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TECHNICAL PAPER

Effect of addition of lime on coir fiber admixed BC soil

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Abstract

Expansive soils, having predominantly montmorillonite clay mineral, pose acute construction problems for many civil engineering structures. Admixing lime is popular and cost-effective which is used widely. However, BC soil has inherent low tensile strength but a high compressive strength. Incorporating fiber reinforcement that is capable of absorbing tensile loads or shear stresses will address the problem. In this context, the use of cheaply and abundantly available natural coir fibers as soil reinforcement in the BC soil along with lime is investigated. The effect of lime reaction and associated heat of hydration on coir fiber was investigated in terms of unconfined compressive strength (UCC) of BC soil. XRD and SEM studies on surface characteristics of coir fiber were studied. It was found that, at longer curing periods after addition of lime, plate-like particles are replaced by foil-like membranes and fine filaments due to flocculation–agglomeration of soil particles along with carbonation. XRD confirmed that these fine filaments are foils consisted of calcium silicate hydrate gel that increases strength due to cementation. It was observed that admixing both untreated and treated coir fibers in lime-stabilized BC soil beyond 7 days of curing causes decrease in the UCC due to heat of hydration of lime reaction that seems to affect the fiber characteristics.

Keywords BC soil · Untreated coir fiber · Treated coir fiber · Optimum lime content

Introduction

The particle structure and affinity toward water molecules of montmorillonite clay mineral of black cotton soil (BC soil) create considerable variation of shear strength when it comes into contact with water. The shear strength of BC soil in dry state is high, whereas addition of water causes reduction in shear strength, leading to severe damage in roads, foundations and embankments. In India, nearly around 20–30% of geographical area is covered by BC soil [1, 2]. Studies on the strength of clay soil indicated improvement by the addition of lime and ductility by the addition of fiber reinforcement [3]. Coir fiber is an agro-waste by-product obtained from coconut plantation and in terms of coir production; India is the second largest country in the world. Utilization of coir fiber for ground improvement contributes to improve in rural economy. Coir fiber is suitable for reinforcing soils because of their availability, low cost and sustainability. It has high lignin content in comparison with other natural fibers such as jute flax, linen and cotton and hence can be considered as strongest among all-natural fibers [4, 5]. Lime is the most popular admixture used to improve strength of many problematic types of clay by modifying its plasticity [6, 7]. However, BC soils admixed with lime tend to become brittle in nature [8]. A possible solution is to include randomly distributed natural coir fiber to increase ductility of BC soil and reduce inherent development of cracks due to addition of lime [9].The mechanism by which fibers improve the strength is mainly due to discreet distribution within the soil matrix that induces stress isotropy [10, 11]. However, coir fiber, which is a natural fiber and biodegradable, needs to be tested for its performance when introduced as reinforcement along with lime-admixed BC soil. Previous studies on water absorption of coir fibers have indicated that the alkali

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treatment of coir fibers reduces water absorption of fibers, thereby enhancing its biodegradability [12–18]. Experimental studies on the effect of length of fibers (aspect ratio) indicated that short fibers, between 10 and 20 mm lengths, gave better performance in terms of strength improvement and overall performance in clay predominant soils [19–25]. In the present study, both untreated and treated coir fibers of average length 10–20 mm were used to assess their performance because of exothermic reaction associated with lime addition with curing period. The length of fiber to be used in the present investigation was arrived at based on undrained triaxial test conducted on BC soil using untreated coir fibers added to BC soil in the range of 0–3% fiber content, which gave maximum shear strength parameters [19, 20]. When lime is admixed in the soil, the partial carbonation of the lime is found to cause increase in strength [26–31]. However, the evidence available suggests that carbonation makes a negligible contribution to its strength development, and in fact, less lime is available for "pozzolanic" activity [32–35].

Very few studies in literature are available on the performance of coir fiber in lime-admixed BC soil, especially about the possible strength degradation of the fiber due to changes in fiber surface characteristics with curing. In the present study, BC soil was first admixed with untreated coir fiber (UCF) in lime-admixed BC soil and the performance was compared with treated coir fiber (TCF) in lime-admixed BC soil. XRD and SEM studies were conducted to analyze and verify the fiber surface characteristics of coir fiber, due to exothermic lime reaction that may be responsible for variation in strength. The effect of changes in shear strength of lime-admixed BC soil with both UCF and TCF was studied in terms of UCC with curing period ranging from 0 to 28 days to arrive at conclusions regarding performance of coir fiber-reinforced BC soil admixed with lime.

Materials and methods

The soil used in this study was BC soil collected form Bennehalli village, Davangere district, Karnataka, India, from a depth of 1 m below the ground level. Pulverized and air-dried BC soil passing BIS sieve No. 40 was used in the present study to characterize the strength of lime-admixed and fiber-reinforced BC soil. The soil was classified by unified soil classification system using plasticity properties, such as liquid limit, plastic limit and grain size analysis enlisted in Table 1.

Table 1 Properties of BC soil used and soil classification

Properties	Values
Liquid limit (LL) in %	67
Plastic limit (PL) in %	22
Shrinkage limit (SL) in %	11
Specific gravity, *G*	2.66
Fine sand fraction in %	21
Silt fraction in %	20.2
Clay fraction in %	58.8
Soil classification based on unified soil classification	CH

Coir fibers

Coir fibers used in the present study were brown in color and were obtained from the local small-scale factory in Gubbi, Karnataka, India. Chemical analysis of coir fiber was carried out at Central Silk Board, Bangalore, Karnataka State, India. Table 2 depicts the chemical composition of coir fiber used, that indicated high lignin content of 49.23%, along with tensile strength and mechanical properties of coir fiber.

When natural fibers are introduced in soils as an admixture, especially in the lime-admixed BC soil, heat is generated during initial stages of pozzolanic reaction associated with lime addition. The present investigation uses one among the natural fiber such as coir, to assess their performance over a period ranging from 0 to 28 days. The objective of the present study is to assess the effect of associated heat of hydration of addition of lime that may alter fiber surface characteristics in terms of changes in shear strength of BC soil. The test results thus can be applicable to many other natural fibers that are biodegradable as well as affected by thermal changes. Further, the present study aims to comparatively assess the performance of untreated coir fiber over treated coir fiber. The alkaline treatment that reduces water absorption and enhances its inherent tensile strength has been adopted in the present investigation [21]. The same authors [19, 21, 22] present description of the adopted alkaline treatment along with epoxy coating and stone dust sprinkling. A brief description of the tensile strength and mechanical properties of both UCF and TCF are presented in Table 2. The performance of UCF-admixed BC soil as well as TCF-admixed BC soil was studied comparatively to assess their performance on terms of UCS in lime-stabilized BC soil.

SEM studies shown in Fig. 1a indicate that the surface of untreated coir fiber is covered with layer of oil substances such as extractives of wax, which become part of processing of natural coir fibers. Figure 1b shows the alkali-treated fiber with a rough texture due to removal of extractives of wax and oil. Figure 1c shows alkali treated, and epoxy resin coated with stone dust sprinkled coir fiber—whose surface exhibits significantly higher rough surface texture than alkali-treated fiber.

