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Effect of addition of treated coir fibres on the compression behaviour of clay

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Abstract

The paper presents the potential and effect of treated coir fibres (15 mm in length) on the unconfined compressive strength of clay. Dry, sodium hydroxide and carbon tetrachloride–treated coir fibres were used in the study. The coir fibre content was varied from 0.4 to 1.6%. The results indicated that the unconfined compressive strength of clay and clay with dry coir fibres can be increased by treatment with carbon tetrachloride and sodium hydroxide. The increase in unconfined compressive strength was highest with carbon tetrachloride treatment. The clay reinforced with treated fibres was able to bear higher strains at failure as compared to clay and clay with dry fibres. With the increase in coir fibre content (0.4–1.6%) in clay, there was an increase in the unconfined compressive strength. The clay with treated coir fibres can be used for making bricks for mud houses in rural India.

Keywords: Coir fibre, treatment, unconfined compressive strength, *XRD, SEM*

1. Introduction

Mud house is one of the traditional housing types that are used by poor families in rural areas in India. The mud house is typically one or two stories and their walls are characterized by insignificant strength. To tackle this problem, the reinforcing of mud with coir fibres has been emerged as a promising solution. Amongst various natural materials used for soil-reinforcement, the coir fibre is the most prominent due to it’s easy availability. The paper presents the study of the effect of inclusion of treated coir fibres on stress-strain behaviour of the clay reinforced with dry/treated fibres in random arrangement for possible use in making mud houses in rural India.

2. Background

Many researchers (Andersland and Khattack, 1979; Maher and Ho, 1994; Al Wahab and El-Kedrah, 1995; Nataraj and McManis, 1997; Zeigler et al., 1998; Feuerharmel, 2000; Kumar and Tabor, 2003; Casagrande et al., 2006) in the past have shown that fibre reinforcement can significantly improve engineering properties of clay. Maher and Ho (1994) and Casagrande et al. (2006) reported that fibre characteristics and the soil characteristics influence the behavior of the clay–fibre composite. Maher and Ho (1994) reported that the peak compressive strength of kaolinite clay increased by the inclusion of randomly distributed paper pulp fibres. Al Wahab and El-Kedrah (1995) reported that fibre reinforcement decrease the swelling potential of low plasticity clay. Casagrande et al. (2006) reported that the inclusion of randomly distributed fibres increased the peak shear strength of bentonite. The use of the coir fibres as soil reinforcement is a cost-effective method of soil improvement in countries like, India, Philippines, Indonesia, Brazil, etc., where it is cheap and locally available. Rao and Balan (2000) reported significant gain in strength parameters and stiffness of sand by the inclusion of coir fibres. Banerjee et al. (2002) investigated the dimensional and mechanical properties of coir fibres as a function of fibre length. Rao et al. (2005) reported that the behavior of sand reinforced with coir fibres and geotextiles were similar to that observed with synthetic fibres and meshes. Babu and Vasudevan (2008) reported that the strength and stiffness of tropical soil was increased with the inclusion of discrete coir fibres of about 1-2% by weight. Mwasha (2009) reported that the coir fibres have good strength characteristics and resistance to bio-degradation over a long period of time. Ramesh et al. (2010) reported that the unconfined compressive strength of black cotton soil reinforced with bitumen coated coir fibres shows marginal variation in strength as compared to uncoated coir fibres. Dasaka and Sumesh (2011) reported that varying the length of coir fibres and content in soil results improvement in strength characterstics. They further reported that length of fibres play a significant contribution in the strength enhancement of soil in compression. The present paper tries to explore the effect of coir fibre on stress-strain behavior of clay available locally from Hamirpur district of Himachal Pradesh, India. The coir fibres used for reinforcing of soil are (i) untreated (ii) treated prior to use with NaOH (iii) treated prior to use with CCl_4. The observations of stress-strain curve for different conditions of fibre are supplemented by mineralogical and SEM studies. The post peak behaviors for various cases have also been analyzed.

3. Materials used

The clay used in this study was brought from Mattan Sidh a place near Hamirpur, Himachal Pradesh, India. The soil is having a specific gravity of 2.65, liquid limit of 36.4 % and plastic limit of 21.2 %. The maximum dry unit weight and optimum water content as obtained by standard proctor test was found to be 20.9 kN/m^3 and 17.4 % respectively. As per Universal Soil Classification System, the clay was classified as clay of low compressibility.

