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ENGINEERING PROPERTIES OF BLACK COTTON SOIL STABILIZED WITH COFFEE HUSK ASH AND LIME

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KEYWORDS: Black cotton soil; Coffee husk; lime; Stabilization; Bearing capacity.

ABSTRACT

Nowadays, the utilization of locally available waste materials for the improvement of poor soil properties is adapted in the stabilization method. In this study, coffee husk ash (CHA) is used as an admixture to improve the properties of black cotton (BC) soil for use as a road sub-grade. In order to assess the properties of an expansive soil admixed with different percentages of lime and CHA for each lime content, standard proctor compaction, Atterberg limits and California bearing ratio (CBR) tests were performed. Microanalysis and elemental analysis were conducted using scanning electron microscopy (SEM). The laboratory test results demonstrated that expansive soil stabilized with lime and CHA mixture is more effective than lime-stabilized soil by reducing the plasticity index and improving bearing capacity. Adding CHA to lime-stabilized soil increases the bearing capacity (the addition of 15% CHA to soil stabilized with 6% lime increased the CBR by 19.5%). In addition, CHA-stabilized soil has less swelling and shrinkage. From the elemental analysis, it was observed that the concentration of calcium increased for increased CHA content. In addition, X-ray diffraction (XRD) reveals that the appearance of cementitious product on both CHA and lime-treated samples, which majorly contributed to the improvement of the geotechnical properties of the BC soil.

INTRODUCTION

Black cotton (BC) soil is an expansive soil and a poor material to employ in road construction. This soil type is mainly known for its high swell-shrink capacity, poor bearing capacity, and for containing high percentages of plastic clay. Excessive plastic material in pavement results in surface cracking in roads and other structures (Alzubaidi et al., 2013; Mamatha and Dinesh, 2017). The properties of sub-grade soil affect the service life of roads, and roads built on BC soil tend to result in damage from its low bearing capacity when wet and severe cracking when dry due to its high swelling-shrinking properties (Voottipruex and Jamsawang, 2014; Osnibi et al., 2015). BC soil covers large geographical areas, and in areas where it occurs, it covers such a significantly large area that avoiding it is not possible (Etim et al., 2017). As a result, a soil replacement option is not cost effective. To improve the properties of such soils, different methods have been adapted, and stabilization is one of the possible methods to improve its poor properties by adding a stabilizing agent.

Lime stabilization is a proven technique that has been used for sub-grade, sub-base and base-course materials over the last several decades (Bell, 1996; Prusinski and Bhattacharja, 1999; Khemissa and Mahamedi, 2014; Calik and Sadoglu, 2014; Alrubaye et al., 2018). Lime stabilization improves sub-grade stability, which provides the pavement structure with long-term stability and lowers pavement life cycle costs through reduced pavement maintenance (Agarwal et al., 2016). When lime is added to clay soils in the presence of water, a number of reactions occur, leading to an improvement in the properties of a soil. These reactions include cation exchange, flocculation, carbonation and a pozzolanic reaction (Al-Rawasaa et al., 2005; Al-Mukhtar et al., 2010). In practice, improvements in engineering properties can be obtained immediately by making small additions of lime to clayey soils. However, the effectiveness of such treatment depends on the quantity of lime as well as the mineralogical composition of the soil (Al-Mukhtar et al., 2010).

Currently, an efficient alternative material (locally available and low cost) is in high demand (Rekha et al., 2016). Using waste materials as an admixture in improving expansive soil properties has been investigated in several studies. Several researchers (Anupam et al., 2013; Peter et al., 2016; Dang et al., 2016; Yu et al., 2016; Jamsawang et al., 2017; Etim et al., 2017) studied the effects of using waste materials (bagasse ash, rice husk ash, coir waste, bagasse fibres, blast furnace slag, iron ore tailings) on the engineering properties of lime-stabilized expansive soils. They concluded that these waste materials have a significant effect on improving the plasticity and shrink-swell potential, as well as the strength of the expansive soils.

However, care should be taken when selecting a stabilization agent. It has to be proven that the stabilization agents are effective, economically efficient and eco-friendly materials. In addition, the availability and feasibility of the material at a specific locality should be considered. This study aims to investigate the feasibility of CHA as a locally-available stabilization agent.

CHA is the by-product of coffee production found after burning the coffee husk. Coffee husk is a waste material that poses major environmental concerns, as its abundant storage can lead to serious environmental problems due to the presence of toxic materials, such as caffeine and tannins (Fan et al., 2003; Dzung et al., 2013). The potential use of this waste material as an admixture for soil stabilization has dual advantages: a reduction in waste material disposal (reduction in environmental concerns) and soil property improvement (economic benefit). In improving the properties of clayey soils, the most important feature is the ability of stabilizers to provide a sufficient amount of calcium (Wang, 2002). CHA mainly contains calcium and potassium (Acchar et al., 2013). Calcium ions help in reducing the swelling potential of soils by forming aggregations (Sharma and Sivapullaiah, 2016).

This study aims to evaluate the effectiveness of CHA as an admixture for lime-stabilized BC soil for use in road sub-grade construction. CHA effectiveness as an admixture for lime-stabilized BC soil strength, swelling and plasticity properties are investigated. Samples were prepared with various proportions of CHA (5%, 10%, 15%, and 20%) and lime (4%, 6% and 8%). Standard proctor compaction, Atterberg limits and CBR tests were conducted. The changes in the mineralogical composition and microstructures of stabilized samples were studied using XRD and SEM, respectively. In addition, the elemental composition analyses of untreated and treated samples were conducted with energy-dispersive X-rays (EDX) incorporated with SEM.

MATERIALS

Black Cotton Soil

BC soil covers around 3% of the world's land area, including Africa, specifically in Sudan, South Africa, Tanzania and Ethiopia (Ramesh et al., 2010; Bhavsar and Patel, 2014). The BC soil used in this study was collected from Ambo. Ambo is located in the central part of Ethiopia around 120km west of Addis Ababa (Fig.1a). There are two main seasons in this area: dry and wet. In the wet season (June to August), there is heavy rainfall. BC soil swells in the periods of precipitation by absorbing water, and shrinks in the dry season when water content decreases due to evaporation (Fig.1b). The presence of highly-expansive clay mineral (montmorillonite) in BC soil and the change in the volume of this soil due to seasonal variation results in damage to civil engineering structures (Etim et al., 2017). Therefore, it is important to adopt a technique in order to modify the properties of the BC soil. In the present study, the stabilization technique was selected and the possible effect of adding a mixture of lime and CHA to improve the properties of the BC soil was investigated.

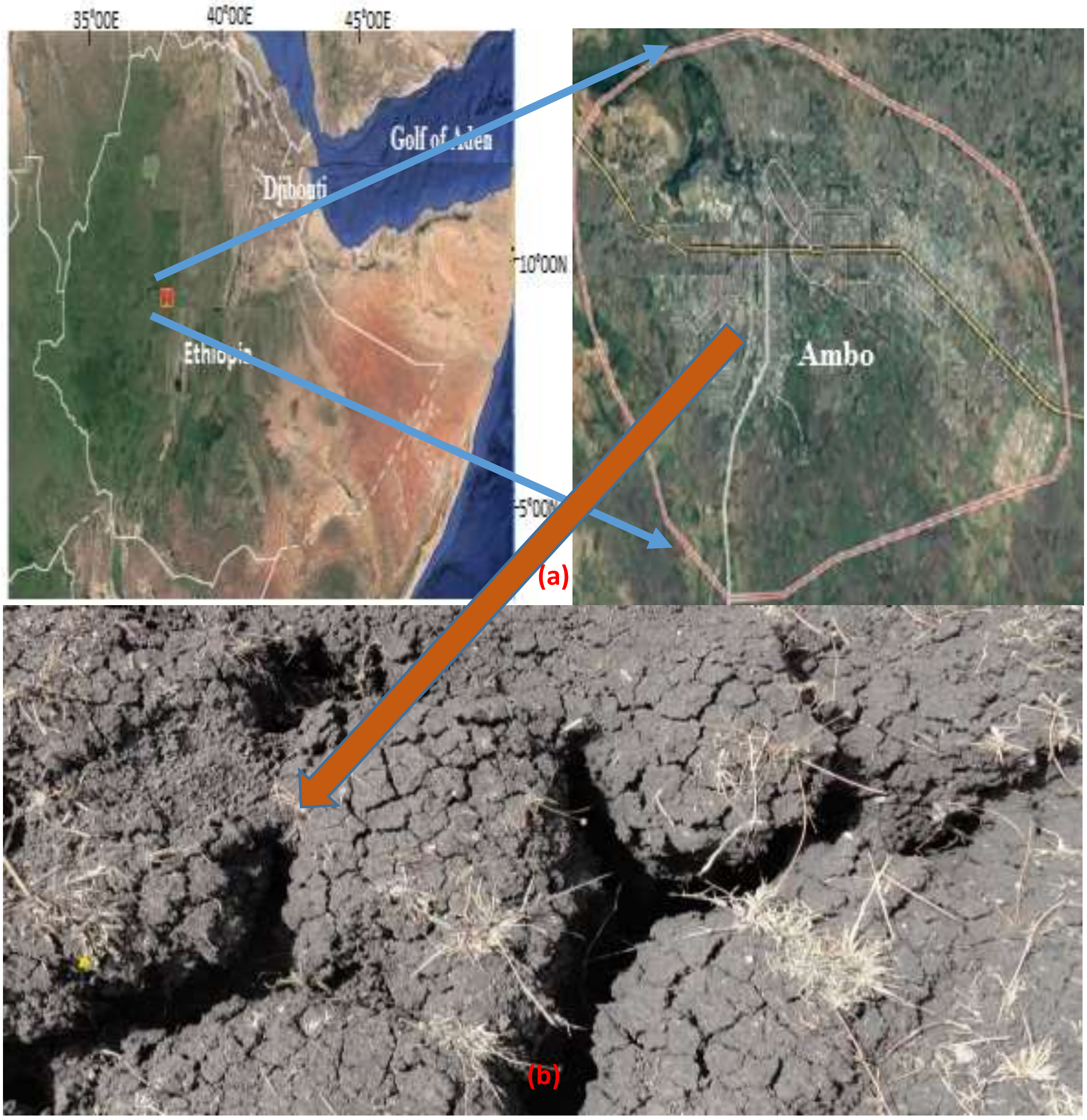


Fig. 1. Area studied (a) (https://www.google.co.uk/maps/place/Ambo,+Ethiopia) and BC soil (b)

