Utilization of Coconut Coir Fibre For Improving Subgrade Strength Characteristics Of Clayey Sand

S. Muthu Lakshmi[1*], S. Sasikala[2], V. Padmavathi[2], S. Priya[2], V. Saranya[2]

[1]*Faculty of Civil Engineering, Rajalakshmi Engineering College, Chennai, Tamil Nadu, India.*
[2]*Student of Civil Engineering, Rajalakshmi Engineering College, Chennai, Tamil Nadu, India.*

Abstract - *Strength of subgrade soil plays a vital role in determining the thickness and service life of a pavement. Thickness of pavement can be reduced by improving the strength and stability of subgrade soil, thus reducing the cost of construction and also helps in saving the conventional construction material for future generations. In this paper, an experimental study has been conducted to improve the strength of soil by reinforcing the soil by means of non-woven randomly distributed Coconut Coir Fiber (CCF). Laboratory tests were conducted on locally available soil to classify the soil based on its index properties and the soil was found to be SC soil (Clayey Sand). CCF was added to the soil in varying percentages of 0.3%, 0.6%, 0.9%, 1.2% and 1.5% and in varying lengths of 1cm, 2cm, 3cm, 4cm and 5cm, to determine the optimum percentage and optimum length of CCF at which maximum strength of soil was observed in Unconfined Compression test and soaked CBR test. From the experimental results, it was observed that soil with 1.2 % CCF of length varying from 2cm to 3cm showed maximum increase in UCC strength of 43.2 % and 47.4 % respectively and soaked CBR value was found to increase by approximately four times that of unreinforced soil.*

***Key Words*: Coconut coir fiber, fiber reinforced soil, subgrade, unconfined compression test, soaked CBR**

1. INTRODUCTION

All the civil engineering structures whether small or huge, simple or complex rests on the ground surface and ultimately transfers the structure load to soil or rock. Stability of any such structure depends on the properties of the underlying soil. If we can improve the strength of existing soil by means of some ground improvement techniques utilizing the waste material generated locally, then the cost of construction can be reduced drastically. Under the traffic loads, the soil sub-base is subjected to compression in the vertical direction accompanied by tension in the lateral direction (Meshram et al. [1]). Most of the available soil generally shows good compressive strength and sufficient shear strength but are weak in tension. Fiber reinforced soil is effective in all types of soils like sand, silt and clay (Kumar et al. [2]). Earth reinforcement is an ancient technique, demonstrated abundantly in nature by animals, birds and the action of tree roots. These reinforcements interact with the soil through friction and adhesion and resists tensile stress developed within the soil mass thereby restricting shear failure. (Chaple and Dhatrak [3]).

In construction of pavements, either rigid or flexible if the underlying soil (subgrade) is of good quality then the thickness of pavement becomes less thus reducing the construction cost and saving the conventional natural resources for the next generation. Also the life of pavements depends on the strength and stability of underlying subgrade soil. One of the reasons for rapid deterioration of a pavement structure is due to poor subgrade which increases the maintenance cost, leads to traffic interruptions and causes inconvenience to public. Deformations in subgrade due to repeated traffic loads can be avoided and strength of subgrade soil can be improved by reinforcing the soil by means of natural fibers like coconut coir, jute, bamboo, straw etc. and by using synthetic fibers like polypropylene, polyester, polyethylene, glass fiber, shredded rubber tire, geo-synthetic or goe-textile etc. In this experimental study, non-woven randomly distributed coconut coir fibers (CCF) were used to reinforce the soil. CCF is produced in large quantities in South Asian countries like India, Malaysia, Philippines, Indonesia etc. Coconut coir is a natural fiber belonging to the group of hard structural fibers (Maurya et al. [4]). It can be extracted from the husk of coconut which is easily and locally available, cheap, biodegradable and eco-friendly. It is waste by product of the coir manufacturing industry and for every ton of fiber extracted, about two tons of coir waste is produced (Jayasree et al. [5]).