The coir fibres were obtained from the coir rope (Fig. 1 (a)) procured from the local market in Hamirpur, Himachal Pradesh, India. The yarns of the coir ropes were separated and the fibres were cut in the length of 15 mm and the separated fibres are shown in Fig. 1(b). The properties of these coir fibres are reported by Banerjee et al. (2002) and are shown in Table 1. The coir fibres obtained as shown in figure 1 (b) were treated with sodium hydroxide solution and CCl_4 solution for 24 hours. After 24 hours, fibres were removed from the beaker and allowed to dry at room temperature for a week. The concentration and composition of chemical used for treatment of coir fibres are given in Table 2.

(a) Coir fibre rope

(b) Separated fibres

Fig. 1. Preparation of fibres

Table1
Properties of coir fibres (after Banerjee et al., 2002)

Property	Fibres < 100 mm in length
Breaking load, N	217.8
Tenacity (cN/tex)	11.5
Modulus (Initial) (cN/tex)	85.9
Modulus offset) (cN/tex)	9.5
Breaking extension, %	41.7
Energy to break (Joules)	0.0062
Thickness in 1/100th mm	13.57
Linear density (tex)	18.9

Table 2
Concentration and composition of chemical used for treatment of coir fibres

Carbon tetra chloride	Sodium hydroxide
Assay (GLC) = 99%	Carbonate 2%
Wt. per ml at 20ºC =1.590 gm	Chloride 0.01%
Boiling range (95%) =76-77º C	Sulphate 0.05%
N.V.M. - 0.003% max.	Potassium 0.1%
	Silicate 0.05%
	Zinc 0.02%
	N/10 solution

4. Experimental program

The Unconfined Compression Strength (UCS) tests were conducted on the unreinforced clay and clay reinforced with the dry/treated coir fibres at varying content. All the specimens were prepared corresponding to optimum moisture content and maximum dry unit weight values. A metallic mould 38 mm inner diameter × 76 mm long with detachable collars was used to prepare the specimens. For reinforced soil specimens, the fibres were added as a percentage of dry weight of soil. The specimens were prepared with fibre content of 0.4 %, 0.8 % and 1.6 %. The test was conducted as per IS-2720 Part 10 (1991, reaffirmed in 1995) at a strain rate of 0.04 mm/min. The stress-strain curves for were plotted for various cases and compared.

5. Results

5.1 Stress-Strain Behavior

The axial stress-strain behavior of the clay reinforced with varying percentage of dry coir fibres is shown in Fig. 2. A careful study of Fig. 2 reveals that the peak axial stress of clay increases with the increase in dry fibre content. For example, an axial stress of 63.98 kPa for the pure clay increased to 79.67 kPa when the clay specimen was reinforced with 0.4 % dry fibres. The axial stress further increased to 114.77 kPa when the content of dry fibres was raised to 1.6 %.

