Journal of King Saud University – Engineering Sciences (2018) 30, 305–312

King Saud University

Journal of King Saud University – Engineering Sciences

www.ksu.edu.sa
www.sciencedirect.com

ORIGINAL ARTICLES

Effect of curing time on strength development in black cotton soil – Quarry fines composite stabilized with cement kiln dust (CKD)

A.A. Amadi [a,*], A.S. Osu [b]

[a] Department of Civil Engineering, Federal University of Technology, Minna, Nigeria
[b] Department of Civil Engineering, Federal Polytechnic, Nasarawa, Nigeria

Received 4 December 2015; accepted 4 April 2016
Available online 11 April 2016

KEYWORDS

Cement kiln dust;
Compaction;
Curing time;
Quarry fines;
Unconfined compressive strength

Abstract Combined treatment techniques have been adopted by many pavement designers and site engineers to improve the strength and stability of subgrades or foundation soils of expansive sites. In this regard, research was conducted to investigate the effect of curing time on strength development of black cotton soil (BC soil) stabilized with 10% quarry fines (QF) and varying percentages (0–16%) of cement kiln dust (CKD). Preliminary tests such as Atterberg limits, compaction parameter test together with a series of unconfined compression tests were conducted on soil mixtures. Specimens for unconfined compression tests were prepared at their respective optimum moistures, compacted using British standard light (BSL) compaction effort and tested at curing times of 7, 14, 21 and 28 days. Data from the study revealed that the curing duration exerted a significant influence on the stress–strain behavior of soil mixtures together with the strain at failure which decreased by about 30–50% as the curing time increased. Unconfined compressive strength data showed improved strength values ranging from 1.25 to 5.25 times higher than the value for specimens tested immediately after preparation. Data developed in this study are expected to be useful to pavement designers and site engineers in the field implementation of the stabilization scheme such as when to open the stabilized layer to construction traffic or when to proceed with further construction works.

1. Introduction

Black cotton soils (BC soils) are inorganic clays characterized by very low bearing capacity, high compressibility, low permeability and high volume change under changing moisture conditions. They tend to lose strength further upon wetting and other physical disturbances. These soils are especially troublesome as pavement sub-grades and unsuitable for construction of embankments, buildings or other load bearing engineering

* Corresponding author. Tel.: +234 8034516603.
E-mail addresses: agapitus.amadi@futminna.edu.ng, agapitusahamefule4@yahoo.com (A.A. Amadi).
Peer review under responsibility of King Saud University.

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.jksues.2016.04.001
1018-3639

structures in their natural state (Arora, 2009; Murthy, 2009; Nelson and Miller, 1992; Amadi et al., 2013a).

In Nigeria, BC soils form a major soil group in the north – eastern region (Ola, 1983; Osinubi, 2000a; Ijimdiya et al., 2009; Oriola and Moses, 2011) where their presence accounts for the high incidence and frequency of road pavement failures and instability to lightly loaded engineering structures (Ola, 1983; Amadi et al., 2013b). Specifically, the BC soils of north-eastern Nigeria derive their origin from basalts of the upper Benue trough and quaternary sediments of lacustrine origin from the Chad basin consisting mainly of shales and clay sediments. The clay mineralogy of BC soil in this area is dominated by montmorillonite with a low percentage of kaolinite and/or illite minerals with the resultant manifestation of expansive tendencies (NBRRI, 1983; Ola, 1983; Osinubi and Medubi, 1997).

Experience of damages and continued failures of structures and pavements built on sites dominated by BC soils have given rise to intensive research to find ways of improving the strength of BC soils (Ola, 1983; Osinubi, 1998, 1999, 2000a; Osinubi et al., 2009; Eberemu et al., 2011; Amadi, 2014). The common practice is to use chemical additives to stabilize the soils before they are built upon. Cement kiln dust (CKD), an industrial waste from cement production similar in appearance to Portland cement is finding application in the stabilization of soils. Records from the literature show that CKD is an effective stabilizer in the improvement of the strength properties of fine grained soils (Peethamparan and Olek, 2008; Oriola and Moses, 2011; Amadi and Eberemu, 2012). Evidence of improvement has been found particularly on specimens cured over a period of time. In general, the longer the curing period, the better is the strength development, due to the pozzolanic reaction (Kezdi, 1979). Nelson and Miller (1992) suggested that curing periods should extend to at least 28 days in order to provide idealized conditions for the cementitious and pozzolanic reactions.

The pozzolanic reaction occurs once the pore chemistry in the soil system achieves a sufficiently alkaline condition. The resulting alkalinity of the pore water promotes dissolution of silica and alumina from the clays, which then react with the Ca^{2+} ions, forming calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH). These compounds crystallize and harden with time, thereby enhancing the strength of the soil mixtures.