Lime

Soil stabilization using lime in the quick or hydrated form in order to improve the properties of poor soil is an obvious technique. Hydrated lime reacts with clay particles and permanently transforms them into a strong cementitious matrix (NLA, 2006). The lime used in this investigation is hydrated lime obtained from the Senkele lime factory in Ambo, Ethiopia.

Coffee Husk Ash

The coffee husk used for this study was collected from farmlands and factories (Jimma and Wollega, Ethiopia), and kept at 550°C in a furnace for five hours to get the resulting ash. From the Atterberg limit test, the CHA used was classified as a non-plastic. Fig 2. Shows the EDX analysis results of the materials (BC soil, lime, and CHA) used in this study. From this result, the main elements present in the BC soil are silicon (Si) and aluminium (Al). Calcium (Ca) and potassium (K) are the main elements in the CHA, and the lime mainly contained Ca.

Experimental Procedure

Initial Lime Consumption (ILC)

The ILC was estimated using a PH test. The lowest percentage of lime in the soil that produces a laboratory pH of 12.4 is the minimum lime percentage for stabilizing the soil (NLA, 2006), however, the optimum amount of lime required to stabilize soil is determined by performing tests for specific characteristics (ASTM D6276). As shown in Fig. 3, the amount of lime to get a PH of 12.4 is 6% by dry weight of soil. In this study, the amount of lime selected for BC soil treatment was 4%, 6% and 8% by dry weight of soil.

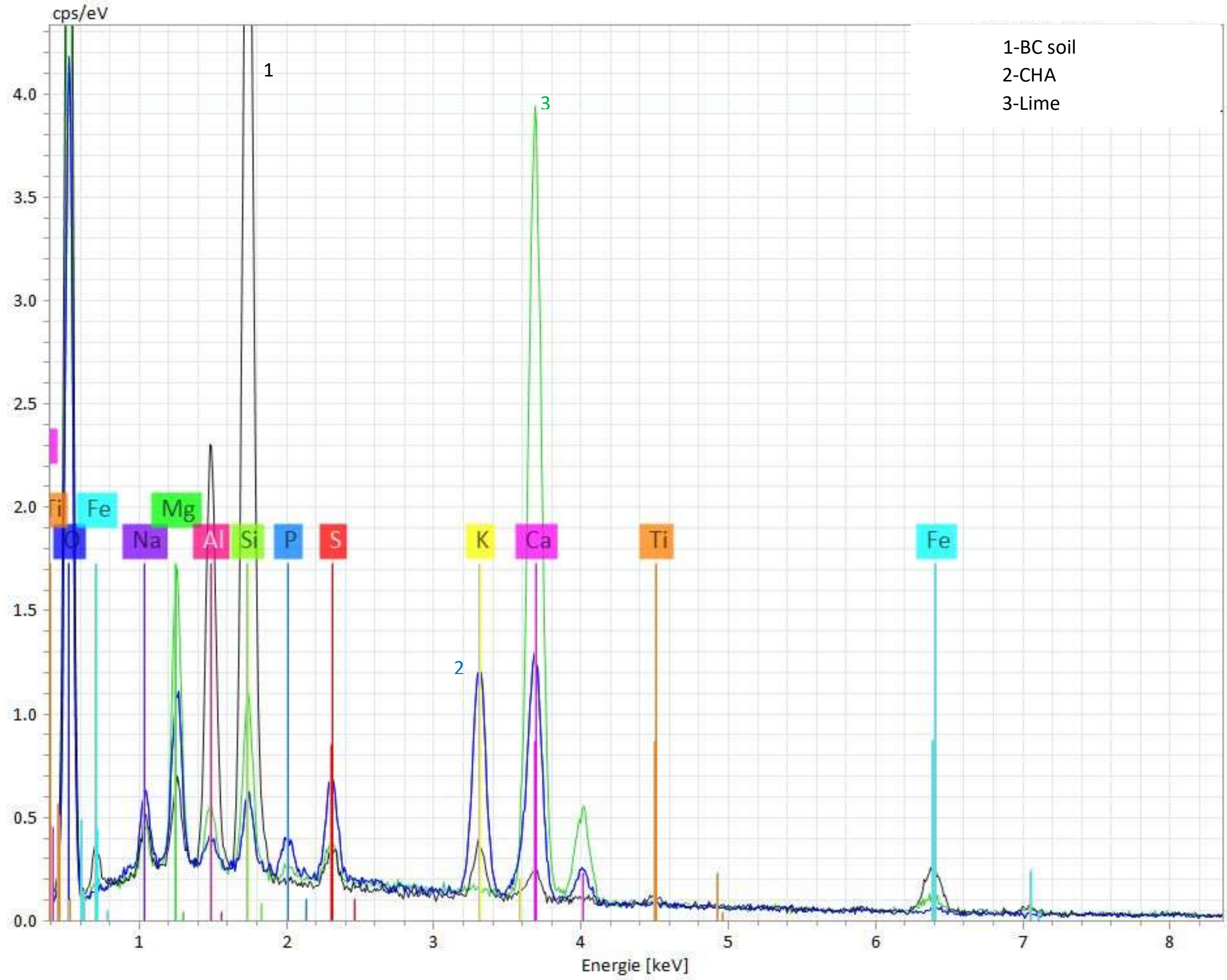


Fig. 2. EDX spectra of BC soil, lime and CHA.

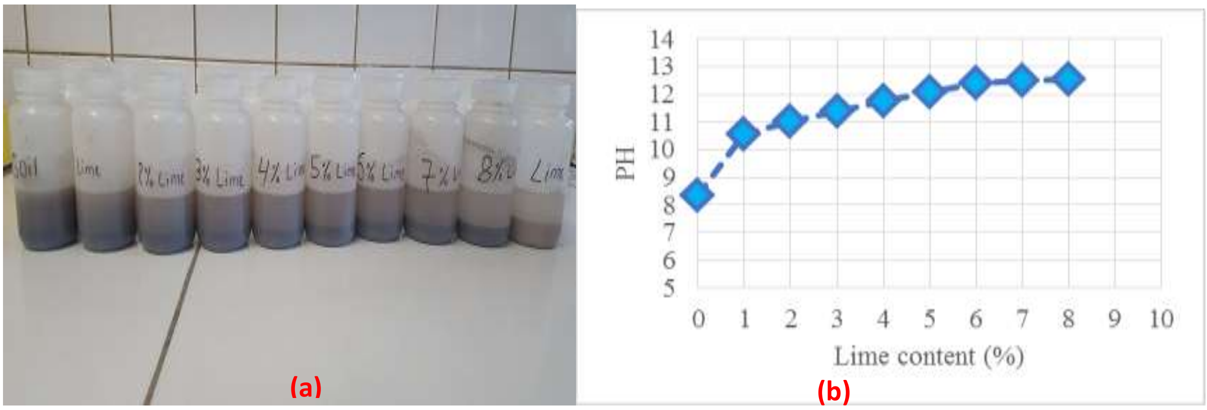


Fig.3 Soil-lime mixture readied for PH test (a) and PH value for different lime contents (b).

Mixture Proportion

Laboratory tests such as Atterberg limits, standard compaction, and CBR were conducted for various combinations of BC soil-CHA, BC soil-lime and BC soil-lime-CHA mixtures. Lime and CHA concentration is defined as a percentage of the weight of each additive in the dry weight of the soil as presented in Table 1. The soil was dried, the required amount of lime and CHA were added to the soil, and then mixed properly. To see the effect of CHA on lime-stabilized soils, various concentrations (5%, 10%, 15%, and 20%) of CHA were added to the BC soil for each lime content (4%, 6% and 8%) on a dry weight basis.

Table 1 Mixture proportion.