Durability of natural fiber can be improved by chemical treatment and by coating the fiber with Phenol, Bitumen and polymer (Abhijith [6]). As coconut fiber has high lignin content and low cellulose content, it is resilient, strong and highly durable (Enokela and Alada [7]). Compared to jute fiber, service life of coir is more up to 10 years because of its high lignin content (Rowell *et al*. [8]). According to Goyal et al. [9], degradation of coir depends on the medium of embedment and the climatic conditions and is found to retain 80% of its tensile strength even after six months. Coir has low tenacity but the elongation is much higher (Babu and Vasudevan [10]) and it shows better resilient response against synthetic fibers by higher coefficient of friction (Chouhan *et al*. [11]). Coir retains much of its tensile strength when wet and shows reduced swelling tendency of the soil (Subaida *et al*. [12]).

Many researchers have worked on CCF reinforced soil. Mali and Singh [13], observed that soft silty or clayey soils can be improved with randomly distributed fibers of natural and synthetic types. When loaded, the fibers mobilize tensile resistance, which in turn imparts greater strength to the soil.

Toughness of soil can be increased with fiber inclusion and pullout resistance of synthetic fibers is less compared to that of natural fibers (Babu and Vasudevan [10]). According to Singh and Mittal [14], composite effect of natural fiber changes the brittle behavior of the soil to ductile behavior. According to Chaple and Dhatrak [3], provision of coir reinforced layer reduces the settlement and improves the bearing capacity ratio up to 1.5 to 2.66.

2. EXPERIMENTAL WORK

In the present study, disturbed soil sample collected from Walajabad, in Kanchipuram district in Tamil Nadu was used in the experimental work. Series of test like wet sieve analysis, specific gravity test, Atterberg's limit test and free swell index test were conducted in the laboratory to determine the index properties of the soil. Soil was classified as per Indian Standard Soil Classification System (ISCS) based on the index properties of the soil. CCF purchased from the market was of 0.5 mm diameter and the fiber was cut into varying lengths of 1 cm, 2 cm, 3 cm, 4 cm and 5 cm. Standard Proctor Compaction test (SPCT) was conducted on unreinforced soil/ control specimen (CS) and on soil samples with varying percentage of CCF of 3 mm length (i.e. 0.3%, 0.6%, 0.9%, 1.2% and 1.5%) to determine the maximum dry density (MDD) and optimum moisture content (OMC). Remoulded soil specimen for Unconfined Compression (UCC) test and soaked CBR test were prepared at 97% relative compaction based on the OMC & MDD obtained from SPCT. From the experimental results, soil with optimum percentage of CCF was found based on the strength gain observed in UCC test and soaked CBR test. For the soil with optimum percentage of CCF, different lengths of CCF (i.e. 1cm, 2cm, 3cm, 4cm and 5cm) were added to determine the optimum length of CCF for which soil showed maximum strength gain in UCC test and soaked CBR test. Increase in strength, for soil with varying percentage of CCF and of varying lengths were determined with respect to CS and thickness of pavement was calculated based on the charts of IRC:SP:20-2002.

3. RESULTS AND DISCUSSION

Results of the tests conducted in the laboratory to determine the index properties of soil are presented in Table 1. Soil sample was classified as per ISCS based on the index properties of the soil.

Table – 1: Soil Classification as per ISCS

Name of the test	Result
Specific Gravity	G = 2.703
Atterberg's Limits Liquid Limit Plastic Limit Plasticity Index Shrinkage Limit	 w_L = 27 % w_P = 16.03 % I_p = 10.97 % w_s = 6.22 %
Sieve Analysis	Gravel = 0.76 % Sand = 57.18 % Silt and Clay = 42.06 %
Free Swell Index	20 %
As per ISCS, soil was classified as SC – Clayey Sand	

3.1 Standard Proctor Compaction Test on soil with varying percentage of CCF

Moisture content (w) and dry density (ρ_d) values obtained from SPCT, conducted on CS and on soil with varying percentage of CCF were plotted in Chart 1. Table 2 shows OMC and MDD obtained from SPCT for soil with varying percentage of CCF.