For problematic soils such as BC soil, a single additive may not result in maximum improvement in the required properties of the soils (Amadi et al., 2013a; Amadi, 2014; Osinubi, 2000b; Osinubi et al., 2009; Eberemu et al., 2011; Ijimdiya et al., 2009). Consequently, incorporation of quarry fines which recently has become useful in improving the geotechnical properties of deficient soils such as the grading curve with consequent enhancement in the strength, compaction characteristics, reduction in the plasticity and swell characteristics was considered (Soosan et al., 2005; Amadi, 2011, 2014; Eze-Uzoamaka and Osondu, 2010). Combining the two treatment techniques has the potential to provide an improved strength and stability of subgrade soils or foundation soils thereby presenting a sustainable and cost effective solution to the engineering problems associated with this soil.

The present study however focussed on improvement in the stress strain and strength behavior under unconfined compression strength of the stabilized soil as a function of time. Knowledge of how the strength varies with time can provide a basis for field curing requirements for projects located in areas with these unsuitable soils. This guides the site engineer on when to open the stabilized layer to construction traffic or other construction activities.

2. Materials and methods

2.1. Soil

The BC soil used in this study is greyish black in color, obtained from Damsa Local Government Area of Adamawa State, Nigeria. Samples were collected by open excavation from a trench with the following dimensions: 1.5 × 1.5 × 1 m.

2.2. Cement kiln dust (CKD)

The cement kiln dust (CKD) used was obtained from freshly deposited heaps of the by – product at the Benue Cement Factory located in Gboko, Nigeria and stored in – air tight bags.

2.3. Quarry fines (QF)

The QF used for the study was obtained in Abuja, Nigeria. It was sieved through British Standard No. 4 (4.75 mm) sieve and stored before usage.

2.4. Testing methods

The laboratory tests conducted on the natural soil sample and soil mixtures include: particle size distribution, Atterberg limits, specific gravity, compaction, and unconfined compressive test (UCT). For the UCT, specimens were compacted using the British standard light (BSL) compaction effort adopting curing periods of 7, 14, 21 and 28 days. All tests were carried out in accordance with the specifications contained in BS 1377 (1990) and BS 1924 (1990).

2.4.1. Preparation and testing of specimens

Part of the air dried soil samples were pulverized to pass through British Standard No. 4 (4.75 mm) for compaction and strength tests while samples for Atterberg limit tests were passed through BS No. 40 (425 μm). The air dried and pulverized soil was first mixed with 10% quarry fines prior to mixing with varying percentages of 0%, 4%, 8%, 12% and 16% of cement kiln dust on dry weight basis. Laboratory tests listed above were conducted on thoroughly blended mixes after hydrating with water in the required quantity depending on the test.

2.4.2. Unconfined compression testing (UCT)

UCT samples were prepared at the optimum moisture contents determined from the compaction curves. The prepared UCT samples were sealed in a plastic bag to cure in the humidity room where the temperature was maintained at 20 ± 2 °C for 7, 14, 21 and 28 days before conducting the test. Unconfined compression tests were conducted on a strain-controlled triaxial testing frame at a strain rate of 1%/min without application of the cell pressure (σ_3 = zero). The

Table 1 Properties of natural black cotton soil.

Characteristics	Quantity
Percent passing BS No. 200 sieve (%)	88
Natural moisture content (%)	26.05
Liquid limit (%)	85
Plasticity index (%)	38.09
Linear Shrinkage (%)	35.41
USCS Classification	CH
AASHTO Classification	A-7-6
Specific gravity	2.26
pH	7.2
Color	Greyish black
Dominant clay mineral	Montmorillonite

Table 2 Oxide composition of study soil and cement kiln dust (CKD).

Oxide	%	
	Black cotton soil	Cement kiln dust*
CaO	0.9	67.72
SiO_2	48.70	11.50
Al_2O_3	18.70	3.10
Fe_2O_3	2.40	3.55
MgO	2.22	ND
SO_3	ND	0.78
Mn_2O_3	ND	0.12
Na_2O	1.55	–
K_2O	0.7	1.14
TiO_2	ND	0.35
Ag_2O	–	1.55
CaO/SiO_2	0.02	5.89
Silica:sesquioxide ratio	2.3	1.73
Loss on ignition	10.20	8.70

* *Source:* Benue Cement Factory, Gboko, Benue State – Nigeria; ND – Not determine.

maximum load was converted to the unconfined compression strength of the sample.

3. Results and discussion

3.1. Mineralogy and physical properties of the test materials

Results of the physico-chemical tests conducted on the soil sample are presented in Table 1, while the oxide composition of the soil together with that of the CKD is reported in Table 2. The particle size analysis (Fig. 1) indicates that the soil has sand content of about 12% while the clay and silt content constitute 88%. The average natural moisture content of the soil was found to be 26.05%. Based on these properties, the soil was classified as A-7-6 and CH group under AASHTO (AASHTO, 1986) and the USCS classification systems (ASTM, 1992) respectively and therefore rated as fair to poor sub-grade highway materials.

