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Effect of Modification on Coir Fiber in Durability and Shear Parameters in Flyash Soil Mixture

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Abstract. Coir known as Cocos nucifera is a natural fiber known for its high lignin content which can be effectively made use of provided they are given suitable treatment. Major disadvantage of natural fiber is its polarity, as they are exposed to diverse pH, salinity, moisture and microbial attack it makes it incompatible with hydrophobic matrix. This study focuses on modification of coir fiber in improving the durability of fiber and thereby analyzing the improvement in the strength characteristics of weak Thonnakal soil with help of suitable sustainable material. With this view, Flyash was used as a sustainable material. The main reason behind the usage of industrial products is not only conserve the natural resources but a way of implementing two suitable materials to create a 'synergy' within the ecosystem. The present work involves modification of coir fiber using chemical treatment called quick precipitation method where nanoparticles of $Ca(OH)_2$ are impregnated into the pores and surface of the fiber. To study the effectiveness upon modification both untreated and modified coir fiber were subjected to neutral and alkaline pH conditions for alternate wetting and drying cycles and its durability was assessed by measuring individual fiber tensile load test. Different percentage of both untreated and modified coir fiber were added in 0.5 to 1.5% to the soil-flyash mix to study the strength improvement by conducting unconfined compressive test. The modified coir fiber withstood the adverse durability conditions much better comparing to untreated coir fiber. Nanomodification of fibers enhanced the tensile strength, interfacial adhesion and had good interaction with the soil flyash matrix. There by it improved the strength parameter of the soil.

Keywords: Coir, Quick precipitation, Durability, Tensile strength

1 Introduction

Soil is a construction material which has been used from time immortal. Thonakkal soil is building challenges to civil engineers in improving its properties based upon the need because of its poor mechanical properties. Hence this soil was adopted for the study. From the start of the industrial and economic revolution the most important issue in ahead of the industries is that the disposal of the industrial waste and it is a major issue within the current situation. The solution to the above problem is to use these industrial wastes to a most level for varied functions like road construction, highways and embankments. Therefore, flyash was used in the study and its optimum dosage to soil was found out. Many a lot of work has been studied and done on the strength deformation behavior and characteristics of fiber strengthened soil and it's been obtained that addition of fiber in soil improves the overall engineering properties of soil. Analyzing the addition of treated fiber in soil is less attempted. Natural fibers are lot more advantageous over synthetic due to their handleability, availability, low cost, and they are biodegradable hence will not cause disposal problem [1]. The effectiveness of fiber depends on the strength of fiber and its interaction at normal stress with the soil. Among the natural fibers, coir fiber is used in study which has highest lignin content of all. The tensile strength, durability of coir fibers can be altered by changing the cellulose packing and physical changes in it. The hydroxyl groups (OH) present in cellulose and their hydrogen bond formation is what makes coir fiber amenable to chemical modification. Quick precipitation method was chosen were the structure of coir fiber was altered using $CaCl_2$ and NaOH solution. Therefore the aim of the research is to identify the applicability of proposed modification on coir fiber by conducting tensile strength, water absorption and durability of individual fiber and analyzing the unconfined compressive strength of soil-flyash mix using modified fibers and thereby improving the soil properties of clay using naturally available material and waste material as additives.