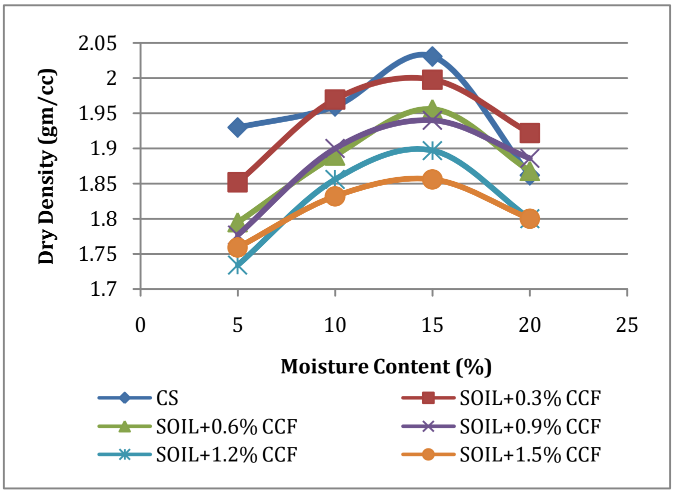

Chart -1: Graph of Moisture content v/s Dry Density for soil specimen with varying percentage of CCF

Table – 2: OMC and MDD for soil specimen with varying percentage of CCF

Soil Specimen	OMC (%)	MDD (gm/cc)
CS (Soil + 0% CCF)	12	2.031
Soil + 0.3 % CCF	12.3	1.998
Soil + 0.6 % CCF	12.5	1.956
Soil + 0.9 % CCF	12.7	1.94
Soil + 1.2 % CCF	13	1.897
Soil + 1.5 % CCF	13.3	1.856

From the results it can be observed that as the percentage of CCF in soil was increased from 0 % to 1.5 %, OMC was found to increase from 12 % to 13.3 % and MDD was found to decrease from 2.031 gm/cm³ to 1.856 gm/cm³. According to Hejazi et al. [15], the percentage of water absorption increases with an increase in the percentage of coir. Thus it can be inferred that water gets retained within soil due to the presence of CCF because of which OMC increases and MDD decreases with increasing percentage of CCF. Also the presence of CCF in soil interferes with interlocking of soil particles thus decreasing MDD with increasing percentage of CCF.

3.2 Unconfined Compression Test on soil with varying percentage of CCF

UCC strength values for CS and for soil with varying percentage of CCF and their corresponding percentage increase with respect to CS given in Table 3 were plotted in Chart 2.

Table – 3: UCC strength of soil specimen with varying percentage of CCF

Soil Specimen	UCC Strength (q_u) kPa	% Increase in UCC Strength w.r.t. CS
CS (Soil + 0% CCF)	89.94	-
Soil + 0.3 % CCF	104.53	16.2
Soil + 0.6 % CCF	112.05	24.58
Soil + 0.9 % CCF	122.01	35.66
Soil + 1.2 % CCF	132.59	47.4
Soil + 1.5 % CCF	121.16	34.7

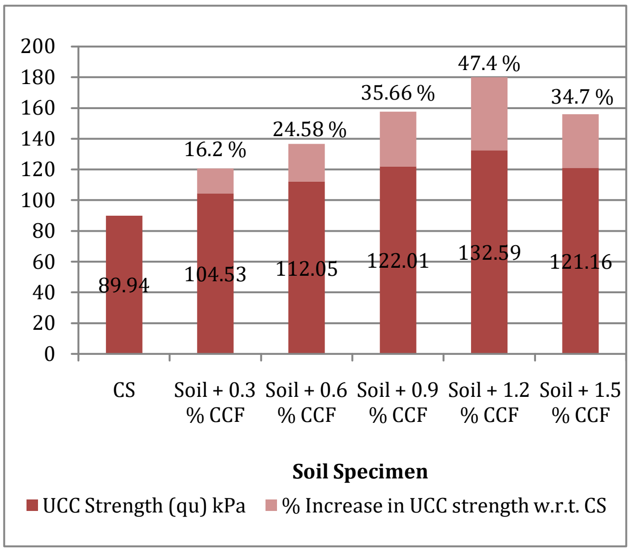

Chart -2: UCC strength and percentage increase in UCC strength for soil specimen with varying percentage of CCF

