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Influence of random inclusion of treated sisal fibres on the unconfined compressive strength of highly compressible clay

E.R. Sujatha*, **E. Lakshmipriya, A.R. Sangavi, and K.V. Poonkuzhali**

School of Civil Engineering, SASTRA University, Thanjavur-613401, Tamilnadu, India.

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KEYWORDS

Unconfined compressive strength;
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Sisal fibre;
Post peak strength;
Failure pattern.

Abstract. Reinforcement in the form of strips, grids, and fibres enhances engineering properties of soil. In this study, an attempt has been made to use treated sisal fibres to reinforce the soil so that unconfined compressive strength can be enhanced. The compaction characteristics, stress-strain behavior, strength and failure patterns of the unreinforced, and reinforced sisal fibre reinforced soil were investigated. The inclusion of sisal fibres increases the strength and modifies compressibility and permeability of the soil. The results of the study show that the addition of sisal fibres to soil causes an increase in optimum moisture content and a decrease in dry density. The unconfined compressive strength and post-peak strength of the reinforced soil increase with fibre content of 2%. Failure pattern shows that fibre has a significant control over the development of cracks. Fibre inclusion suppresses the development of long cracks as they act as tension reinforcements. The use of sisal fibres gives the advantage of an eco-friendly material that aids sustainable development, in addition to the beneficial modification of soil properties.

1. Introduction

Reinforcing soil is an effectual and commonly adopted practice to enhance the capacity of the ground as it is an economic alternative, with ease of adaptation and reproduction. It improves the shearing resistance of the soil and, thereby, helps enhance the bearing capacity of the soil. It also facilitates the modification of permeability and compressibility of the soil and, hence, finds application in filter design and drainage control. Fibres made up of artificial polymer compounds, metal fibres/strips, etc. are most commonly used as reinforcement materials since they possess uniform material properties, and the results are reproducible.

Lately, natural fibres have been also used to reinforce soil and are preferred to artificial fibres for a number of reasons, some of which are their affordable cost, bulk availability, strength, and eco-friendly nature [1]. The use of natural fibres also aids in sustainable development as it adds commercial value to these fibres, which otherwise are useless and are to be disposed by either dumping or incineration. Both of these processes result in polluting the ground and water. However, the use of such fibres also has inherent drawbacks, such as bio-degradability and non-reproducibility of results. Chemical coating of polymer compounds on natural fibres [1] is an effective solution to avoiding the problem of bio-degradability in natural fibres.

Traditional reinforcement embraces inclusion of

*. *Corresponding author. Tel.: +91 4362 264101; Fax: +91 4362 264120*
E-mail addresses: r.evangelin@gmail.com (E.R. Sujatha); priyalakshmi152@gmail.com (P.E. Lakshmi); sangaviaraghavan@gmail.com (A.R. Sangavi); poonguzhali17@gmail.com (K.V. Poonkuzhali)

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continuous strips, fabrics, or grids in a sequential pattern into the soil; however, a modification of this pattern by random inclusion can help create a unitary coherent soil matrix by means of interlocking of particles [2]. Random inclusion of fibres also facilitates maintaining the strength isotropy and preventing the possible development of failure planes along the parallel orientation of the reinforcement [2,3].

A plethora of natural fibres are available for soil reinforcement; however, the most commonly researched fibres are bamboo, jute, and coir [4]. A number of authors, like Gray and Ohashi [5], Prabakar and Sridhar [4], Lekah [6], Vishnudas et al. [7], Adili et al. [2], and Patel and Singh [8], studied the effect of fibre inclusion on soils, particularly natural fibres and reported favorable improvement of engineering properties of soil. Triaxial test, direct shear strength test, unconfined compressive strength test, and CBR test were used to understand the impact of fibre-reinforcement on shear strength of soil; the results show betterment of strength through fibre inclusion [2,9,10]. The characteristics of the fibre and soil have a significant influence on the behavior of clay-fibre matrix [11,12]. Studies have also shown that fibre inclusion increases the peak compressive strength and controls the swelling behaviour of clay [12,13].