2 Literature Review

Natural fiber and its application in geotechnical engineeering have attracted researches from past many years. Coir is a natural biodegradable fiber which has high amount of lignin content around 40-45% and cellulose content of 32-43% and hemi-cellulose content of 0.15-0.25% [2]. The coir fiber has individual fiber tensile strength more compared to other natural fiber. This individual strength of fiber will be mobilized and works together with the soil. Hence coir as reinforcement helps in improving the strength at an early stage and it provides good stability to soil because of high initial strength [3]. Addition of randomly distributed fibers to soil in improving geotechnical properties of soil has found to be beneficial. Test results from the graph indicated that unconfined compression test and indirect tensile test was higher at 1% addition of fiber which is clear from the graph showing higher slope at 1% fiber indicating more ductile behaviour in soil-lime mixture [4]. More fiber content dominated the fiber-fiber interaction and there by forming lumps and full contact with soil particles is not possible. 1 to 1.5% of coir fiber helped in reducing swelling and compressibility of soil to large extent [5]. Natural fibers are easily amenable to modifications done chemically due to hydroxyl groups present throughout it and its capability in forming hydrogen bond with the new particles. Many researchers have tried lot of surface coating and chemical treatment on fibers to improve its tensile strength and durability. The effect of gum resin coating on sisal fiber in shear and compressive strength on soil-fiber mix was investigated. Initially the UCC value was low but upon drying it improved. Thus, gum resin could improve the shear property and potential durability of fiber soil mix [6]. A study was analyzed on the comparison between CCl_4 and NaOH treated fiber on consolidated undrained test. The results showed that the peak deviator stress can be significantly improved by the presence of treated fiber and this improvement, cohesion, friction angle was highest for the one treated with CCl_4 [7]. Behavior of NaOH treated coir fiber in clay-pond ash mixture stabilized with cement was investigated. The rate of reduction in peak strength, stiffness was observed by the addition of treated coir fiber and the behavior of the composite changed to ductile nature which initially showed brittle behavior [8].

Nanotechnology is a recent approach of fiber modification by impregnating with nanoparticles onto the surface and pores, thereby introducing a new function onto the fiber surface and improving their mechanical properties. The effect of nanomodification in coir fiber through quick precipitation method and its effect on properties of soil are less attempted. The effect of reinforcement by nanomodification method in water hyacinth (WH) fibers by ferric hydroxide was studied. The water absorption capacity in treated fiber reduced as the surface changed to hydrophobic nature and also because it was less exposed to water surface. The treated fiber compared to unmodified WH fiber increased the tensile strength around 1.25 times. This improvement in tensile strength of modified fibers reflected in the increase of unconfined compressive strength of soil–fiber mix [9]. The effect of nanomodification on coir fiber through quick precipitation method in limed marine clay improved the tensile strength by 63% and 33% for $Al(OH)_3$ and $Fe(OH)_3$ modified fibers. The shear strength, cohesion intercept, frictional angle and durability increased by the modification of fiber [10].

3 Experimental Studies

3.1 Materials

The soil used in the study is collected from a depth of more than 5 m at Thonnakkal region at Trivandrum district. The soil properties are tabulated in Table 1. Flyash used in the study was collected from Tuticorin thermal power plant, India. Obtained Class F flyash was one with high siliceous content and low calcareous content according to IS 3812–1. Chemical composition of flyash is shown in Table 2. Coir fiber was collected from Neyyattinkara Coir Cluster, Trivandrum.

Table 1. Properties of soil

Property	Value
Colour	Pinkish white
Natural moisture content (%)	20
Specific gravity	2.5
Liquid limit (%)	46
Plastic limit (%)	25
Plasticity index (%)	21
Sand (%)	48
Silt (%)	14
Clay (%)	38
Maximum dry density (g/cc)	1.8
Optimum moisture content (%)	16.67
Unconfined compressive strength (kN/m^2)	28.49
California bearing ratio	2.68

Table 2. Properties of flyash

Chemical composition	Component (wt %)
$SiO_2 + Al_2O_3 + Fe_2O_3$	92.11
SiO_2	61.53
MgO	0.63
SO_3	0.82
Na_2O	0.39
Total Chlorides	0.008
LOI	0.95
Mean particle size	24µm
Fineness-specific surface (Blaine)	365 m^2/kg

3.2 Nano modification of coir fiber

The process is carried out through Quick precipitation method in which $Ca(OH)_2$ nanoparticles were loaded onto the surface of fibers and into the fiber pores. The procedure was carried out at ambient conditions of temperature and pressure. The procedure is as follows. Initially, 50 g of coir fibers was submerged into 500 ml aqueous solution of 0.5M $CaCl_2$ for 24 hours in order to uniformly fill the pores and the fiber surface with $CaCl_2$ solution. Then the submerged coir fibers were separated and incubated in a different beaker containing 500 ml of 0.5M sodium hydroxide solution. After that it was kept in ambient conditions for another 24 h. Here $Ca(OH)_2$ quickly precipitates as nanoparticles on the fiber surfaces and on its pores. Finally, the coir fibers were separated from sodium hydroxide solution and the unwanted residue such as NaCl and NaOH were removed washing with distilled water. At last fibers are dried at ambient room temperature. The chemical reaction undergoing during the process is represented through a chemical equation given below and the entire process of modification is depicted in the Fig 5.1