The particle size distribution curve of the quarry fines (QF) used in the study is presented in Fig. 1 while other engineering properties can be summarized as follows: effective size: 2.70 mm, specific gravity: 2.75, uniformity coefficient: 1.37 and coefficient of curvature of 0.9.

3.2. Results of Atterberg limits test on soil mixtures

The addition of CKD changed the Atterberg limits (i.e., liquid limit, plastic limit and plasticity index) of the BC soil – QF composite. The liquid limit (LL) decreased from 85% for the natural BC soil to 72.5% when 10% QF was introduced and decreased further with the addition of CKD as shown in Fig. 2. Thus the minimum LL value of 44.62% was recorded upon addition of 16% CKD.

The plastic limit (PL) generally decreased as the CKD content increased, recording 38.09% and 25.5% respectively for 0% and 16% CKD content. The resulting plasticity index (PI) for all soil mixtures was consistently lowered as the CKD content increased as shown in Fig. 2. This, in addition to other improved properties ensures good workability on site during field implementation. PI values as low as 12.6% was achieved for 16% CKD which is equivalent to levels achieved with fly ash stabilization (Amadi, 2010).

The liquid limit of the black cotton soils is essentially controlled by the thickness of the diffused double layer and the shearing resistance at particle level. The addition of CKD results in the decrease of liquid limit due to the effect of reduction in the diffused double layer thickness as well as due to the effect of dilution of the clay content of the mix.

3.3. Compaction characteristics of stabilized soil mixtures

The results of compaction tests revealed the relationship between dry unit weight and moisture content of each mixture of the BC soil – QF upon stabilization with CKD. The change

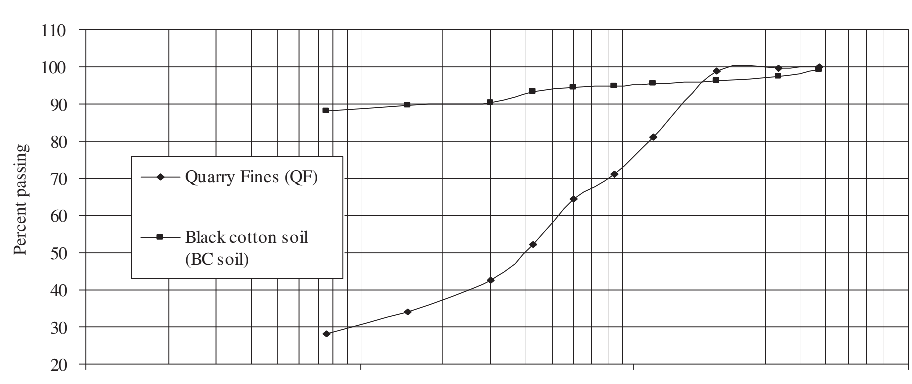

Figure 1 Particle size distribution curves for quarry fines and BC soil used in the study.

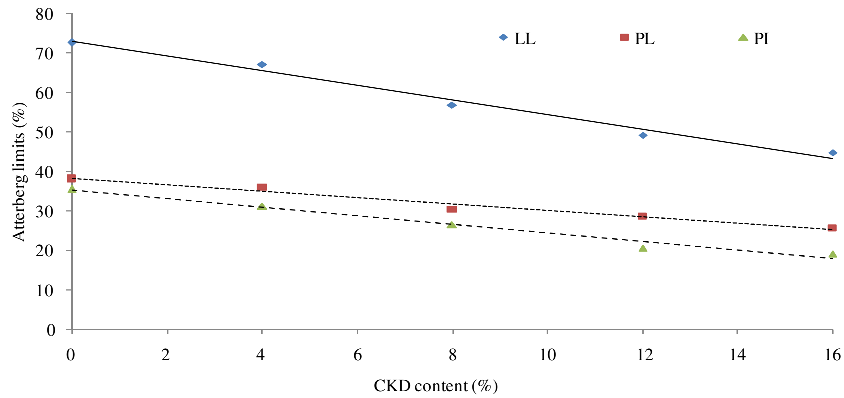

Figure 2 Variation of Atterberg limits for soil mixtures with CKD content.

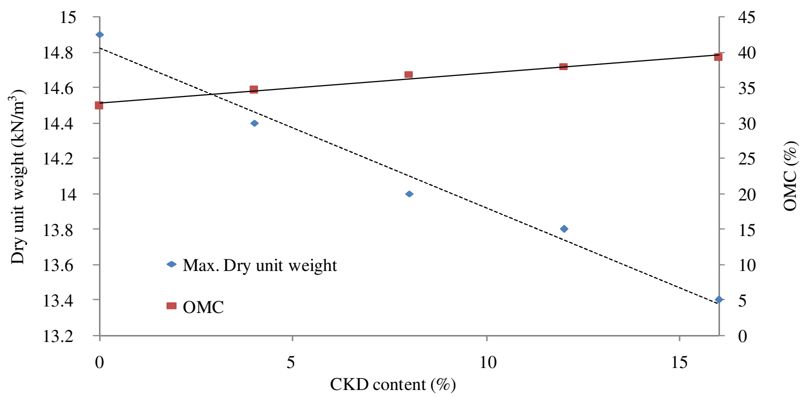

Figure 3 Variation of maximum dry unit weight and optimum moisture content of soil mixtures with 10%QF and different CKD contents.