Table 2 a: Tensile strength of natural and NaOH treated and coated with stone dust coir fiber, b: mechanical properties of coir fibers used

Type of fiber	Tensile strength in MPa
(a)	
Natural coir fiber (untreated coir fiber—UCF)*	133.1
6% NaOH treated coir fibers (ATCF)	324.7
NaOH treated and coated with stone dust (TCF)*	344
Properties	**Value**
(b)	
Average aspect ratio	
(1) Natural coir fiber (UCF)	38.50
(2) 6% NaOH treated coir fiber (ATCF)	103.45
(3) Treated coir fiber (TCF)	32.60

*Both UCF and TCF were used in the study along with lime-admixed BC soil

Quick lime

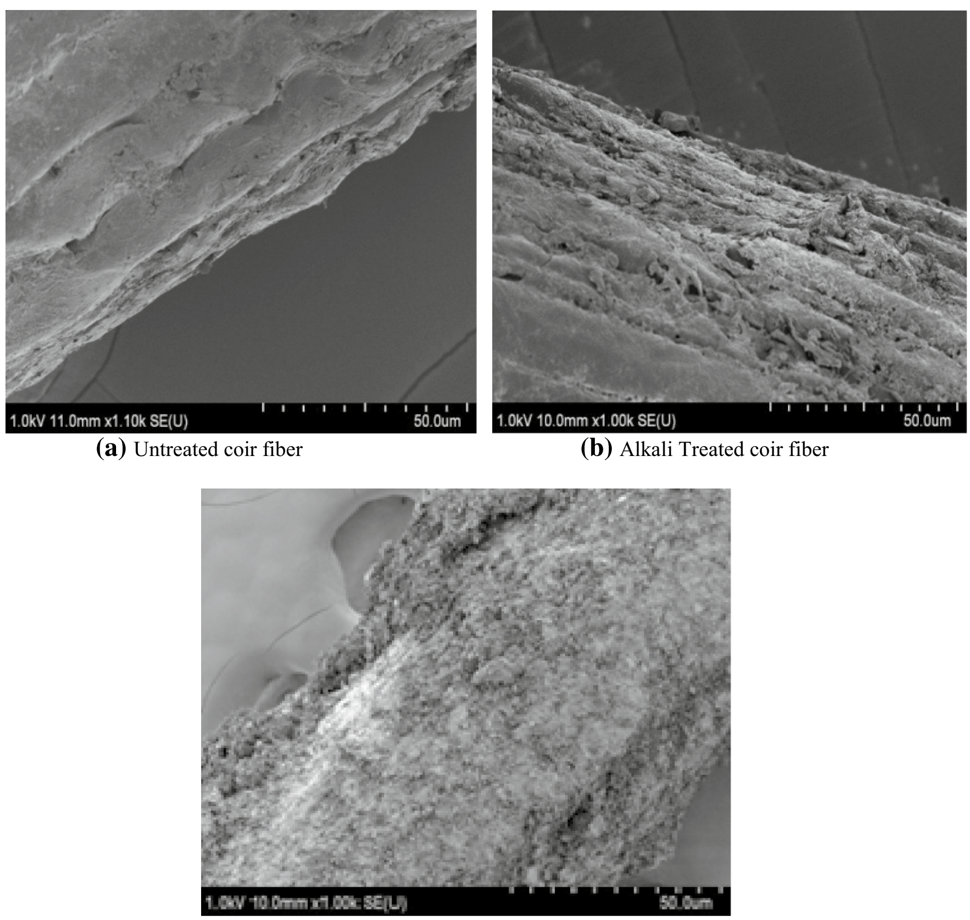
Class F hydrated lime was used in the present investigation which was obtained from *SD Fine-Chemicals Limited, Mumbai*, India. The chemical compositions of lime used indicated the presence of Calcium oxide as CaO and Magnesium oxide as MgO by mass on ignited basis at around 77.49% and silica (as SiO_2), aluminum and ferric oxide at around 13.6%.

Methodology

Light compaction test as per relevant standard (BIS-2720-PART-7-1980) was carried out on BC soil alone, BC soil with different percentage of lime, BC soil admixed with different percentages of UCF, TCF with and without optimum lime content (OLC). The optimum lime content was found to be 3%, and optimum fiber content was 0.5% for both UCF and TCF with and without lime, the results of which are published y the same authors elsewhere [21]. Optimum moisture content (OMC) and maximum dry density (MDD) values obtained from the compaction test were used to prepare remolded samples for unconfined compression strength test (UCC) as per BIS 2720-10 Part 10 on BC admixed with 0.5% UCF and 0.5% TCF with and without 3% of OLC.

The remolded samples for UCC test were prepared by first mixing the fiber and BC soil in dry state thoroughly. In all, 60 samples have been tested with three samples for

Fig. 1 SEM machine, images of untreated and surface treated of coir fibers



(a) Untreated coir fiber

(b) Alkali Treated coir fiber

(c) Epoxy resin coated with stone dust sprinkled coir fiber each combinations were used in the study for 0-, 7-, 15- and 28-day curing. Average of the three samples in terms of UCC is plotted. Based on several trials, it was found that mixing dry fibers in dry clay resulted in less fiber lump and fiber segregation when water was added and mixed [21, 22]. A 38 mm diameter and 76 mm high specimens were prepared for all the tests. A calculated amount of water to reach the target moisture content was sprayed to mix both soil and fiber by hand to prepare a uniform mixture. The prepared specimens were kept in sealed desiccators to maintain humidity and hence the moisture content during the curing period. On the day of testing, the weight of the specimen was measured to check any loss of moisture content. The specimen was prepared in a cylindrical tube, the inside surface of which was greased to reduce frictional effect, which was later extracted and kept for curing. To achieve a uniform distribution of fibers within the soil specimens, fibers of average length of 10–20 mm were used. The prepared mixture was kept in a sealed container for different curing periods of 0, 7, 15 and 28 days.

To measure the amount of heat generated due to addition of lime to BC soil, temperature recording was done in containers having: (1) BC soil alone, (2) lime alone mixed with water, (3) BC soil admixed with UCF alone, (4) BC soil admixed with TCF alone, (5) BC soil mixed with 3% OLC, (6) BC soil admixed with 3% OLC along with 0.5% UCF and (7) BC soil admixed with 3% OLC along with 0.5% TCF, which were compacted to a depth of 150 mm at corresponding OMC and MDD obtained from compaction test. One container with water alone was used to measure the room temperature. Temperature in all the containers were recorded by embedding the thermometer in all the containers to a minimum depth of 75 mm from the top, for a period until the temperature increase stabilized and all samples were kept in desiccators to observe temperature readings.

In general, it can be stated that, during the stage of lime addition with BC Soil, heat is generated in the soil specimen because of exchange of cations (Ca^{++}) as shown in Eq. (1).

$$CaO + H_2O \rightarrow Ca(OH)_2 + \text{Heat}. \quad (1)$$

The effect of lime treatment is thus to release heat during initial periods. Heat generated during such reaction may have an impact on surface characteristics of UCF and TCF admixed with lime-treated BC soil that changes the soil particle texture causing flocculation–agglomeration. [25–27] which is also evident in XRD and SEM studies conducted in the present investigation. However, the silica and alumina that exist in soil minerals become soluble thereby causing an increase in pH of the soil [24–26]. Cementation due to carbonation causing increase in shear strength is due to reactions shown in Eqs. (2) and (3). All these reactions are expected to have a bearing on natural coir fibers over a period of time until the increase in temperature gets stabilized, when introduced into lime-admixed BC soil.

$$Ca(OH)_2 + SiO_2 \rightarrow CaO - SiO_2 - H_2O \quad (2)$$

$$Ca(OH)_2 + Al_2O_3 \rightarrow CaO - Al_2O_3 - H_2O. \quad (3)$$

Figure 2 shows the variation of temperature for several combinations thus tested. Temperature increased quickly from 17° to 36° in lime–water sample. Whereas in BC soil admixed with 0.5% UCF and TCF along with 3% OLC, the increase is found to be from 17° to 30° and those without lime content an increase raging form 17° to 18° were recorded in a span of one day, i.e., 24 h. Increase in temperature reached a constant value at around a curing period in the range of 2–3 days. The variation in temperature in lime-admixed BC soil clearly indicates that the increases in temperature stabilize after at around 2–3 days, and thereafter, the temperature remains constant over a period of 10 days measured in the present investigation. The sustained increase in temperature in coir fiber-admixed BC soil along with lime thus is expected to affect and change fiber surface characteristics and thereby shear strength of coir fiber-admixed BC soil. Effect of exothermic reaction on coir fiber was studied using XRD, SEM using similar remolded samples of BC soil combinations prepared for UCC tests, and the variation in shear strength in terms of UCC was comparatively assessed.

XRD and SEM studies

XRD and SEM studies were conducted by remolding the soil samples to the corresponding OMC and MDD obtained from the compaction test and cured for 0 and 28 days. Samples were remolded and cured in a desiccator. Samples of BC soil alone, BC soil admixed with OLC, BC soil admixed with OLC, 0.5% UCF, BC soil admixed with OLC and 0.5% TCF were used by curing the specimens for 0 and 28 days in order to assess morphological changes. Ten samples, with two samples for each such case, were remolded to study both XRD and SEM.