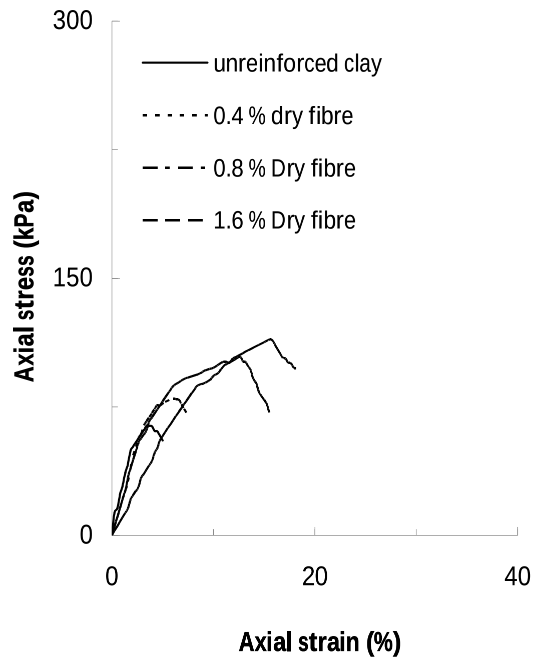


Fig. 2. Axial stress- strain behavior of clay reinforced with dry fibres

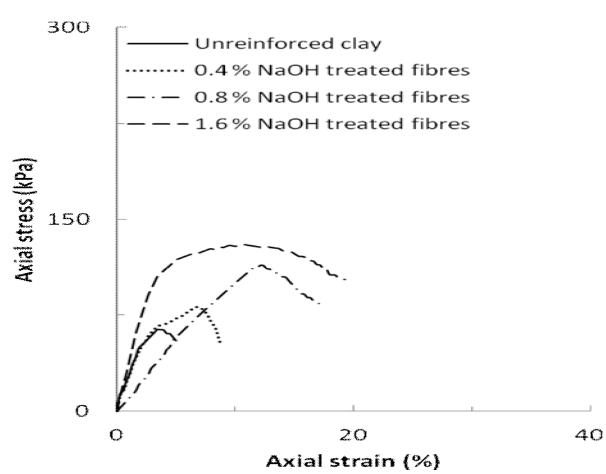


Fig. 3. Axial stress-axial strain behavior of clay reinforced with NaOH treated coir fibres

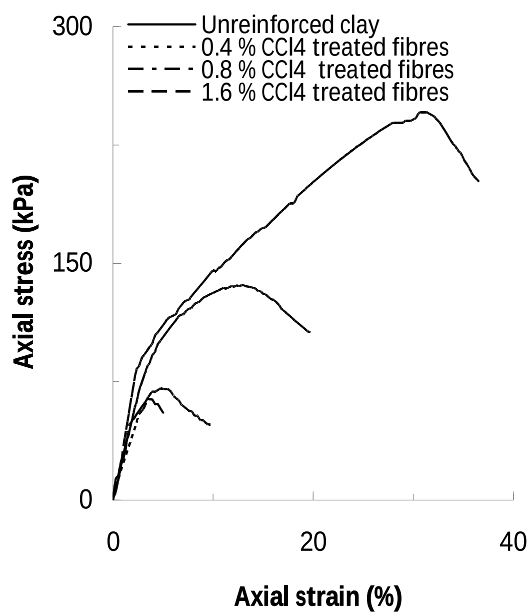


Fig. 4. Axial stress-axial strain behavior of clay reinforced with CCl_4 treated fibres

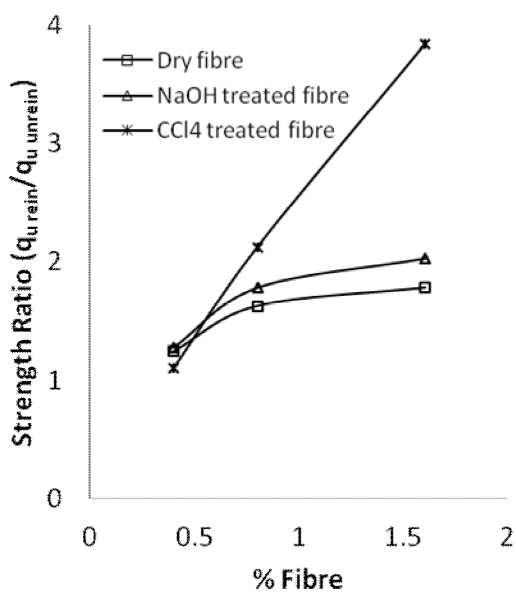


Fig. 5. Variation of normalized unconfined compression strength for different fibre percentage

The stress-strain curves for the clay reinforced with NaOH and CCl_4 treated fibres were shown in Figs. 3 and 4 respectively. Study of these figures reveal that a similar trend was noted for clay reinforced with NaOH and CCl_4 treated fibres. The peak axial stress of clay reinforced with 0.4 % NaOH treated fibre was 81.47 kPa which increased to 130.03 kPa when the fibre content was raised to 1.6 %. Further, when the clay specimen was reinforced with 0.4 % CCl_4 treated fibres; the peak stress observed was 70.69 kPa. The peak stress increased to 245.78 kPa with an increase in fibre content to 1.6 %. Figs 2, 3 and 4 further reveal that the addition of coir fibres (dry/treated) will lead to improvement in the peak stress as well as higher strains at failure in comparison to unreinforced clay. It implies that the material can sustain higher loads at large deformations. A close examination of Figs. 2, 3 and 4 further reveal that amongst the different forms of coir fibre (dry, NaOH treated, CCl4 treated), the improvement brought out by CCl_4 treated fibre was the highest. The unconfined compression strength (q_u) of soil reinforced with 1.6 % CCl4 treated fibre was about 3.84 times that of unreinforced clay (refer Figure 5).