In line with these literature reviews, an attempt was made to study the impact of random inclusion of discrete sisal fibres in highly compressible clay soil. Limited scope of research has been carried out using sisal fibres. These studies deal with the influence of sisal fibres on compaction characteristics and strength of the soil. This study focuses on the effect of fibre inclusion on stress-strain behavior, post peak strength, and failure pattern, in addition to compaction characteristics and unconfined compressive strength. A complete spectrum of reinforced soil behavior before, during, and after failure is reported. This will help assess the choice of using sisal fibres to modify soil properties of highly compressible clay; in other words, it can be used to either improve strength or modify permeability and compressibility.

2. Materials

2.1. Soil

Clay soil for the study was obtained from Kattur, Tiruchirapalli district, Tamilnadu. The soil was retrieved at 1.5 m below ground level. A test trench was made to a depth of 1.5 m. It was observed that up to 0.6 m below the ground level, the soil was loose and unconsolidated. It also showed the presence of organic content like dried leaves, twigs, etc. However, beyond 0.6 m, the soil was uniform clay, dark brown in colour with a characteristic pungent odour. A similar trench made up to 2 m below ground level also showed a comparable soil profile. It was decided to retrieve samples at a 1.5 m for convenience.

The index and engineering properties of unreinforced soil are depicted in Table 1. The low specific gravity indicates the possible presence of organic matter in the soil. The soil is highly plastic (plasticity index > 17) and falls in the highly compressible clay category (liquid limit > 60) as per both the Unified Soil Classification System and Indian Standard Soil Classification system. The compaction characteristics of the soil are typical as that of a cohesive soil with high optimum moisture content [4,14,15].

2.2. Sisal fibres

Sisal fibre is a long, creamy white to yellow colored fibre derived from leaf. The average length of the fibre varies between 0.6 and 1.2 m. These fibres are coarse, strong, and resilient. They also have the ability to stretch, good insulation properties, resistance to damage under bacterial action and deterioration in saltwater [16]. The fibre lies along the length of the leaf, concentrated near the surface of the leaf, and is long and strong

Table 1. Index and engineering properties of the soil.

Serial number	Soil properties	Values
1	Specific Gravity	2.09
2	% silt	10 %
3	% clay	70 %
4	Liquid limit	65.5
5	Plastic limit	28.65
6	Plasticity index	36.85
7	Soil classification	CH
8	Optimum moisture content (%)	18
9	Maximum dry density (kN/m^3)	15.19
10	Unconfined compressive strength (kN/m^2)	152
11	Coefficient of compression	0.4995

Table 2. Properties of sisal fibres.

Serial number	Properties of sisal fibers	Values
1	Specific gravity	0.962
2	Unit weight (kN/m^3)	962
3	Initial moisture loss (%)	3.5
4	Modulus of elasticity (GPa)	15
5	Average diameter (μm)	300
6	Density (g/cm^3)	1.45
7	L/D ratio	65
8	Lignin content (%)	5
9	Cellulose content (%)	85-88
10	Elongation at break (%)	2-2.5

in this region. The fibres in the inner region of the leaf are weak and discarded during processing. The treated sisal fibre used in this study was procured as fibre from Tirunelveli district of Tamilnadu, India. The choice of the fibre is attributed to its strength, rigidity, availability, and economy. In addition, essentially, as a renewable natural resource, it is bio-gradable. It integrates into the soil after its life without causing any adverse effects on the soil environment. Thereby, it forms a part of sustainable development and is a step forward in preventing soil pollution. The properties of the sisal fibre used for the study are presented in Table 2.

3. Sample preparation and testing

Soil samples were dried in a thermostatically controlled oven at temperatures between 100° to 105°C, and then pulverized and sieved through appropriate sieve for laboratory testing. Sisal fibres of an average 300 μm diameter and 20 mm length were included randomly into the oven dried soil samples at percentages of 0.1%, 0.5%, 1%, 1.5%, 2% and 2.5% and thoroughly mixed. The choice of percentage of sisal fibre used for reinforcing soil is based on the similar works of various fibre reinforcements [2,4,8,9,14,17]. Standard proctor and unconfined compressive strength tests were conducted on the unreinforced and reinforced soils, with the above-said fibre contents. Testing procedures were in accordance with IS: 2720 [15] recommendations. Samples for the unconfined compressive strength were prepared at the optimum moisture content.

