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Engineering and mineralogical properties of stabilized expansive soil compositing lime and natural pozzolans

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HIGHLIGHTS

- Black cotton soils found in abundant in Kenya are potentially expansive.
- Natural pozzolan is an attractive stabilizer to allow making use of such clays.
- Physical-mechanical properties of lime stabilized soil with such ashes were studied.
- Optimum blend ratio was given to make such soil meet criterion of roadbed fillings.
- Change in mineralogical phases was considered to investigate stabilization mechanism.

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ABSTRACT

Black cotton soils (BCSs) were stabilized with various percentage of lime, natural volcanic ash (VA) and their combinations. The laboratory tests were performed to evaluate the influence of the stabilizers on the physical-mechanical properties of BCS. These laboratory tests included Atterberg limits, California bearing ratio (CBR), swell percent and unconfined compressive strength (UCS). The changes of minerals were also derived by performing X-ray diffraction, Infrared spectroscopy and scanning electron microscope, which were employed to explain the stability mechanism of BCS together with pH test. Results revealed that the added stabilizers improved greatly the physical-mechanical properties of BCS. The use of combinations of lime and VA showed superior results when compared with the single stabilizer. BCS can meet the performance requirements of roadbed materials referring to JTG D30-2015 just by mixing with 3% lime and 15% VA. The increased pH of the stabilized BCS indicated that solubility of the silicate and the aluminate increased, which accelerated the pozzolanic reaction between clay soils and stabilizers. The intrinsic lamellar structures of clay mineral were destructed in the reaction process. Moreover, several new minerals were produced to stabilize the soil fabric. Overall, the use of VA can reduce the consumption of lime in BCS stabilization and actualize the utilization of vast resources BCS as a low-cost roadbed material.

1. Introduction

Municipal roads, highways and railway lines have developed rapidly in Kenya. Many heavy constructions have been conducted in recent years, such as Nairobi Southern Bypass and Nairobi - Mombasa railway line. These constructions are frequently faced with problems brought about by black cotton soil (BCS). BCS forms a major soil group in Kenya [1]. This type of clays has the high shrink/swell potential as exposure to water [2,3]. The foundation BCSs have to be excavated out since the shrink/swell behavior of such clays will damage embankment and pavement [4]. The untreated BCSs are hard to meet the performance requirements of roadbed material and have to be thrown away. With the development of the traffic engineering construction, the excavation and abandonment of BCS are increasing every year, and have thus resulted in serious cost issues and environmental concerns. To overcome these problems, a facile but low-cost strategy has to be found to utilize such clay soils. Soil stabilization, which is widely

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used in the word, can diminish the volume change of such clays as exposure to water [5–8]. The conventional stabilizers, such as hydrated lime, ordinary Portland cement, petroleum sulfonate and asphalt are often used to improve the physical-mechanical properties of such clays [9–14]. However, the generous use of these stabilizers will increase greatly the construction cost. Therefore, it is necessary to find a local natural resource replaceable as soon as possible. Volcanic ash (VA), which is a natural pozzolan and found abundantly in Kenya, is an attractive choice to reduce the stabilization cost of such clays.

Volcanic ash, which is produced by volcanic activity, consists of rocks, minerals and volcanic glass fragments. The pozzolanic properties of such ashes can be utilized to cement the clay particles together and decrease moisture absorption of those clays. As a result, soil stabilization with VA not only reduces the swelling potential and plasticity index but also improves the durability and strength of clay soils [15]. Unfortunately, small content of calcium oxide in natural volcanic ashes will lead to the insufficiency of pozzolanic reaction between clay soils and such ashes. In the limited study, the VA was used to stabilize expansive soil when compositing with lime and cement [16]. The calcium hydroxide from natural lime or cement hydration reacts chemically with the active ingredient of VA. The new minerals, such as hydrated calcium silicate and hydrated calcium aluminate are produced to improve the water stability and strength of the expansive soils. The utilization of VA in soil stabilization reduces the consumption of cement and lime and also represents the reduction in greenhouse gas emission and energy consumption. Increased utilization of VA results in a low-cost roadbed material and provides an environmentally friendly method to dispose of the VA and BCS.

This paper presents the laboratory test results to investigate the engineering properties of stabilized BCS incorporating VA, lime and their combinations, using Atterberg limits, California bearing ratio (CBR), swell percent and unconfined compressive strength (UCS) tests. The research on BCS stabilization using lime and VA as the composite soil stabilizer in Kenya is quite limited. The mineralogical characters of VA stabilized BCS remain unknown up to now. Although some studies were performed to investigate the mineralogy from the perspective of geological evolution [17], the direct utilization of BCS as roadbed materials has not been yet reported. Herein, X-ray diffraction (XRD), Infrared (IR) spectroscopy and scanning electron microscope (SEM) were performed to study the mineralogy changes in stabilized BCS.

