Strength and Deformation Characteristics of lime admixed Black Cotton Soil Reinforced with Sisal Fibres

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Abstract. Sustainable ground improvement techniques have led to the use of natural fibres to improve the shear strength properties of soil. Lime was admixed to black cotton soil starting from 1, 2, 3nd 4% and optimum lime content was arrived at based on maximum value of dry unit weight and corresponding water content from compaction test. Using the optimum lime content thus obtained, black cotton soil was reinforced with randomly distributed sisal fibres of average length 10-20mm and analyzed for shear strength in terms of unconfined compression test. Sisal fibres were added in varying percentages starting from 0, 0.5, 1, 2, and 3%, and compaction characteristics was assessed. Remolded specimens were prepared to have corresponding maximum dry unit weight obtained from compaction test were tested for unconfined compressive strength to study the effect of curing with and without lime at different period of 0, 10, 20, and 30days. The result indicated sisal fibre content of 0.5% indicated maximum shear strength with and without optimum lime. The surface characteristics of sisal fibre admixed soil along with lime using X-ray refraction and scanning electron microscopic study revealed better bonding strength between soil and sisal fibre.

Keywords: BC Soil; sisal fibre; unconfined compression test; compaction.

1. Introduction

Black Cotton Soils originate from basaltic rocks formed over millions of years due to volcanic action and cooling of lava are referred to as “Expansive Soils” and contribute to almost 20% of the terrains covering central India [2, 3]. Owing to the presence of high amounts of montmorillonite, these soils exhibit a peculiar swelling and shrinkage behaviour when subjected to changes in moisture content causing detrimental effects on the structures constructed over it [5,6,9]. Many years of research contributed to finding ways to stabilize these soils in order to control and alter their properties as per the construction requirements [1,4,7,8,14]. Sisal fibre is very long, with an average length of 0.6 to 1.2 m and it is creamy white to yellowish in color. It is coarse and strong, durable and can stretch. It also has good insulation properties and it is highly resistant to bacterial damage and to deterioration in saltwater. Sisal fibre, modified soy protein resins, and composites were characterized for their mechanical and thermal properties. Sisal fibre is exceptionally durable and a low maintenance with minimal wear and tear. It contains 65% Cellulose, 12% Hemicelluloses, 9.9% Lignin, and 2% Waxes. Sisal fibre is known to increase the tensile property, CBR value and shear strength of the soil [13,15,16,17,18]. Lime stabilization generates a long-term pozzolanic strength-gain due to reaction between lime and the silica and alumina minerals present in cay, forming calcium silicates and calcium aluminates [19,20,21,22]. In the present study BC soil admixed with optimum lime obtained from compaction test and reinforced with different percentage of sisal fibres was subjected to unconfined compression test (UCCS) after curing the specimens for different periods of 0, 10, 20, and 30days. Similarly, BC Soil admixed with different percentage of sisal fibres, 0.5, 1, 2, and 3% are added do find the optimum percentage with and without lime. The test results were analyzed for the efficacy of use of sisal fibers in BC soil admixed with and without lime [23,24].

2. Materials and Methods

Black cotton soil (BC Soil) was collected from Bidar district. Karnataka India, form a depth of 0.9m below the ground level. BC soil was pulverized airdried and sieved through sieve no. BIS-40. Properties of BC soil is as shown in Table 1. Class F Hydrated Lime was purchased form local hardware shop. The sisal fibres were procured from Kovai Green Fibres, Coimbatore, Tamil Nadu and fibres that were cut to have average length of 10-20mm [11,12,19] was used in the present study. All the Basic properties were carried out as per IS codes.