Discussion on XRD studies

XRD examination of the BC soil alone confirms the presence of quartz/montmorillonite mineral along with zinc sulfide as shown in Fig. 3. Table 3 indicates the strong presence of major clay mineral is montmorillonite at basalt spacing of 27 Å and zinc sulfide at 2θ spacing of 21 Å, 28 Å and 29 Å.

Figure 4a shows XRD for BC soil admixed with 3% OLC for 0-day curing period. The major predominant minerals present in the sample being montmorillonite at basalt spacing of 27 Å, anorthite (Al, Ca, Na, O and Si) at 2θ spacing of 10, 21, 27, 34 and 39 Å, respectively,

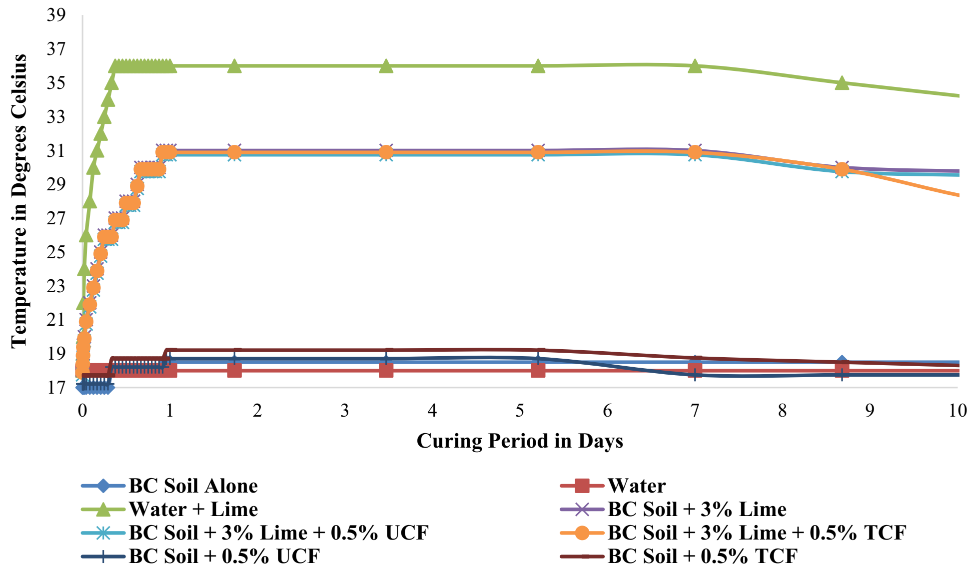


Fig. 2 Effect of lime on BC soil + UCF and TCF with different curing periods

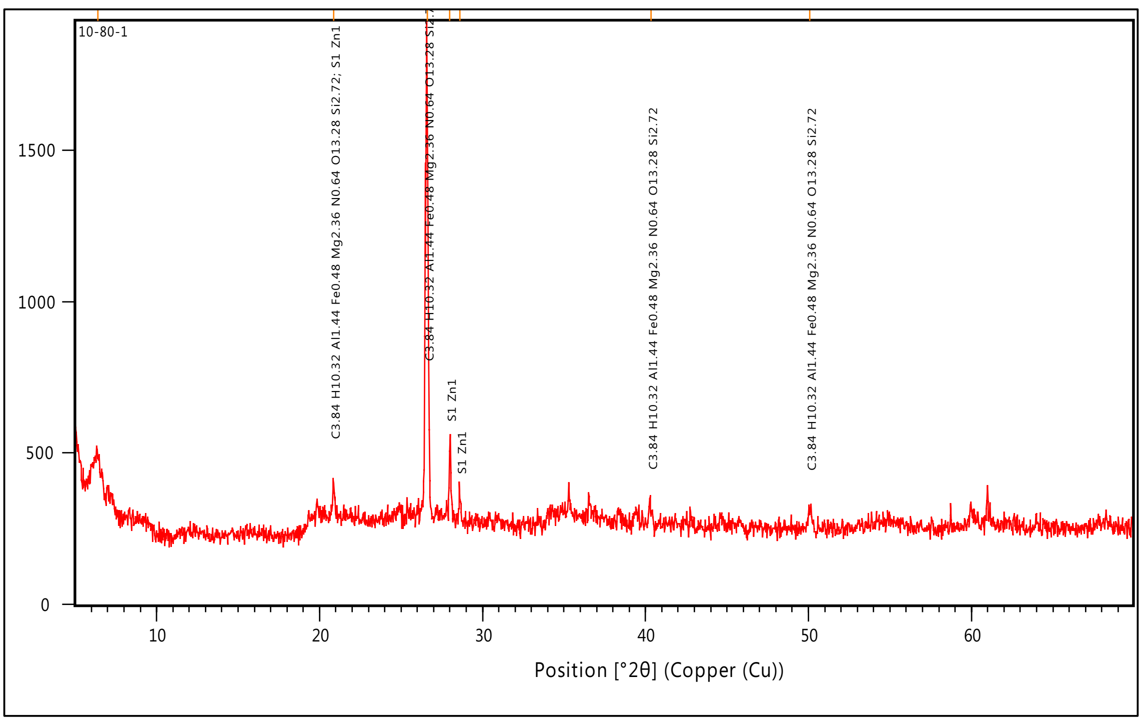


Fig. 3 XRD image of BC soil alone

cordierite (H1, Al Mg, Na, O and Si), and orthoenstatite (Mg, O, Si) was present at 2θspacing of 10, 34, 39 and 69 Å. Figure 4b indicates the presence of vermiculite (C, H, Al, Fe, Mg, N, O and Si) at 2θspacing of 21, 23, 26, 35 and 50 Å. Table 4 shows the compound names, chemical formula with atomic percentage, for lime-treated BC soil with 0 day and 28 days of curing period. Change in chemical compounds form 0-day curing period to 28 days indicates flocculation–agglomeration of soil particles due

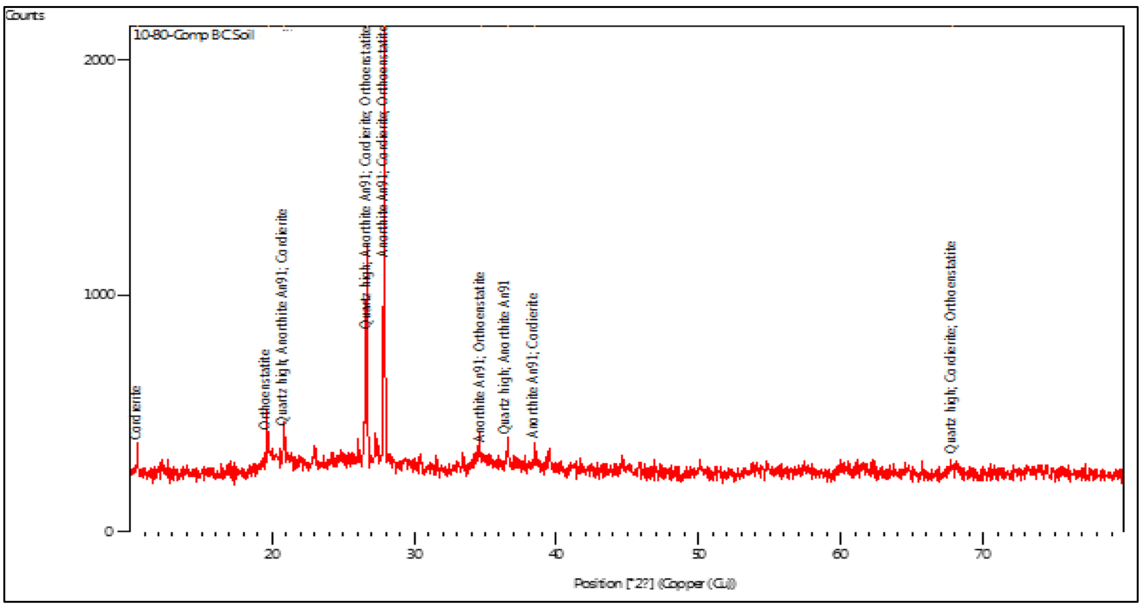
Table 3 Compounds present in the BC soil with chemical formula