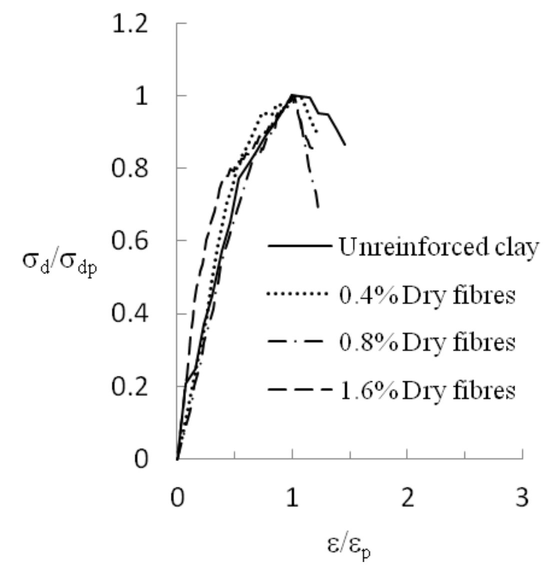


Fig. 6. Normalized stress strain curve for clay reinforced with dry fibres

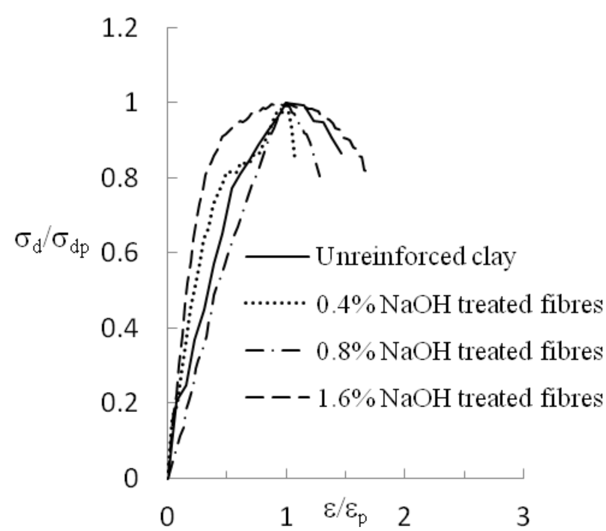


Fig. 7. Normalized stress strain curve for clay reinforced with NaOH treated coir fibres

5.2 Post Peak Behavior

To better understand coir fibres toughening characteristics in the post peak region, the stress axis of the stress-strain diagram was normalized with respect to the peak axial stress, and the strain axis was normalized with respect to the strain at the peak axial stress. The variation of normalized stress strain curve for clay reinforced with dry/treated coir fibres is shown in Figs. 6, 7 and 8. An examination of Figs. 6, 7 and 8 reveals that the post peak behaviour clay without coir fibres and clay with dry/treated coir fibres is similar. There is a gradual decline after attaining the peak in the normalized stress-strain curve. The improvement in post peak region was slightly better for the treated coir fibres as compared to the dry fibres.

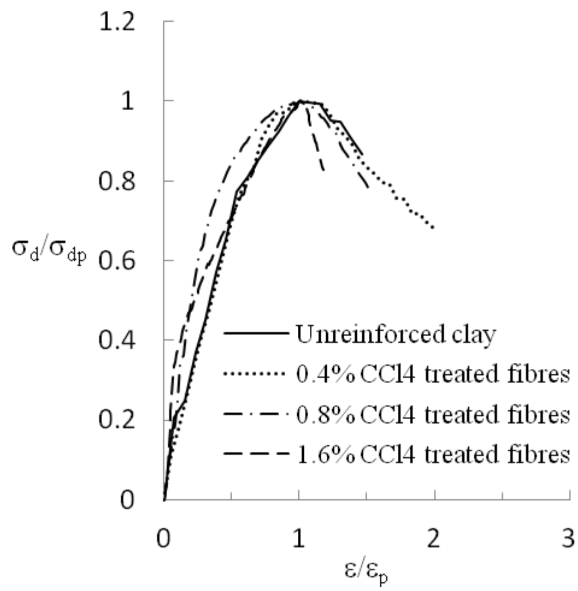


Fig. 8. Normalized stress strain curve for clay reinforced with CCl_4 treated coir fibres

6. Mineralogical study

To study the improvement in UCS of the clay reinforced with dry/ treated coir fibres and to identify the formation of crystalline phases, XRD and SEM analysis were carried out. The failed specimen of the clay reinforced with dry/treated coir fibres were used for XRD analysis, whereas for the SEM analysis, dry/treated coir fibres were utilized.

