

## Effect of Addition of Treated Coir Fibres on the Compression Behaviour of Clay

*Rakesh Kumar Dutta*<sup>1)</sup>, *Vishwas Nandkishor Khatri*<sup>2)</sup> and *V. Gayathri*<sup>3)</sup>

- <sup>1)</sup> Associate Professor, Department of Civil Engineering, National Institute of Technology, Hamirpur – 177005, Himachal Pradesh, India (Corresponding Author), E-Mail: rakeshk Dutta@yahoo.com  
<sup>2)</sup> Assistant Professor, Department of Civil Engineering, National Institute of Technology, Hamirpur – 177005, Himachal Pradesh, India, E-Mail: vishuiisc@gmail.com  
<sup>3)</sup> Associate Professor, Department of Civil Engineering, Institute of Technology and Management University, Gurgaon, India, E-Mail: vgayathri@itmindia.edu

### ABSTRACT

This paper presents the 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 fibres, Treatment, Unconfined compressive strength, XRD, SEM.

### 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 of one or two stories and its walls are characterized by insignificant strength. To tackle this problem, the reinforcing of mud with coir fibres has emerged as a promising solution. Amongst various natural fibres used for soil-reinforcement, the coir fibre is the most prominent due to its easy availability and better durability in comparison to other natural fibres. This 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 bricks to construct mud houses in rural India.

### 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 soil characteristics influence the behaviour of the clay-fibre composite. Maher and Ho (1994) reported that the peak compressive strength of

---

Accepted for Publication on 30/7/2012.

kaolinite clay increased by the inclusion of randomly distributed paper pulp fibres. Al Wahab and El-Kedrah (1995) reported that fibre reinforcement decreased 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 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 behaviour of sand reinforced with coir fibres and geotextiles was similar to that observed with synthetic fibres and meshes. Babu and Vasudevan (2008) reported that strength and stiffness of tropical soil were increased with the inclusion of discrete coir fibres of about 1%-2% by weight. Mwashu (2009) reported that coir fibres have good strength characteristics and resistance to bio-degradation over a long period of time. Ramesh et al. (2010) reported that unconfined compressive strength of black cotton soil reinforced with bitumen coated coir fibres showed 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 in improvement in strength characteristics. They further reported that length of fibres plays 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 behaviour 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 the stress-strain curve for different conditions of fibre are supplemented by mineralogical and SEM studies. The post peak behaviour for various cases has also been analyzed.

### MATERIALS USED

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

Table 1. 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 1/100 <sup>th</sup> mm	13.57
Linear density (tex)	18.9



(a) Coir fibre rope



(b) Separated fibres

**Figure 1: Preparation of fibres**

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  $\text{CCl}_4$  solution for 24 hours. After 24 hours, the fibres were removed from the beaker and allowed to dry at room temperature for a week. The concentration and composition of chemicals used for the treatment of coir fibres are given in Table 2.

### 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 contents. All the specimens were prepared corresponding to optimum moisture content and maximum dry unit weight values. A metallic mould of 38 mm inner diameter  $\times$  76 mm length with detachable collars was used to prepare the specimens. For reinforced soil specimens, the fibres were added as a percentage of dry weight of the soil. The specimens were prepared with fibre contents 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 were plotted for various cases and compared.

### RESULTS

#### Stress-Strain Behaviour

The axial stress-strain behaviour 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 %.

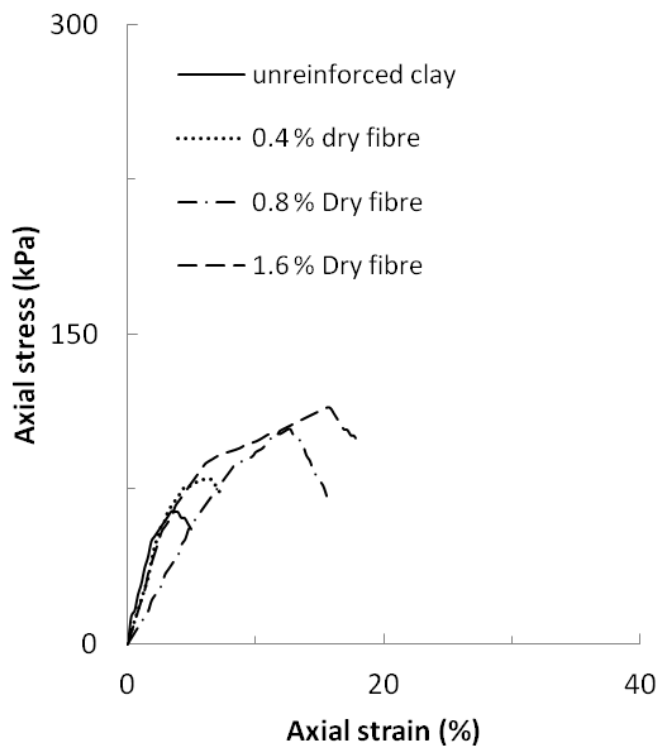
The stress-strain curves for the clay reinforced with NaOH and  $\text{CCl}_4$  treated fibres were shown in Figs. 3 and 4, respectively. Study of these figures revealed that a similar trend was noted for clay reinforced with NaOH and  $\text{CCl}_4$  treated fibres. The peak axial stress of clay reinforced with 0.4 % NaOH treated fibres 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 %  $\text{CCl}_4$  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 an improvement in the peak stress as well as higher strains at failure in comparison to unreinforced clay. This implies that the material can sustain higher loads at large deformations. A close examination of Figs. 2, 3 and 4 further reveals that amongst the different forms