$$CaCl_2 + 2NaOH \rightarrow Ca(OH)_2 + 2NaCl \quad (1)$$

3.3 Testing programme

SEM analysis

The surfaces of chemically modified and unmodified coir fibers were examined with scanning electron microscope. For proper conduction the samples were sputtered by ejecting gold atoms. The properly sputtered samples were then positioned inside the SEM chamber for obtaining micrographs. The micrograph is obtained at 1000x magnification and the images are then digitally analyzed.

Water absorption

The water absorption was carried out by drying the fiber and immersing in distilled water in accordance with Saha et. al. (2012) [11] at room temperature. The portion of fiber was taken out from distilled water at fixed time interval. It was wiped with a cloth carefully to remove the excess water and the weighed to get the water absorption. This process is done for longer immersion time period until a steady value of water absorption is obtained.

Tensile test

Coir fibers were randomly selected and tension test was done as per ASTM D3379-75: 1989 in Universal Testing Machine at constant rate of extension of 5mm/min. Samples of uniform shape and average thickness 0.15 mm were tested at gage length of 20 $\pm$ 5mm.The tab was prepared according to ASTM D-3379-75 [12] as shown in figure 1. Strands of fiber were subjected to tensile test and average breaking load was taken, expressed in newtons (N).

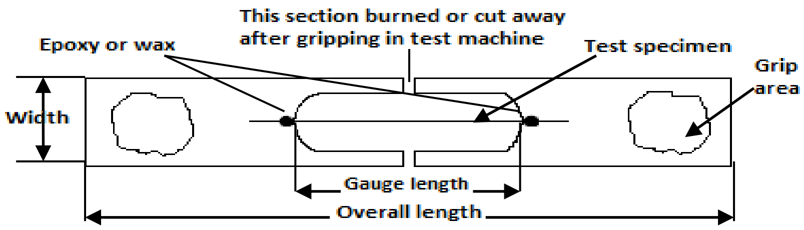


Fig. 1. Set up for holding individual fiber strand for tensile test

Alternate wetting and drying study

To study durability on untreated and modified coir fiber, alternate wetting and drying process were carried out, as per the condition mentioned in Sumi et al. (2018) [13]. The fiber samples were carefully weighed accurately and immersed in alkaline medium (pH 10.0) and neutral medium (pH 7.0) separately at room temperature (27 ± 1 °C) for seven days. For complete immersion of fiber in solution during the test period, fiber to solution ratio (by weight) was maintained 1:10 in a tray. Afterwards fibers were removed and placed on steel container to drain out excess water for 30mts and exposed to sunlight for seven days. 1 cycle was considered as 7 days of wetting and 7 days of drying and the tensile test of each set of fibers was determined at the end of each cycle. At the end of the durability test period, the fibers were taken out and unconfined compressive strength of sample reinforced with these fibers (at optimum percentage alone) was found out.

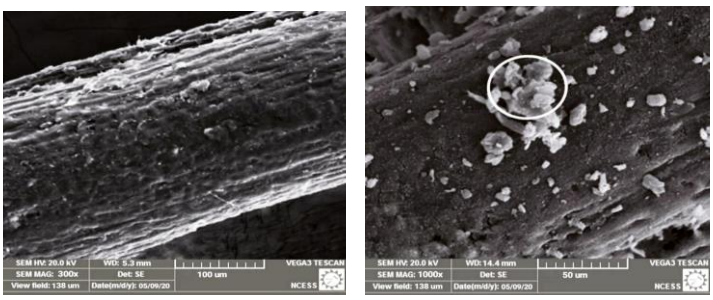
Unconfined compressive strength

UCC was done to find out the optimum flyash content and then different percentage of untreated and modified fiber (0.5, 1, 1.5%) were added to soil-optimum flyash mix to study the effect of modification of coir fiber in the mix. The samples are prepared at OMC and compacted to maximum dry density (MDD) obtained from compaction test. The samples were wrapped with plastic sheet and kept for curing for 7, 28 days prior to testing.