4. Results and discussions

Highly compressible clay soil is reinforced by random inclusion of sisal fibres at various fibre contents between 0.1% and 2.5% by weight in an attempt to study the influence of sisal fibre reinforcement on the compaction characteristics and strength of the selected clay soil.

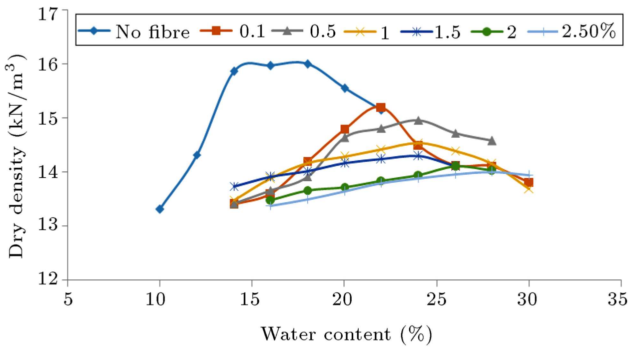

Figure 1. Effect of random inclusion of sisal fibres on the compaction characteristics.

4.1. *Effect of sisal fibres on compaction characteristics of clay*

Results of the light compaction test reveal that the profiles of compaction curves (Figure 1) for unreinforced and reinforced soils with sisal fibres are analogous. Dry density shows an increase with the increase in moisture content until the Optimum Moisture Content (OMC) is reached. Besides, a further increase in water content causes a decrease in dry density for all cases of fibre inclusion. There is a perceptible shift in the compaction curves to the right in general, indicating the rise of optimum water content with the addition of more fibres (Figure 1). It is observed from Figure 1, the compaction curves depict the same trend for any percentage of fibre reinforcement, and compaction characteristics of the unreinforced soil are significantly different from those of reinforced soil. It is clearly visible that fibre controls the compaction behavior of the reinforced soil [4]. The compaction curves appear much flatter beyond 1.5% fibre inclusion, indicating that the modification of dry density is not appreciable with the rise of water content beyond 1.5% fibre inclusion [8]. In addition, Figure 1 clearly depicts that the compaction curves are flatter and tend to overlap at higher percentages of fibre inclusion. The nature of the compaction curves (Figure 1) indicates that fibre inclusion causes a parallel orientation of the soil particles, modifying the compressibility behavior of the soil.

4.1.1. Optimum Moisture Content (OMC)

OMC of unreinforced soil is 18% and increases (Figure 2(a)) to a maximum of 28% at 2.5% fibre inclusion. OMC increases initially with fibre inclusion till 0.5%, yet remains unchanged between 0.5% and 1.5%, and then again shows an appreciable increase with further addition of fibres. The subtle discrepancies in the increase in water content can be attributed to the random inclusion of fibres over which there is very little control and the nature of the fibres to encourage a parallel arrangement of soil particles. The increase in OMC can be attributed to the presence of water in

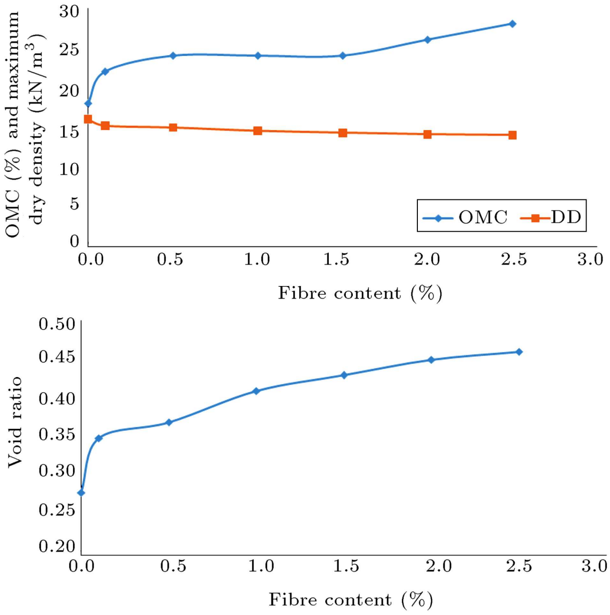

Figure 2. (a) Influence of sisal fibre inclusion on OMC and maximum dry density. (b) Impact of sisal fibre inclusion on void ratio.