of coir fibre (dry, NaOH treated, CCl<sub>4</sub> treated), the improvement brought out by CCl<sub>4</sub> treated fibres was the highest. The unconfined compression strength ( $q_u$ )

of soil reinforced with 1.6 % CCl<sub>4</sub> treated fibres was about 3.84 times that of unreinforced clay (refer to Figure 5).

**Table 2. Concentration and composition of chemicals used for treatment of coir fibres**

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



**Figure 2: Axial stress-strain behaviour of clay reinforced with dry fibres**

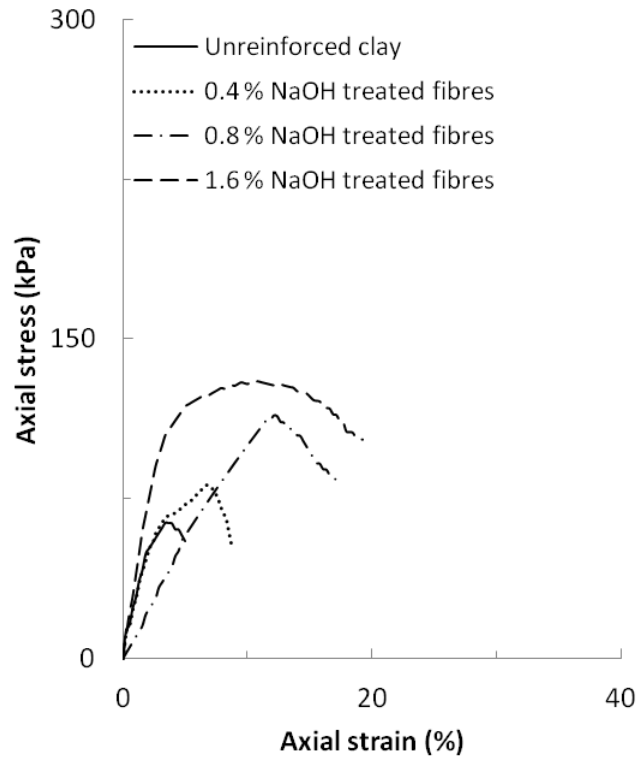


Figure 3: Axial stress-axial strain behaviour of clay reinforced with NaOH treated coir fibres

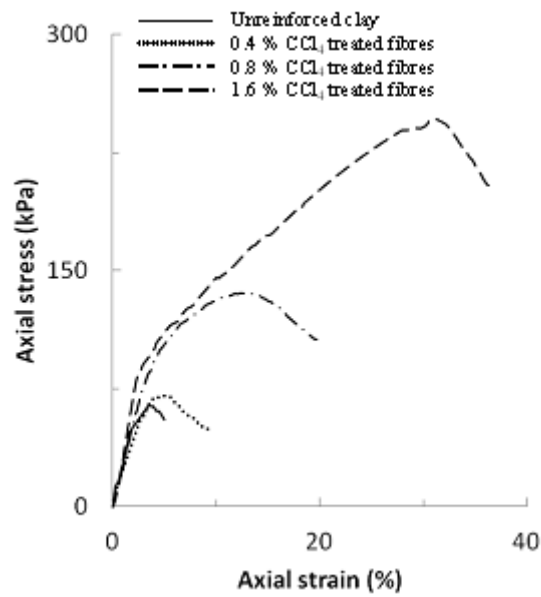


Figure 4: Axial stress-axial strain behaviour of clay reinforced with CCl<sub>4</sub> treated fibres