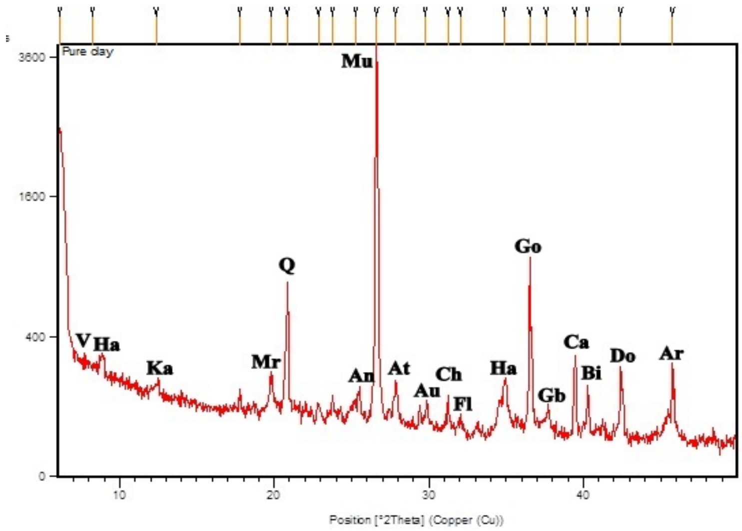


Fig. 9. XRD Analysis of unreinforced Clay

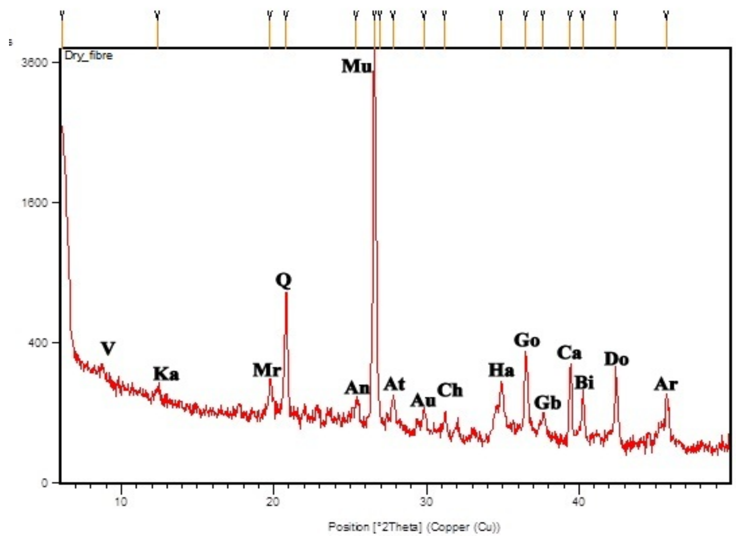


Fig. 10. XRD Analysis of Clay reinforced with untreated fibres

6.1 XRD Analysis

For XRD analysis, the failed samples of clay reinforced with dry/treated coir fibres were preserved in plastic bags so as to prevent the interaction with environment. The results of XRD of unreinforced clay and clay reinforced with dry/treated coir fibres are shown in Figs. 9 to 12 and the comparative graph is shown in Fig. 13. The various minerals present in the tested specimens are identified as per their diffraction angles. Study of Figs. 9 to 13 reveal that the emergence of new peak of Palygorskite can be observed in case of specimen reinforced with NaOH treated fibres. Further, a new peak indicating the presence of Chamosite as well as Palygorskite can be seen in case of specimen reinforced with CCl_4 treated fibres. Further study of Fig. 13 reveals that there is further increase in the intensity of Quartz peak in the specimens reinforced with CCl_4 treated coir fibres. Thus, the increase in

UCS as observed experimentally for clay specimens reinforced with NaOH and CCl_4 treated coir fibres can be attributed to the presence of these new phases.