4 Results and Discussion

4.1 SEM analysis

Figure 2(a) and 2(b) illustrate the SEM image of the fiber surface of unmodified and modified coir fiber, respectively. It is seen that clusters of the proposed materials, at range of 110nm, changed the morphology into a relatively rougher surface



(a) (b)

Fig. 2. Surface structure of coir fiber (a) unmodified (b) $Ca(OH)_2$ modified

4.2 Water absorption

Treatment on fiber helped to reduce the hydrophilicity of the fiber. Figure 3 shows variation in water absorption with time. In chemical treatment, the lignin and water dissolvable constituents were initially removed to some extent and dissociable groups were partly blocked by the treatment which might have led to a reduction in swelling tendencies. There was 160% water absorption in untreated fiber which was reduced to 74% upon treatment.

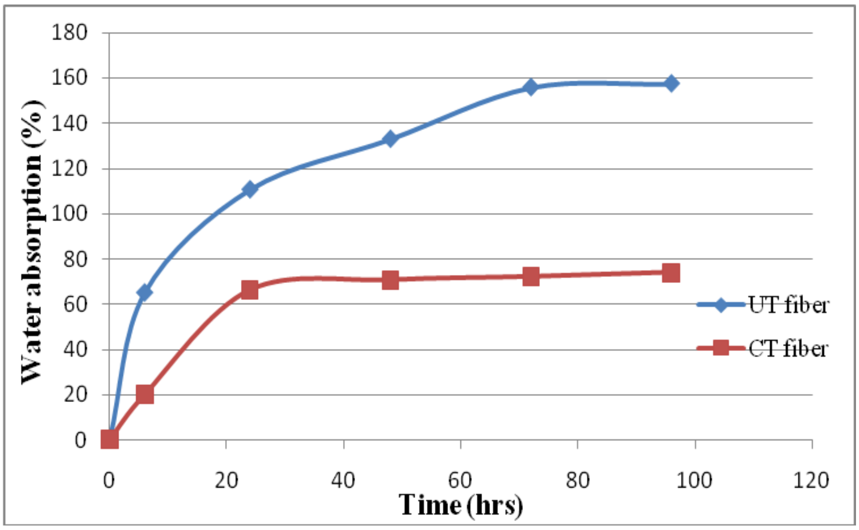


Fig. 3. Percentage variation in water absorption of fibers with time

4.3 Tensile test and elongation

As per IS 235-1989 code tensile test of individual fiber is expressed in terms of its breaking strength, i.e., the maximum force supported by a specimen until rupture in a tensile test [14]. It is usually expressed in newtons (N). The average tensile load of untreated was 6.58N and when it was chemically treated it increased to 8.05N ie 22.4% increase. Figure 4 shows the load extension graph of treated and untreated fiber. The extension of fiber was also found to increase. This is due to the nanoparticle formation within the fiber and this might increase the surface area of fiber acting as a single unit during tensile test.

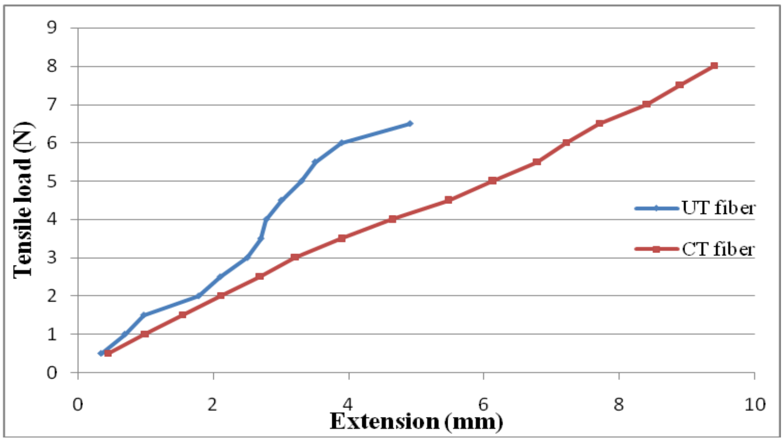


Fig. 4. Load extension curve of fibers

4.4 Effect of treated fiber on unconfined compression test

Addition of flyash showed a great increase in unconfined compressive strength with a brittle failure. Figure 5 shows the behavior of stress strain curve with addition of flyash. It showed a distinct failure stress at strain about 4.5- 6.5% after which they collapsed. 10% flyash showed maximum unconfined compressive strength which was 109.74kN/m^2. Hence that was taken as optimum. After that different percentage of fiber was added to soil-optimum flyash mix. The variation in UCC value upon addition of untreated (UT) and chemically treated fiber (CT) for 0, 7, 28 days is shown in figure 6. Fiber reinforced soil samples exhibited a ductile behavior more at 1% fiber content.