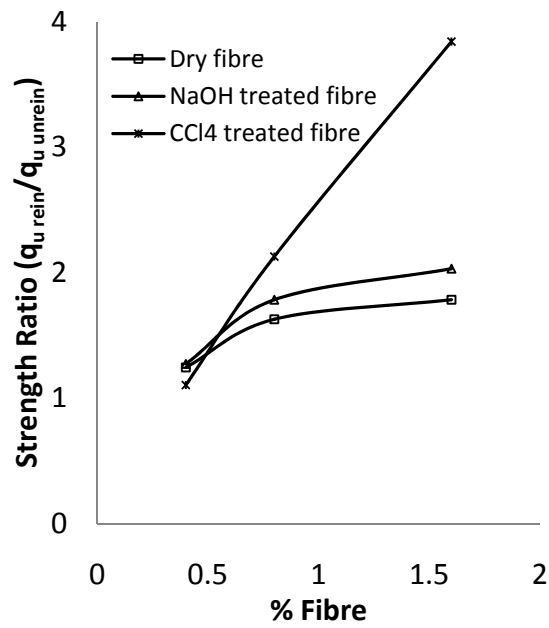


Figure 5: Variation of normalized unconfined compression strength for different fibre percentages

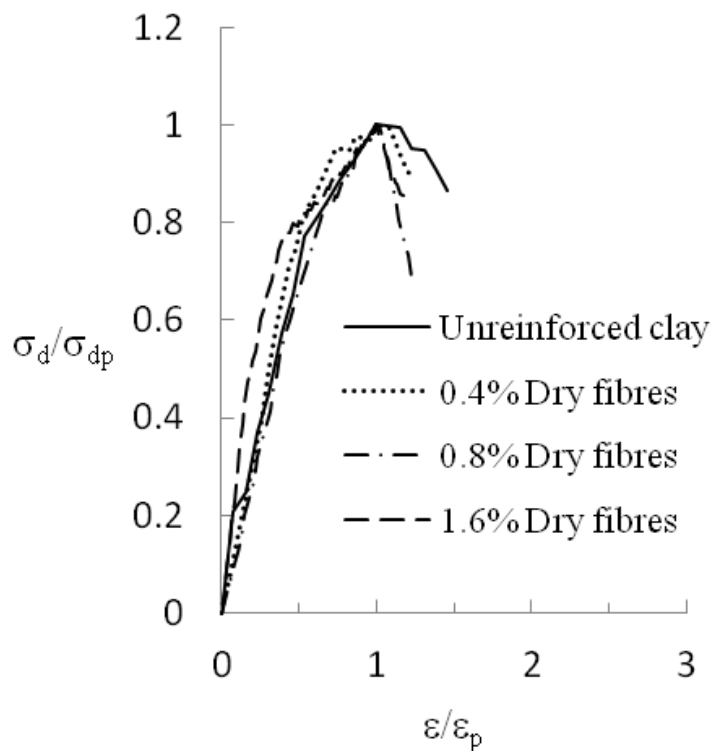


Figure 6: Normalized stress-strain curve for clay reinforced with dry fibres

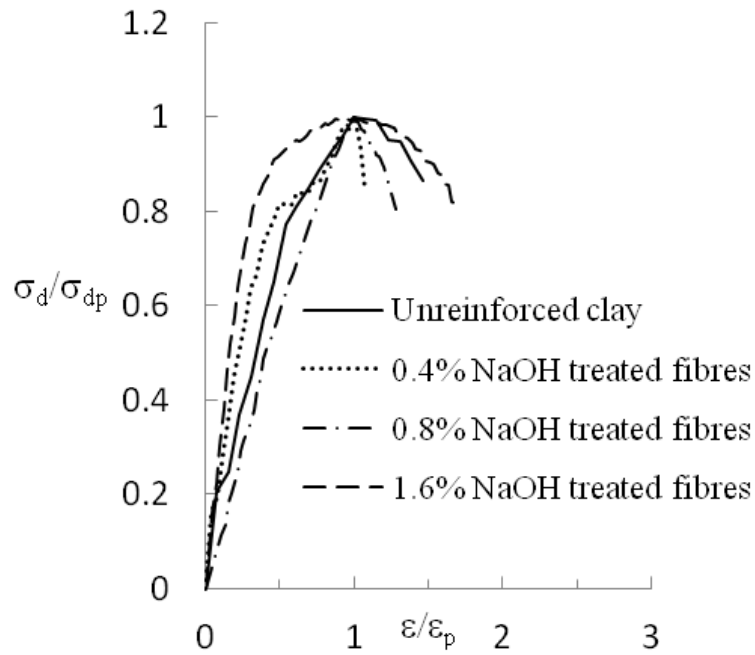


Figure 7: Normalized stress-strain curve for clay reinforced with NaOH treated coir fibres

