bearing ratio test was carried out on both stabilized and unstabilized soil samples of A and B in order to ascertain the effect of the two additives on the soils' resistance to plunger penetration of the CBR machine. Tables 1 and 2 and Figs. 7 and 8 contained the results of CBR for samples A and B.

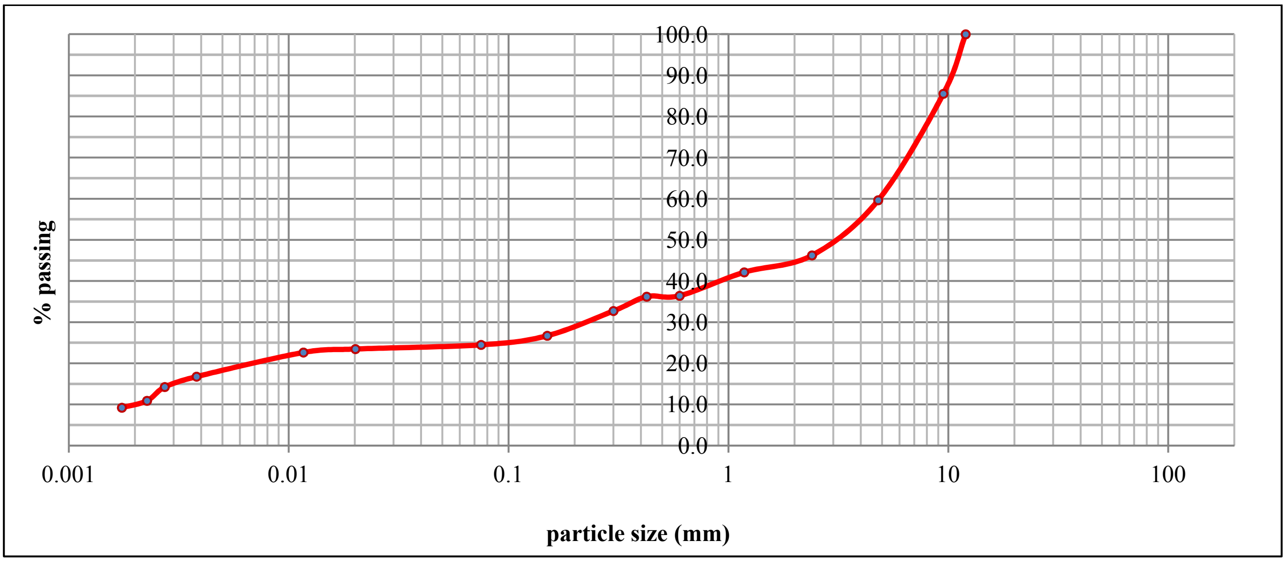


Fig. 5 Grading curve for soil sample A.

