Effect of Fibers on Properties of Clay

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Abstract - **The use of natural fibers such as coir for soil improvement is highly attractive in countries like India where such materials are locally and economically obtainable, in view of the preservation of natural environment and cost effectiveness. This paper compares the effect of random inclusion of locally available coir fibers and commercial polypropylene fibers on compaction characteristics and California Bearing Ratio (CBR) values of soil. Standard Proctor tests and CBR tests are done on locally available cohesive soil (CH) with low percentage of reinforcement (0–1.5% by weight of oven-dried soil). The Maximum Dry Density (MDD) of fiber stabilized soil goes on decreasing and Optimum Moisture Content (OMC) goes on increasing with increase in percentage addition of coir and polypropylene fiber, irrespective of the percentage of addition of fiber. CBR test results reveal that the inclusion of randomly distributed fibers in soil increases the CBR values of the soil by two times. Coir fibers show very close percentile improvement in CBR value of soil when compared with polypropylene stabilized soil. Hence the inclusion of discrete coir fibers in random fashion significantly improves the CBR value of clay and hence could be effectively used for pavement sub-grade purposes.**

Index Terms— **CBR value, clay, coir fiber, polypropylene fiber, stabilization**

I. INTRODUCTION

The primary purpose of reinforcing a soil mass is to improve its stability by increasing its bearing capacity, and by reducing settlement and lateral deformation. Conventional reinforcing methods make use of continuous inclusions of strips, fabrics, and grids into the soil mass. The random inclusion of various types of fibers is a modification of the same technique, in which the fibers act to interlock soil particles and aggregates in a unitary coherent matrix.

In comparison with conventional geosynthetics (strips, geotextile, geogrid, etc.), the advantages of using discrete fiber are as follows: (1) The discrete fibers are simply added and mixed randomly with soil, like in mixing soil with cement, lime, or other additives. (2) Randomly distributed fibers limit potential planes of weakness that can develop in the direction parallel to the conventionally oriented reinforcement. (3) The inclusion of fiber only changes the physical properties of soil and has no impact on the environment. For these reasons, researchers have shown an increasing interest in the behaviour of fiber reinforced soils.

Many studies have been conducted relating to the behaviour of soil reinforced with randomly distributed fibers. Puppala and Musenda, 2002 [1] carried out unconfined compression tests, consolidation tests on expansive clays reinforced polypropylene fiber (length 25mm and 50mm, 25mm referred as short fiber and 50mm as long fiber) and reported that short fibers encouraged more in effective stabilization and reduced swell pressure to a considerable extent.

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Maliakal and Thiyyakkandi, 2013 [2] discusses the shear strength of clay reinforced with randomly distributed coir fibers based on a series of consolidated undrained triaxial compression tests. Test results show that major principal stress at failure for clay-coir fiber matrix increases with increase in fiber content (W_f) and fiber aspect ratio (A_r). In general, the study identifies that the inclusion of discrete coir fibers in random fashion significantly improves the shear strength of clay.

Sivakumar Babu et al, 2008 [3] reports the results of comprehensive experimental investigations using tri-axial shear tests, swelling, and consolidation tests to quantify the improvement of strength, swelling and compressibility characteristics of black cotton soil reinforced with coir fibers in a random manner. The study facilitates the use of combination of black cotton soil and coir fibers for sustainable development purposes.

Ramesh, et al., 2013 [4] describes the compaction and strength behavior of black cotton soil (BC soil) reinforced with coir fibers. BC soil reinforced with coir fiber shows only marginal increase in the strength of soil, inhibiting its use for ground improvement. In order to further increase the strength of the soil-coir fiber combination, optimum percentage of 4% of lime is added. It is found that strength properties of optimum combination of BC soil-lime specimens reinforced with coir fibers is appreciably better than untreated BC soil or BC soil alone with coir fiber. Lime treatment in BC soil improves strength but it imparts brittleness in soil specimen. BC soil treated with 4% lime and reinforced with coir fiber shows ductility behavior before and after failure. An optimum fiber content of 1% (by weight) with aspect ratio of 20 for fiber was recommended for strengthening BC soil.

Pradhan et al., 2012 [5] presents the effect of random inclusion of polypropylene fibers on strength characteristics of soil. They have conducted direct shear tests, unconfined compression tests and CBR tests on un-reinforced as well as reinforced soil to investigate the strength characteristics of fiber-reinforced soil. The test results reveal that the inclusion of randomly distributed polypropylene fibers in soil increases peak and residual shear strength, unconfined compressive strength and CBR value of soil. It is noticed that the optimum fiber content for achieving maximum strength is 0.4–0.8% of the weight of oven-dried soil for fiber aspect ratio of 100.