Compound name	Chemical formula with atomic %
Quartz/montmorillonite (C6 H14 N O2 loaded)	C3.84, H10.32, Al1.44 Fe0.48, Mg2.36, N0.64 O13.28, Si2.72
Zinc sulfide	S1 Zn1

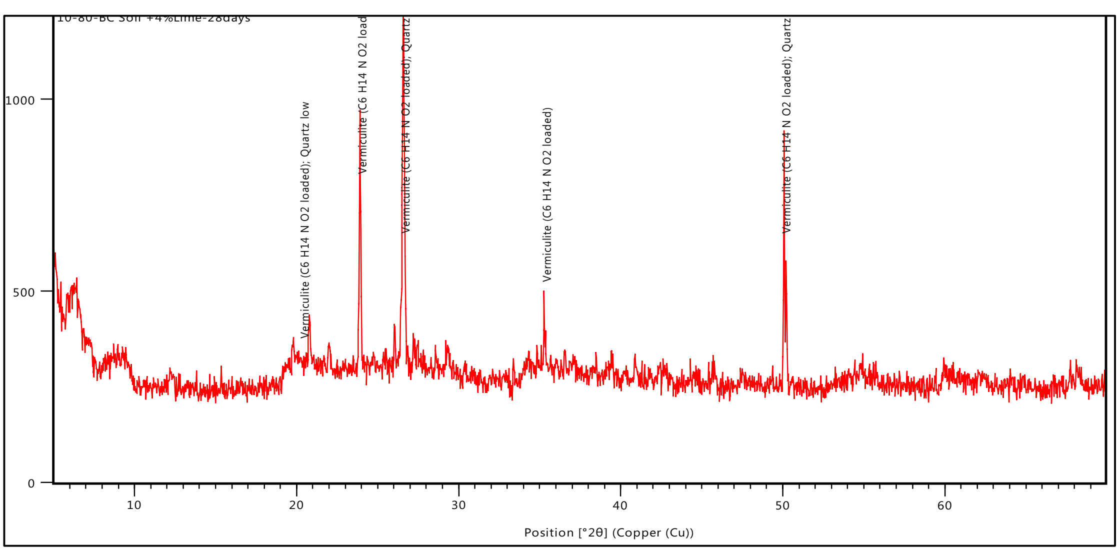
to lime and siliceous material getting precipitated as fine fibrous and foil-like calcium silicate hydrated gel [31].

The trend in result is attributed to the fact that there occurs a general breakdown of the clay particles due to chemical attack by the lime. Thereby the calcium ions are initially adsorbed on to clay particle surface by cation exchange. This gradually breaks apart the structural layers of the clay and associating reaction produces foils and filaments of iron, potassium aluminum dioxide, clinopyroxene and sodium hydrated gel.

Figure 5a shows XRD for BC soil + 0.5% UCF +3% lime for 0–day curing period and indicates the presence of lime (calcium oxide, CaO and aluminum Al) at spacing of 21 Å along with strong appearance of montmorillonite at basalt spacing of 27 Å. Figure 5b shows XRD for BC soil + 0.5% UCF +3% lime with 28-day curing period, showing the presence of quartz, iron, potassium aluminum dioxide, clinopyroxene and sodium. Similar trend is observed in Fig. 6a, b. Figure 6a confirms the presence of carbon, quartz, anorthite,



(a) BC Soil + 3% OLC at 0-Day Curing



(b) BC Soil + 3% OLC at 28-Days Curing

Fig. 4 XRD for BC soil admixed with 3% OLC for 0- and 28-day curing period

Table 4 Compound names and chemical formals for BC soil admixed with 3% lime for 0-day and 28-day curing period

Compound name	Chemical formula
(a) BC soil + 3%OLC 0-day curing	
Quartz high/montmorillonite	O2 Si1
Anorthite	Al2 Ca0.91 Na0.09 O8 Si2
Cordierite	H1.44 Al2 Mg2 Na0.08 O18.72 Si7
Orthoenstatite	Mg1 O3 Si1
(b) BC soil + 3%OLC 28-day curing	
Vermiculite (C6 H14 N O2 loaded)	C3.84 H10.32 Al1.44 Fe0.48 Mg2.36 N0.64 O13.28 Si2.72
Quartz	O2 Si1

Sodian, and Fig. 6b confirms that presence of quartz, biotite, maganoan and bornemanite.

Figure 7a, b shows the XRD for BC soil + 0.5% UCF at 0-day curing period and BC soil + 0.5% UCF at 28-day curing period. There is no much change in the chemical compounds as quartz and oligoclase both are present in 0-day and 28-day curing period, indicating no reaction between soil and fibers. Similar trend was observed in the BC soil + 0.5% TCF at 0 day and 28 days of curing period; the major chemical compound in both XRD was quartz, biotite, annite and graphite, as depicted in Fig. 8a, b.

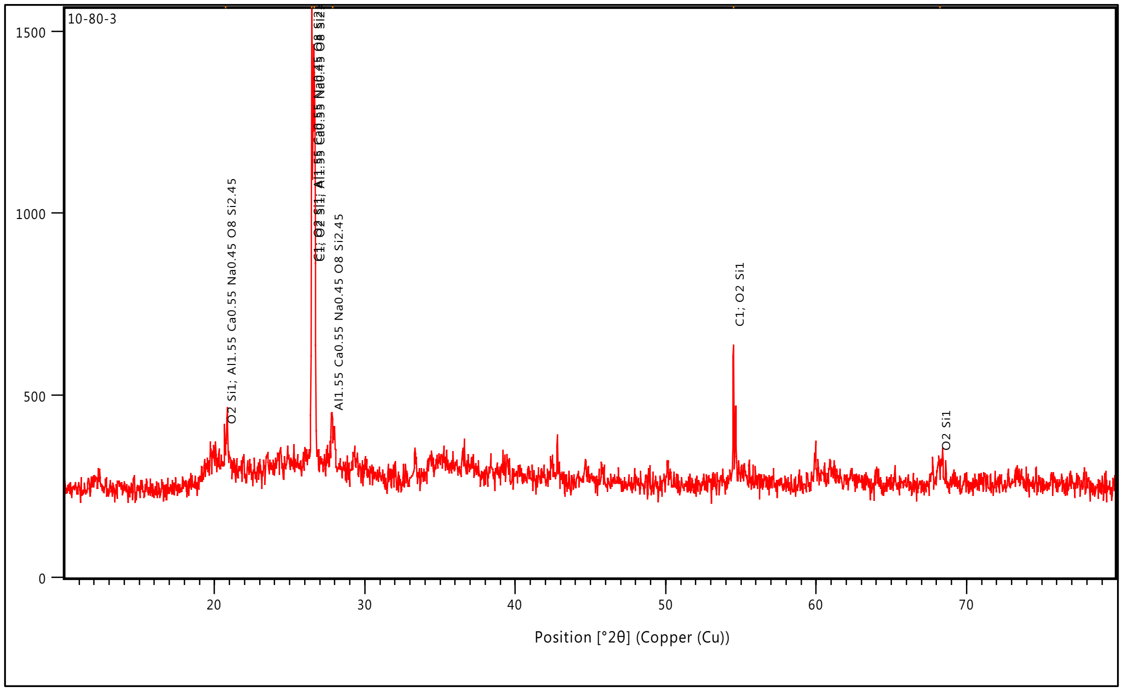
The XRD analysis of lime-admixed BC soil at 0- and 28-day curing clearly indicated major chemical changes. The exothermic reaction of lime leads to breakdown of the clay particles and adsorption of calcium ions by cation exchange. This leads to changes in structural layers of the clay to produce foils and filaments, which significantly lead to greater adherence of coir fibers with clay particles due to their rough surface texture. Greater adherence of coir fibers caused changes in surface characteristics of fibers due to associated exothermic heat. These associated surface changes of coir fibers were also analyzed using SEM studies, and changes in UCC were comparatively assessed in order to conclude on the performance of UCF and TCF in lime-admixed BC soil.