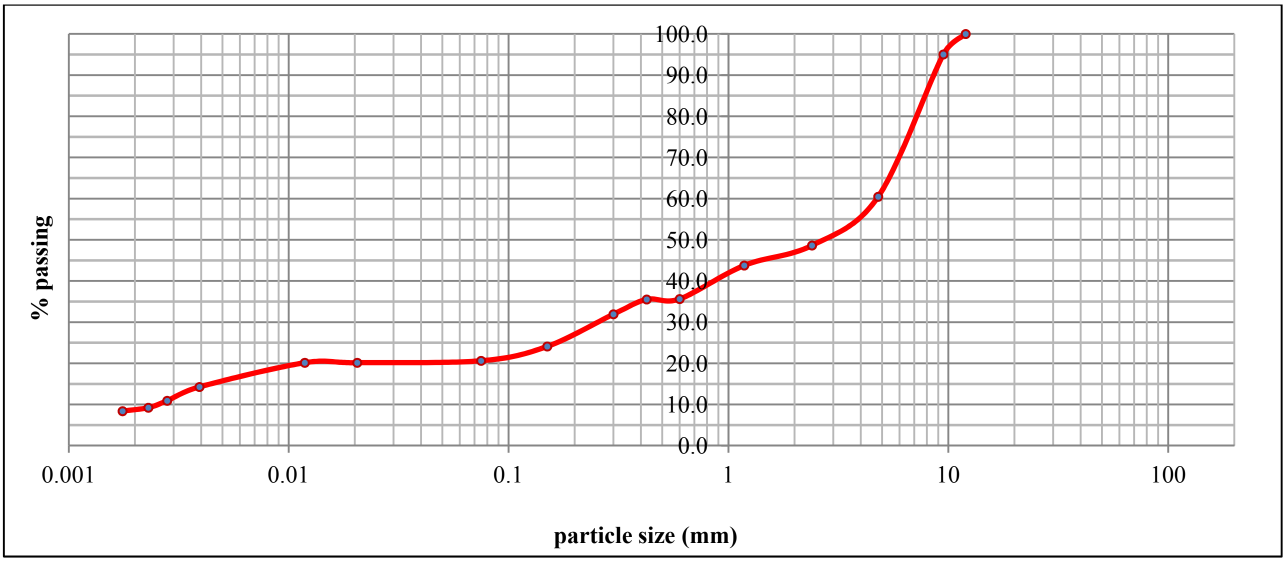


Fig. 6 Grading curve for soil sample B.

Table 1 Summary of CBR test result for soil sample A.

Bitumen/cement content	4%	6%	8%
Control	19.6	19.6	19.6
100/0	49.1	61.9	78.4
75/25	68.8	78.6	88.4
50/50	140.5	160.4	180.5
25/75	172.1	196.4	224.2
0/100	218.5	249.4	288.1

Table 2 Summary of CBR test result for soil sample B.

Bitumen/cement content	4%	6%	8%
Control	22.6	22.6	22.6
100/0	72	81.8	94.1
75/25	79.5	90.3	103.9
50/50	162.3	184.5	212.1
25/75	198.8	225.9	259.7
0/100	252.4	286.8	329.9

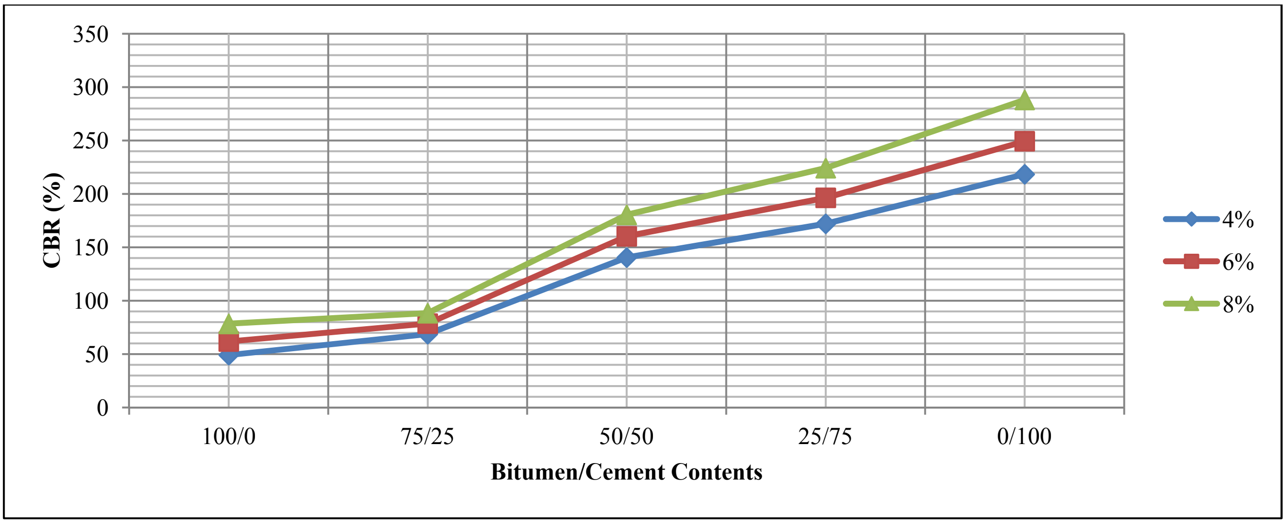


Fig. 7 CBR vs. bitumen/cement content for soil sample A curve.