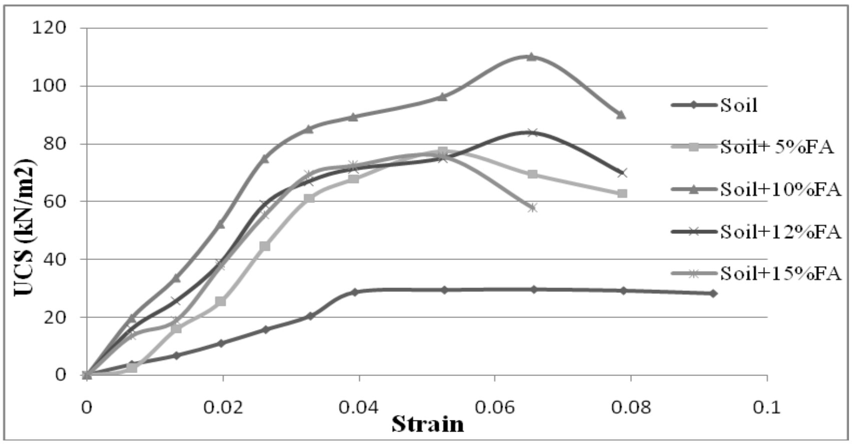


Fig. 5. Stress vs. strain curves for various flyash content

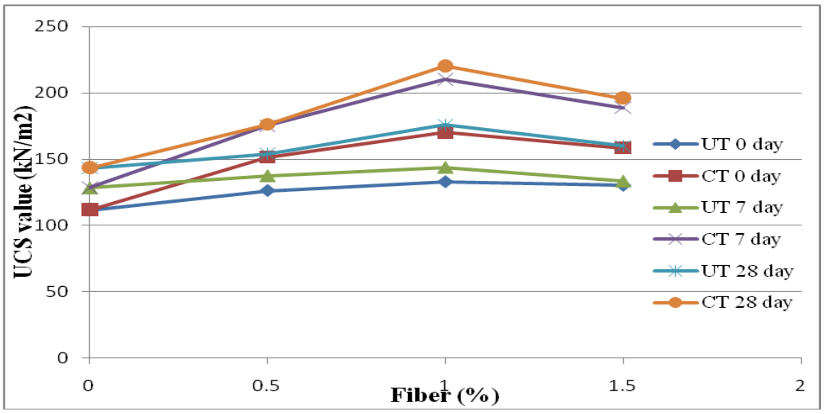


Fig. 6. Variation in UCS value upon addition of treated and untreated fiber

Above 1% fiber added, UCS value reduced, that might be due to large content of fiber adhere themselves and its contact and bond with soil becomes less. Addition of chemically treated fiber showed a higher unconfined compressive strength improvement in soil. Maximum value was observed at 28days curing at 1% fiber content. This increase is because of improved tensile strength of fiber upon treatment improved the overall strength of soil. Upon curing the UCS value also increased which might be due to the of crystallization of nanoparticles within the surface and cellulosic pores of fiber and the surface of fiber changed the morphology to a rougher surface, as evident in SEM analysis, which led to more interfacial adhesion with soil and frictional resistance to force application improvement and consequently the strength of soil-flyash-fiber mixture increased.