CHA %	0%Lime	4%Lime	6%Lime	8%Lime
0	BC soil	SL4	SL6	SL8
5	SC5	SL4C5	SL6C5	SL8C5
10	SC10	SL4C10	SL6C10	SL8C10
15	SC15	SL4C15	SL6C15	SL8C15
20	SC20	SL4C20	SL6C20	SL8C20

Testing Methodology

To characterize the effect of the additive on the engineering properties of the stabilized soil, various tests can be used. In this study, Atterberg limits, compaction, California bearing ratio (CBR), XRD and SEM tests were conducted. The BC soil samples were mixed with lime and CHA on a dry weight basis, and the additives added are defined by percentage as the ratio of the weight of additive to the dry weight of the BC soil. For Atterberg limit tests, the material passing through the 0.425mm sieve was mixed thoroughly with distilled water to get a paste. To get moisture equilibrium, the paste was kept in a desiccator for 24 hours. Thereafter, liquid limits and plastic limits were determined according to the American Society of Testing Materials (ASTM) 4318-17. The standard proctor compaction tests were conducted according to ASTM D698-12 to determine the maximum dry density and the optimum moisture content of stabilized samples. California bearing ratio tests were conducted according to ASTM D1883−16 using the data obtained (maximum dry density and optimum moisture content) from the compaction test. The samples from all mixture proportions were compacted at their respective optimum moisture contents and maximum dry densities, and then CBR tests were conducted after four days of soaking. For SEM and XRD analysis, stabilized samples were cured at room temperature for seven days. At the end of the curing process, samples were oven dried at 105°C for 24 hours, then pulverized with a mortar and pestle until the material passed through a 63µm sieve. SEM analyses were done with a field emission scanning electron microscope (SEM, MERLIN® VP Compact, Co. Zeiss, Oberkochen) equipped with an energy-dispersive X-ray (EDX) detector. The XRD study was conducted using a Bruker CCD-diffractometer with Cu-Kα radiation (λ = 0.15406 nm). `MATCH!´ (CRSTAL IMPACT) software was used to identify the mineralogical phases.

RESULTS AND DISCUSSION

Grain Size Analysis

Atahu et al., 2017 performed grain size analysis on the BC soil and CHA used for this study, the result shows that the soil contains 85% silt and clay. As the clay fraction (finer than 0.002 mm in soil diameter) increases, the swelling potential increases (Emarah and Seleem, 2018). The soil used in this study is fine-grained with high plasticity (PI=52%). Lime stabilization is suggested for soils if more than 25% passes through a 0.075mm sieve and the PI is greater than 20% (ERA, 2013). According to ASTM C977-10, hydrated lime used for soil stabilization shall not have more than 3% retained on a 590µm sieve and not more than 25% retained on a 75µm sieve. As shown in Fig.4, the hydrated lime used for this study met the grain size requirement for soil stabilization. The grain size of CHA depends on the degree of the burning process. For this study, CHA with 57.1% sand and 42.9% silt and clay size were used. Fig.5 shows micrographs of the BC soil, lime and CHA.

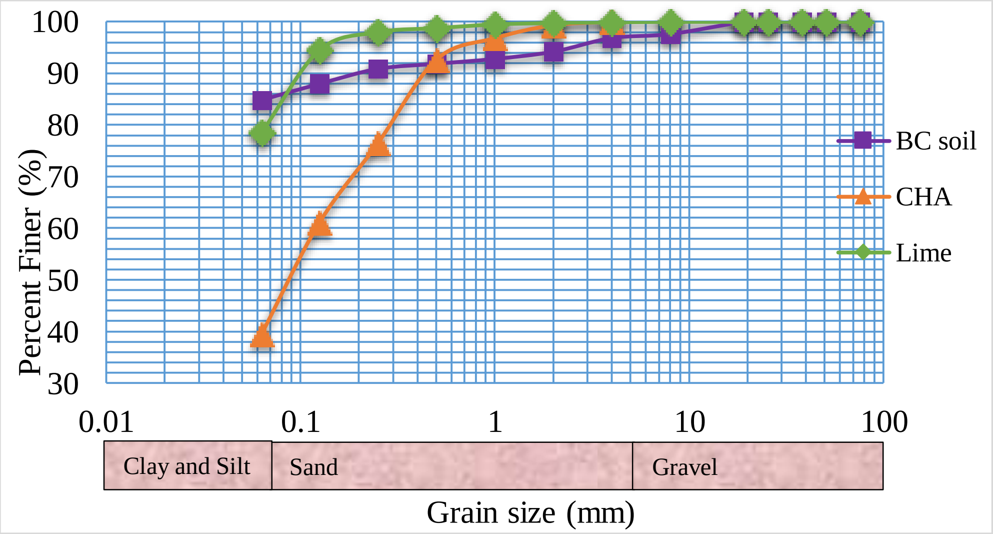
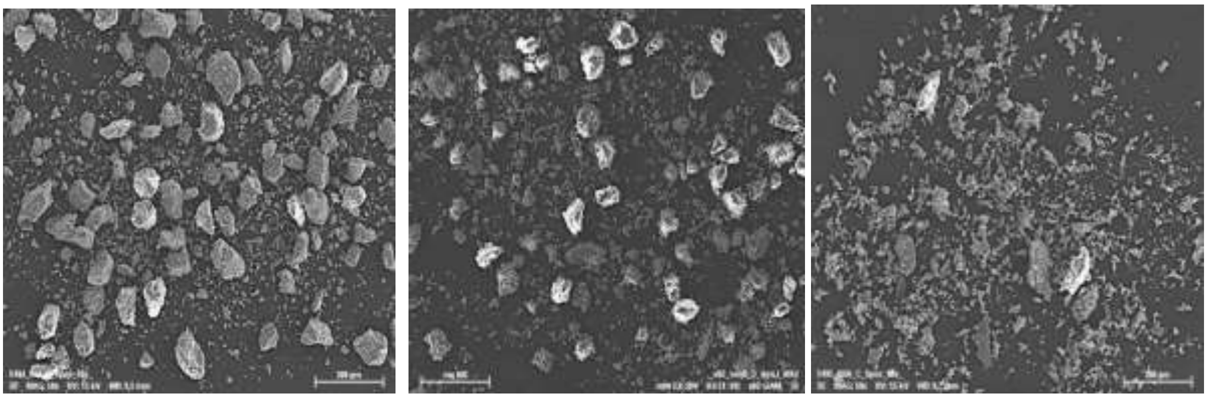


Fig. 4 Grain size distribution of soil, CHA and lime.



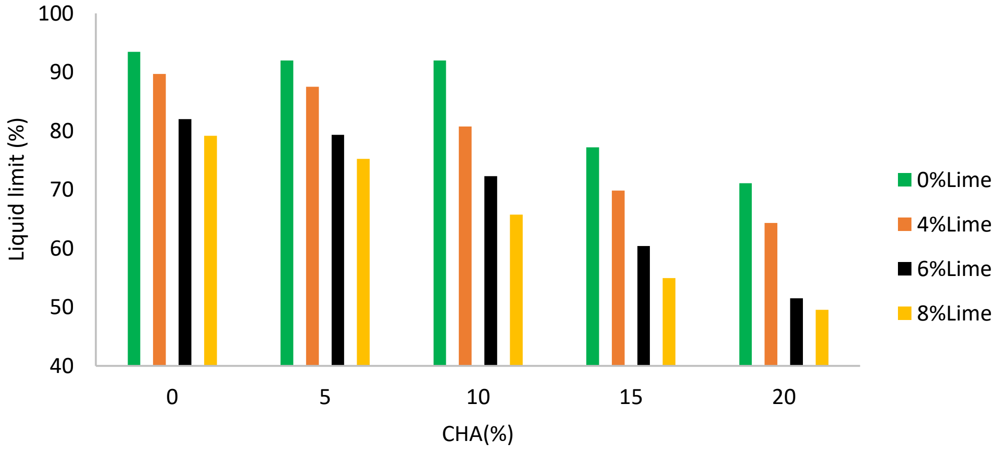
(a) (b) (c)

Fig.5. Micrographs of BC soil (a), lime (b) and CHA (c).