Discussion on SEM studies

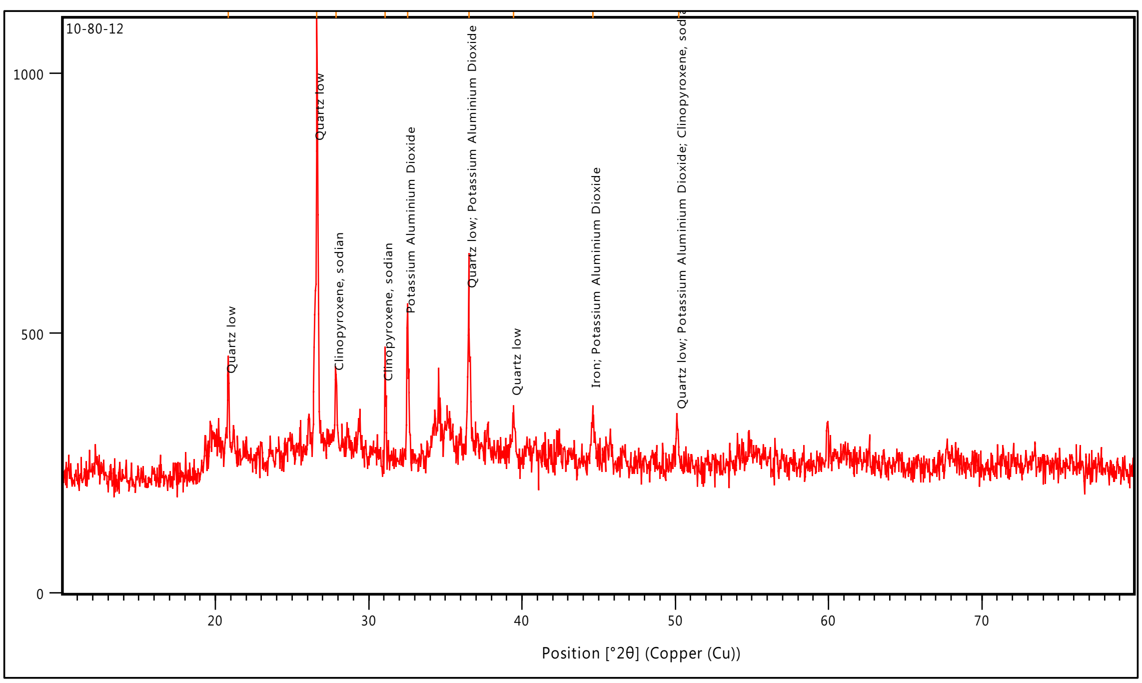
SEM studies were also conducted in order to assess associated microstructural changes due to the addition of lime and addition of coir fibers in lime-admixed BC soil. Figure 9a shows the SEM image of BC soil alone. Figure 9b shows the BC soil admixed with 3 percent OLC for 0-day curing period. Presence of lime patches indicates flocculated structure with more voids in soil structure in the initial stages. Figure 9c shows the BC soil admixed with 3% OLC for 28-day curing that indicated flocculated-agglomerated structures with less voids due to carbonation.

Figure 10a shows the lime-treated BC Soil with 0.5% UCF for 0-day curing period, and Fig. 10b shows lime-treated BC soil with 0.5% UCF for 28-day curing period. Evidence of lime hydration and exothermic reaction affecting breaking of coir fiber along with thinning of UCF causing its deterioration at 28 days of curing period is evident. Similar trend is observed in Fig. 10c, d, which shows lime-treated BC soil with 0.5% TCF at zero, and 28 days of curing period, in spite of the fact that the TCF had an epoxy resin coating, over which stone dust was sprinkled which can be seen in Fig. 10c. The SEM obtained at 28-day curing for lime-treated BC soil with TCF indicated erosion of stone dust that caused a transformation of fiber surface into smooth texture along with thinning of fiber. However, in comparison of UCF, the severity of deterioration can be seen to be less in TCF as no fiber was broken. Thus, it is concluded based on the above discussions, that the associated exothermic reaction of lime due to its addition to BC soil affects natural fibers—consequently may affect its shear strength.

In order to assess the effect of changes in surface characteristics of coir fibers due to associated exothermic changes, the shear strength of BC soil was verified in terms of unconfined compressive strength (UCC). All the combination of said stabilized BC soil was tested using remolded samples compacted at corresponding OMC and MDD and cured in a desiccator for a period of 0–28 days. Figure 11 shows the results of variation of UCC with curing period for UCF- and TCF-reinforced BC soil, with and without lime content. UCC of TCF reinforced with lime-treated BC soil shows significant increase in UCC (up to 1200 kPa) for a curing period of 7 days compared with UCF reinforced lime-treated BC soil for the same curing period due to lime soil reaction (cation exchange, flocculation–agglomeration and carbonation). Further, beyond 7-day curing period, the strength decreased and reached a constant UCC of 450 kPa at 28-day curing period for both UCF- and TCF-reinforced lime-treated BC soil. UCC of BC soil alone is 200 kPa, whereas UCF- and TCF-reinforced BC soil without lime content had a value of UCC at around 400 kPa and 500 kPa, respectively, at 28-day curing period. Though both UCF and TCF admixed, BC soil had higher UCC when compared with BC soil alone, the effect of exothermic reaction of lime-admixed BC soil seems to contribute to reduction in UCC with curing period. This is attributed to the consequent deterioration/degradation of coir fiber, which needs to be taken into consideration with regard to the use of natural fiber in lime-admixed soils. The extent of degradation of natural coir fiber may also depend on the extent of lime used as well as curing period—which needs further probe to assess its long-term performance.



(a) BC Soil + 0.5% UCF +3% OLC at 0 Day Curing Period



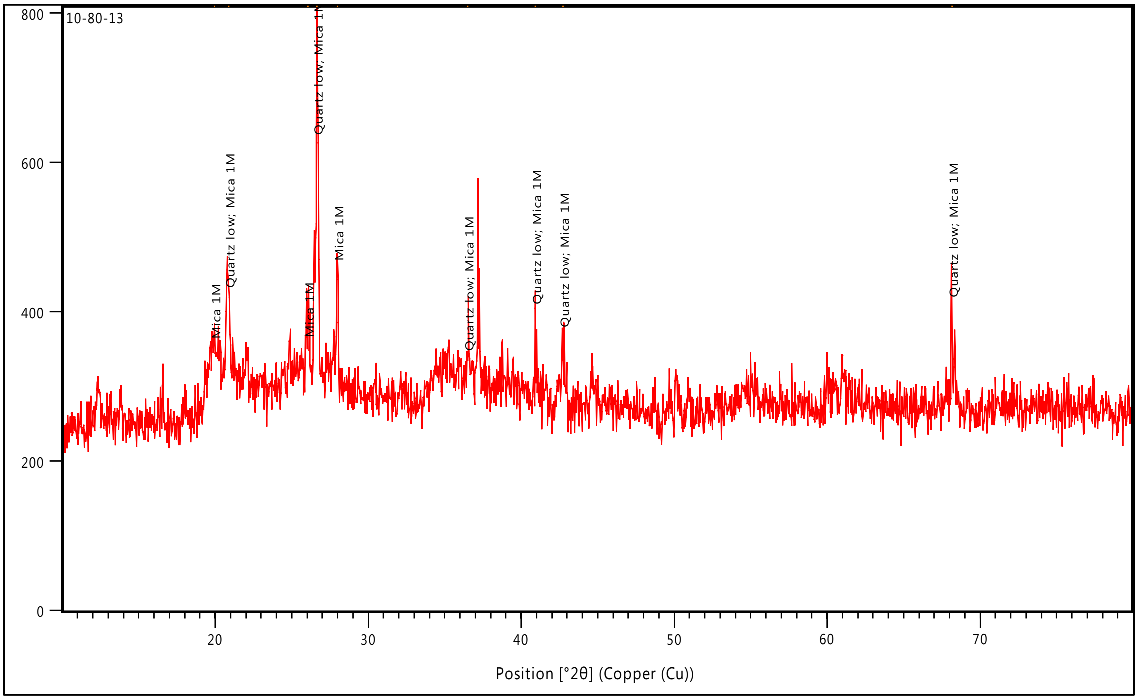
(b) BC Soil + 0.5% UCF +3% OLC at 28 Day Curing Period