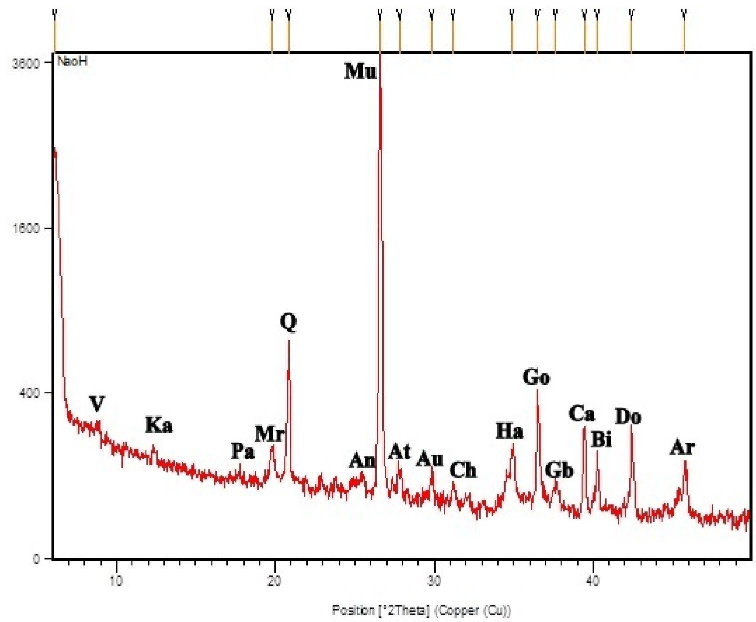


Fig. 11. XRD Analysis of Clay reinforced with NaOH treated fibres

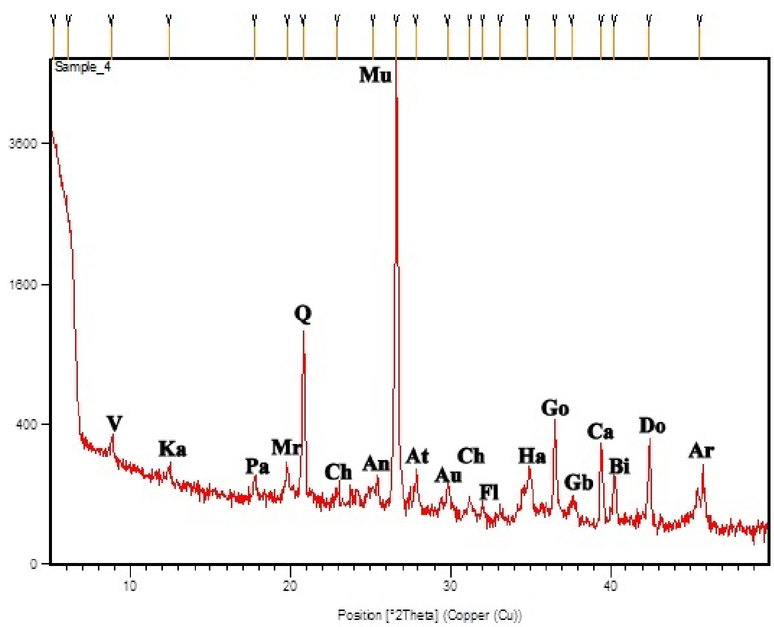


Fig. 12. XRD Analysis of Clay Reinforced with CCl_4 treated fibres

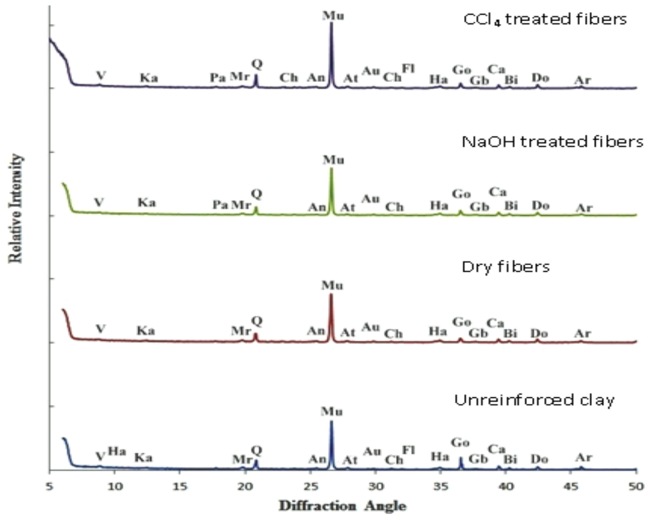
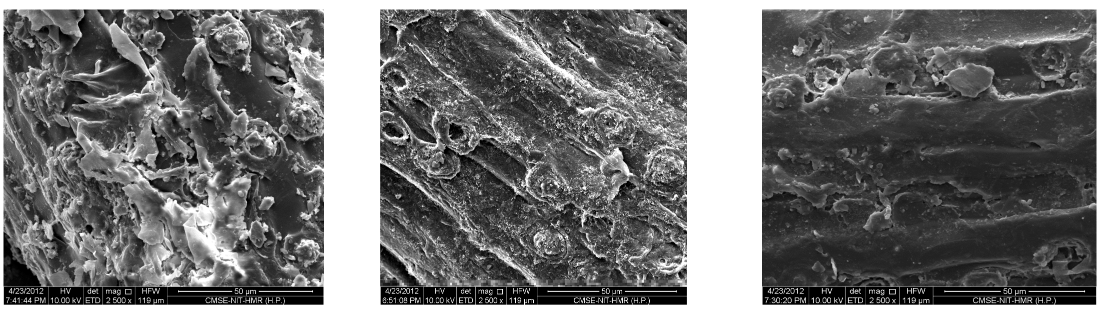
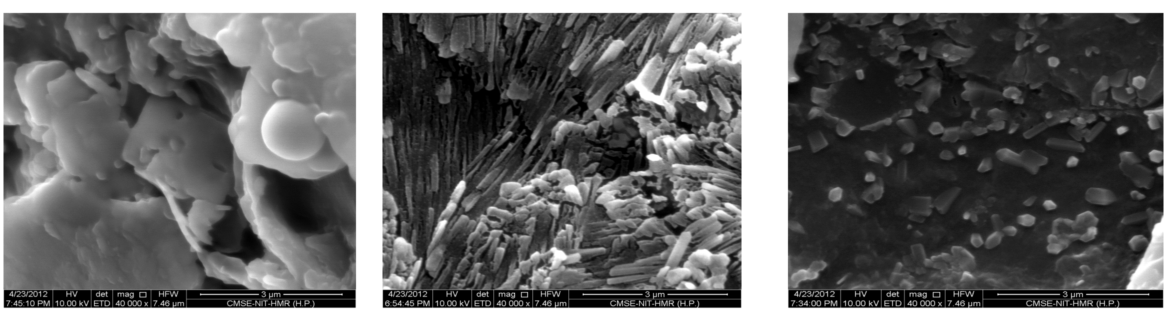


Fig. 13 XRD of unreinforced clay and clay reinforced with dry/treated coir fibres



(a) (b) (c)



(d) (e) (f)

Fig. 14 SEM images at (a) Pure fibres (10 kV; ×2,500 magnifications) (b) NaOH Treated Fibres (10 kV; ×2,500 magnification) (c) CCl_4 treated fibres (10 kV; ×2,500 magnification. (d) Pure fibres (10 kV; ×40,000 magnification) (e) NaOH Treated Fibres (10 kV; ×40,000 magnification) (f) CCl_4 treated fibres (10 kV; ×40,000 magnification.

6.2 SEM Analysis

The coir fibres were treated with NaOH and CCl_4 so as to improve the interaction of coir fibres with clay. In order to know the change which takes place on the surface of coir fibres with treatment with NaOH and CCl_4, SEM studies were carried out and are shown in Fig. 14. Study of Fig. 14 (a) and (d) reveals that clay with dry fibres show impurities present on its surface. These impurities are removed and surface irregularities are quite visible when dry fibres were treated with NaOH and CCl_4 as evident from Figs 14(b), (c), (e) and (f). These surface irregularities help in improving the interaction between coir fibres and clay which results in the increase in unconfined compressive strength in comparison to dry fibres as shown in Figs. 3 and 4.

7. Conclusion

This study examined the effect of dry/treated coir fibres on the stress strain response of clay reinforced with varying fibre content. The results revealed that:

1. The unconfined compressive strength of the clay reinforced with coir fibres can be significantly improved by treating them with NaOH and CCl_4.
2. The increase in unconfined compressive strength was highest with the treatment provided with CCl_4.
3. The clay reinforced with treated fibres was able to bear higher strains at failure as compared to clay and clay with dry fibres.
4. With the increase in coir fibre content (0.4–1.6%) in clay, there was an increase in the unconfined compressive strength.
5. The improvement in post peak region was better for the treated coir fibres as compared to the dry fibres.
6. The improvement in unconfined compressive strength with the use of NaOH treated coir fibres is due to the presence of new phase of Palygorskite where as the improvement in unconfined compressive strength with the use of CCl_4 treated coir fibres is due to the presence of new phases of Chamosite and Palygorskite.

Hence the clay + treated fibre mix can be used in mud houses construction and other ground improvement measures. Further, its use will also provide environmental motivation for providing a means of recycling large quantities of coir fibres.

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