2. Materials and methods

2.1. Materials and characterizations

2.1.1. Black cotton soil

Black cotton soil (BCS) used in this research was sampled from the Southern Bypass located in the southwest region of Nairobi, Kenya. X-ray diffraction pattern of BCS obtained according to the Chinese petroleum and natural gas industry standards (SY/T 5163-2010) [18] is presented in Fig. 1. It indicates the presence of clay minerals such as montmorillonite (M), illite (I) and kaolinite (K), and other non-clay minerals such as goethite (G), feldspar (F) and quartz (Q).

Table 1 gives the mineral content of BCS obtained from X-ray quantitative phase analysis as well as the chemical composition, pH and Cation Exchange Capacity (CEC). It was 50.6% composed of average clay minerals such as montmorillonite (36.5%), illite (1.3%) and kaolinite (12.8%), and 49.4% of other non-clay minerals such as goethite (1.0%), feldspar (2.6%) and quartz (45.8%).

Cation exchange capacity (CEC) was measured according to T 0163-1993 (JTG E40-2007) [19]. The CEC, Na^+ and Ca^{2+} values of the BCS are 58.3 meq/100 g, 2.73% and 47.1%, respectively. The results explain the great surface activity of such soil, which leads to the high potential of water absorption.

The Atterberg limits, free swell index and other tests were measured according to JTG E40-2007 (Chinese standard). The test results are presented in Table 2. The soil presented a high free swell index (FSI = 165%) and a low CBR (1.6%) at an optimum Proctor compaction. Liquid limit of most soil samples plotted on the right of 'B' line, meanwhile, plasticity index of these soils located above the 'A' line (Fig. 2).

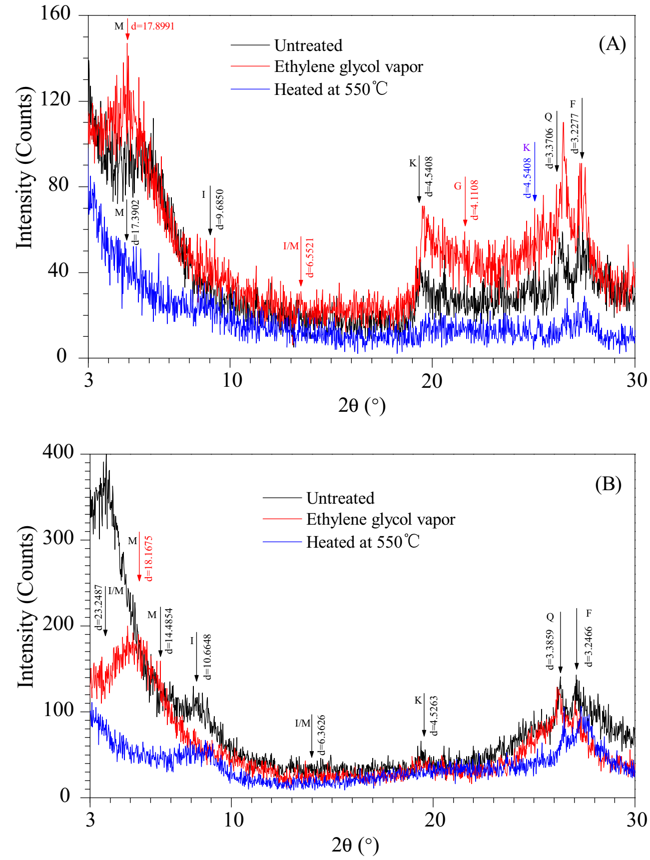

Fig. 1. X-ray diffraction pattern of selected BCS samples, from km (A) 2.3 and (B) 4.5.

Table 1
Mineralogical compositions and chemical properties of BCS.

Properties	Test values
Mineralogical composition (%)	
Montmorillonite	36.5
Illite	1.3
Kaolinite	12.8
Quartz	45.8
Feldspar	2.6
Goethite	1.0
Chemical composition (%)	
SiO_2	50.34
Al_2O_3	16.89
Fe_2O_3	9.44
TiO_2	0.90
MnO	0.30
MgO	0.95
CaO	1.70
Na_2O	0.76
K_2O	1.01
P_2O_5	0.02
Loss of ignition	17.65
pH	8.2
Cation exchange capacity (meq/100 g)	58.3

Thus, such soils belong to CH (clay with high plasticity) according to the classification of JTG E40-2007. The mineralogical, chemical and physical properties indicate that BCS is potentially expansive.

2.1.2. Volcanic ash

Volcanic ash (VA) used in this study was sampled from a quarry in Simba, Kenya. BCS, natural pozzolans and fine grinding volcanic ash are shown in Fig. 3. The chemical composition of VA measured by X-ray Fluorescence (XRF) is presented