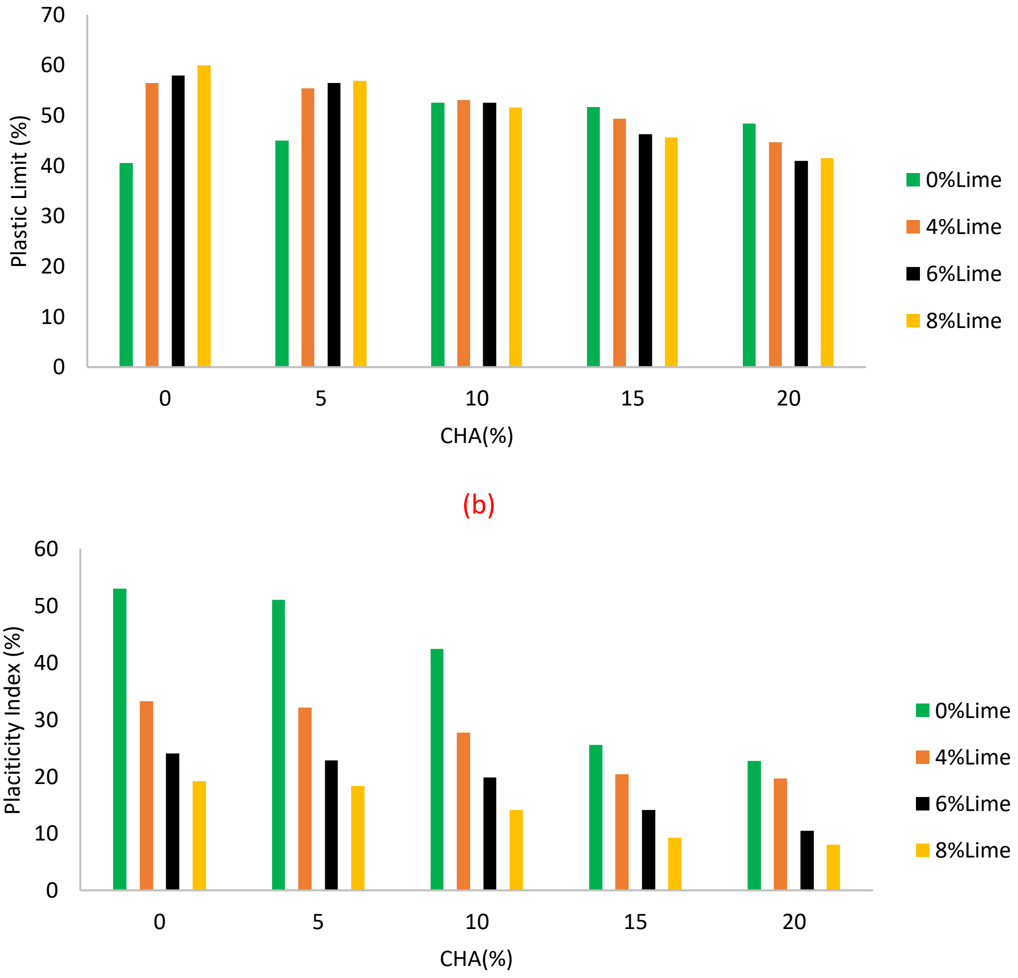
Plasticity Characteristics

BC soils are troublesome materials to use in road construction due to their high plasticity behaviour. The soil studied has a liquid limit (LL) of 93% and a plasticity index (PI) of 52% (Fig.6). According to MORTH, 2013 soil having a liquid limit of greater than 71% and plasticity index of greater than 45%, respectively, is unsuitable for sub-grade. In this study, CHA and lime were selected to improve the plasticity of the BC soil. When lime is added to a plastic material, it flocculates the clay and substantially reduces the plasticity index (ERA, 2013). Fig.6 presents the Atterberg limits for the different amounts of additives. The plasticity of the BC soil was significantly affected by the addition of CHA, lime, and with the mixture of CHA and lime. The addition of CHA alone reduces both the LL and PI of the BC soil in an appreciable way: reductions in LL from 93% to 71%, and PI from 52% to 22%, respectively, were observed for 20% CHA. The addition of 15% CHA alone reduced the PI by 51%. With the addition of 4% lime alone, the PI was reduced to 33%, and it is obvious that the addition of lime improves the plasticity behaviour of the soil; a similar trend was found by several researchers (Al-Mukhtar et al., 2010; Al-Swaidani et al., 2016; Emarah and Seleem, 2018; Muhammad and Marria, 2018). The treatment with CHA could be an effective treatment option in reducing the plasticity of the BC soil. However, the admixture of lime and CHA shows a better reduction in LL and PI. Fig. 7 and Fig. 8 show the classification of untreated and treated samples according to the Unified Soil Classification System (USCS) and Association of State Highway and Transportation Officials (AASHTO), respectively. According to USCS (Fig.7), the BC soil is classified as high plasticity clay (CH). As the content of additives increased, both LL and PI decreased shifting the samples downward on the PI-axis and left on the LL-axis from an area of high plasticity clay (CH) to high plasticity silt and low plasticity silt. From Fig. 8 (AASHTO chart), it can be observed that the BC soil is classified as A-7-5, which shifted to A-5 with the addition of 6% lime and 15% CHA, and goes downward left as the percentage of additives increases.

According to the ratings of sub-grade materials by AASHTO, the treated samples perform better as a sub-grade material compared to the untreated BC soil. The improvement in the plasticity behaviour of the BC soil could be attributed to the chemical reaction between additives and soil causing a colloidal reaction. This reaction includes the replacement of naturally carried cations on clay surfaces with Ca2+ cations. This interplay reduces the water absorption of the soil particles, making them less plastic (Khemissa and Mahamedi, 2014; Al-Swaidani et al., 2016; Oluwatuyi et al., 2018). The reduction in the plasticity of the BC soil indicates that it became less sensitive to water, leading to less expansive and better compactable. Consequently, the treated BC soil gains stability and durability with respect to the deformations due to the seasonal variations of water content (Khemissa and Mahamedi, 2014). In addition, the decrease in the PI of treated samples indicates an improvement in the workability of the soil, the lower the PI, the smaller the swelling potential (Al-Swaidani et al., 2016).



(a)



(b)

(c)

Fig.6 Atterberg limits of CHA-treated samples with varying amounts of lime. Liquid limit (a), plastic limit (b) and plasticity index (c).

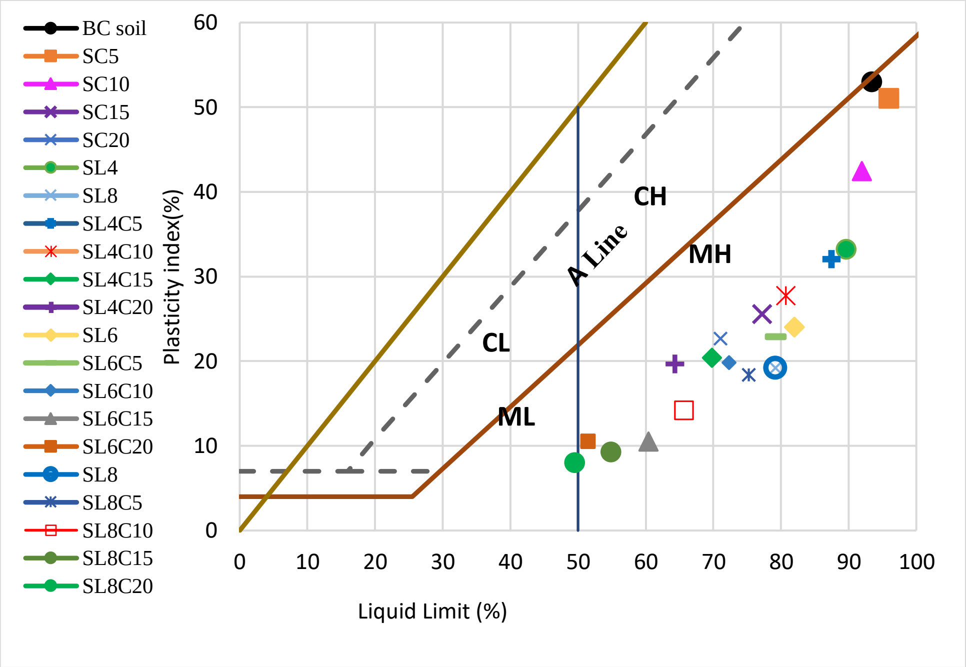


Fig. 7 Plasticity index versus liquid limit for untreated and treated samples (USCS chart)

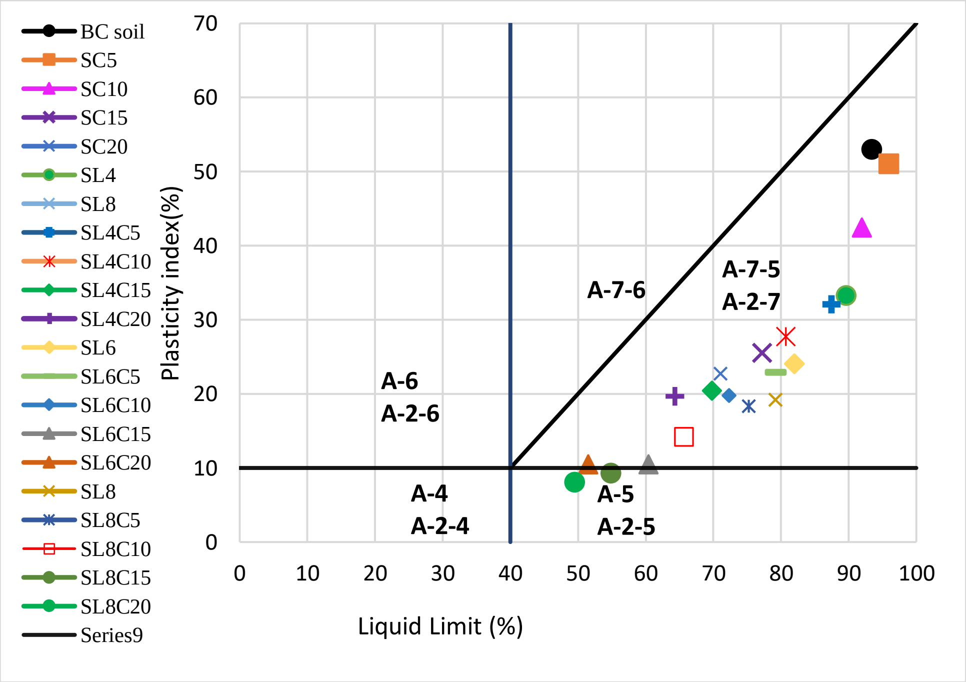


Fig. 8 Plasticity index versus liquid limit for untreated and treated samples (AASHTO chart).

