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Enhancing durability of quarry fines modified black cotton soil subgrade with cement kiln dust stabilization

Agapitus Ahamefule Amadi *

Department of Civil Engineering, Federal University of Technology, Minna, Nigeria

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ABSTRACT

For soil materials to be effective as pavement subgrades, satisfying the durability conditions is essential especially in tropical latitudes where wet and dry climatic conditions prevail. This study investigated the use of cement kiln dust (CKD) to enhance the durability of black cotton soil (BC soil) subgrade modified with quarry fines (QF). Durability was assessed by California bearing ratio (CBR) swell and loss of strength upon immersion tests carried out on soil mixtures prepared with BC soil mixed with constant dosage of 10% QF and five levels of CKD concentration (0%, 4%, 8%, 12% and 16% by dry weight of soil). Specimens were compacted using British standard light (BSL) effort under optimum moisture condition, cured and then subjected to prolonged soaking. Test results show that mixtures containing 0% and 4% CKD failed the CBR and associated swell limits as well as the resistance to loss of strength criterion while both tests deemed soil mixtures containing 8–16% CKD durable. Moisture content evaluation revealed that inclusion of CKD reduced the moisture susceptibility of mixtures. Overall, the testing programme produced data showing that mixtures with CKD admixture have significant durability when exposed to prolonged saturation.

Introduction

Highway engineers are often concerned with the durability of pavement structures especially when subgrades that exhibit high volumetric instability such as expansive black cotton soils (BC soils) are encountered. BC soils normally found in semi – arid regions of tropical and temperate climate zones generally rate as poor pavement subgrade materials. The majority of these soils classify as AASHTO A-7-6, meaning they are predominately fine-grained silt and clay soils. Primary characteristics of these soils include poor strength, poor workability, high volumetric instability and poor durability in response to environmental fluctuations. In practically every location where they are encountered, roads constructed over BC soil subgrades show poor performance, unless appropriate technology is adopted to transform them into effective construction materials. Consequently, their presence is one of the crucial factors that significantly impact costs of road projects.

BC soils owe their characteristics to their mineralogical assemblage i.e., presence of active montmorillonite clay mineral with expanding lattices. Structurally, montmorillonitic clays have 2:1 layers (consisting of two tetrahedral sheets with an octahedral sheet between them), which allow for isomorphous substitution in the sheets, hence exhibit a high degree of cation exchange, hydration and swelling (Grim, 1968).

Many procedures have been adopted to improve the physical behavior of this soil by incorporating a wide range of stabilizing agents, additives and conditions.

* Tel.: +234 0834516603.
E-mail address: agapitusahamefule4@yahoo.com.

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Undoubtedly one of the most cost-effective methods involves the use of granular materials such as sand or quarry fines (QF). Recently, QF has becomes a useful addition to natural soils to improve their grading characteristics with a consequent enhancement in the strength, compaction characteristics, reduction in the plasticity, and swell characteristics (Ingles and Metcalf, 1972; Soosan et al., 2005). Although the addition of QF increases the strength and rigidity of soils, the resulting mixture is highly susceptible to loss of strength when subjected to prolonged contact with moisture. For example, results of studies reported by Eze Uzomaka and Agbo (2010) as well as Amadi (2011) indicate that cylindrical specimens made with different combination of quarry fines and lateritic soil disintegrated inside the water bath while others collapsed at the commencement of loading. This loss of strength and integrity results from the deterioration of the matrix and the presence of excess water in the stabilized material after saturation.

Accordingly, any technology to be adopted in stabilizing such subgrades, must meet certain requirements particularly the ability to retain stability and integrity over years of exposure to environmental loading. This is often accomplished by physicochemical alteration of soil properties with calcium rich admixtures such as cement kiln dust (CKD) that renders the soil permanently stable.

Permanency of stabilization is related to adequate formation of secondary cementitious products such as calcium aluminate hydrates (CAH) and calcium silicate hydrates (CSH) during elevated pH and ion exchange (Osinubi, 1998). While the ion exchange occurs rapidly, long term cementation of the flocculated particles may take days or even years to fully develop and will continue in a high pH environment (above 10) until the silica in the clays is consumed or until the pH drops from inadequate amounts of lime.

Use of quarry fines and cement kiln dust in combination was contemplated as a means to possibly providing workable, cost effective yet durable subgrades in high plasticity soils. In addition, the need to effectively utilize this superfluous by-product of the cement manufacturing process provided additional impetus for this study.

Materials and methods

Black cotton soil

The black cotton soil used in this study was obtained along New-Marte road, Borno State, Nigeria. The location lies within latitude 10° 19′N and longitude 11° 30′E which is a semi-arid region with long periods of dry weather and short spells of wet weather (Carter et al., 1963).

Stabilizers

Cement kiln dust (CKD)

The cement kiln dust used was obtained from the Benue cement production plant located in Benue state, Nigeria and was stored in sealed plastic bags.

Quarry fines

The quarry fines used in this study was produced from a quartz – based rock in a local quarry in Minna, Nigeria. Only the fraction passing through BS sieve No. 4 (4.76 mm) was used in the study.

Admixture proportions and tests conducted

The experimental programme included particle size analysis, Atterberg limits, compaction, and durability tests. Two standardized laboratory test methodologies adopted for the assessment of durability of stabilized soil mixtures are: California bearing ratio (CBR) swell test and loss of strength upon immersion tests. These methods are preferred in tropical climates to the freeze-thaw test highlighted in ASTM (1992) as they replicate the severe weather conditions prevalent in these regions (Ola, 1974).

California bearing ratio (CBR) and California bearing ratio (CBR) swell test as well as loss of strength upon immersion tests were carried out on the natural and stabilized specimens. The tests were carried out following procedures outlined in British Standards (BS 1377, 1990; BS 1924, 1990) for the natural and stabilized soils respectively. Samples collected as clods were air dried and pulverized to obtain particles passing sieve BS No. 4, (4.75 mm aperture). Soil mixtures were prepared by combining dry BC soil with 10% QF together with cement kiln dust in proportions of 0%, 4%, 8%, 12% and 16% by weight of soil.

Compaction test

The moisture – unit weight tests conducted on raw and stabilized soil were used to determine the compaction parameters namely optimum moisture content (OMC) and maximum dry unit weight.

CBR swell test

In the original form of this testing method (BS 1924, 1990), there was no requirement for specimens to be tested for strength (by CBR); however this has been amended which now stipulates that the soaked CBR specimen should be tested for both strength and swell (HA 74/07, 2007). Therefore, the CBR and CBR swell tests were conducted on soil mixtures compacted at the optimum moistures using British standard light (BSL) compaction effort (i.e., 'Proctor' compaction) and then sealed in polythene in a humidity room at a temperature of 20 ± 2 °C. The standard curing regime for CBR is 7 days which requires a 3 day air cure and a 4 day soak prior to testing. In the swell test, however, specimens were soaked for 28 days which is longer than specified CBR standard testing procedure. Swell measurements were taken by vernier calipers immediately after soaking.

Loss of strength on immersion test

The unconfined compressive strength (UCS) test remains the standard and most common strength test used to characterize stabilized soils and has been found to be a competent indicator of the durability of soils.

As in the CBR swell test, the protocol involved compaction of soil mixtures at optimum moisture content (OMC)