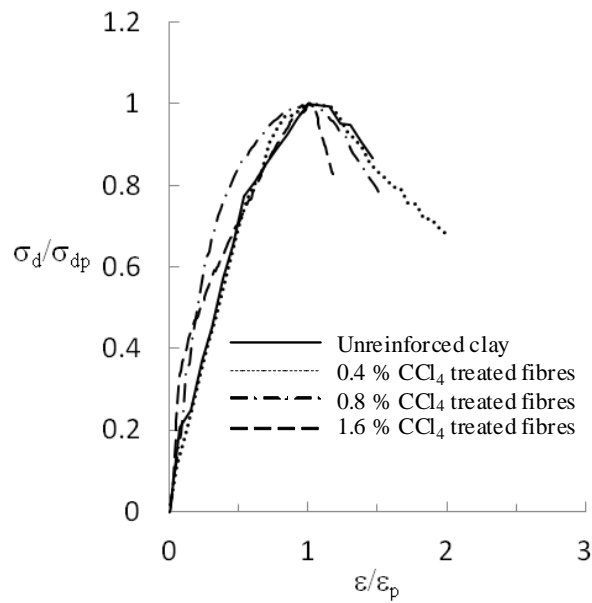


Figure 8: Normalized stress-strain curve for clay reinforced with CCl<sub>4</sub> treated coir fibres

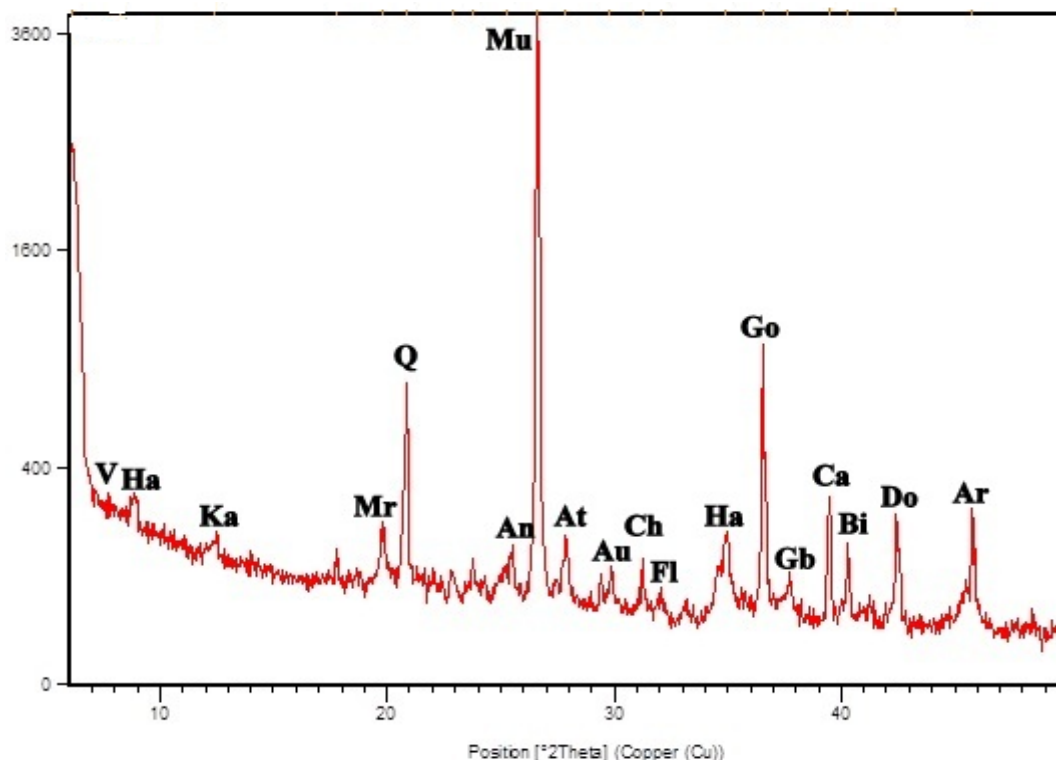


Figure 9: Diffractogram of clay

### Post Peak Behaviour

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 of 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.

### MINERALOGICAL STUDY

To study the improvement in UCS of clay reinforced with dry/ treated coir fibres and to identify

the formation of crystalline phases, XRD and SEM analysis were carried out. The failing specimens of clay reinforced with dry/treated coir fibres were used for XRD analysis, whereas for the SEM analysis, dry/treated coir fibres were utilized.