Compaction Characteristics

The effect of CHA on the compaction characteristics of the lime-treated BC soil was evaluated by conducting a standard proctor test. It can be seen that the maximum dry density (MDD) of untreated and CHA-treated soils decreases as the lime content increases (Fig. 9). Conversely, the optimum moisture content (OMC) increases as the lime content increases (Fig. 10). Similar behaviour in MDD and OMC was observed when lime was added to expansive soils (Seco et al., 2011; Al-Taie et al., 2016; Etim et al., 2017). The MDD of lime-treated samples decreased slightly and the OMC increased from 37% to 44% when the amount of lime added was increased from 0% to 8%. These changes in compaction behaviour due to lime treatment could be the result of a pozzolanic reaction between the soil and the lime, which is responsible for the increase in OMC (Harichane et al., 2011). The aggregation of the particles to occupy larger spaces due to the addition of lime and the lower specific gravity of the lime could be responsible for the decrease in MDD (Harichane et al., 2011).

On the contrary, the addition of CHA to the lime-stabilized soil slightly increases the MDD and decreases the OMC, as shown in Fig. 9 and Fig. 10. The OMC decreases as the percentage of CHA increases for all lime content. The reduction in the OMC of CHA-stabilized samples could be attributed to the amount of water needed to reach an optimum state is lower for CHA-stabilized samples compared to untreated samples; this is because of the lower affinity of CHA particles for water.

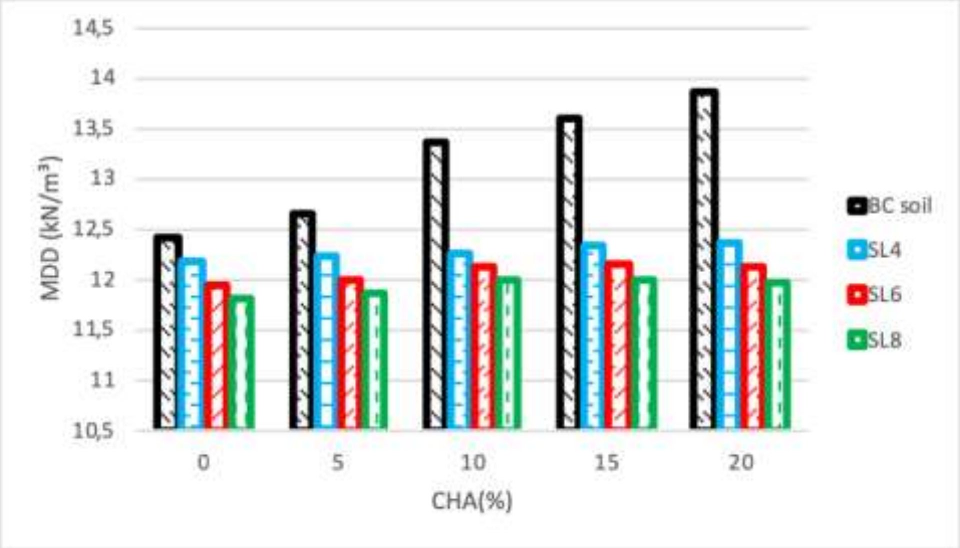


Fig. 9 Variation of MDD with additive content.

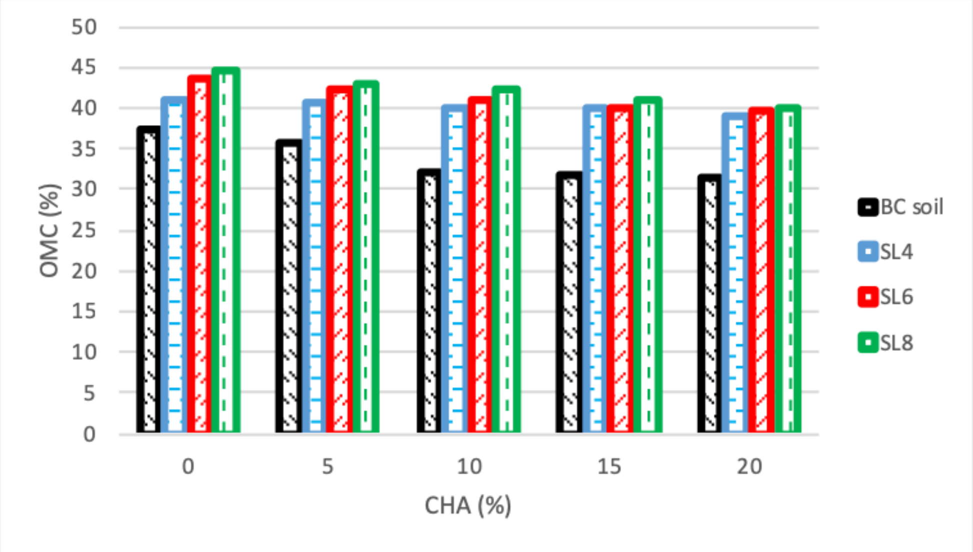
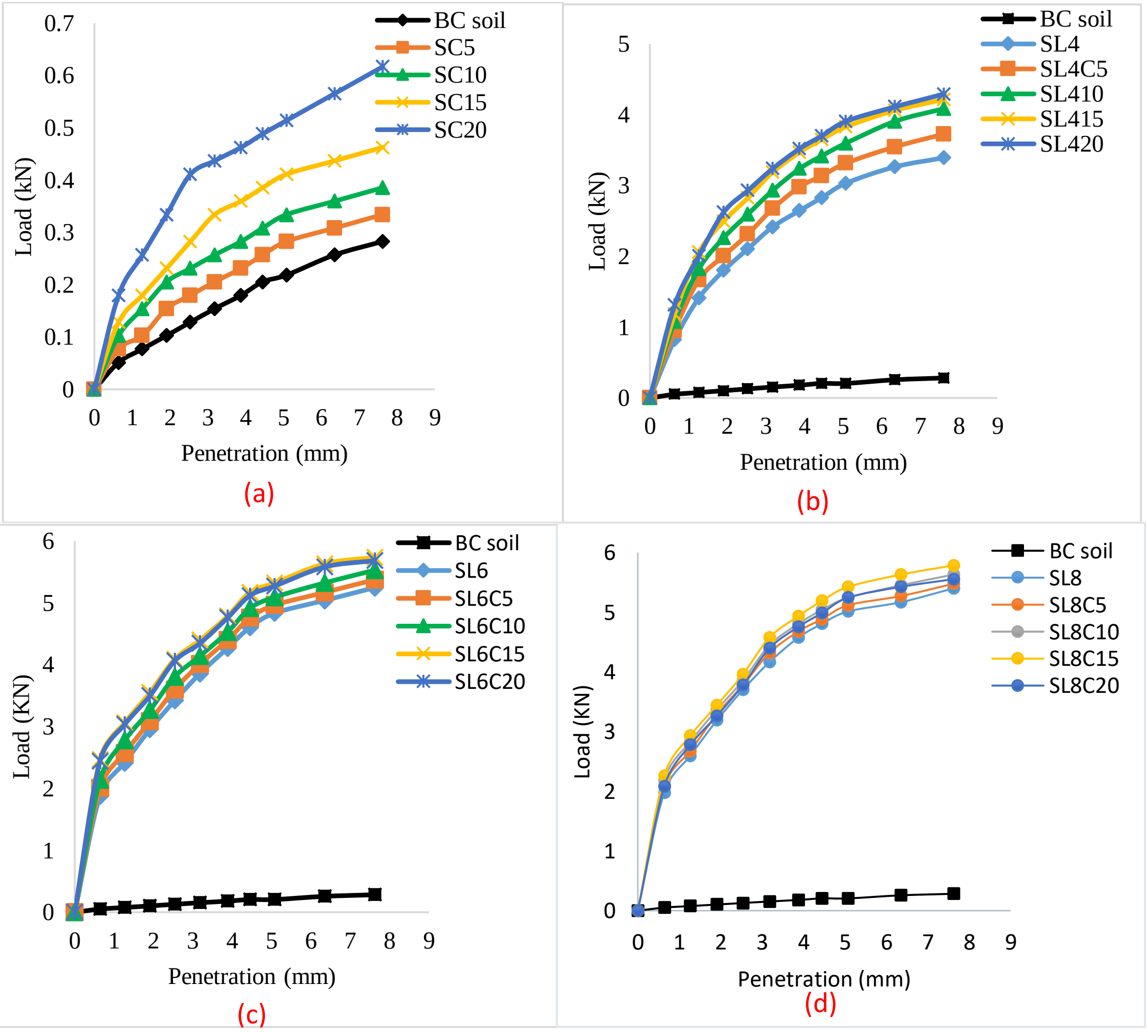


Fig.10 Variation of OMC with additive content.