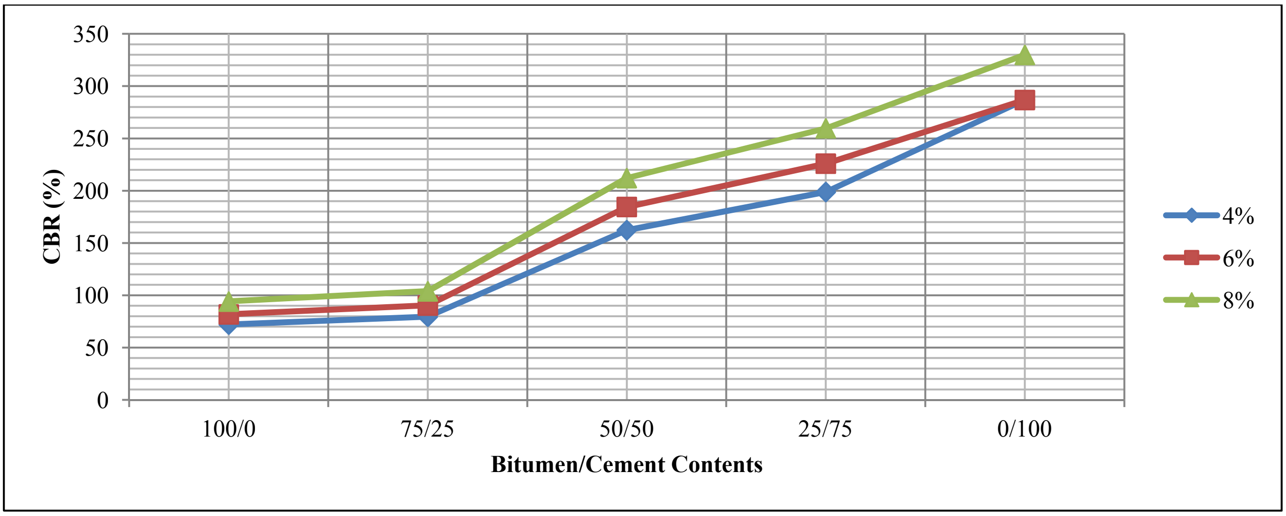


Fig. 8 CBR vs. bitumen/cement content for sample B curve.

The CBR (Tables 1 and 2) of samples A and B increased with increasing in cement proportion of the additives. For instance, the unstabilized sample A CBR was 19.6% rose to 49.1% on addition of 4% additive. Similarly, this trend was observed with 6% and 8% additives. Also, the CBR value increased as the percentage of additive increased of the mix proportions. It was also observed that the influence of cement on the strength of stabilized soil was more than that of bitumen emulsion. The 6% additive with 100% bitumen emulsion in soil sample B increased its CBR to 81.8% while that of 100% cement was 286.8%. The same trend occurred for 4% and 8% additive. The result was in agreement with Ogundipe [22] who observed that excess bitumen in soil stabilization resulted in strength reduction. The addition of cement in the additives compensated for the supposed loss of soil strength due to excess bitumen. The Federal Ministry of Works' General Specification (Roads and Bridges) gave strength requirements in terms of CBR for road pavement structures on Nigerian roads. The minimum CBR value for subgrade was given as 20%, for subbase, 30% and base material with 80% CBR values. Based on the results in Tables 1 and 2, the materials are suitable to be used as base course for road works after stabilising with additives with least cement/bitumen emulsion proportion 75/25%.