It can be observed from the results that as the percentage of CCF was increased from 0 % to 1.5 %, UCC strength of soil specimen was found to increase from 89.94 kPa for CS to 132.59 kPa for soil with 1.2 % CCF after which it decreased. Thus it can be concluded that optimum percentage of CCF to be added to soil is 1.2 % at whcih maximum UCC strength can be achieved and percentage increase in UCC strength with respect to CS was found to be 47.4 %. According to Kumar et al. [2], randomly oriented discrete inclusions incorporated into soil mass improves its load deformation behavior by interacting with the soil particles mechanically through surface friction and by interlocking. Fiber reinforcement works as frictional and tension resistance element. Thus interfacial friction characteristics increased with increase in fiber content of soil up to 1.2 % CCF, beyond which it interfered with the interlocking of soil particles and thus decrease in UCC strength was observed.

3.3 Soaked CBR Test on soil with varying percentage of CCF

Chart 3 shows the load penetration curve obtained from soaked CBR test conducted on CS and on soil specimen with varying percentage of CCF prepared at 97 % relative compaction.

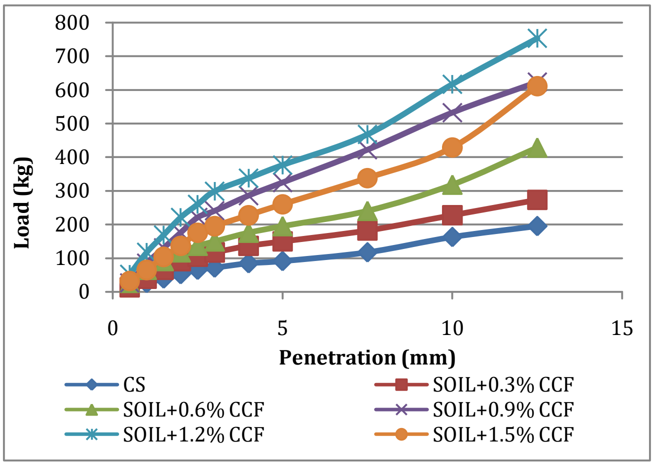

Chart -3: Load Penetration curve of soaked CBR test for soil specimen with varying percentage of CCF

Table 4 shows soaked CBR values for the soil with varying percentage of CCF and the corresponding thickness of pavement calculated based on the charts given by IRC:SP:20-2002. CBR method of pavement design is one of the popular methods of design wherein, the thickness of pavement above a certain layer is based on CBR value of that layer. Chart 4 shows graphical representation of the soaked CBR values and its increase calculated in Table 4.

Table – 4: Soaked CBR values with corresponding pavement thickness required for soil specimen with varying percentage of CCF

Soil Specimen	Soaked CBR value (%)	Increase in soaked CBR w.r.t. CS	Pavement Thickness (mm)	% Decrease in Pavement Thickness w.r.t. CS
CS (Soil + 0% CCF)	4.74	-	426.5	-
Soil + 0.3 % CCF	7.59	1.6 times CS	275	35.5
Soil + 0.6 % CCF	9.96	2.1 times CS	275	35.5
Soil + 0.9 % CCF	16.13	3.4 times CS	216	49.3
Soil + 1.2 % CCF	18.98	4 times CS	189.9	55.5
Soil + 1.5 % CCF	12.81	2.7 times CS	247	42.1