California Bearing Ratio

The California bearing ratio test is performed to evaluate the bearing capacity of the BC soil treated with CHA, lime and lime-CHA mixture. The results obtained from CBR tests conducted on the BC soil treated with CHA, lime and with the mixture of lime and CHA are shown as load-penetration curves in Fig. 11. The results show that the CBR value increased from 1% to 3% when the amount of CHA added increased from 0% to 20% (Fig. 12). From these results, the CBR value of the CHA-treated soil at OMC and MDD is three times greater than the natural BC soil. The addition of 4% lime alone increased the CBR value to 16% from 1% for the untreated BC soil. The mixture of lime and CHA treatment showed more enhancements on the bearing capacity of the BC soil compared to both lime and CHA treatment. As shown in Fig. 12, the CBR values of the samples are almost inversely proportional to their plasticity index. The highest CBR values were found at 20% for CHA treatment, at 8% for lime treatment and at 6% lime and 15% CHA for the mixture, respectively. The improvement in the bearing capacity could be attributed to the formation of cementitious compounds due to the reaction between the soil and the additives (Al-Swaidani et al., 2016).

According to Hossain et al., 2007, the minimum CBR value usually required by many specifications for pavement subgrade is 15%. Thus, the minimum CBR value was attained for all samples treated with lime alone and with the mixture of lime-CHA (Fig. 12).



(a)

(b)

(c)

(d)

Fig. 11 Load versus penetration curves for 0% lime (a),4% lime (b) 6% lime (c) and 8% lime (d).

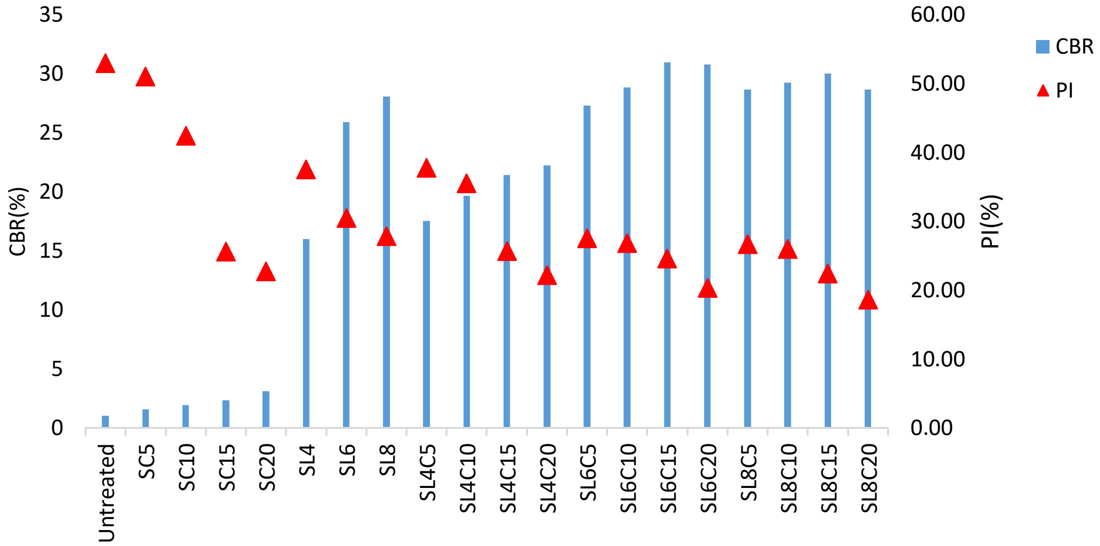


Fig. 12 Variation of CBR and PI values for different concentrations of additives.

X-ray Diffraction Analysis

X-ray diffraction (XRD) analysis was carried out to observe the minerals present in the BC soil and to find out the effect of CHA, lime, and lime-CHA on the mineralogical properties of the BC soil. The minerals present in the BC soil are quartz, kaolinite and montmorillonite. Fig. 13 shows the XRD patterns of the untreated BC soil, SC15, SC20, SL6, SL6C10 and SL6C15. It was observed that the peak intensities of these minerals changed after the treatment. The mineral, quartz, appears in all samples. However, there was a reduction in the peak intensities of quartz for all mixtures (Fig. 13). It was also observed that the peak intensities of kaolinite were reduced for the treated samples, and the disappearance of kaolinite peaks was also noticed. The disappearance of peaks could be related to the appearance of new peaks in the pattern due to the reaction of additives with the soil, forming crystalline phases such as calcite (Gupta and Kumar, 2017). For soils treated with lime, similar behaviour was reported by Al-Muktar, 2010; Modarres and Nosoudy, 2015; Gupta and Kumar, 2017. Both lime and CHA treatment leads to the formation of new minerals, mainly calcite. Calcite is known as a hardening material, which helps in improving the strength of the treated samples. It could be formed from the reaction between the calcium in the additives, water in the samples and carbon dioxide in the atmosphere (Ahmed, 2015). For SC10, the calcite peak appeared and for SC15, the intensities of this peak became higher. Further, additional calcite peaks also appeared for SC15. CHA-treated samples showed lower peak intensities of clay minerals and the appearance of crystalline phases. However, lime-treated samples showed more peaks and higher calcite peak intensities compared to samples treated with CHA only. The increase in the intensities of calcite peaks may be attributed to the availability of more calcium from the additives, as the concentration of the additives increased. The formation of more cementitious compounds, mainly calcite, could also be due to admixture content. This result is in agreement with the CBR value of the treated samples, which increased as the content of the admixture increased.