in composition of the stabilized mixtures reflected in the changes in the maximum dry unit weight and the optimum moisture content. Generally, dry unit weights were lower while the optimum moisture content (OMC) increased after the addition of CKD. For example, while the maximum dry unit weight of the BC soil + 10%QF composite was established as 14.9 kN/m^3 at optimum moisture content (OMC) of 32.4%, the maximum dry unit weight of specimens on application of CKD exhibited reduction with a resultant increase in optimum moisture content. The results further showed that maximum dry unit weight of 13.4 kN/m^3 was recorded for the soil mixture containing 16% CKD with a corresponding OMC value of 39.20% which is higher than both the OMC of the natural BC soil (= 28.4%) and the average natural moisture content of the BC soil sample used in the study (= 26.05%). These variations in compaction characteristics (i.e., maximum dry unit weight and optimum moisture content) of soil mixtures reported in Fig. 3 are similar to the effect of lime and other additives on BC soil (Osinubi, 1998, 2000b; Åhnberg et al., 2003; Ijimdiya et al., 2009; Osinubi et al., 2009).

The decrease in maximum dry unit weight may be attributed to replacement of BC soil/QF particles in a given volume by particles of CKD thereby reducing dry unit weight and increasing the water absorbing ability of the soil mixtures.

Beyond these compaction parameters measured immediately after specimen preparation, the post-curing dry unit weight and water content of soil mixtures were measured from UCS test specimens. Figs. 4 and 5 represent the variation of post-curing unit weight and water content of soil mixtures with curing time. While the post-curing dry unit weight increased with curing time, the post-curing water content exhibited decreasing tendency with curing time.

The time dependent pozzolanic reactions that produced solid cementation products resulted in reduction of the water content which eventually increased the dry unit weight of the treated soil.

3.4. Curing time effect on strength characteristics of soil mixtures

Time – strength development is crucial in the study of strength characteristics of soils treated with stabilizers as the structure of such materials evolves with time due to continuing hydration/pozzolanic reactions (Al-Refeai and Al-Karni, 1999; Oriola and Moses, 2011; Peethamparan and Olek, 2008; Salahudeen et al., 2014). To illustrate the strength evolution with time for BC soil specimens treated with combined QF and 4%, 8%, 12% and 16% CKD, the stress–strain response was recorded for each of the mixtures which were cured for 0, 7, 14, 21 and 28 days to produce the stress–strain curves reported in Fig. 6(a–d) respectively.

Typical of soils treated with cementitious materials, the stress–strain curves of soil mixtures shift towards the left hand side as the strain at failure reduced with both an increase in

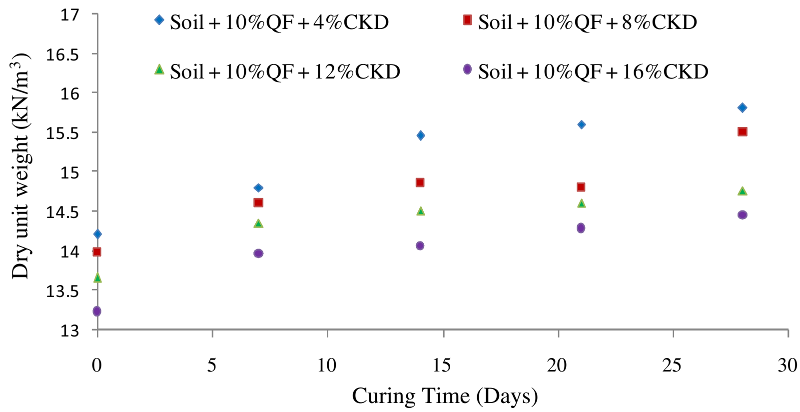

Figure 4 Variation of post curing dry unit weight with time.

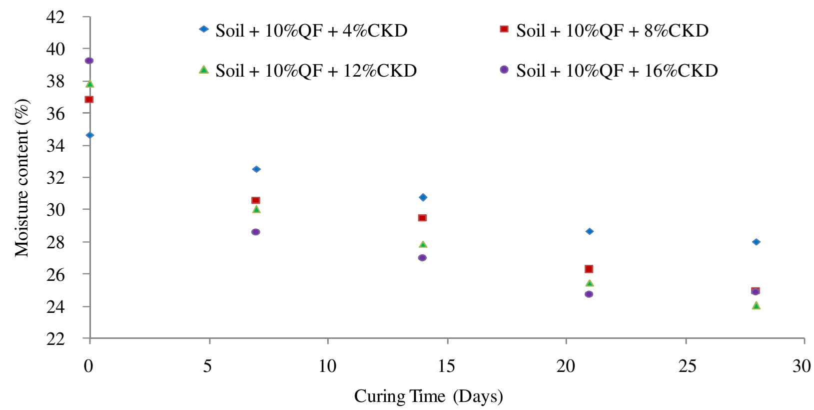

Figure 5 Variation of post curing moisture content with time.