Mali and Singh,2014 [6] reviews the strength behavior of cohesive soils reinforced with coir fibers, polypropylene fibers and scrap tire rubber fibers as reported from experimental investigation, that includes triaxial, direct shear and unconfined compression tests.

Singh and Mittal, 2014 [7] did UCC tests and CBR tests without and with coir fiber. The percentage of coir fiber by dry weight of soil is taken as 0.25%, 0.50%, 0.75% and 1% and corresponding to each coir fiber content unsoaked and soaked CBR and UCS tests are conducted in the laboratory. Tests result indicates that both unsoaked and soaked CBR value of soil increases with the increase in fiber content.

Fig.1 Samples of Coir Fiber and Polypropylene fibers

II. MATERIALS USED

A. Clay

The soil used in this study was collected from a piling site at Chetpet, Chennai, Tamilnadu. The sample was obtained from a depth of 5m below the ground level. The sample was thoroughly oven dried and stored in sacks at room temperature. The index properties of the soil were thoroughly studied in the laboratory. The soil was tested for liquid limit, plastic limit, compaction characteristics and free swell.

Table-1: Index Properties of soil

PROPERTY	VALUE
Specific gravity	2.78
Liquid limit	51%
Plastic limit	26.25%
Plasticity index	24.75%
Optimum moisture content	13.65%
Maximum dry density, ρ_{dmax}	2.08g/cc
Free swell index	31%

The properties are listed in Table-1. From the Atterberg limits, the soil is classified as clay of high compressibility (CH) as per IS: 1498 – 1970 [8].

B. Coir

The coir fiber is obtained from the fibrous layer of the coconut and it is separated from the hard shell manually by driving the fruit down onto a spike to split it (de-husking). The coir fiber is cut into pieces of 10 mm to maintain l/d ratio of 50. The properties of the coir fibers used in this study are listed in Table-2.

Table.2: Properties of coir fiber

Sl. No.	Properties	Value
1	Density	1.13 g/cc
2	Cut Length	10 mm
3	Diameter	0.2 mm
4	Colour	Brown
5	Water absorption	92-105%

C. Polypropylene fiber

The most commonly used synthetic material; polypropylene fiber is used in this study. Polypropylene fibers are hydrophobic, non-corrosive and resistant to alkalis, chemicals and chlorides. Polypropylene fibers having length 12 mm with average diameter of 0.06 mm (aspect ratio of 200) were purchased from the market and used in experimental programme. A sample of the coir and polypropylene fiber used in this study are shown in Fig. 1.

III. METHODOLOGY

A. Sample preparation

The coir fibers are cut into required size (10 mm) as shown in Fig. 2 and it is added to the soil in 0.5%, 1% and 1.5% of dry weight of soil.

Fig. 2 Coir fibre cut into required size

The polypropylene fibers are also added in 0.5%, 1% and 1.5% of dry weight of soil. The soil and the fibers are mixed by hand thoroughly and water is added as per requirement as shown in Fig. 4.

Fig. 3 Mixing of fiber and soil

B. Testing of samples

Standard Proctor test

The compaction tests on un-reinforced and reinforced soil + fiber mixes were conducted in accordance with Indian Standards Specifications (Bureau of Indian Standards (BIS) 1980 I.S.2720 (7) [9]). The test procedure consists of mixing of soil with different water contents and compacting in metal moulds of 100 mm diameter in three layers (25 blows on each layer with thickness of 5-8 cm) using a free fall hammer of 2.5 kg dropping from 305 mm height. The compaction test has been performed on soils with different fiber contents of 0.5%, 1%, and 1.5 % of dry mass.

CBR test

The soil samples of unreinforced and reinforced soil for CBR test were prepared as per standard procedure. The desired amount of oven dried (100-105^{0}C) soil was taken and mixed thoroughly with water corresponding to its optimum moisture content (OMC) in the CBR mould having 150 mm diameter and 175 mm high with detachable perforated base plate (IS:2720-XVI) [10]. The soil was then compacted to its maximum dry density obtained by laboratory standard Proctor test. For the preparation of soil samples of reinforced soil the desired amount of fiber was mixed in dry state before the addition of water and then compacted to same Proctor density as per IS: 2720, Part VII- (1974). The top surface of the specimen in the CBR mould was made level and a filter paper and a perforated metallic disc were placed over the specimen. The CBR mould along with compacted soil and surcharge load of 5 kg was then transferred to a tank containing water for soaking of the sample as shown in Fig. 4. After 4 days (i.e. 96 hours) of soaking, the mould assembly was taken out from water and the top surface of sample was left exposed to air for half an hour.