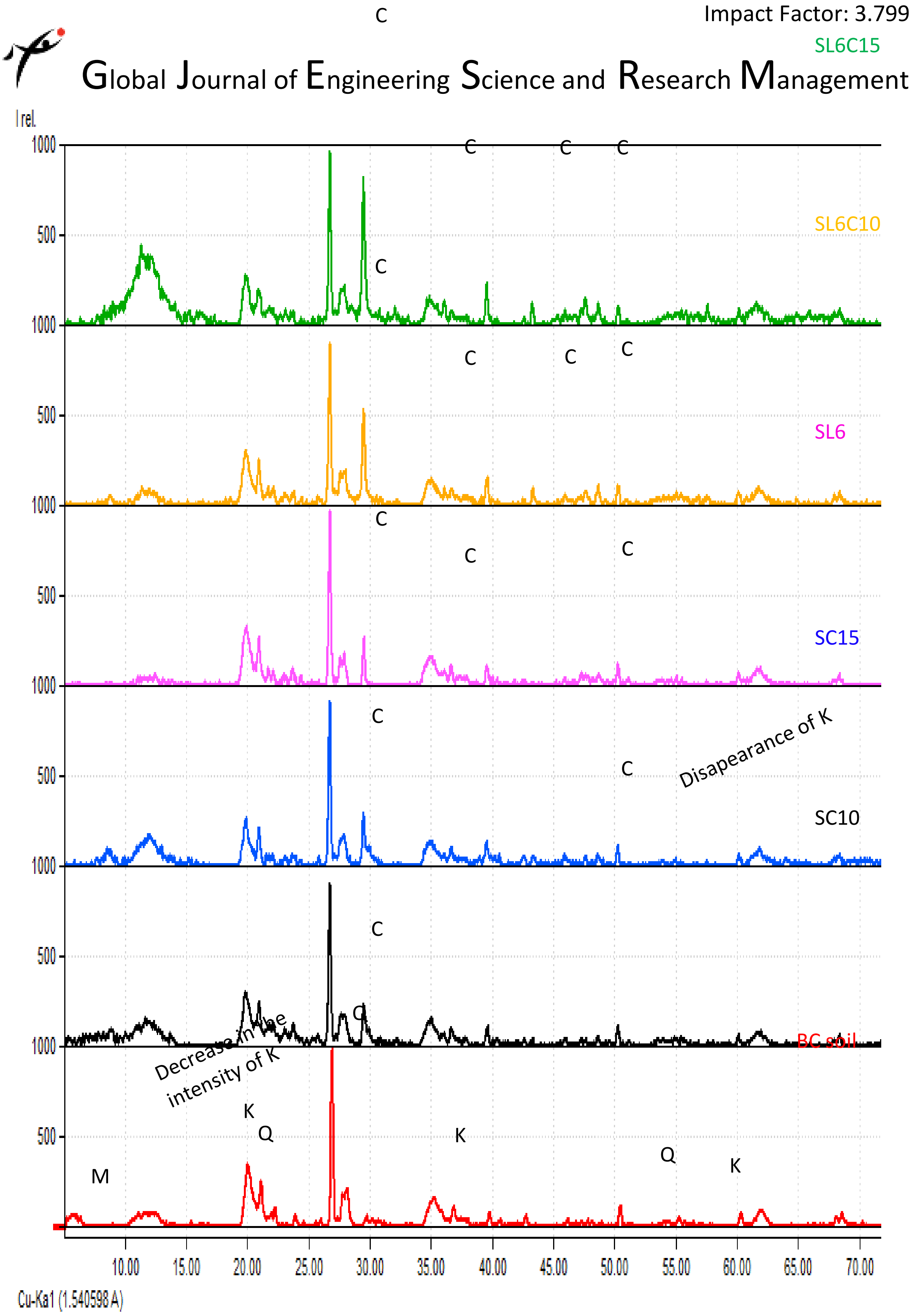


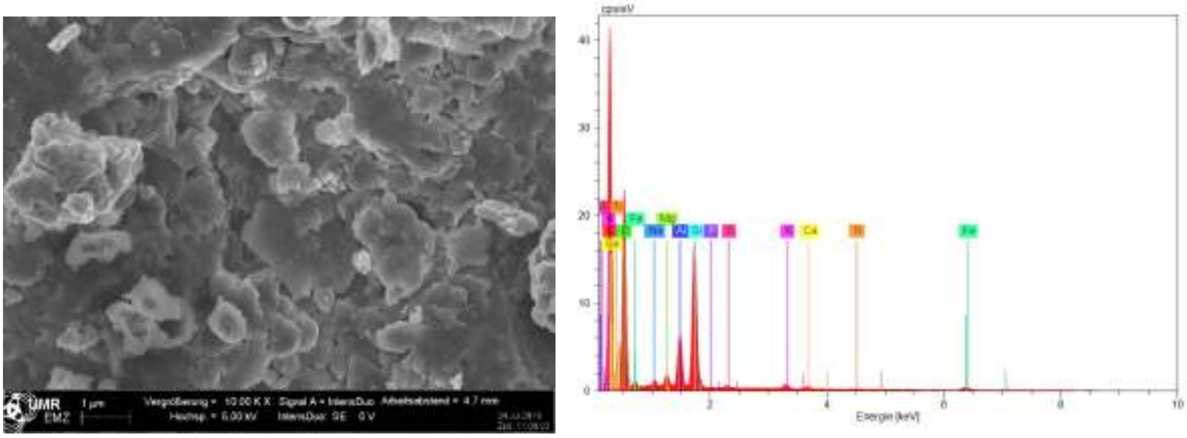
Fig. 13 X-ray diffraction of untreated BC soil, SC10, SC15, SL6, SL6C10 and SL6C15.

SEM and EDX Analysis

Scanning electron microscopy was used to observe the effects of additives on the morphological structure of the BC soil. The micrographs of untreated BC soil, SC15, SC20, SL6, SL6C10, and SL6C15 at magnifications of 10000X were taken. Furthermore, the EDX spectrum was used to analyse the changes occurring in the chemical composition of the BC soil after treatment. EDX analyses were performed at representative areas of the examined samples.

As shown in Fig. 15a, the presence of pores is evidenced in the microstructure of the BC soil, and these pores are more visible compared to treated samples (Fig. 15 (b-f)), which could be attributed to the nonexistence of hydration products to form a continuous surface in the untreated sample. After treating the BC soil with CHA, lime and lime-CHA mixtures, changes in its microstructure were observed. The treated samples showed the formation of white lumps of calcium ions and cementitious compounds.

From EDX results (Fig.14), it was observed that the BC soil contains mainly Si and Al. After treatment, changes in the elemental composition of the BC soil were observed. The amount of Si and Al decreases as the additive content increases. Besides, this result is supported by the EDX spectrum of Ca and K as shown in Fig. 15. It is clear that the increase in the additives content has a significant effect on the amount of Ca, and the formation of cementitious products. The increase in the calcium content gave an indication of the formation of additional cementitious product; this result is in agreement with the XRD analysis (Fig. 13), which indicated the formation of additional peaks of the calcite as the content of the additives increased. The formation of cementing materials indicated that the reaction had taken place between Si and Al from the soil, and Ca from the additives. These cementitious products are characterized by their high strength and low volume change (Al-Swaidani et al., 2016). The observed changes in the microstructures of the treated samples could also be a reason for the improvement in the plasticity characteristics of the BC soil.



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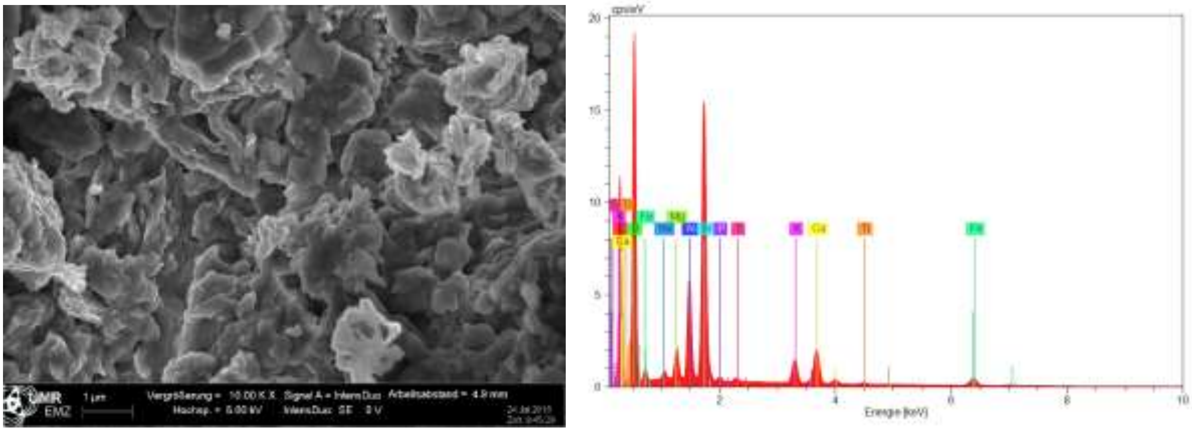

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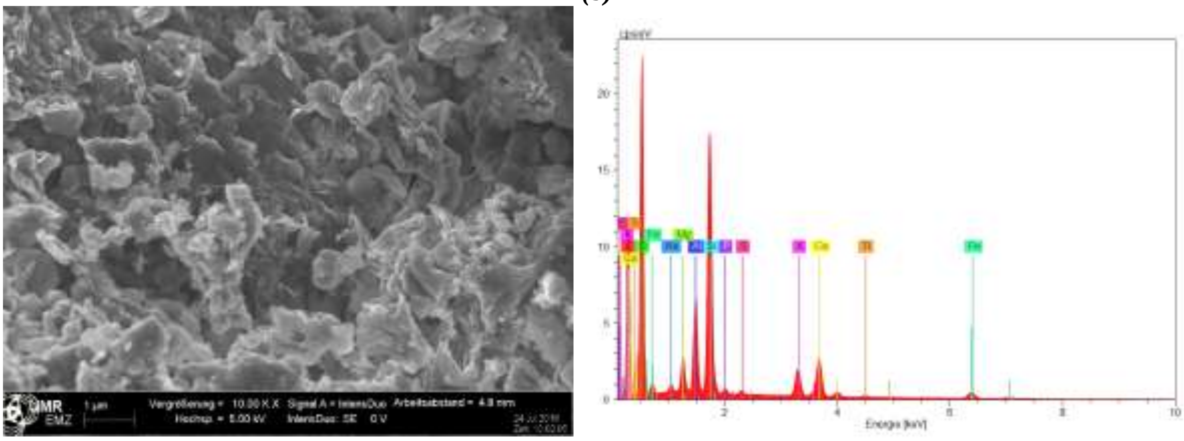
UMR
EMZ
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Signal A = InlensDuo
Arbeitsabstand = 4.8 mm
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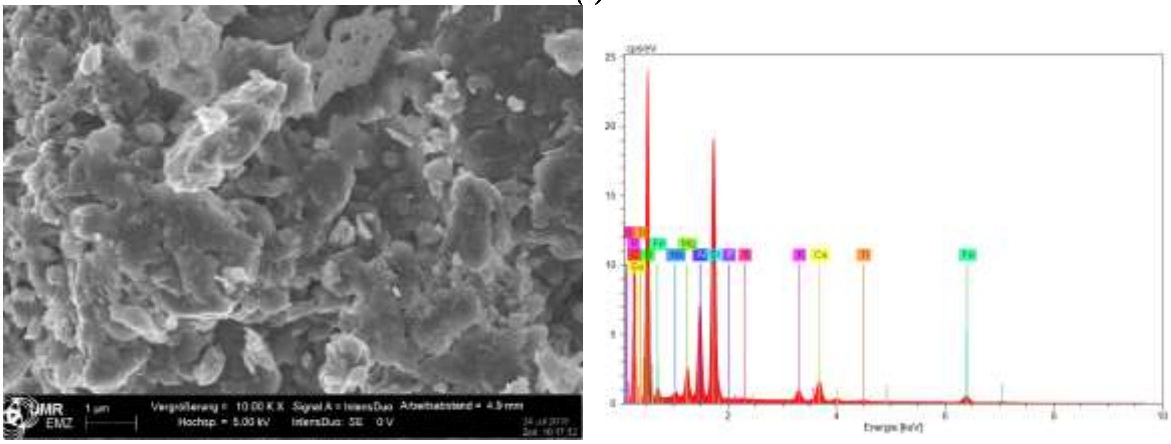
(c)