admixture content and curing time. It can also be observed that the stress–strain relationship for soil mixtures tested immediately after preparation exhibited relatively ductile stress–strain behavior with gradual and continuous deformation until a peak stress was reached. On the other hand, maximum shear stress occurred at very low strain for the specimens with higher amounts of admixture especially for the longer curing periods which was generally followed by a sudden drop in the post-peak stress. For example, the maximum shear stress of specimens stabilized with 4% CKD + 10%QF cured for 7 days reached 220 kN/m^2 at a strain of about 1.8% while specimens of similar constitution cured for 28 days achieved a maximum stress of 603 kN/m^2 at 1.25% strain. This represents a 30% decrease in axial strain at failure when compared to the strain at failure for specimens cured for 7 days. Similarly, a 50% decrease in the strain at failure was established for duplicate specimens containing 10%QF + 16% CKD that were cured for 7 and 28 days. Intermediate values were obtained for 14 and 21 day cured mixtures.

The variation of measured strain at failure for soil mixtures with curing time is reported in Fig. 7. Despite some scatter in the data, it can be seen that the measured strains at failure decreased with increasing curing time. The measured axial strains at maximum stress ranged from 0.75% to 3.05%. Thus, the soil mixtures became stiffer due to pozzolanic reaction as curing time increased and can reach the maximum stress at a much smaller strain. It is further observed that the axial strains at failure for 10%QF + 12% CKD and 10%QF + 16% CKD mixtures was essentially coincident from 21 days. This suggests the axial strain at failure for the two mixtures.

Visual observations of tested specimens show that the shear failure mode of specimens with higher admixture content cured over longer periods was more of brittle behavior when compared to mixtures tested immediately after preparation or cured over a shorter duration.

The effect of curing time on the strength development of soil mixtures was further demonstrated by a variation analysis of the unconfined compressive strength (UCS) at different curing durations represented in Fig. 8. The UCS at each curing time has been normalized by the UCS at 0 day curing. It can be observed that the timeline presents a slow rate of increase in strength between the 7th day and 14th day which is followed by a steeper increase that extends to the 28th day. The seeming delay in strength development at the initial stage of curing probably represents the induction period necessary for pozzolanic reaction between soil particles and the chemical stabilizer in the mixtures resulting in the formation of cementation products. Similar trend was reported by Jalali et al. (1997) as well as Consoli et al. (2001) for lime – fly ash soil stabilization. However, it is important to note that Jalali et al. (1997)