Table 1. Properties of BC soil Used

Description	Values
Liquid Limit (LL)	64
Plastic Limit (PL)	25
Shrinkage Limit (SL)	12
Specific Gravity (G)	2.61
Sand (%)	38%
Sil and Clay (%)	62%

Strength of Sisal fibre-reinforced soil depends on dry unit weight and corresponding moisture content, which in turn depends on percentage of sisal-fibres admixed in the BC soil. Further, sisal being a low-density fibre causes reduction in dry unit weight when admixed in BC soil. In this context, the compaction characteristics of sisal-fibre-reinforced BC soil assumes importance which needs to be verified. To analyze the lime reaction on admixed sisal fibre BC soil, the sisal fibres mixed in lime-treated BC soil was also studied. Sisal fibre was mixed to BC soil at optimum lime content which was determined using provisions for "light compaction test as per relevant BIS standards [10]. The compaction test was followed in the present study was similar light compaction test provisions by adding sisal fibre by dry weight percentage of BC soil. The average length of Sisal fibres used was in the range of 10–20 mm [19].

To achieve uniform distribution of fibre, based on several trials and methods, the most suitable method of mixing the dry fibres with BC soil was adopted and water is then added to this dry mixture which produced less fibre lump formation. The lime percentage varied to get optimum lime content was 1, 2, 3 and 4% and to get optimum sisal fibre content was 0.5, 1, 2, and 3% with different curing period in UCCS tests was 0, 10, 20 and 30 days. The effect of curing period on unconfined compression strength was assessed with different curing period of 0,10,20 and 30 days.

XRD and SEM tests were conducted at different curing periods to assess microstructural changes. Table 2 shows variation maximum dry unit weight (MDU) and optimum moisture content (OMC) at different percentage of lime added to BC soil, which indicates that maximum dry unit weight (MDU) was obtained with corresponding OMC at 3% lime content. Hence, for the BC soil used in the experimental investigation, 3% lime was considered as optimum lime content (OLC).

Table 2. Variation MDU and OMC at Different Percentage of Lime Added to BC Soil.

Lime (L) in %	MDU (kN/m$^{3)}$	OMC (%)
BC Soil Alone	16.11	16.96
BC Soil +1% L	15.79	17.59
BC Soil + 2% L	16.26	18.43
BC Soil + 3% L	16.97	19.41
BC Soil + 4% L	15.87	20.72

3. Results and Discussions

Compaction characteristics of sisal-fibre admixed BC soil without lime and with OLC were determined. Table 3 shows the variation of MDU and OMC with different percentages of sisal-fibre. It clearly indicates that increase in percentage of low-density sisal fibres in BC soil decreases density of BC soil. However, addition of 0.5% sisal fibre increases marginally the dry unit weigh as compared to BC soil. It is attributed to possibility of uniform distribution of fibres at lower dosage leading to increase in bonding between soil particles.

Table 3. Variation Maximum Dry Unit Weight (MDU) and Optimum Moisture Content (OMC) for Sisal Fibre Admixed BC Soil.

Sisal Fibre (SF) in %	MDU (kN/m^{3})	OMC (%)
BC Soil Alone	16.11	16.96
BC Soil +0.5% SF	16.50	16.98
BC Soil + 1% SF	16.00	20.37
BC Soil + 2% SF	15.81	21.12
BC Soil + 3% SF	15.37	24.22

3.1 Unconfined compression strength

To ascertain the strength characteristics of BC soil, unconfined compression tests were carried out with different percentages of lime and cured at periods of 0, 10, 20 and 30days. Fig. 1 shows the variation of unconfined compression strength (UCCS) of BC soil admixed with different lime content 0, 1, 2, 3 and 4% with different curing periods were tested and it concludes that at 3% lime is optimum combination is higher dry unit weight for all the curing periods. Hence both compaction test and UCCS tests have indicated that 3% lime content is optimum for the BC soil used in the present study.