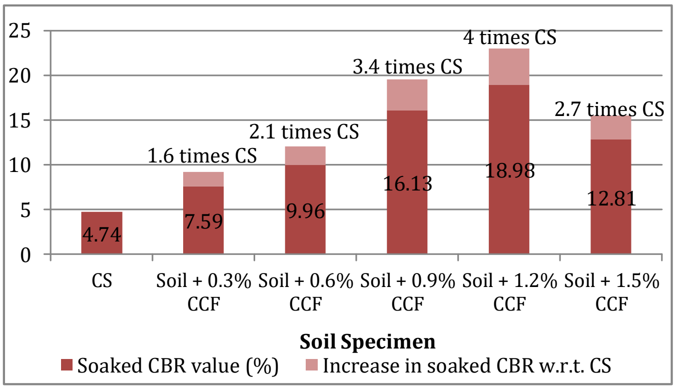

Chart -4: Soaked CBR values and increase in soaked CBR for soil specimen with varying percentage of CCF

From the results it can be observed that, as the percentage of CCF increased from 0 % to 1.5 %, soaked CBR value of soil specimen was found to increase from 4.74% for CS to 18.98% for soil with 1.2% CCF after which it decreased. Soil with 1.2 % CCF was found to show 4 times the increase in soaked CBR value compared to CS. Thus it can be concluded that optimum percentage of CCF to be added to soil is 1.2 % at which the soil showed maximum gain in strength compared to CS. Pavement thickness calculated based on the charts of IRC: SP: 20-2002, was found to be 189.9 mm for soil with 1.2 % CCF and percentage decrease in pavement thickness with respect to CS was found to be 55.5% thus resulting in an economical construction.

3.4 Standard Proctor Compaction Test on soil with varying lengths of CCF

Moisture content (w) and dry density (ρ_d) values obtained from SPCT, conducted on soil with optimum percentage of CCF (1.2 %) by varying the lengths of CCF were plotted in Chart 5. Table 5 shows OMC and MDD obtained from SPCT for different soil specimens with varying lengths of CCF.

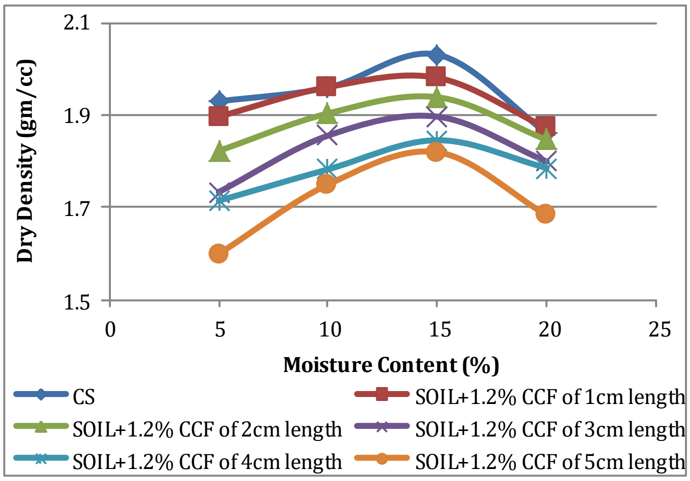

Chart -5: Graph of Moisture content v/s Dry Density for soil specimens with varying lengths of CCF

Table – 5: OMC and MDD for soil with 1.2 % CCF of varying lengths

Soil Specimen	OMC (%)	MDD (gm/cm³)
CS (Soil + 0% CCF)	12	2.031
Soil + 1.2 % CCF of 1 cm length	12.3	1.981
Soil + 1.2 % CCF of 2 cm length	12.5	1.939
Soil + 1.2 % CCF of 3 cm length	13	1.897
Soil + 1.2 % CCF of 4 cm length	13.2	1.846
Soil + 1.2 % CCF of 5 cm length	13.5	1.82

From the results it can be observed that, as the length of CCF was increased from 1 cm to 5 cm, OMC was found to increase from 12.3 % to 13.5 % and MDD was found to decrease from 1.981 gm/cm³ to1.82 gm/cm³. Increasing length of CCF results in more water absorption by the fibre thus increasing OMC and reducing MDD.

3.5 Unconfined Compression Test on soil with varying lengths of CCF

UCC strength values for soil with optimum percentage of CCF (1.2 %), by varying the lengths of CCF and the corresponding percentage increase in UCC strength with respect to CS given in Table 6 were plotted in Chart 6.