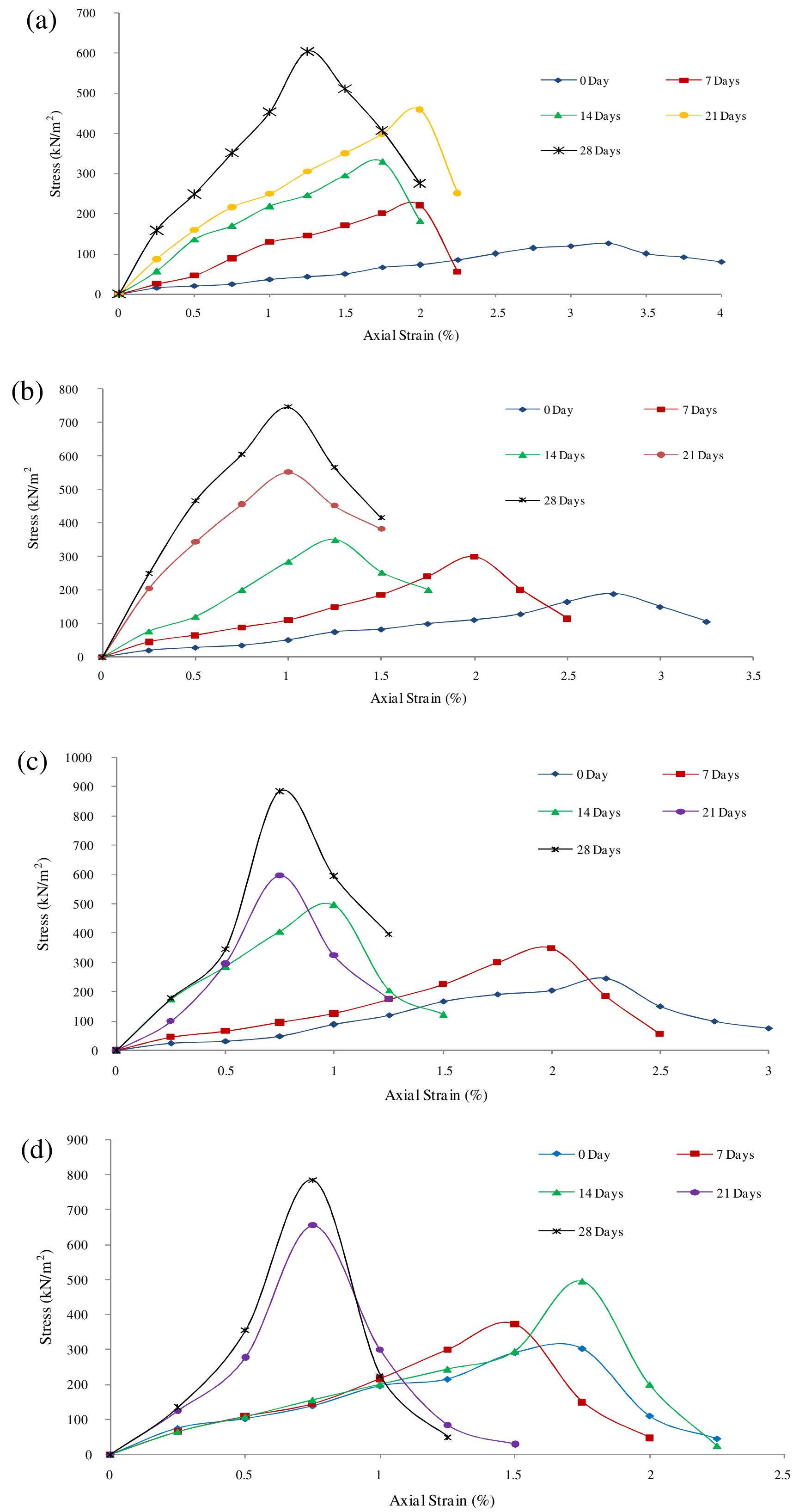

Figure 6 Stress–strain curves from the UCT for soil mixture containing (a) 4 (b) 8 (c) 12 and (d) 16% CKD.

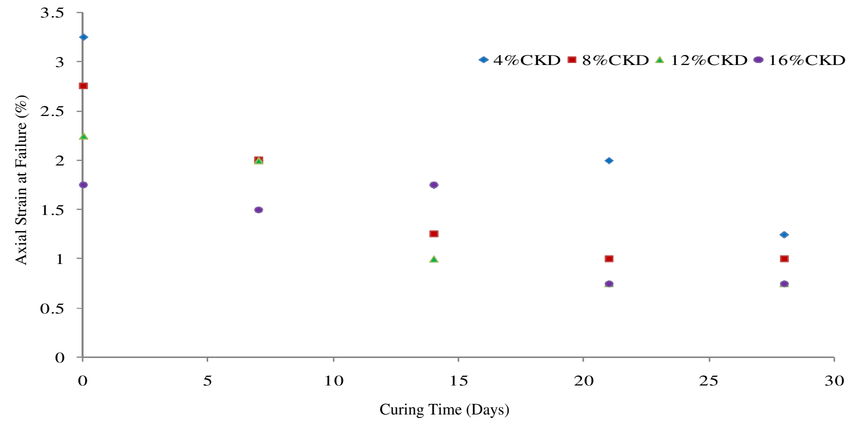

Figure 7 Variation of axial strain at failure with curing time.

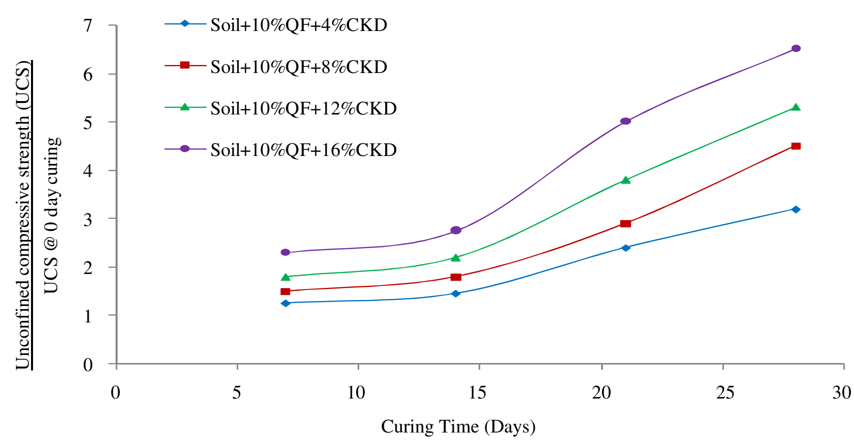

Figure 8 Development of compressive strength with time for compacted soil with different admixture percents.

pointed out that the delay period was strongly dependent on the curing temperature of mixtures.

Soil mixture containing 4% CKD achieved an increase of about 1.25 times the initial 0-day (i.e., immediately after preparation) strength after 7 days, which increased to 3.2 at 28 days.

Similarly, an increase in strength of more than 2.3 times in 16% CKD specimens was recorded after 7 days and 5 times at 28 days was achieved.