4.5 Effect of treatment on durability of fiber and UCC value

The fiber was subjected to accelerated degradation study and the tensile load was noted at the end of each cycle. Percentage reduction in tensile load at neutral and alkaline medium is expressed in Figure 7. At the end of fifth cycle there was 27.38% decrease for untreated fiber at neutral medium and 30.39% decrease at alkaline medium whereas upon treatment the rate of decrease was less, which was 8.11% under neutral medium and 12.52% under alkaline medium. The 1% of degraded fiber samples (optimum percentage from UCC test) obtained at the end of fifth cycle of durability study was added to soil to study the effect of decrease in UCC value. The values are tabulated in table 3. The untreated fiber in alternate wetting and drying cycle test had faster loss in tensile load compared to treated fiber. It is because more water penetrates during wetting cycle and more released during drying cycle causes hydration-dehydration. This behavior can be extended for a longer immersion period of time. Under chemical treatment the surface morphology changed and it reduced the dissolution of lignin especially in alkaline medium. The enhanced tensile strength may be due to the crystallization of the $Ca(OH)_2$ particle into the cellulosic pores and available capillaries present within the fiber. Alkaline medium resulted in faster lose of strength which can be due to the capacity of alkali to remove the waxy and oily coating of fiber and exposing them to moisture intake. Treatment on fiber showed sufficient durability and they were able to resist the adverse pH condition compared to untreated fiber. Thus from results it is clear that $Ca(OH)_2$ impregnation into the fiber was found to be effective in its potentiality for long term use.

Table 3. Tensile load of fiber and UCC of soil sample by the addition of fibers subjected to alternate wetting and drying cycles

Fiber type	Untreated fiber		Chemically treated fiber	
	Neutral medium	Alkaline medium	Neutral medium	Alkaline medium
Tensile load of fiber at the end of fifth cycle (N)	4.778	4.58	7.397	7.042
% decrease	27.38	30.39	8.11	12.5
UCC value (kN/m^2) (Soil+10%flyash+1%fiber)	120.11	113.98	162.01	158.9
% decrease	10	14	2	4

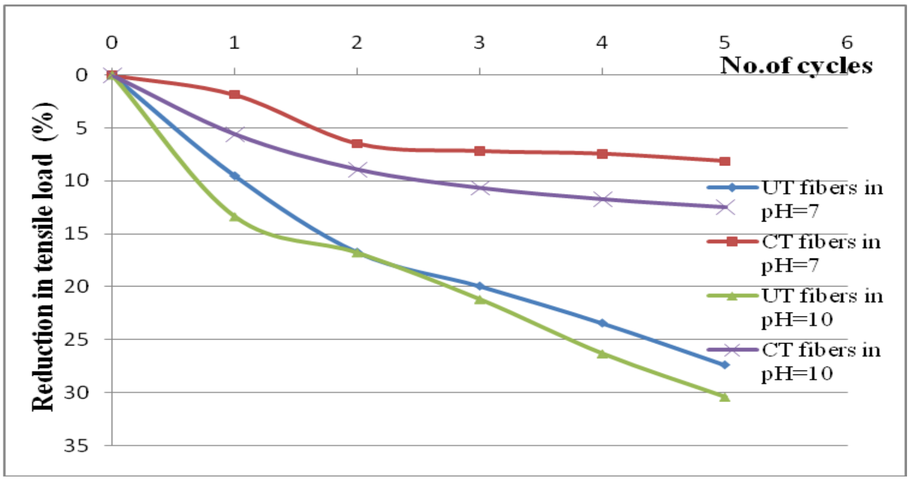


Fig. 7. Percentage reduction in tensile load with cycle for fibers in neutral and alkaline medium

5 Conclusions

1. $Ca(OH)_2$ nanoparticle impregnation was tested for improving the durability or extending the life of coir fiber under adverse condition. Suitably pretreated coir fiber

by the above process showed much retention of its tensile strength after different cycles under neutral and alkaline medium.

2. Percentage reduction in water absorption up to about 74% from 160% could be attained with this treatment.
3. Modification of fiber did not reduce the mechanical property of fiber. There was 22.4% increase in tensile load upon treatment.
4. The morphology of fiber changed to a rougher surface; thereby it provided better adhesion and interlocking ability with the soil.
5. The optimum flyash was obtained to be 10%, hence the combination of 10% flyash and 1% treated fiber showed the maximum unconfined compressive value. Its effect of curing was also studied which showed improvement in UCS value
6. Addition of degraded modified fiber obtained at the end of durability test showed less decrease in UCC value compared to degraded untreated fiber

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