Fig. 5 XRD for BC soil admixed with UCF with OLC at different curing periods

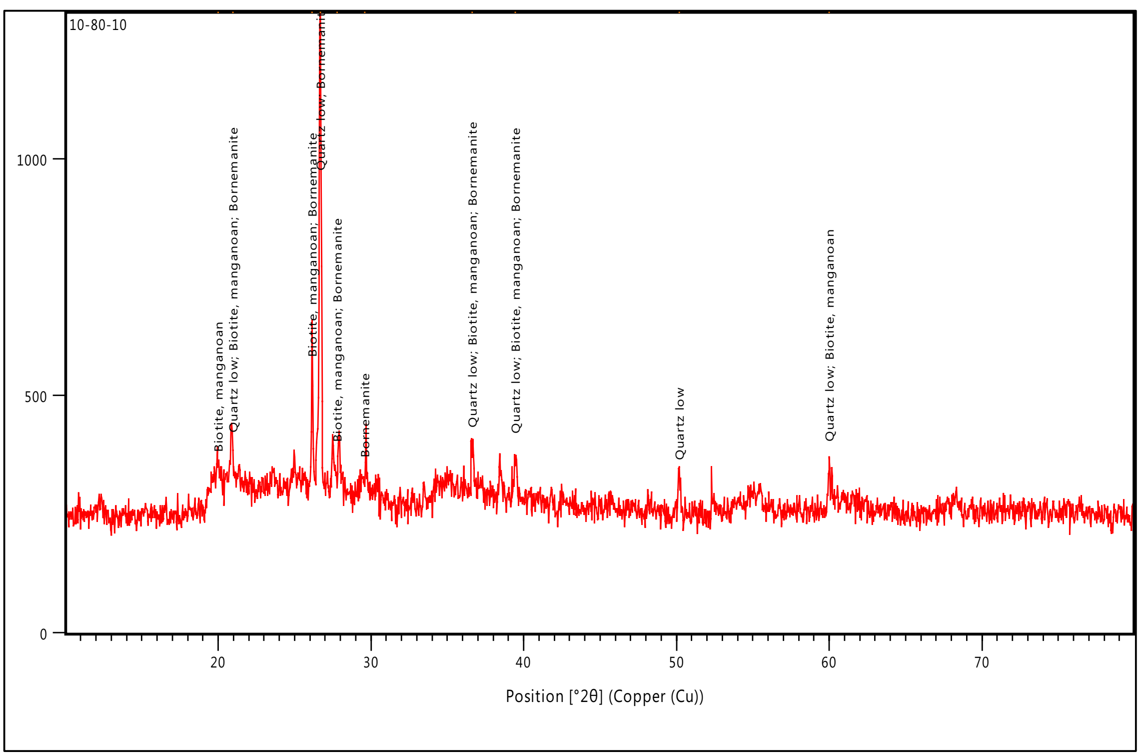
Conclusions

The objective of the present study is to verify the effect of exothermic reaction of lime-admixed BC soil on coir fiber reinforcement. Based on the present experimental study, coupled with XRD and SEM studies, the following major conclusions have been drawn:

1. An increase in temperature in the range up to 38° for lime admixed with water and for BC soil admixed with

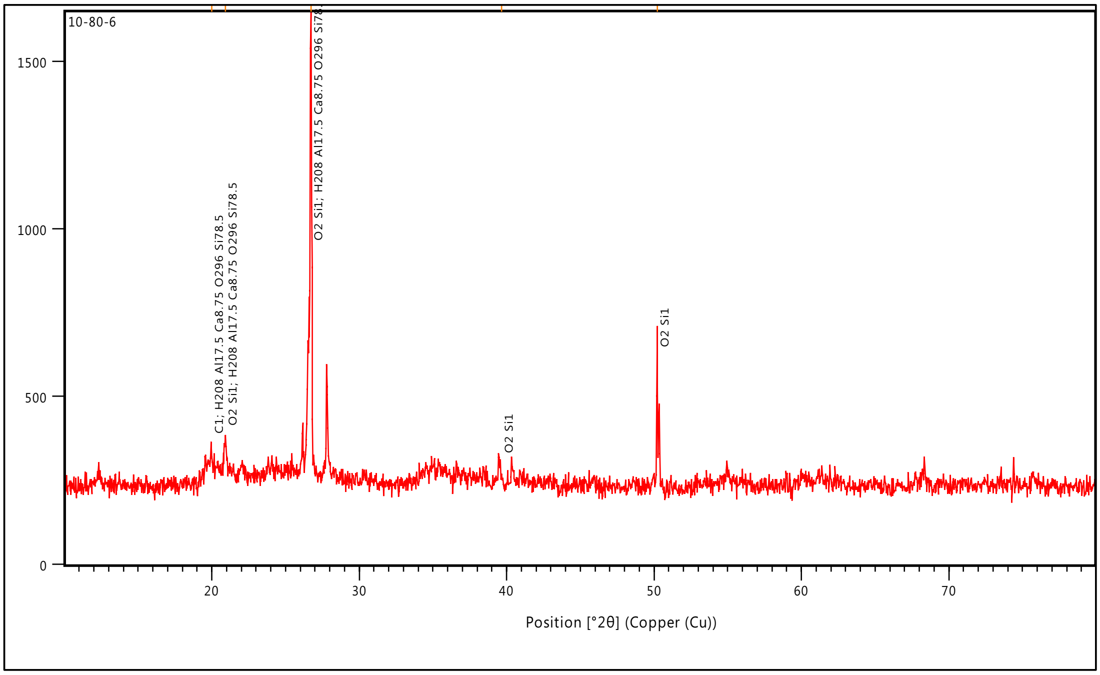


(a) BC Soil + 0.5% TCF +3% OLC at 0 Day Curing Period

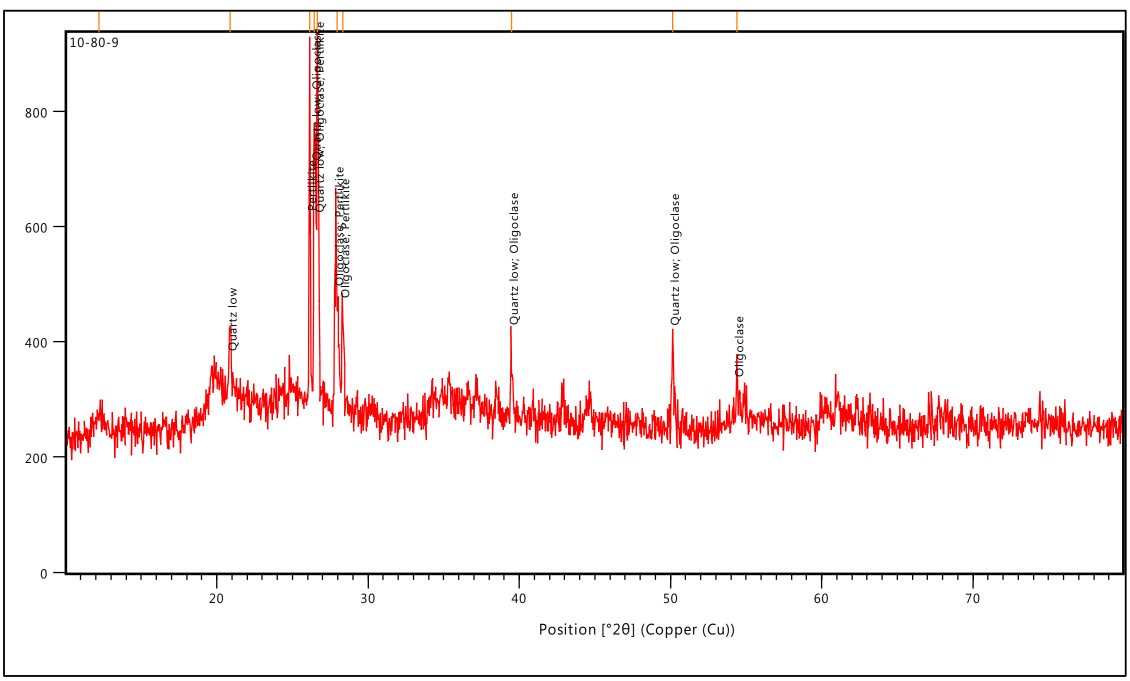


(b) BC Soil + 0.5% TCF +3% Lime at 28 Day Curing Period

Fig. 6 XRD for BC soil admixed with TCF with OLC at different curing periods

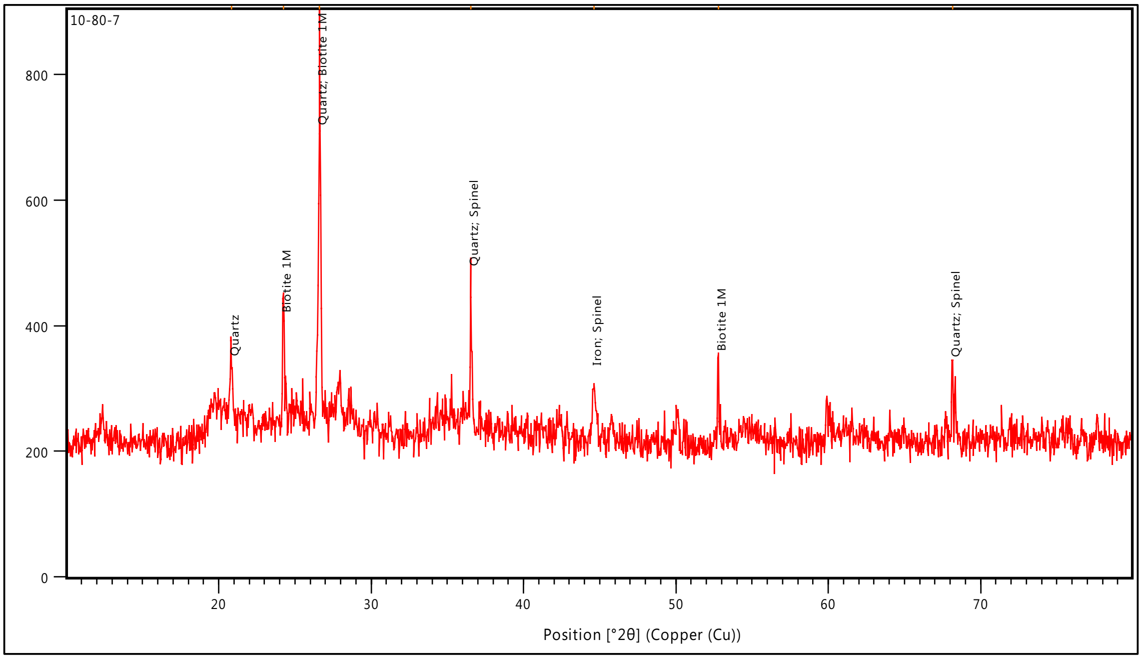


(a) BC Soil +0.5% UCF at 0 days Curing Period

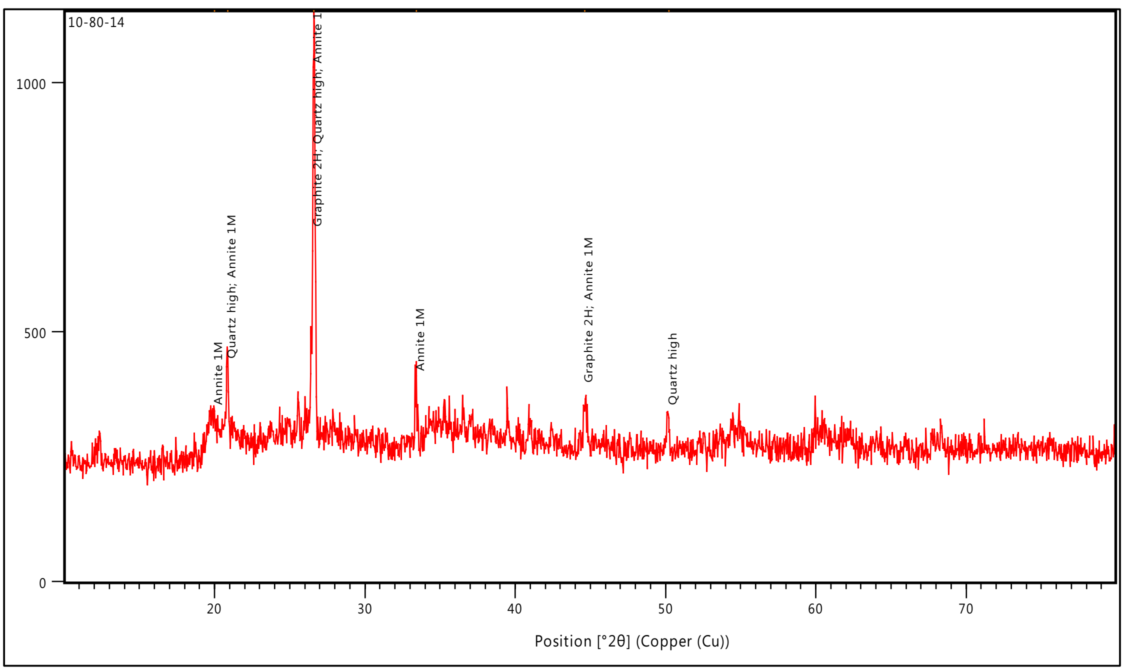


(b) BC Soil +0.5% UCF at 28 Day Curing Period

Fig. 7 XRD for BC soil admixed with UCF at different curing periods



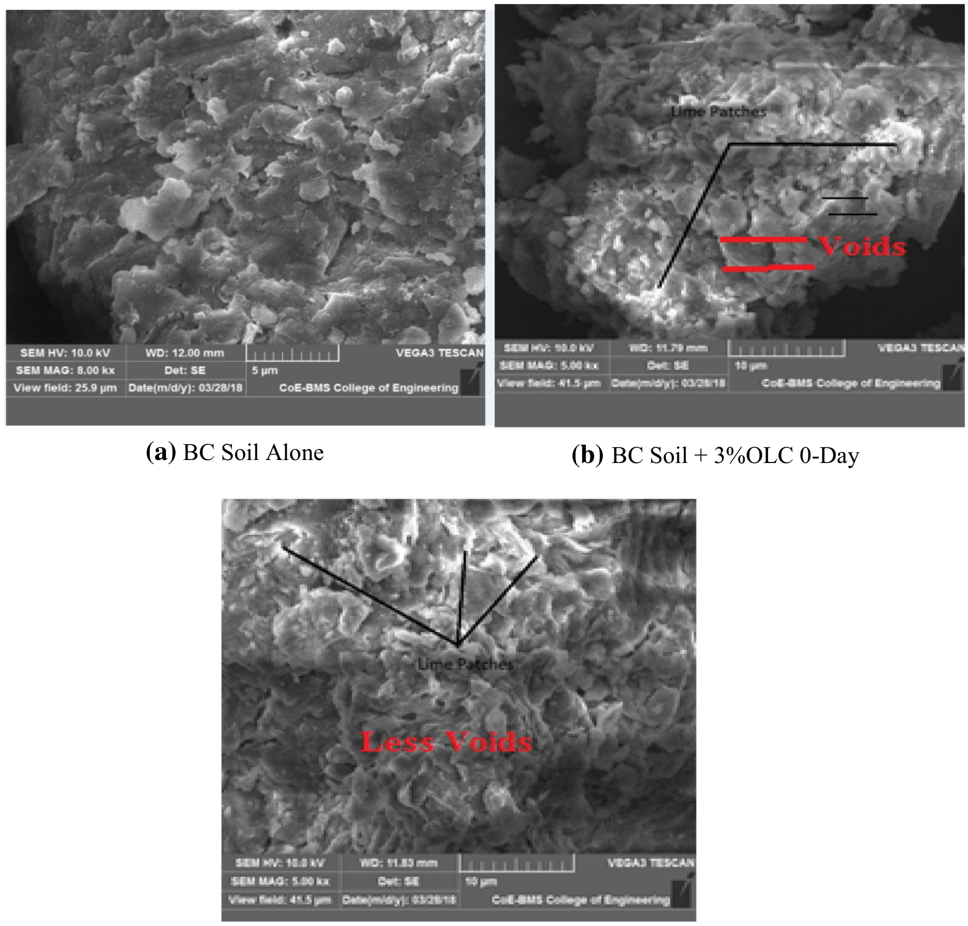
(a) BC Soil +0.5% TCF at 0 Day Curing Period