Another trend that can be observed from the data in Fig. 8 is that soil mixtures with higher CKD content expectedly plotted above those with lower CKD fraction.

Based on these results, it is obvious that curing time exerts a strong effect on the development of strength of the BC soil – quarry fines mixture stabilized with CKD and is therefore identified as a major variable affecting the strength development of the stabilized soil mixtures.

The increase in strength is probably due to time dependent pozzolanic reactions that resulted in the formation of various compound such as calcium silicate hydrates (CSH), calcium aluminates hydrates (CAH) and calcium aluminum silicate hydrates (CASH). It is the presence of these compounds that is responsible for strength development in the mixtures (Amadi, 2014; Miller and Azad, 2002; Oriola and Moses, 2011; Osinubi, 2000; Peethamparan and Olek, 2008; Salahudeen et al., 2014; Sreekrishnavilasam et al., 2007).

4. Conclusions

In this study, the influence of curing time on the strength properties of black cotton soil stabilized with combined quarry dust and CKD admixture measured in an unconfined compression test was evaluated. Soil mixtures prepared at optimum compaction parameters and compacted with British standard light (BSL) compaction effort were tested after 0, 7, 14, 21 and 28 curing days. Preliminary tests carried out on the soil mixtures showed that there was reduction in LL, PI and dry unit weight, irregular trend in the variation of plastic limit and an increase in OMC of soil mixtures.

Results further indicate a general increase in UCS values with increasing CKD content as well as the curing time for soil mixtures. Improvement in UCS values ranged from 1.5 to 5 times higher than those tested immediately after preparation.

The study revealed that the stabilized soil mixtures like soils stabilized with other cementitious admixtures have the potential for a time-dependent increase in strength and therefore with additional curing time, further strength may develop. On this subject, further studies considering longer curing times and possibly higher CKD contents are necessary.

Data developed in this study are expected to be useful to pavement designers and site engineers in the field implementation of the stabilization scheme such as when to open the stabilized layer to construction traffic or when to proceed with further construction works.

References

AASHTO, 1986. Standard Specification for Transportation Materials and Methods of Sampling and Testing, 14th ed., Washington, DC.

Åhnberg, H., Johansson, S.-E., Pihl, H., Carlsson, T., 2003. Stabilising effects of different binders in some Swedish Soils. Ground Improv. 7 (1), 9–23.

Al-Refeai, T.O., Al-Karni, A.A., 1999. Experimental study on the utilization of cement kiln dust for ground modification. King Saud Univ. Eng. Sci. 11 (2), 217–232.

Amadi, A.A., 2010. Evaluation of changes in index properties of lateritic soil stabilized with fly ash. Leonardo Electro J. Pract. Technol. (LEJPT) 9 (17), 69–78.

Amadi, A.A., 2011. Evaluating the potential use of lateritic soil mechanically stabilized with quarry fines for construction of road bases. Nigerian J. Eng. 17 (2), 1–12.

Amadi, A.A., 2014. Enhancing durability of quarry fines modified black cotton soil subgrade with cement kiln dust stabilization. J. Transport. Geotech., Elsevier 1 (1, 55–61), 2214–3912. http://dx.doi.org/10.1016/j.trgeo.2014.02.002, ISSN: 2214-3912.

Amadi, A.A., Eberemu, A.O., 2012. Performance of cement kiln dust in stabilizing lateritic soil contaminated with organic chemicals. Adv. Mater. Res., Trans Tech Publications, Switzerland 367, 41–47. http://dx.doi.org/10.4028/www.scientific.net/AMR.367.41.

Amadi, A.A., Eberemu, A.O., Momoh, H.O., 2013a. Use of coir fiber reinforcement technique to improve strength of cement kiln dust treated black cotton soil subgrade, Proc. of Int. Conf. on Geosynthetics for Water Resources and Energy Challenges (Geosynthetics 2013), 1-4 April, California, U.S.A. Session 202: Natural Fiber Geosynthetics, pp. 223–229.

Amadi, A.A., Alhaji, M.M., Sule, A.B., 2013b. Forensic Investigation of premature failure of a township road in Minna, Niger state, Nigeria, Book of Proc., 3rd Biennial Engineering Conference on Challenges of Energy Supply and Infrastructural Development in Developing countries, 14 – 16 May, Minna, Nigeria. Session 3D: Science and Technical Education, pp. 59–65.

Arora, K.R., 2009. Soil Mechanics and Foundation Engineering, seventh ed. A. K. Jain Publishers 1705-B, New Delhi – 110006.

ASTM, 1992. Annual Book of ASTM Standards Vol. 04.08. American Society for Testing and Materials, Philadephia.

BS 1377, 1990. Methods of Testing Soils for Civil Engineering Purposes. British Standard Institution, London.

BS 1924, 1990. Methods of Tests for Stabilized Soils. British Standard Institution, London.