the sisal fibres and the capacity of the sisal fibres to absorb water [8]. A similar trend is observed when soil is reinforced with various fibres like papyrus [2], sisal fibres [2,17], polyester fibres [9], polypropylene [14], etc. This also indicates that the fibres have a tendency to absorb water and are preferable to coat them with water repellents before using them as soil reinforcement.

4.1.2. Maximum dry density

A decrease in maximum dry density is observed with the increase in percentage of fibre inclusion (Figure 2(a)). The low specific gravity of fibre reduces the unit weight of the reinforced soil and the lesser resistance offered by the fibres to compaction causes reduction in the dry density as the fibre content increases [2,9,14]. Interaction between the fibre and soil controls the compaction behavior of the reinforced soil. The inclusion of fibre increases the tendency of the soil structure to arrange itself in a dispersed fashion as the fibres orient themselves in the horizontal plane during compaction. An excess of fibres also aids the sliding of soil particles in reducing the dry density and increasing the water content.

Void ratio increases with the inclusion of fibres; however, this increase in the void ratio with random fibre inclusion is not appreciable (Figure 2(b)). It varies between 0.28 for unreinforced soil and 0.46 for the maximum fibre inclusion of 2.5%. The inclusion of fibres produces non-uniform distribution of voids preventing denser packing, again leading to a reduction in dry density. This effect is more profound at higher percentages of fibre inclusion.

4.2. Effect of sisal fibres on the strength of clay

Unconfined compressive strength of soil reinforced with sisal fibre represents a change in strength with the random inclusion of fibres. The unconfined compressive strength is defined as the maximum load per unit area or the load per unit area at 15% axial strain, whichever occurs first during the performance of a test [8]. Fibre was mixed thoroughly with soil in dry state at various proportions before preparation of cylindrical sample. Cylindrical soil samples of 38 mm diameter and 76 mm height [15] were prepared at the optimum moisture content and tested at a strain of 1% per minute. Unconfined compressive strength of soil at 0.1% fibre inclusion decreases by 36%; however, on further increase in fibre content, it is observed to increase till 2% (Figure 3). The increase in unconfined compression strength with the increase in fibre dosage can be attributed to the increase in surface area, which provides more surface for soil-fibre interaction [8]. The increase in the unconfined compressive strength of fibre-reinforced soil with the increase in fibre content can also be attributed to the increase in number of fibres intersecting the failure planes, the increase in tensile strength of the soil, and improved interlocking between the fibres and clay soil [10]. At 2% fibre inclusion, a maximum unconfined compressive strength of 300 kPa is observed; however, with further increase in fibre content, the compressive strength considerably decreases and goes lower than that of the unreinforced soil. The decrease in the strength of soil with excessive fibre inclusion can be attributed to fibre clumping resulting from the improper mixing between soil and fibre [8,9]. Excessive fibre also leads to a decrease in contact between soil particles, reducing dry density and the cohesion in soil and also increasing water content [10,18]. This increases the ease of sliding between soil particles, resulting in the reduction of compressive strength. Similar results are observed for soil treated with various fibres [2,4,9,17]. The studies [2,4,9,17] report an increase in unconfined compressive strength

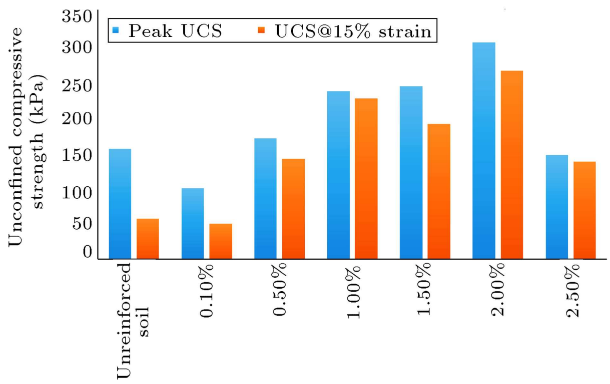

Figure 3. Impact of random fibre inclusion on the strength.

with an increase in fibre content, indicating that the addition of fibres increases strength and capacity of the soil to withstand compressive forces.