(b) BC Soil +0.5% TCF at 28 Day Curing

Fig. 8 XRD for BC soil admixed with TCF at different curing periods

Fig. 9 SEM of BC soil alone, BC soil + 3% OLC 0 day and BC soil + 3% OLC 28 days



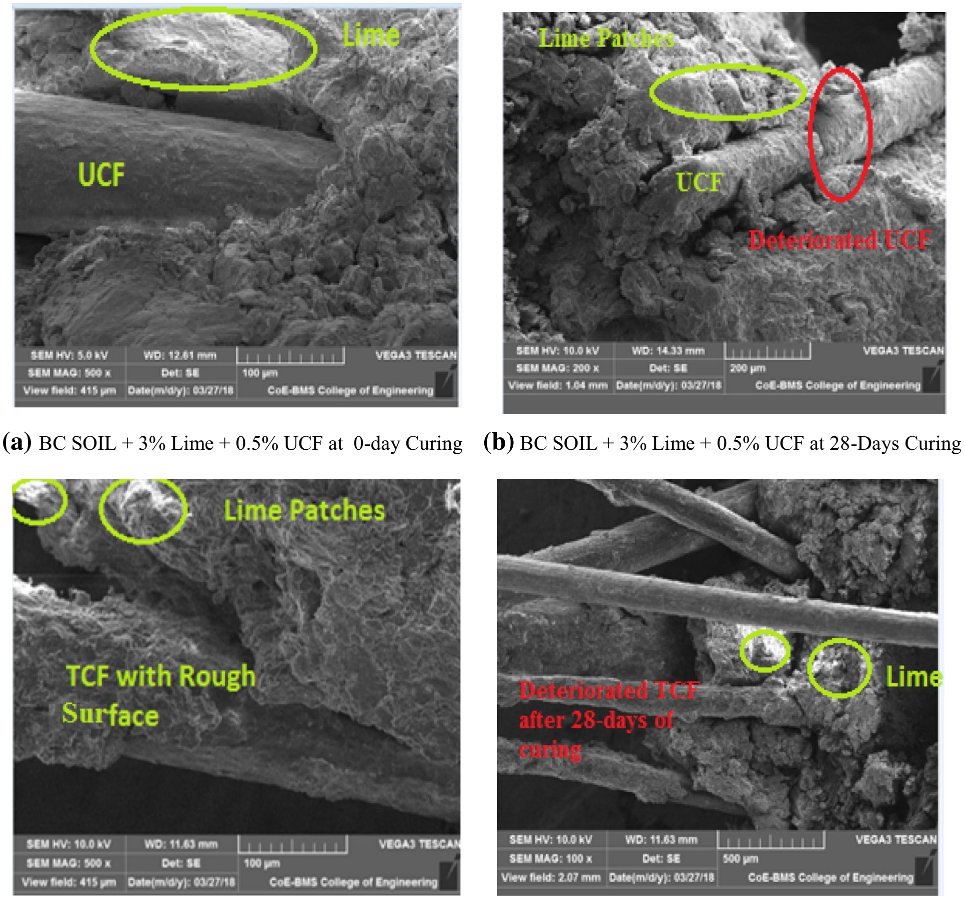
(a) BC Soil Alone

(b) BC Soil + 3%OLC 0-Day

(c) BC Soil + 3%OLC 28-days

lime along with UCF and TCF up to 31° indicates exothermic reaction of addition of lime. When BC soil is admixed with UCF and TCF without lime, no such phenomenal temperature increase was observed. Thus, the heat of hydration due to associated pozzolanic reaction has an impact on surface characteristics of admixed coir fiber.

2. The associated soil–lime reaction at longer curing period leads to formation of foil-like membranes and fine filaments that causes flocculation–agglomeration of particles. XRD analysis confirms that these fine filaments are foils consisting of calcium silicate hydrate gel, which contains a small amount of aluminum and presence of zinc sulfide. Examination of microstructure of the particles of cured soil–lime samples indicates formation of platelets and foils that eventually result in modification of particles.
3. SEM analysis shows that there is degradation of both UCF and TCF admixed with lime-treated BC soil because of exothermic lime reaction. Introduction of natural fibers such as coir in lime-admixed soil shall take into consideration the effect of heat of hydration that consequently affects the fiber characteristics.
4. UCC of lime-admixed BC soil along with UCF and TCF increases the UCC strength up to 1000 kPa and 1200 kPa, respectively, in the initial stage of reaction 0–7 days of curing period. Further, beyond 7 days of curing, decrease in the UCC occurs due to heat of hydration of lime reaction affecting the fiber characteristics. Alteration of surface characteristics of coir fiber due to exothermic reaction of lime-admixed BC soil eventually leads to degradation of natural coir fibers that causes reduction in UCC of fiber-reinforced BC soil with curing period.



(a) BC SOIL + 3% Lime + 0.5% UCF at 0-day Curing **(b)** BC SOIL + 3% Lime + 0.5% UCF at 28-Days Curing

(c) BC SOIL +3% lime +TCF at 0-Day Curing **(d)** BC SOIL +3% lime +TCF at 28-Days Curing

Fig. 10 SEM images of BC soil with UCF and TCF for different curing periods

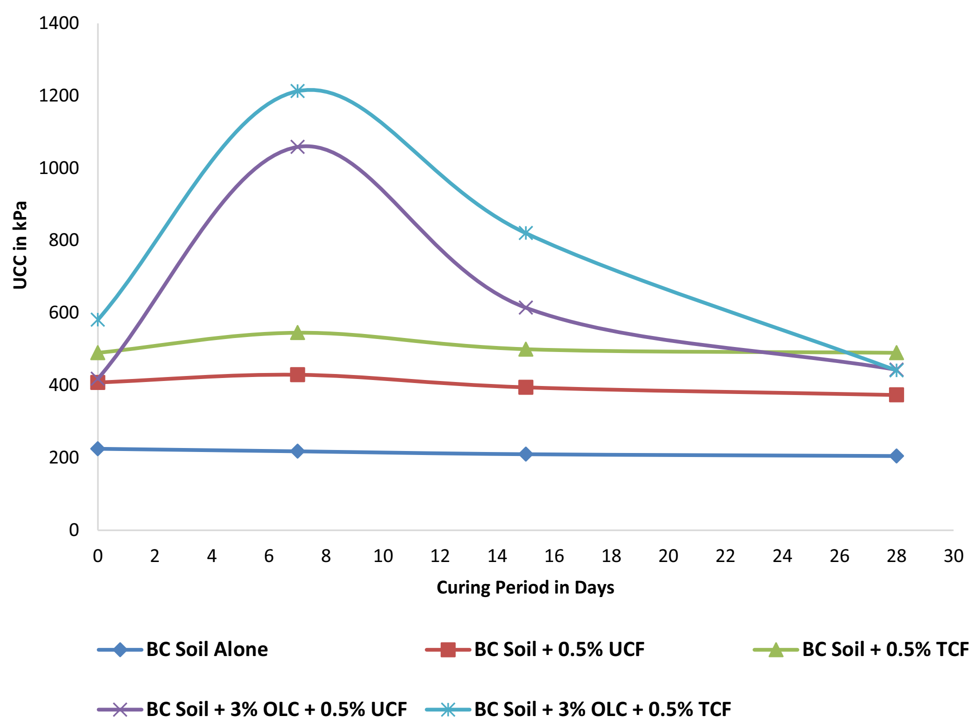


Fig. 11 UCC strength of BC soil with OLC and BC soil admixed with UCF and TCF

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