The CBR mould along with soaked soil sample was brought to a motorized loading frame for testing as shown in Fig.5. The CBR values of the test samples of unreinforced and reinforced soil were determined corresponding to plunger penetrations of 2.5 mm and 5 mm as per the standard procedure laid down in IS: 2720, Part XVI (1965).

Fig. 4 Soaking of sample

Fig. 5 CBR Test in loading frame

IV. RESULTS AND DISCUSSIONS

A. Proctor test results

Compaction characteristics were studied by conducting standard proctor tests. The tests were carried out on the soil samples containing 0%, 0.5%, 1% and 1.5% of Coir and Polypropylene in order to determine the maximum dry density and optimum moisture content (OMC). Chart. 1 shows proctor compaction curves for different proportions of coir.

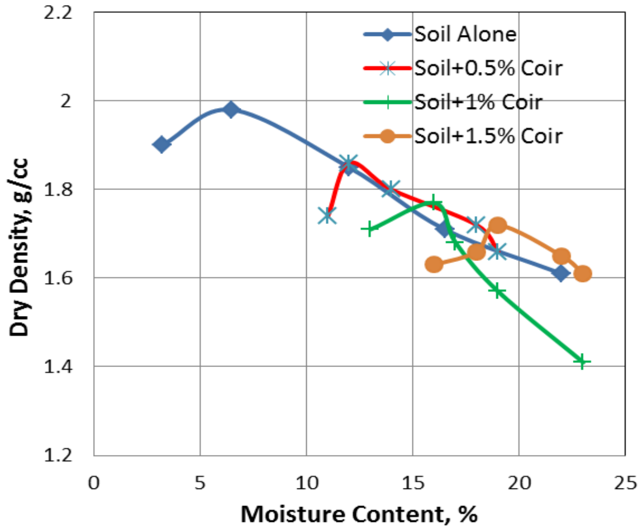

Chart. 1 Compaction curves of soil with different % of coir

From the curves MDD (Maximum Dry Density) and OMC are obtained and listed in Table 3.

Table 3: MDD and OMC values for soil with different percentage of addition of coir fibers

Description	MDD	OMC
Units	g/cc	%
Soil Alone	1.98	6.5
Soil+0.5% Coir	1.86	12
Soil+1% Coir	1.77	16
Soil+1.5% Coir	1.72	19

From Table-3, it is observed that the maximum dry density decreases for increasing percentage of coir. MDD showed a decrease of 6.06 %, 10.6 % and 13.1 % respectively, for 0.5, 1 and 1.5% addition of coir fibers to the soil. This is mainly due to the lower value of specific gravity of coir fiber as compared to the higher value of specific gravity (2.78) of soil.

The OMC values are constantly increasing upon increasing percentage of coir. OMC showed an increase of 1.85, 2.46 and 2.92 times the value of soil alone. This variation is too high and may be due to the water absorption (92-105%) of coir fiber. Hence coating of coir is advised to reduce the moisture ingress.

The standard proctor results of soil samples containing 0%, 0.5%, 1% and 1.5% of are shown in Chart. 2. From the curves, it is obtained that the dry density values are decreasing and the curves shift to the wet-side of optimum for the addition of fibers.