Table – 6: UCC strength of soil with 1.2 % CCF of varying lengths

Soil Specimen	UCC Strength (q_u) kPa	% Increase in UCC Strength w.r.t. CS
CS (Soil + 0% CCF)	89.94	-
Soil + 1.2 % CCF of 1 cm length	106.32	18.2
Soil + 1.2 % CCF of 2 cm length	128.8	43.2
Soil + 1.2 % CCF of 3 cm length	132.59	47.4
Soil + 1.2 % CCF of 4 cm length	118.4	31.6
Soil + 1.2 % CCF of 5 cm length	94.723	5.32

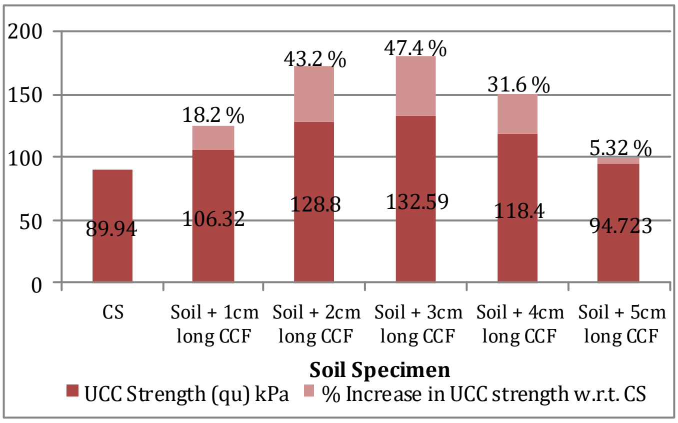

Chart -6: UCC strength and percentage increase in UCC strength for soil with 1.2 % CCF of varying lengths

It can be observed from the results that as the length of CCF was increased from 1 cm to 5 cm, UCC strength of soil with 1.2 % CCF was found to increase from 106.32 kPa to 132.59 kPa for 3 cm length of CCF after which it decreased. Thus it can be conculded that optimum length of CCF to be added to soil is 3 cm at which maximum UCC strength can be achieved and percentage increase in UCC strength with respect to CS was found to be 47.4 %. According to Goyal et al. [9], increase in compressive strength is due to the increased cohesive strength between the soil particles and the fibers. Thus when compressive axial load is imposed on the sample, an internal tensile stress is reduced which tries to prevent the sample from splitting.

3.6 Soaked CBR Test on soil with varying lengths of CCF

Chart 7 shows the load penetration curve obtained from soaked CBR test conducted on soil specimen with optimum percentage of CCF (1.2 %) by varying the lengths of CCF prepared at 97 % relative compaction.

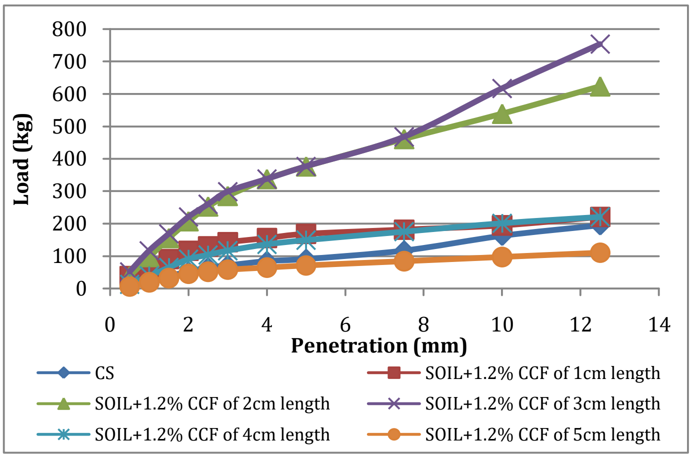

Chart -7: Load Penetration curve of soaked CBR test for soil with 1.2 % CCF of varying lengths

Table 7 shows soaked CBR values for the soil with 1.2 % CCF of varying lengths and the corresponding thickness of pavement calculated based on the charts given by IRC:SP:20-2002. Chart 8 shows graphical representation of soaked CBR values and its increase calculated in Table 7.