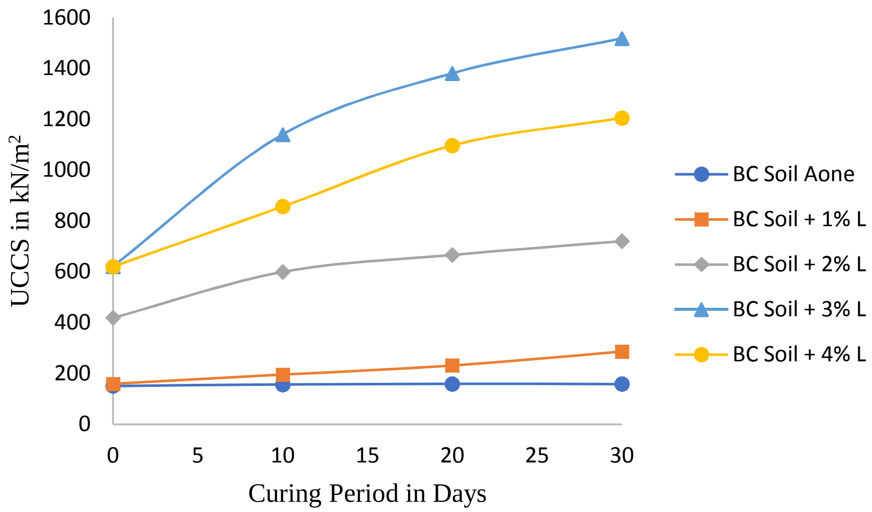

Fig. 1. Variation of UCCS of BC Soil Admixed with Different Lime Content 0, 1, 2, 3 and 4% With Different Curing Periods.

Fig. 2 shows the variation of UCCS with BC soil admixed with sisal fibre content starting from 0, 0.5, 1, 2 and 3%. The test result indicates that 0.5% sisal fibre is optimum combination in terms of higher strength at all curing periods and UCCS is maximum at 30 day curing period. Based on the test results of BC soil admixed with lime alone and sisal fibre alone, it can be concluded that 3% lime and 0.5% sisal fibre are the optimum combination to achieves higher shear strength at 30 days curing period.

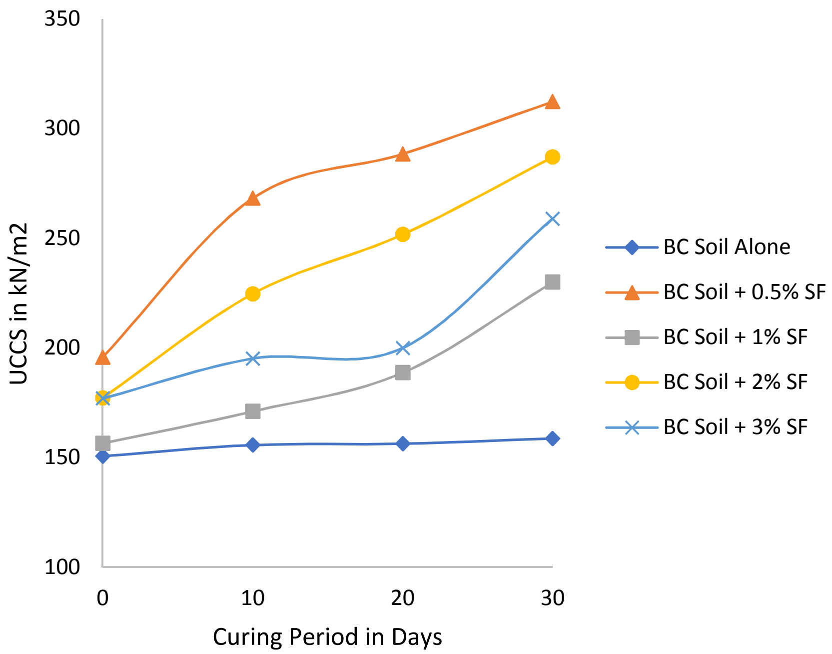

Fig. 2. variation of UCCS with different sisal fibre content of 0, 0.5, 1, 2 and 3% admixed BC soil.

To assess the effect of admixing sisal fibre in lime admixed BC soil, UCCS were conducted by admixing sisal fibre in BC Soil + 3% optimum lime content by varying different percentages of sisal fibre. Fig. 3 shows UCCS of BC Soil + 3% OLC with different Percentages 0.5, 1, 2 and 3% of SF with curing periods. It can be concluded from these results that, higher UCCS of at around 2000kPa at 30 days curing period for BC Soil + 3% OLC with 0.5% SF indicates that sisal fibres are effective in increasing the shear strength of lime admixed BC soil to a large extent.