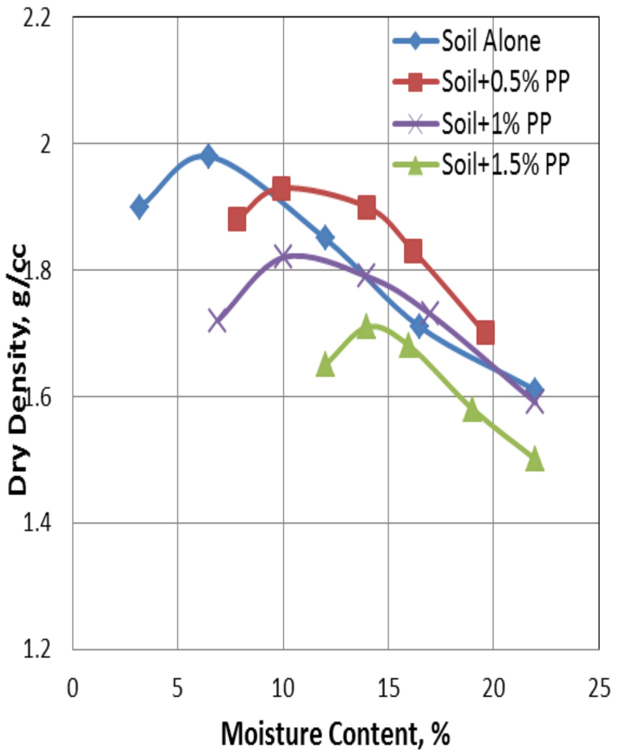

Chart. 2 Compaction curves of soil with different % of PP

From the curves MDD (Maximum Dry Density) and OMC are obtained and listed in Table 4.

Table 4: MDD and OMC values for soil with different percentage of addition of Polypropylene fibers

Description	**MDD**	**OMC**
Units	g/cc	%
Soil Alone	1.98	6.5
Soil+0.5% PP	1.93	9.9
Soil+1% PP	1.82	10.5
Soil+1.5% PP	1.71	13.5

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From Table-4, it is observed that the maximum dry density decreases for increasing percentage of coir. MDD showed a decrease of 2.5 %, 8.08 % and 13.6 % respectively, for 0.5, 1 and 1.5% addition of Polypropylene fibers to the soil. This is mainly due to the lower value of specific gravity of Polypropylene fiber as compared to the higher value of specific gravity (2.78) of soil.

The OMC values are constantly increasing upon increasing percentage of coir. OMC showed an increase of 1.52, 1.61 and 2.07 times the value of virgin soil.

Comparison of Compaction characteristics of Coir and Polypropylene

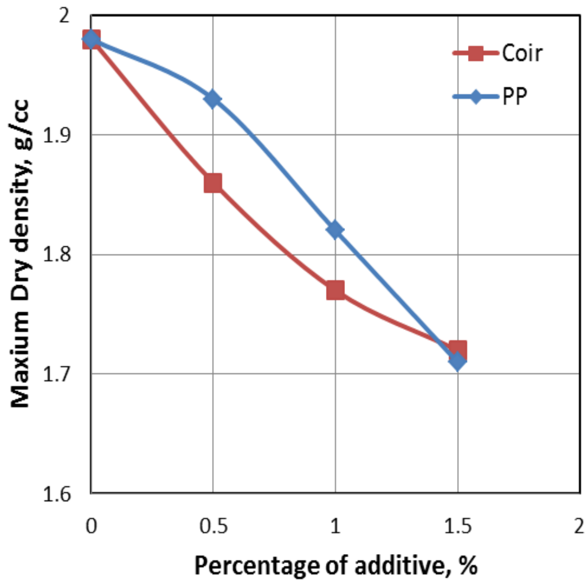

Chart. 3 Comparison of MDD for soil with fibers

Chart.3 shows the MDD of soil with 0.5, 1 and 1.5% addition of coir and polypropylene fibers. Both the additives tend to decrease the MDD of soil with coir in the lower side. This behavior can be attributed to the reduction of average unit weight of solids in the mixture of soil and fiber. For 1.5% addition of fibers, both fibers show a narrowing trend and the MDD values are almost same.

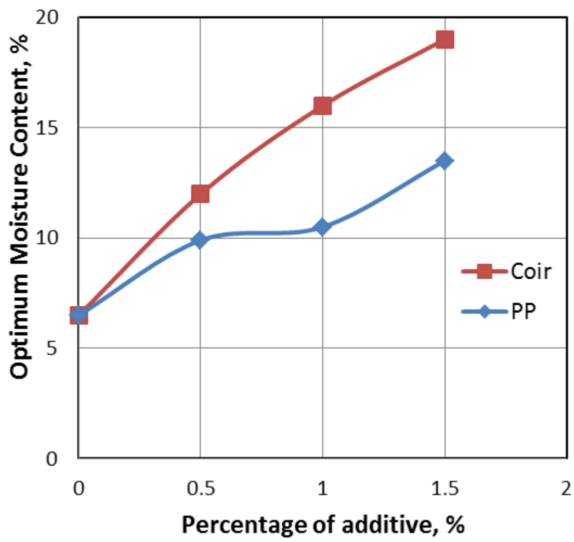

Chart. 4 Comparison of OMC for soil with fibers

From Chart. 4, it is observed that the optimum moisture content does not show a significant change by addition of polypropylene fiber, whereas coir shows a linear increasing pattern of OMC upon increasing the percentage of fibers.