The UCS test results were displayed in Tables 3 and 4 and Figs. 9 and 10. The Highway Manual Part 1: Design (2013) contained the Federal Ministry of Works requirements for strength for various pavement courses. The Manual specified 7-day UCS value range of 1.5 MPa-3.0 MPa for base course at 100% modified AASHTO density and 1.0 MPa-1.5 MPa at 97% AASHTO density. For subbase course, the UCS value ranges from 0.75 PMa to 1.5 MPa at 100% modified AASHTO density and 0.5 MPa-0.75 MPa at 97% AASHTO density. Therefore, with reference to the specification, the optimum combination for subbase material for 4%, 6% and 8% was 75% bitumen emulsion and 25% cement contents with 0.66 MPa, 0.67 MPa and 0.68 MPa respectively for sample A soil at 97% modified AASHTO density.

4. Conclusion

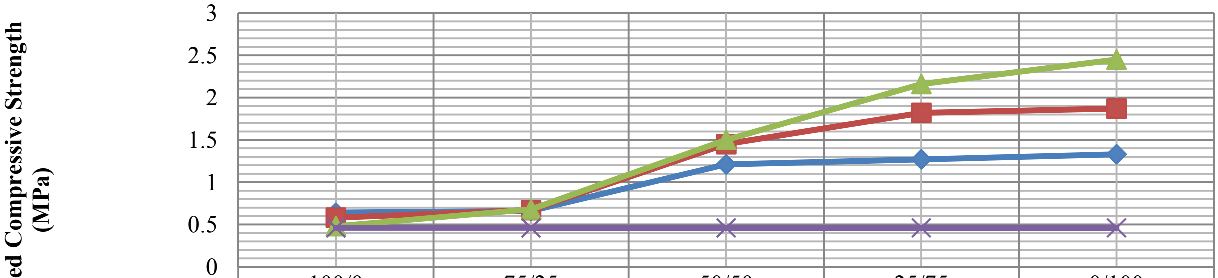
The laboratory UCS and CBR tests conducted on the two soils stabilized with mixtures of bitumen and cement revealed that the soil samples experienced increase in strength as the proportion of cement content increased and proportions of bitumen in the mixture reduced. Also, the optimum combination for subbase material with 4%, 6% and 8% additives was 75% bitumen emulsion and 25% cement contents.

Table 3 Summary of UCS versus bitumen/cement contents for sample A soil.

Bitumen/cement contents (%)	UCS AT 4%	UCS AT 6%	UCS AT 8%
100/0	0.64	0.58	0.48
75/25	0.66	0.67	0.68
50/50	1.21	1.45	1.50
25/75	1.27	1.82	2.16
0/100	1.33	1.87	2.45

Table 4 Summary of UCS versus bitumen/cement contents for sample B soil.

Bitumen/cement contents (%)	UCS AT 4%	UCS AT 6%	UCS AT 8%
100/0	0.82	0.58	0.67
75/25	0.85	0.80	0.76
50/50	1.29	1.39	1.68
25/75	1.94	2.69	2.45
0/100	1.99	2.43	4.14



	100/0	75/25	50/50	25/75	0/100
UCS AT 4%	0.64	0.66	1.21	1.27	1.33
UCS AT 6%	0.58	0.67	1.45	1.82	1.87
UCS AT 8%	0.48	0.68	1.50	2.16	2.45
NO ADDITIVE	0.46	0.46	0.46	0.46	0.46

Fig. 9 Unconfined compression strength vs. bitumen/cement content for sample A curve.

	100/0	75/25	50/50	25/75	0/100
UCS AT 4%	0.82	0.85	1.29	1.94	1.99
UCS AT 6%	0.58	0.80	1.39	2.69	2.43
UCS AT 8%	0.67	0.76	1.68	2.45	4.14

Fig. 10 Unconfined compression strength vs. bitumen/cement content for sample B curve.