Table – 7: Soaked CBR values with corresponding pavement thickness required for soil with 1.2% CCF of varying lengths

Soil Specimen	Soaked CBR value (%)	Increase in soaked CBR w.r.t. CS	Pavement Thickness (mm)	% Decrease in Pavement Thickeness w.r.t. CS
CS (Soil + 0% CCF)	4.7	-	426.5	-
Soil + 1.2 % CCF of 1 cm length	9.49	2 times	275	35.5
Soil + 1.2 % CCF of 2 cm length	18.5	3.9 times	193.5	54.6
Soil + 1.2 % CCF of 3 cm length	18.98	4 times	189.9	55.5
Soil + 1.2 % CCF of 4 cm length	7.59	1.6 times	275	35.5
Soil + 1.2 % CCF of 5 cm length	3.8	-	481.8	-

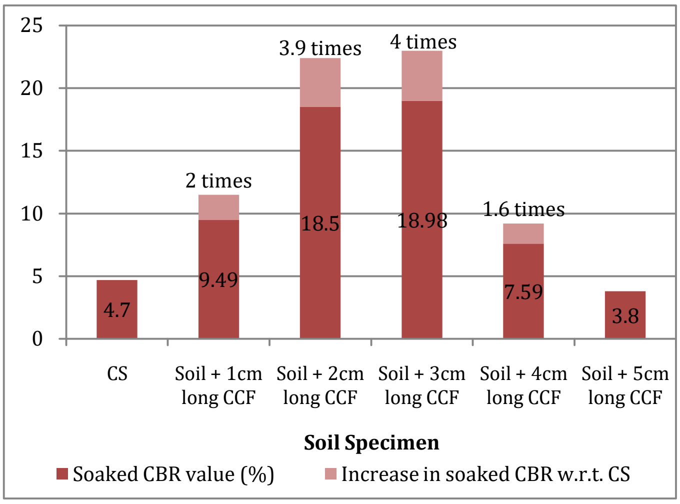

Chart -8: Soaked CBR values and percentage increase in soaked CBR for soil with 1.2 % CCF of varying lengths

From the results it can be observed that, as the length of CCF was increased from 1 cm to 5 cm, soaked CBR value of soil with 1.2 % CCF was found to increase from 9.49% to 18.5 % for 2 cm length of CCF and up to 18.98 % for 3 cm length of CCF after which it decreased. Increase in soaked CBR value was found to be 3.9 times and 4 times that of CS for soil with 2 cm and 3 cm length of CCF respectively. Thus it can be concluded that optimum length of CCF that can be added to soil may vary from 2 cm to 3 cm at which the soil showed maximum gain in strength compared to CS. Pavement thickness calculated based on the charts of IRC:SP:20-2002, was found to be 193.5 mm and 189.9 mm for soil with 1.2 % CCF of 2 cm and 3 cm length respectively whereas percentage decrease in pavement thickness with respect to CS was found to be 54.6 % and 55.5 % respectively thus resulting in an economical construction. According to Kumar et al. [2], CBR value of soil reinforced with same fiber content and same diameter increases with the increase in length of fiber as for shorter fibers, the area in contact with soil is comparatively less and hence there is a less improvement in strength and stiffness of soil. But after particular lengths, fibers do not impart any strength to soil, as more length of fiber remains unattached/ untouched with soil particles and to some extent interfere with interlocking of particles.

4. CONCLUSION

- With increasing percentage and length of CCF, OMC was found to increase and MDD was found to decrease.
- For soil with varying percentage of CCF, maximum UCC strength was observed to be 132.59 kPa and maximum soaked CBR value was found to be 18.98 % at 1.2 % CCF. Soil with 1.2 % CCF was found to show 47.4 % increase in UCC strength and 4 times the increase in soaked CBR value compared to unreinforced soil. Thus optimum percentage of CCF that can be added to soil is 1.2 % at which the soil showed maximum strength gain.
- Soil with 1.2 % CCF of length 2 cm and 3 cm showed maximum UCC strength of 128.8 kPa and 132.59 kPa respectively and percentage increase in UCC strength was found to be 43.2 % and 47.4 % respectively with respect to unreinforced soil. Also maximum value of soaked CBR was observed to be 18.5% and 18.98 % for soil with 1.2 % CCF of length 2 cm and 3 cm respectively and increase in soaked CBR value was found to be approximately 4 times that of unreinforced soil. Thus optimum length of CCF that can be added to soil may vary from 2 cm to 3 cm at which the soil showed maximum gain in strength.
- Pavement thickness calculated based on soaked CBR values showed drastic reduction in thickness of up to 55 % for soil with 1.2 % CCF of length varying from 2 cm to 3 cm compared to unreinforced soil thus resulting in an economical construction.