B. CBR Test Results

Un-soaked CBR

The results of unsoaked CBR tests on virgin soil, soil with 1% coir and soil with 1% PP fibers are shown in Chart.5 and Chart. 6 for 2.5 mm and 5 mm penetration of plunger respectively.

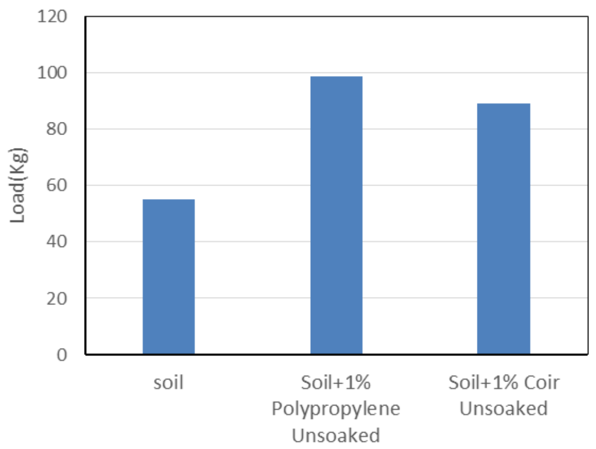

Chart. 5 Load for 2.5 mm in un-soaked condition

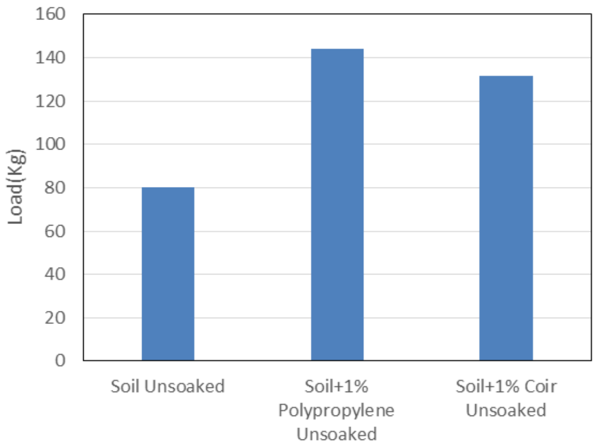

Chart. 6 Load for 5 mm in un-soaked condition

From Chart 5, it is observed that for 2.5 mm penetration of CBR plunger, the load is increased by 62.2% and 79.5 % when compared with virgin soil for coir and polypropylene mixed soil respectively. From Chart 6, it is observed that for 5 mm penetration of CBR plunger, the load is increased by 64.6% and 80% when compared with virgin soil for coir and polypropylene mixed soil respectively.

The results of soaked CBR tests on virgin soil, soil with 1% coir and soil with 1% PP fibers are shown in Chart.7 and Chart. 8 for 2.5 mm and 5 mm penetration of plunger respectively.