Increase in strength with increase in curing period indicates that the sisal fibres can sustain the exothermic reactions associated with lime addition to BC soil and hence effective in increasing shear strength of lime admixed BC soil. It can be attributed to the fact that addition of 0.5% sisal fibre ensures better bonding and addition of 3%OLC along with sisal fibre causes substantial jump in strength compare to all other combinations tested in the present study.

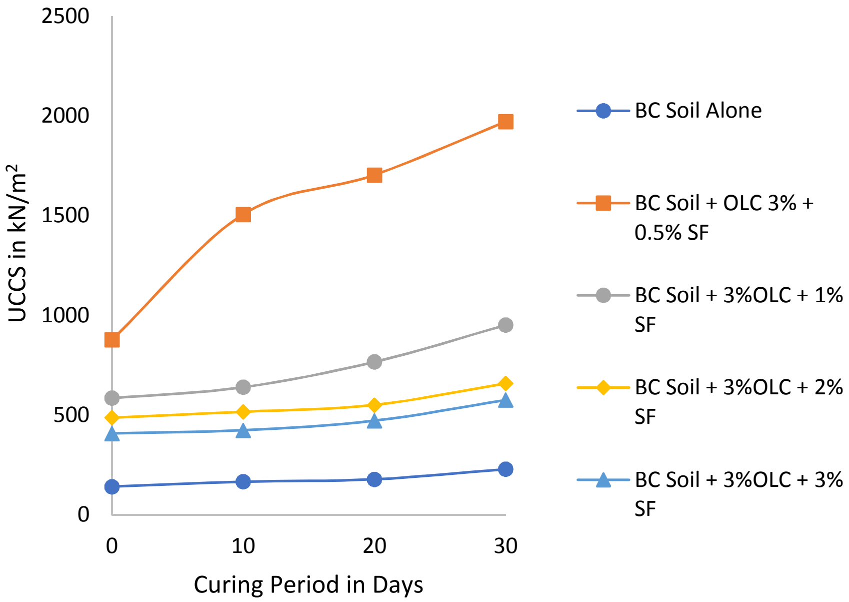

Fig. 3. variation of UCCS with different sisal fibre content of 0, 0.5, 1, 2 and 3% admixed BC soil.

3.2 XRD and SEM Studies

To corroborate the trend in results of compaction test and UCCS test, XRD studies of BC soil admixed with 3% OLC with 0.5% sisal fibre for 0 and 30-days curing period were conducted. Fig. 4 and Fig. 5 shows variation of XRD pattern obtained for BC soil admixed with 3% OLC with 0.5% sisal fibre for 0 and 30-days curing period respectively. BC soil admixed 3% OLC with 0.5% SF at zero days curing period indicate that the soil predominantly has of montmorillonite clay mineral showing peak basalt spacing at 5.75 Å. Quartz/Montmorillonite mineral strongly appeared at spacing of 27.5 Å, BC soil admixed 3% OLC with 0.5% sisal fibre at 30-days curing period indicated that associated lime reaction and presence of quartz mineral at spacing of 28 and 68.