References

[1] Aziz, M. A. 2013. "A New Method of Stabilization of Soft Soils." First International Conference on Case Histories in Geotechnical Engineering. Missouri University of Science and Technology.

[2] Amu, O. O., Ogunniyi, S. A., and Oladeji, O. O. 2011. "Geotechnical Properties of Lateritic Soil Stabilized with Sugar Cane Straw Ash." *American Journal of Scientific and Industrial Research* 2 (2): 323-31.

[3] British Lime Association. 1999. "Improving Poor Ground Conditions, Lime and Cement Stabilization of Weak Soils." *Aggregates Advisory Services*, Digest No, 058.

[4] Little, D. N., Males, E. M., Prusmski, J. K., and Stewart, B. 2003. "Cementitious Stabilization, Report of Committee on Cementitious Stabilization." A2J01, Transport Research Board.

[5] Owolabi, A. O., Oluyemi-Ayibiowu, B. D., and Aderinola O. S. 2004. "Effect of Moisture on the Strength of Lime Stabilized Lateritic Soils (A Case Study of Ojota, Lagos)." *Journal of Civil Engineering*, 10-5.

[6] Guyer, J. P. 2011. *Stabilization for Pavements*. NY.: Continuing Education and Development, Inc.

[7] Little, D. N., and Nair, S. 2009. *Recommended Practice for Stabilization of Subgrade Soils and Base Materials*. Texas: Texas A and M University.

[8] Department of the Army. 1994. The Army, Field Manual 1-1, vol. 2, Washington, D.C., Department of the Army.

[9] Kestler, M. A. 2009. *Stabilization Selection Guide for Aggregate and Native-Surfaced Low Volume Roads*. USA: U.S. Department of Agriculture.

[10] Thagesen, B. 1996. "Tropical Rocks and Soils." In: *Highway and Traffic Engineering in Developing Countries*. B, Thagesen, ed. London: Chapman and Hall.

[11] Makasa, B. 2004. "Utilisation and Improvement of Lateritic Gravels in Road Bases." International Institute for Aerospace survey and Earth Sciences, Delft.

[12] Lambe, T. W., and Whitman, V. R. 1979. *Soil Mechanics SI Version.* New York: John Wiley and Son Inc.

[13] Fookes, G. 1997. *Tropical Residual Soils, a Geological Society Engineering Group Working Party Revised Report.* London: The Geological Society.

[14] Bell, F. G. 1993. *Engineering Geology.* Oxford, London: Blackwell Scientific Publications.

[15] Gidigasu, M. D. 1976. *Laterite Soil Engineering, Pedogenesis and Engineering Principles.* Amsterdam: Elsevier Scientific Publishing Company.

[16] Ola, S. A. 1975. "Stabilization of Nigerian Lateritic Soils with Cement, Bitumen, and Lime." *Proceedings of the 6th Regional Conference for Africa on Soil Mechanics and Foundation Engineering*.

[17] Garber N. J., and Hoel, L. A. 2000. *Traffic and Highway Engineering.* 2nd ed. London: Brooks/Cole Publishing Company.

[18] Neville, A. M., and Brooks, J. J. 1987. *Concrete Technology.* United States: Longman Scientific and Technical co-Published with John Wiley and Sons.

[19] Onyelowe, K. C., and Okoafor, F. O. 2012. Geochemistry of Soil Stabilization. *ARPN Journal of Earth Sciences* 1 (1): 32-5.

[20] Kumar, V. Y., Krishna, M. R., and Mahesh, K. 2017. "Stabilization of Soil by Using Lime and Waste Plastic Fibers." *International Journal of Engineering Research* 5 (1): 191-8.

[21] BS 1377. 1991. *Methods of Test for Soils for Civil Engineering Purposes.* London: British Standard Institution Pub.

[22] Ogundipe, O. M., 2014. "Strength and Compaction Characteristic of Bitumen Stabilized Granular Soil." *International Journal of Scientific and Technology Research* 3 (9): 218-21.