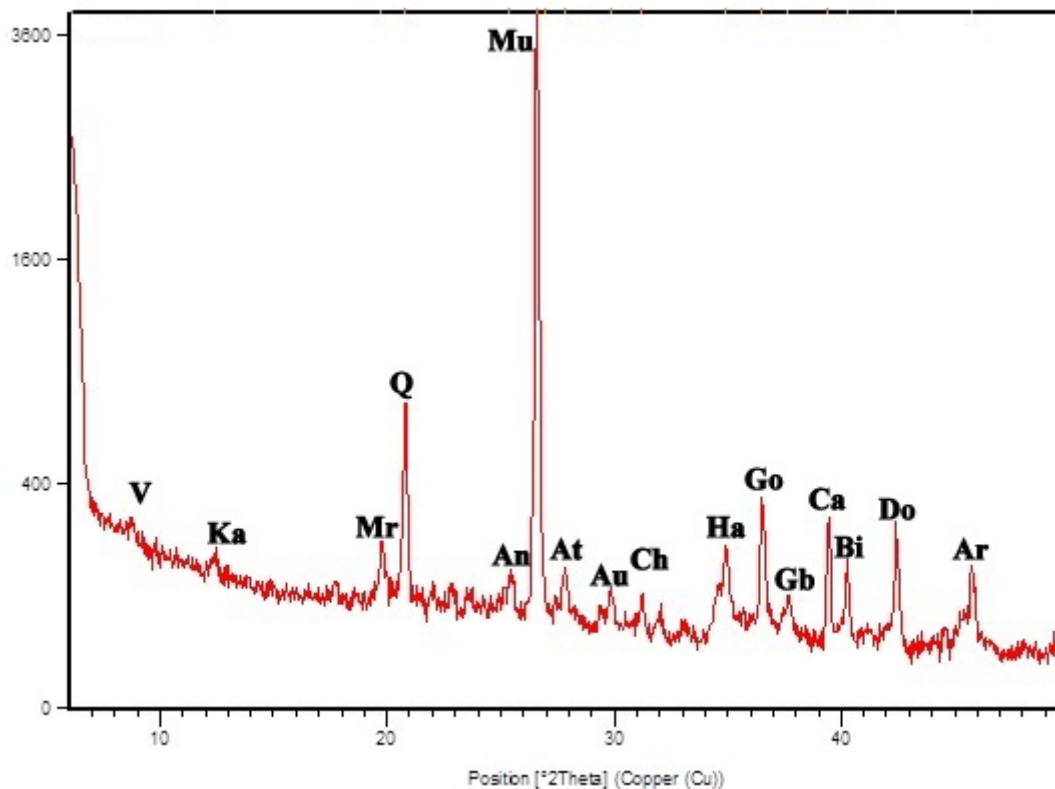
### XRD Analysis

For XRD analysis, the failing samples of clay reinforced with dry/treated coir fibres were preserved in plastic bags so as to prevent the interaction with environment. The XRD diffractograms of unreinforced clay and clay reinforced with dry/treated coir fibres are shown in Figs. 9 to 12 and the comparative diffractogram is shown in Fig. 13. The various crystalline phases present in the tested specimens are identified as per their diffraction angles. Study of Figs. 9 to 13 reveals that the emergence of a new peak of Palygorskite can be observed in case of specimens reinforced with NaOH treated fibres. Further, a new



peak indicating the presence of Chamosite as well as Palygorskite can be seen in case of specimens reinforced with  $\text{CCl}_4$  treated fibres. Further study of Fig. 13 reveals that there is a further increase in the intensity of Quartz peak in the specimens reinforced

with  $\text{CCl}_4$  treated coir fibres. Thus, the increase in UCS as observed experimentally for clay specimens reinforced with NaOH and  $\text{CCl}_4$  treated coir fibres can be attributed to the presence of these new crystalline phases.



**Figure 10: Diffractogram of clay reinforced with untreated fibres**

### SEM Analysis

The coir fibres were treated with NaOH and  $\text{CCl}_4$  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  $\text{CCl}_4$ , SEM studies were carried out and are shown in Fig. 14. Study of Fig. 14 (a) and (d) reveals that clay with dry fibres shows impurities present on its surface. These impurities are removed and surface irregularities are quite visible when dry fibres were treated with NaOH and  $\text{CCl}_4$  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.

### CONCLUSIONS

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 clay reinforced with coir fibres can be significantly improved by treatment with NaOH and  $\text{CCl}_4$ .