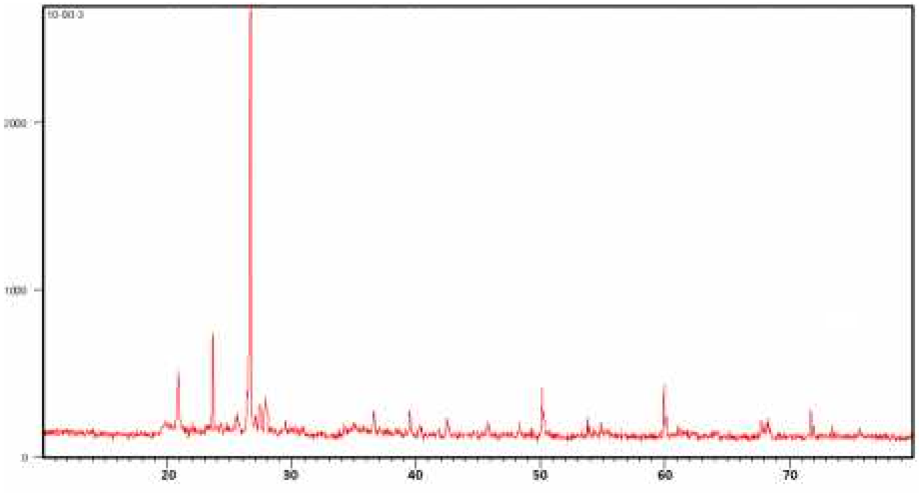

Fig. 4. BC soil admixed 3% OLC with 0.5% SF for zero days curing period

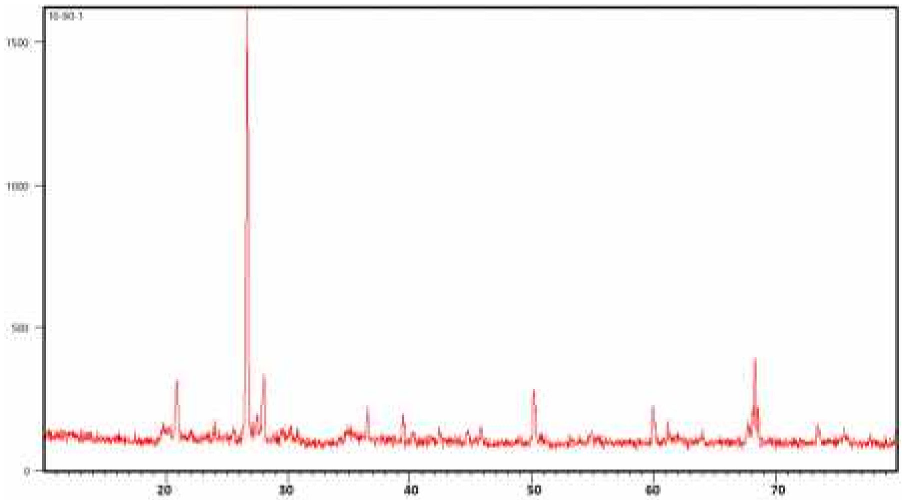

Fig. 5. BC soil admixed 3% OLC with 0.5% SF for 30 days curing period

Further, SEM studies of BC soil admixed with 3%OLC along with 0.5% sisal fibre at 0 and 30 days were also performed. Comparative analysis of Fig.6 and Fig. 7 shows that at 30 days curing, BC Soil admixed 3%OLC with 0.5% sisal fibre indicated presence of white patches around soil particles. This is attributed to formation of calcium carbonate due to pozzolanic reaction of lime-treated BC soil. Fig. 7 clearly bring out the associated bonding between sisal fibres and surrounding particles into BC soil admixed with 3% OLC at 30days curing period. It is clear that 0.5% sisal fibre admixed BC soil at 30 days curing period develops better bonding and hence better interface with surrounding particles in comparison with BC Soil with 3%OLC admixed with 0.5%SF at 0-day curing period.