4.3. Effect of sisal fibres on stress-strain behaviour of clay

Stress-strain behavior of the sisal fibre reinforced soil is presented in Figure 4. The curves display a more ductile behavior characterized with lesser loss of post-peak shear strength. The rate of loss of post-peak shear strength shows a decrease with an increase in fibre content. This shows that the soil exhibits more ductile behavior at higher fibre content. The failure pattern of the specimens is consistent with the ductile behavior and also consistent with the results of the works of other authors like Maher and Gray [11], Michalowski and Zhao [19], Zornberg [20], and Malekzadeh and Bilsel [14], who worked on different fibres to reinforce the soil. The behavior of the soil at lower strain, i.e., the initial portion of the stress-strain curve, is distinctly similar for unreinforced and reinforced soils. The failure of fibre-reinforced soil takes much longer time than that of unreinforced soil, indicating the increase in ductile nature of the reinforced specimen, i.e., the failure stress, and the increase in the corresponding strain with the addition of fibres.

Soil resists the applied load at small strains; however, shear strength mobilized at higher strain levels is influenced by the presence of fibres [14]. The results show that when fibre content increases, strain at peak strength also increases. The strain at peak strength was 11.25% for unreinforced soil; however, in specimen prepared with 2% fibre content, the ultimate strength was observed at the strain level of 33%. This indicates that fibre induced tension can be mobilized at high shear strain rates only. Energy absorption capacity is calculated from the area under the stress-strain curve up to 15% strain. It is a measure of toughness of the fibre-reinforced soil. Either an increase in failure strain or peak strength or both can lead to an increase in the absorbed energy [8]. The increase in fibre content results in the increase in absorbed energy (Figure 4).

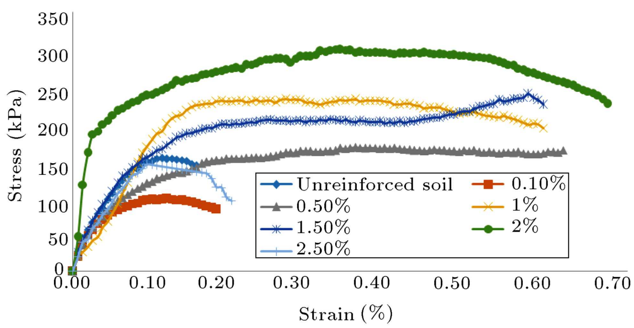

Figure 4. Stress-strain behaviour of the unreinforced and reinforced soil.

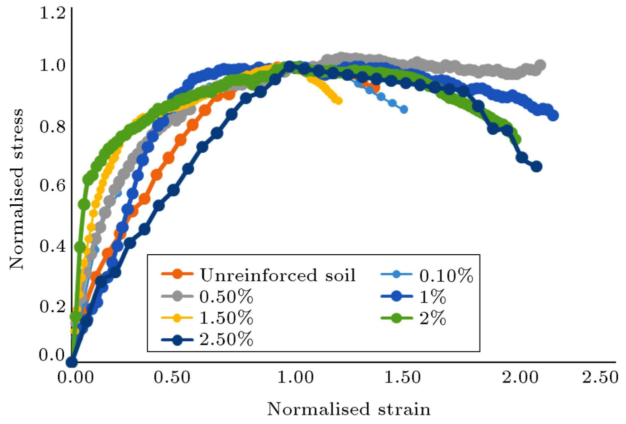

Figure 5. Normalized stress-strain curve for unreinforced and reinforced soil.