Consoli, N.C., Prietto, P.D.M., Carraro, J.A.H., Heineck, K.S., 2001. Behaviour of compacted soil – fly ash – carbide lime mixtures. J. Geotech. Geoenv. Engrg., ASCE 127 (9), 774–782.

Eberemu, A.O., Osinubi, K.J., Oyelakin, M.A., 2011. Improvement of black cotton soil with ordinary portland cement – locust bean waste ash blend. EJGE 16, 619–627.

Ijimdiya, T.S., Nmadu, Osinubi, K.J., 2009. Lime stabilization of black cotton soil using baggasse ash as admixture. Adv. Mater. Res. 62–64, 3–10.

Jalali, S., Abyaneh, M.Y., Keedwell, M.J., 1997. Differential Scanning Calorimetry Tests Applied to Lime – Fly Ash Soil Stabilization. Testing Soil Mixed with Waste or Recycled Materials. STP 1275. ASTM, West Conshohocken, Pa, pp. 181–191.

Kezdi, A., 1979. Stabilized Earth Roads. Development in Geotechnical Engineering. Elsevier Scientific, New York.

Miller, G.A., Azad, S., 2002. Influence of soil type on stabilization with cement kiln dust. Constr. Build. Mater. 14, 89–97.

Murthy, V.N.S., 2009. Soil Mechanics & Foundation Engineering, first ed. CBS Publishers & Distributors Pvt. Ltd..

NBRRI, 1983. Engineering properties of black cotton soils of Nigeria and related pavement design. Nigerian Build. Road Res. Inst. 3, 1–20.

Nelson, J.D., Miller, D.J., 1992. Expansive Soils, Problems and Practice in Foundation and Pavement Engineering. Wiley, New York.

Ola, S.A., 1983. The geotechnical properties of black cotton soils of North Eastern Nigeria. In: Ola, S.A. (Ed.), . In: Tropical soils of Nigeria in Engineering Practice. A.A. Balkema, The Netherlands, Rotterdam, pp. 155–171.

Oriola, F., Moses, G., 2011. Compacted black cotton soil treated with cement kiln dust as hydraulic barrier material. Am. J. Sci. Indust. Res. 2 (4), 521–530. http://dx.doi.org/10.5251/ajsir.2011.2.4521.530.

Osinubi, K.J., 1998. Influence of Compaction Delay on the Properties of Lime Stabilized Clay Soil. J. Eng. Res. 6 (1), 13–25.

Osinubi, K.J., 1999. Evaluation of admixture stabilization of Nigerian black cotton soils. NSE Tech. Trans. 34 (3), 88–96.

Osinubi, K.J., 2000a. Stabilization of tropical black clay with cement and pulverized coal bottom ash admixture. In: Shackelford, Charles D., Sandra, L.H, Chang, Nien-Yui (Eds.), Advances in Unsaturated Geotechnics, ASCE Geotechnical Special Publication, vol. 99, pp. 289–302.

Osinubi, K.J., 2000b. In: Stabilization of Tropical Black Clay with Lime and Pulverized Coal Ash Admixture. In: Shackelford, C.D., Houston, S.L., Chang, N.Y. (Eds.), . Advances in Unsaturated Geotechnics, vol. 99. ASCE Geotechnical Special Publication, pp. 289–302.

Osinubi, K.J., Medubi, A.B., 1997. Evaluation of cement and phosphatic waste admixture on tropical black clay road foundation, Proc. of 4th Int. Conf. on Structural Engineering (SEAM 4). In: Accra, vol. 2, pp. 297–307.

Osinubi, K.J., Ijimdiya, T.S., Nmadu, I., 2009. Lime stabilization of black cotton soil using bagasse ash as admixture. Adv. Mater. Res., 62–64 http://wwwscientific.net (Trans Tech Publications. Switzerland).

Peethamparan, S., Olek, J., 2008. Study of the effectiveness of cement kiln dusts in stabilizing N-montmorillonite clays. J. Mater. Civ. Eng. 20 (2), 137–146.

Salahudeen, A.B., Eberemu, A.O., Osinubi, K.J., 2014. Assessment of cement kiln dust-treated expansive soil for the construction of flexible pavements. Geotech. Geol. Eng. http://dx.doi.org/10.1007/s10706-014-9769-0 (Springer International Publishing Switzerland).

Soosan, T.G., Sridharan, A., Jose, B.T., Abraham, B.M., 2005. Utilization of quarry dust to improve the geotechnical properties of soils in highway construction. Geotech. Test. J. 28 (4), 391–400, Paper ID GTJ11768, 391-400.

Sreekrishnavilasam, A., Rahardja, R., Kmetz, R., Santagata, M., 2007. Soil treatment using fresh and landfilled cement kiln dust. Constr. Build. Mater. 21, 318–327.

Uzomaka, Eze, John, Osondu, 2010. Suitability of quarry dust as improvement to cement stabilized-laterite for road bases. EJGE l (15), 1053–1054.