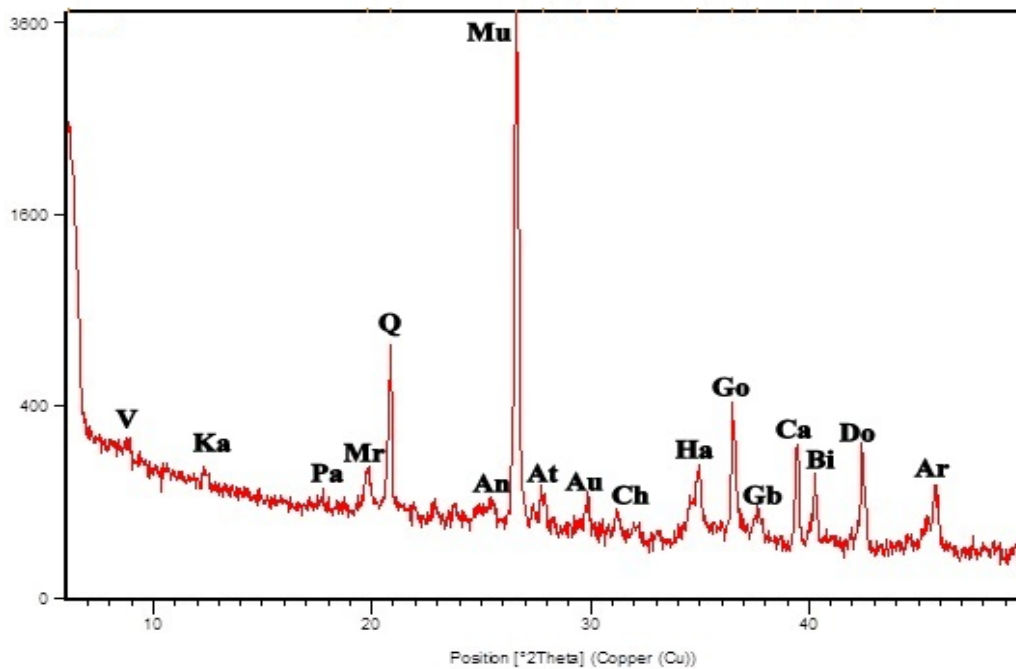


Figure 11: Diffractogram of clay reinforced with NaOH treated fibres

2. The increase in unconfined compressive strength was highest with the treatment with CCl<sub>4</sub>.
3. 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 a new crystalline phase of Palygorskite, whereas the improvement in unconfined compressive strength with the use of CCl<sub>4</sub> treated coir fibres is due to the presence of new crystalline phases of Chamosite and Palygorskite.

Clay reinforced with treated fibres can be used for making bricks to construct mud houses in rural India. Further, its use will also provide environmental motivation for providing a means of consuming large quantities of coir fibres.

**NOTATIONS**

Vermiculite	V
Halleysite	Ha
Kaolinite	Ka
Montmorillonite	Mr
Quartz	Q
Anatase	An
Muscovite	Mu
Anorthite	At
Augite	Au
Chlorite	Ch
Fluorapatite	Fl
Haematite	Ha
Gothite	Go
Gibbsite	Gb
Calcite	Ca
Biotite	Bi
Dolomite	Do
Aragonite	Ar
Palygorskite	Pa
Chamosite	Ch