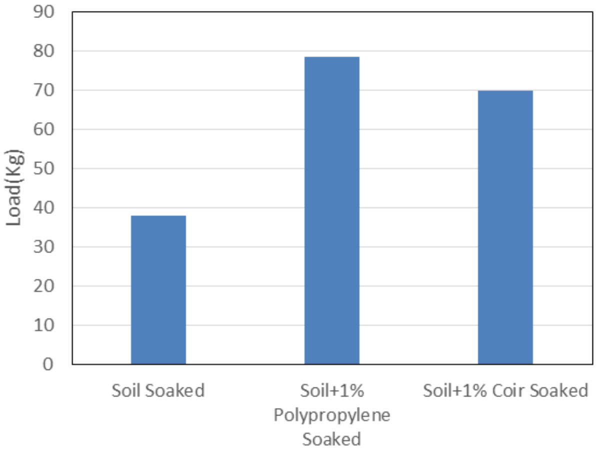

Chart. 7 Load for 2.5 mm in soaked condition

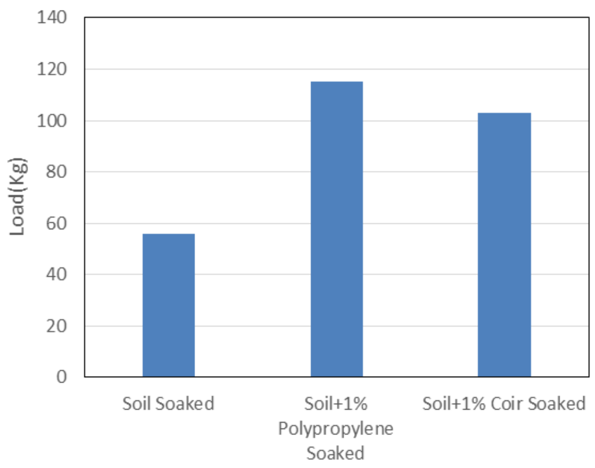

Chart. 8 Load for 5 mm in soaked condition

From Chart 7, it is observed that for 2.5 mm penetration of CBR plunger, the load is increased by 84% and 106.5 % when compared with virgin soil for coir and polypropylene mixed soil respectively. From Chart 8, it is observed that for 5 mm penetration of CBR plunger, the load is increased by 83.8% and 105.7% when compared with virgin soil for coir and polypropylene mixed soil respectively.

The CBR value for 2.5 mm and 5 mm penetration for soil with fibers in soaked and unsoaked conditions are listed in Table 5. From Table 5, it is observed that the CBR value in unsoaked condition for soil with coir and polypropylene is about 1.63 and 1.75 times than that of virgin soil respectively.

Table 5: CBR values of soil with fibers in soaked and unsoaked conditions

Sl. No	Description	CBR Value for Penetration of	
		2.5 mm	5.0 mm
1	Soil Alone - Unsoaked	4.00	3.99
2	Soil + 1% Coir – Unsoaked	6.5	6.4
3	Soil + 1% PP – Unsoaked	7.0	7.2
4	Soil Alone - Soaked	2.8	2.7
5	Soil + 1% Coir – Soaked	5.1	5.0
6	Soil + 1% PP – Soaked	5.8	5.6

Also from Table 5, it is observed that the CBR value in soaked condition for soil with coir and polypropylene is about 1.82 and 2.07 times than that of virgin soil respectively. Hence there is about 2 times increase in CBR value upon addition of fibers. The similar trend of increase in CBR value upon coir fiber addition is noted by [7].

V. CONCLUSIONS

The study focused on the comparison of natural and synthetic fibers on soil stabilization. The study has shown promising use of coir as a stabilizing material for soil and following conclusions can be drawn from the study:

- Coir fiber is a waste material which could be utilized for stabilizing the soil for pavement, embankment constructions, etc.

- The OMC of soil-fiber mix increases with increasing the percentage of coir and polypropylene fiber.
- The MDD of soil-fiber mix decreases with increasing the percentage of coir and polypropylene fiber.
- CBR value of soil is improved by adding coir or polypropylene fibers.
- The CBR values of the reinforced soil are two times greater than the normal soil. Hence, the proportion of 1% fiber with soil may be economically used in road pavement and embankments.

REFERENCES

[1]. Puppala, A.J., and Musenda, C., (2002). "Effect of fibre reinforcement on strength and volume change in expansive soils", Transportation Research Record, No:00-0716, pp. 134-140.

[2]. Maliakal, T and Thiyyakkandi, S., (2013). "Influence of randomly distributed coir fibers on shear strength of clay", Geotechnical and Geological Engineering, 31(2), pp. 425–433.

[3]. Sivakumar Babu G. L,. Vasudevan A. K & Sayida M. K. (2008). "Use of Coir Fibers for Improving the Engineering Properties of Expansive Soils", Journal of Natural Fibers, 5(1), pp. 61-75.

[4]. Ramesh, HN, Manoj Krishna, KV, Mamatha, HV (2010) Compaction and strength behavior of lime-coir fiber treated black cotton soil. Geomechanical Engineering, 2, pp. 19-28

[5]. P. Pradhan, R. Karand and A. Naik (2012), Effect of random inclusion of polypropylene fibers on strength characteristics of cohesive soil, Geotechnical and Geological Engineering, 30(1), pp. 15-25.

[6]. Mali.S and Baleshwar Singh, (2014). "Strength Behaviour of Cohesive Soils Reinforced with Fibers" International Journal of Civil Engineering Research, 5 (4), pp. 353-360

[7]. Singh, R.R and Shelly Mittal (2014). "Improvement of local subgrade soil for road constuction by the use of coconut coir fiber", International journal of research in engineering and technology, 3(5), pp.707-711.

[8]. IS: 1498 – 1970, Classification and identification of soils for general engineering purposes, Bureau of Indian Standards; New Delhi.

[9]. IS 2720 Part- VIII, (1997), Methods of Tests for soils (Proctor's Compaction Test), BIS, New Delhi.

[10]. IS: 2720, Part XVI, 1965. Laboratory determination of CBR, Bureau of Indian Standards; New Delhi.