REFERENCES

[1] Kundan Meshram, S. K. Mittal, P. K. Jain and P. K. Agarwal, "Application of coir geotextile in rural roads construction on black cotton soil subgrade," International journal of engineering and innovative technology, vol. 3(4), 2013, pp. 264-268.

[2] Dharmendra Kumar, Sudhir Nigam, Abhinav Nangia and Shailendra Tiwari, "California Bearing Ratio Variations in Soil Reinforced with Natural Fibres (A Case Study Bhopal Bypass Road)," International Journal of Emerging Technologies, vol. 6(2), 2015, pp. 95-104.

[3] M. Parag Chaple and A. I. Dhatrak , "Performance of Coir Fiber Reinforced Clayey Soil," The International Journal of Engineering and Science, vol. 2(4), 2013, pp. 54-64.

[4] Stuti Maurya, A. K. Sharma, P. K. Jain and Rakesh Kumar, "Review on Stabilization of Soil using Coir Fiber," International Journal of Engineering Research, vol. 4(6), 2015, pp. 296-299.

[5] P. K. Jayasree, K. Balan, Leema Peter and K. K. Nisha, "Volume Change Behavior of Expansive Soil Stabilized with Coir Waste," J. of Materials in Civil Engineering, vol. 27(6), 2015, pp. 1-8.

[6] R. P. Abhijith, "Effect of Natural Coir Fibers on CBR Strength of Soil Subgrade," International Journal of Scientific and Research Publications, vol. 5(4), 2015, pp. 1-4.

[7] O. S. Enokela and P. O. Alada, "Strength Analysis of Coconut Fiber Stabilized Earth for Farm Structures," International Journal of Advancements in Research & Technology, vol. 1(2), 2012, pp. 1-7.

[8] M. Rowell, S. Han and S. Rowell, "Characterization and factors effecting fiber properties," Nat Polym Agr Compos, 2000, pp. 115–134.

[9] Priyank Goyal, Ashutosh Shanker Trivedi and Manoj Sharma, "Stabilization of Black Cotton Soil with Blending of Coir Fiber," Recent Trends in Civil Engineering & Technology, vol. 5(2), 2015, pp. 8-11.

[10]S. Babu and K. Vasudevan, "Strength and stiffness response of coir fiber-reinforced tropical soil," J. of Materials in Civil Engineering, ASCE, vol. 20(9), 2008, pp. 571–577.

[11] S. Chauhan, S. Mittal and B. Mohanty, "Performance evaluation of silty sand subgrade reinforced with fly ash and fiber," Geotext Geomembr, vol. 26, 2008, pp. 429–435.

[12]A. Subaida, , E. Chandrakaran and N. Sankar, "Laboratory performance of unpaved roads reinforced with woven coir," Geotextile Geomembrane, vol. 27, 2009, pp. 204–21.

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

[14] R. R. Singh and Er. Shelly Mittal, "Improvement of Local Subgrade Soil for Road Construction by the Use of Coconut Coir Fiber," International Journal of Research in Engineering and Technology, vol. 3(5), 2014, pp. 707-711.

[15] Hejazi Sayyed Mahdi, Zadeh Mohammed Sheikh, Abtahi Sayyed Mahdi and Zadhoush Ali, "A simple review of soil reinforcement by using natural and synthetic fibers," Construction and Building Materials, vol. 30, 2012, pp. 100-116.