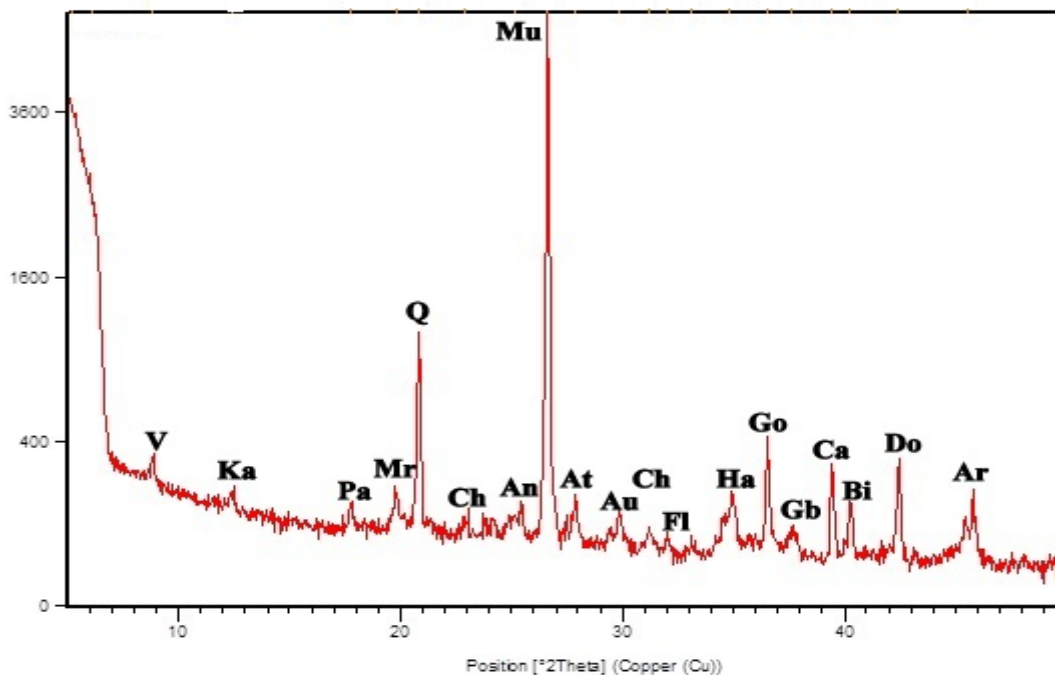


Figure 12: Diffractogram of clay reinforced with CCl<sub>4</sub> treated fibres

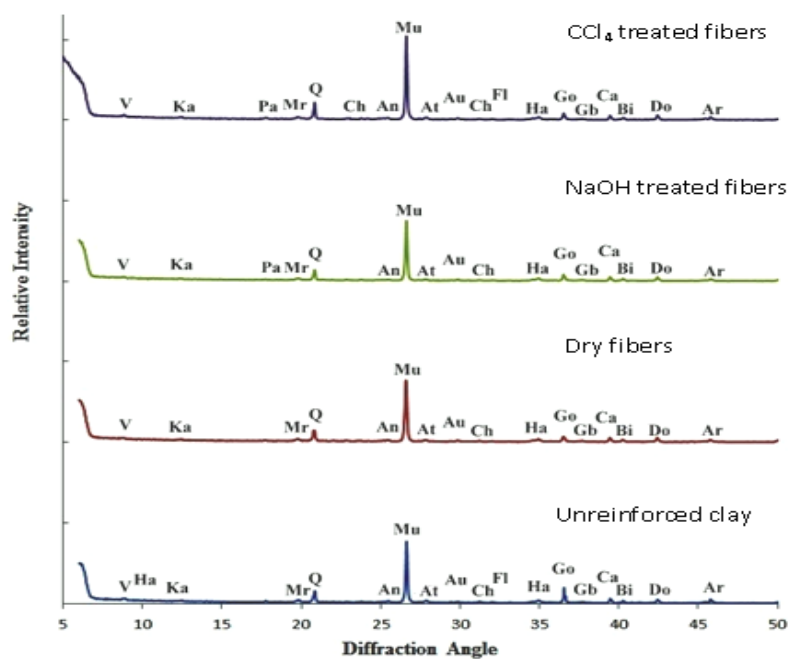
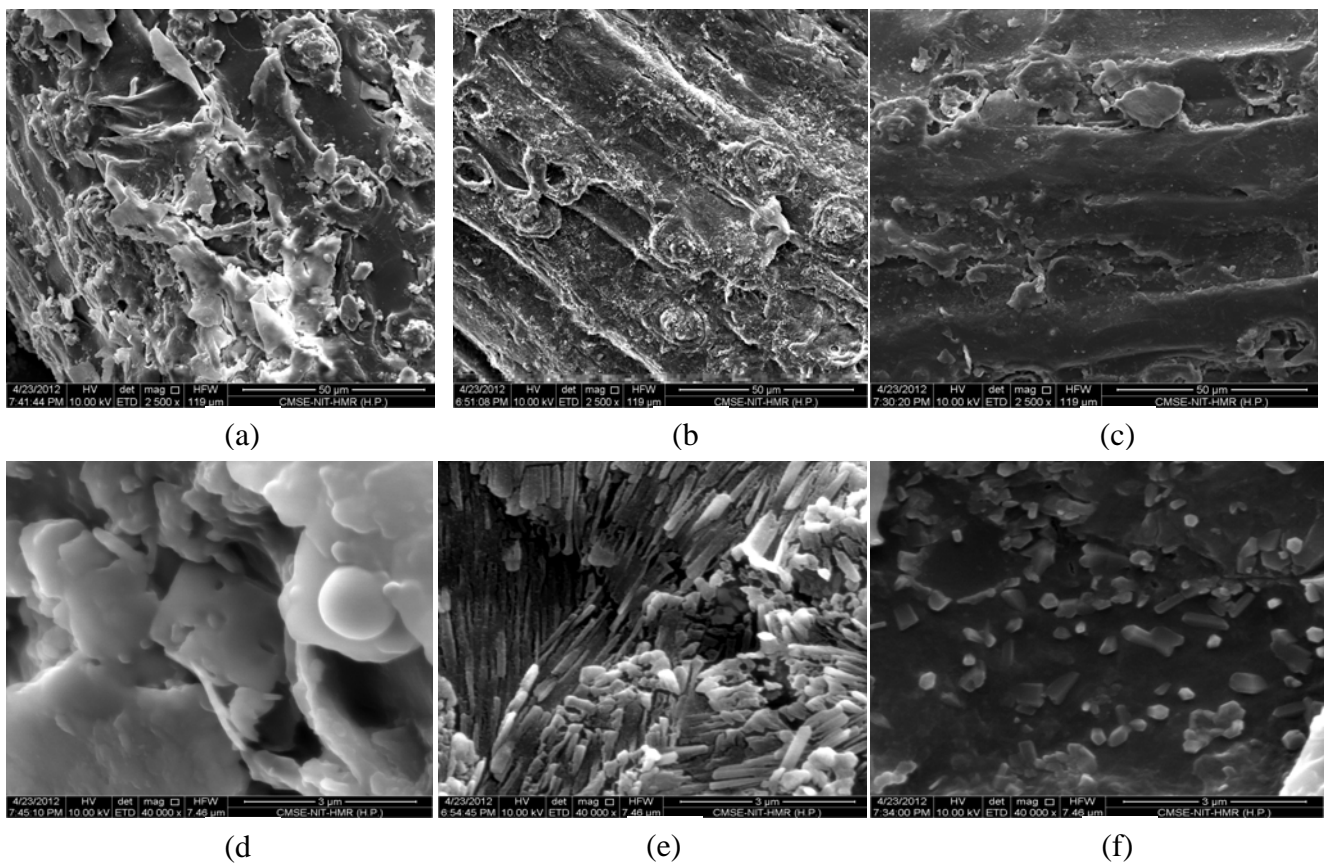