UMR
EMZ
1 µm
Vergrößerung = 10.00 K X
Signal A = InlensDuo
Arbeitsabstand = 4.9 mm
Hochsp. = 5.00 kV
InlensDuo: SE
0 V
cps/eV
25
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5
0
Mg
Ca
Ti
Fe
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4
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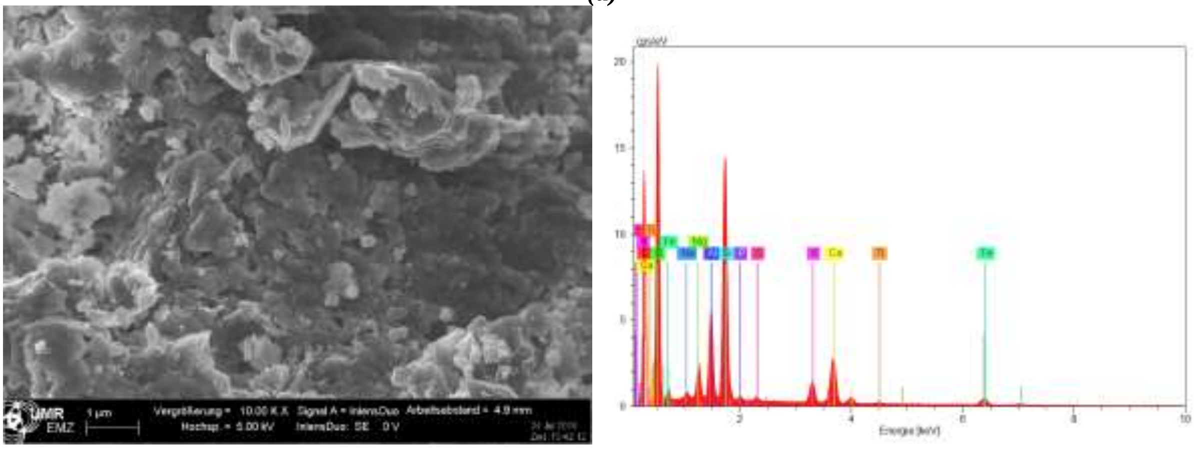
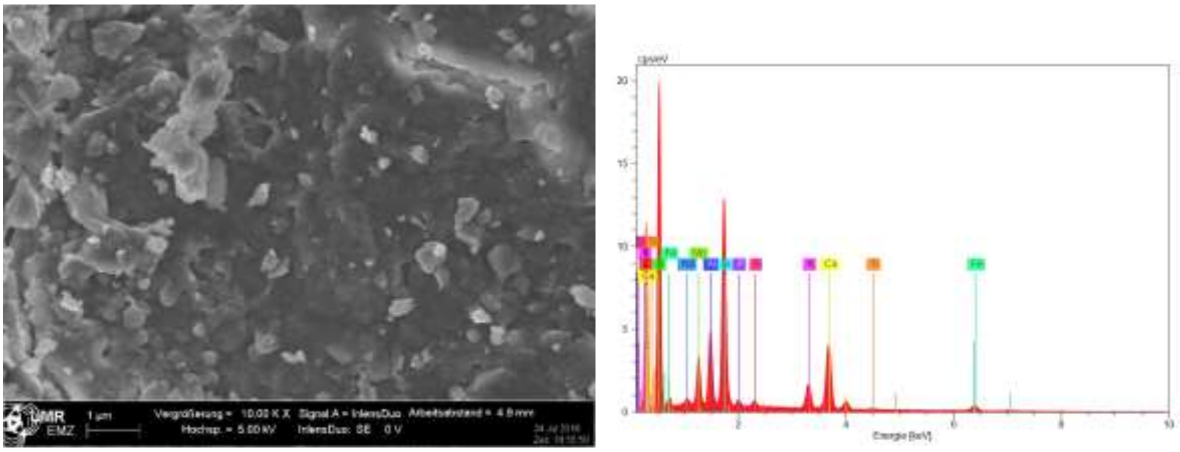
10
Energie [keV]

(d)


UMR
EMZ
1 µm
Vergrößerung = 10.00 K X
Signal A = InlensDuo
Arbeitsabstand = 4.9 mm
Hochsp. = 5.00 kV
InlensDuo: SE
0 V
cps/eV
20
15
10
5
0
Mg
Ca
Ti
Fe
2
4
6
8
10
Energie [keV]

(e)



(f)

Fig.14 Microstructure and elemental composition of untreated BC soil (a), SC10 (b), SC15 (c), SL6 (d), SL6C10 (e) and SL6C15 (f).

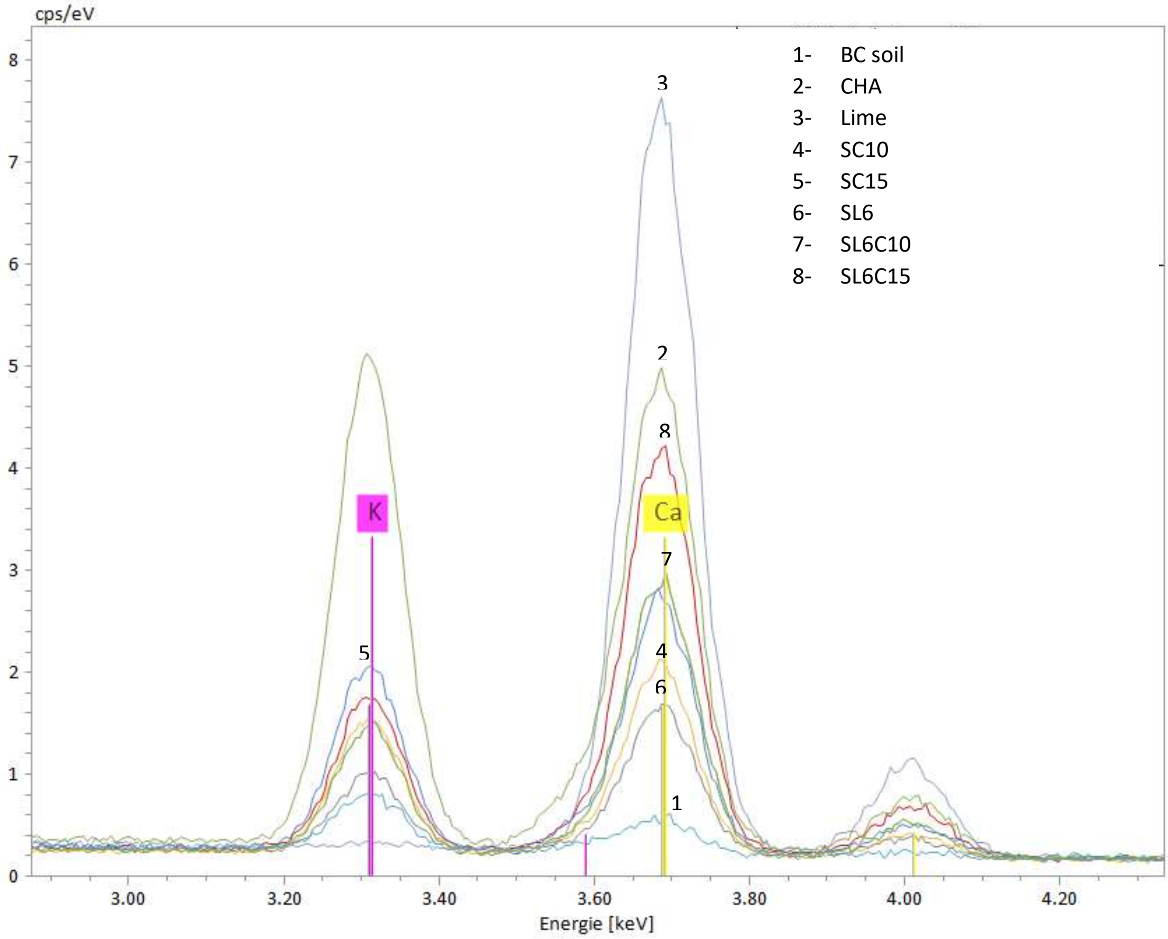


Fig.15 EDX spectrum of K and Ca for untreated and treated samples.

CONCLUSIONS

This study presents the characteristics of the BC soil treated with CHA, lime and a mixture of lime and CHA. Based on the test results obtained from the Atterberg limits, compaction, CBR, microstructural and mineralogical tests, the following conclusion can be drawn.

The BC soil used in this study was classified as high plasticity clay (CH) according to USCS. As the content of the additives increased, both LL and PI decreased, shifting the classification of the BC soil to high plasticity silt and low plasticity silt. These changes in the plasticity behaviour indicate that the treated samples became more workable and stable.

From the compaction test results, it was observed that the maximum dry density (MDD) of the lime-treated samples slightly decreased and the optimum moisture content (OMC) increased as the lime content increased. In contrast, the addition of CHA on lime stabilized the soil, slightly increases the MDD and decreases the OMC. The lime and lime-CHA-treated samples resulted in a considerably higher CBR than the untreated BC soil.

The micrograph of the BC soil indicated discontinuity in its structure and more visible voids. The SEM images of the treated samples showed that the addition of CHA, lime, and lime-CHA has a marked change on the microstructure of the BC soil. EDX results showed a decrement in Si and Al and an increment in Ca content, as the amount of the additives increased. In addition, the XRD results confirmed the formation of cementitious compounds, which is responsible for the improvement in geotechnical properties of the investigated soil.

This investigation reveals the potential use of CHA for road sub-grade construction. It is not limited to the socio-economic advantages in infrastructure developments, but could also play a significant role in reducing the environmental impact arising from the storage of the waste.

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