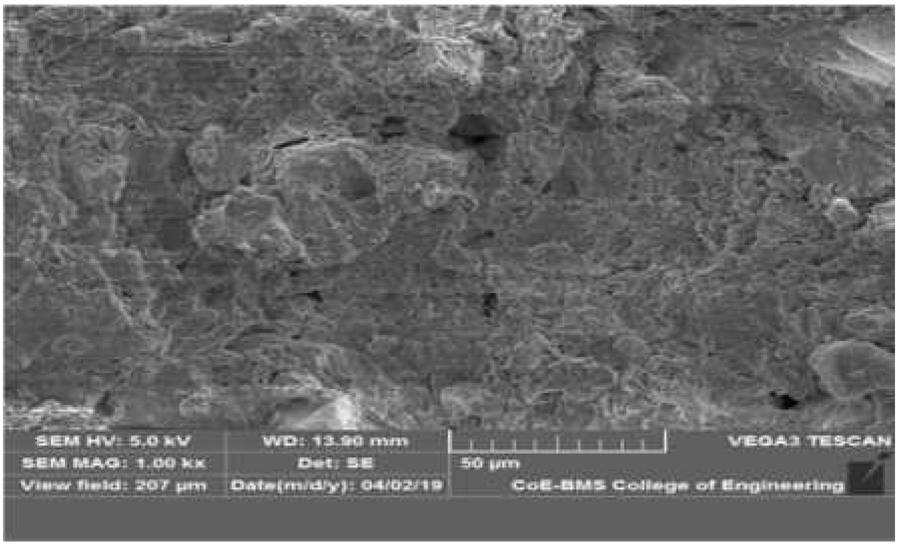

Fig.6. SEM image of BC Soil + 3%OLC + 0.5% sisal fibre at 0 Days Curing Period

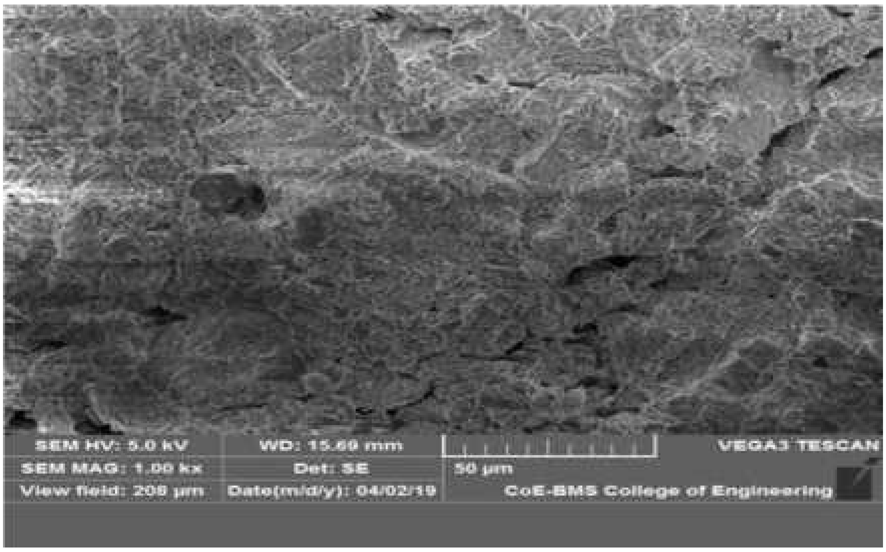

Fig.7. SEM image of BC Soil + 3%OLC + 0.5% sisal fibre at 30 Days Curing Period

4. Conclusions

Based on the experimental observations, the following are the major conclusions
1.The use of low-density sisal fibre decreases MDU with increase in percentage and 0.5% can be considered to be optimum in terms of improvement in compaction characteristics of sisal fibre admixed BC soil.
2.Increase in sisal fibre content causes a reduction in MDU along with the increase in the OMC for the case of both lime and sisal Fibres admixed BC Soil. This is attributed to the fact that, increase in percentage of fibre increases volume fraction of low-density sisal fibres that replaces soil particles.
3. Addition of sisal fibres along with optimum lime content causes an increase in UCCS at all curing periods. This is attributed to addition of lime causes an increase in shear strength due to associated pozzolanic reaction. Presence of sisal fibres along with lime induces better bonding, as envisaged in SEM studies, causing a significant jump in UCCS.
4. Increase in percentage of sisal fibre at all curing period indicates reduction in UCCS. This is because, higher the fibre content causes greater rebounding effect and consequent loss of contact from the surrounding particles due to increase in pore pressure as a consequence of compression. Based on the test results, it can be concluded that 0.50% sisal fibre can be considered optimum in BC soil admixed with and without lime.
5.BC Soil admixed with 3% OLC and 0.5% sisal fibre have indicated greater shear strength both at 0 and 30days curing period in comparison to other combination used in the present study. It is attributed to the fact that better interference prevails for this combination leading to higher shear strength even at zero-day curing-as evidenced in SEM studies. (30 Days-Curing Period)

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