Figure 13: Comparative diffractogram of clay and clay reinforced with dry/treated coir fibres



**Figure 14: SEM images at (a) Pure fibres (10 kV;  $\times 2,500$  magnification) (b) NaOH treated fibres (10 kV;  $\times 2,500$  magnification) (c)  $\text{CCl}_4$  treated fibres (10 kV;  $\times 2,500$  magnification). (d) Pure fibres (10 kV;  $\times 40,000$  magnification) (e) NaOH treated fibres (10 kV;  $\times 40,000$  magnification) (f)  $\text{CCl}_4$  treated fibres (10 kV;  $\times 40,000$  magnification)**

## REFERENCES

- Al-Wahab, R.M. and El-Kedrah, M.M. 1995. Using fibres to reduce tension cracks and shrink/swell in compacted clays. *Geoenvironment 2000, Geotechnical Special Publication No. 46*, Y. B. Acar and D. E. Daniel, eds., ASCE, Reston, Va, 1: 791-805.
- Andersland, O. B. and Khattak, A. S. 1979. Shear strength of kaolinite/fibre soil mixtures. In: *Proc., Int. Conf. on Soil Reinforcement*, Paris, France, 1: 11-16.
- Babu, G. L. S. and Vasudevan, A. K. 2008. Strength and stiffness response of coir fibre-reinforced tropical soil. *Journal of Materials in Civil Engineering*, 20 (9): 571-577.
- Banerjee, P.K., Chattopadhyay, R. and Guha, A. 2002. Investigations into homogeneity of coir fibres, *Indian Journal of Fibre and Textile Research*, 27: 111-116.
- Casagrande, M. D. T, Coop, M. R. and Nilo Cesar Consoli, N. C. 2006. Behaviour of a fibre reinforced bentonite at large shear displacements. *Journal of Geotechnical and Geoenvironmental Engineering*, 132 (11): 1505-1508.
- Dasaka, S.M. and Sumesh, K.S. 2011. Effect of coir fibre

- on the stress–strain behavior of a reconstituted fine-grained soil, *Journal of Natural Fibres*, 17 pages.
- Feuerharmel, M. R. 2000. Analysis of the behaviour of polypropylene fibre-reinforced soils. MSc Dissertation, Federal Univ. of Rio Grande do Sul, Porto Alegre, Brazil (in Portuguese).
- Kumar, S. and Tabor, E. 2003. Strength characteristics of silty clay reinforced with randomly oriented nylon fibres. *Electronic Journal of Geotechnical Engineering*, 8 (B).
- Maher, M. H. and Ho, Y. C. 1994. Mechanical properties of kaolinite/fibre soil composite. *Journal of Geotechnical and Geoenvironmental Engineering*, 120 (8): 1381-1393.
- Mwasha, P. A. 2009. Coir fibre: a sustainable engineering material for the Caribbean environment. *The College of the Bahamas Research Journal*, 15: 36-44.
- Nataraj, M. S. and McManis, K. L. 1997. Strength and deformation properties of soils reinforced with fibrillated fibres. *Geosynthetic International*, 4 (1): 65-79.
- Ramesh, H.N., Manoj Krishna, K.V. and Mamatha, H.V. 2010. Compaction and behaviour of lime coir fibre treated black cotton soil. *Geomechanics and Engineering-An International Journal*, 2 (1): 19-28.
- Rao, G. V. and Balan, K. 2000. Coir geotextiles-emerging trends. Kerala State Coir Corporation Limited, Alappuzha, Kerala.
- Rao, G. V., Dutta, R. K. and Ujwala, D. 2005. Strength characteristics of sand reinforced with coir fibres and coir geotextiles. *Electronic Journal of Geotechnical Engineering*, 10 (G).
- Zeigler, S., Leshchinsky, H. I. L. and Perry, E. D. 1998. Effect of short polymeric fibres on crack development in clays. *Soils and Foundation*, 38 (1): 247-253.