4.4. Post peak behaviour

A normalized stress-strain curve reveals the effect of reinforcement provided by the fibres in the post-peak region [8]. The stress and strain is normalized with respect to that at peak load. The normalized stress-strain curve for the unreinforced and reinforced soils is presented in Figure 5. The post-peak behavior of soil shows a gradual decrease beyond peak for reinforced soil, indicating an improvement of strength in the post-peak region. It is observed that post-peak strength is better for the reinforced soil than for the unreinforced soil. This indicates that reinforcement of soil with sisal fibres has improved the toughening characteristics of the soil, particularly in the post peak region.

4.5. Failure strain

The effect of fibre inclusion on the failure strain studied using strain ratio is shown in Figure 6. Strain ratio is the ratio of the strain corresponding to unconfined compressive strength of soil reinforced with sisal fibre and the unreinforced soil [8]. Strain ratio increases with the augmentation in fibre content, indicating a good improvement in ductility of the soil specimen with the addition of fibres up to 2%, but decreases beyond that. The addition of fibres restricts the movement of soil; moreover, as the fibre content increases, the quantum of fibres across the failure plane increases, resulting in higher resistance to deformation of the soil,

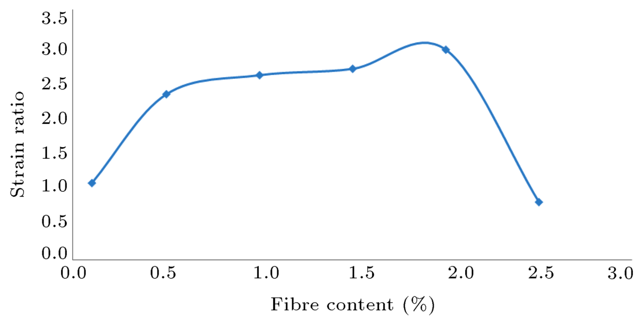

Figure 6. Effect of fibre content on failure strain.

along the failure plane and increased failure strain [8]. This results in the amplification of strength and failure strain of reinforced soil. In addition, while shearing, the load from the soil is shared by the fibres which increases the tensile stress in the fibres. The fibres interlock and intertwine with the soil resisting movement, thereby improving the soil's strength. Therefore, fibre inclusion improves not only the strength of the soil, but also the deformation response. The decrease can be attributed to fibre clumping, which causes non-uniform distribution of fibres with the increase of fibre content beyond 2%.

4.6. Failure characteristics of sisal fibre treated soil

Inclusion of fibre significantly influences the failure mode in soil samples. Unreinforced soil failed by cracking mode expressing brittle behavior with the formation of noticeable cracks from bottom to the middle of soil sample (Figure 7(a)). Most cracks are nearly vertical and exhibit small irregular inclinations.

Sisal fibre reinforced soil takes a considerably longer time to fail than unreinforced soil. This points to the increased ductility on fibre reinforcement. Fracture mode of failure is the most prominent failure mode [21]. Multiple small inclined irregular tension cracks develop with the increase in loading until failure, but the presence of fibres in the soil resists the development of these cracks by holding the soil together resulting in higher failure strain (Figure 7(b)-(f)). The availability of larger surface area for fibre - soil interaction inhibits the development of the tensile crack from propagating further and the axial load is transmitted further in crushing (shortening) of the soil specimen [22]. Fibre reinforced soil has a "poststrong" characteristic, that is, it has a high residual strength at failure and even while cracks develop, the friction between the soil and fibres increases, leading to slower development and progress of further cracks [23]. The treated soil is plastic in course of its failure. Shortening of the sample is observed to a significant level with the increase in the fibre content. This trend is reversed and the sample reverts to a similar behavior of the unreinforced soil when the fibre content is increased to 2.5%. Excessive fibre leads to fibre clumping resulting in lesser surface area for fibre-soil interaction beyond 2% fibre inclusion, and this results in the cracking mode of failure at 2.5%.

At higher fibre content, a significant single failure plane is not observed. The gradual increase in axial strain in compression leads to the development of a network of small cracks, forming progressive failure zones with a barreled shape of the specimen [8]. Fibres confine the soil particles leading to an increase in its strength. The inclusion of fibre, thus, changes the brittle nature of the soil to a more plastic nature which improves with the fibre content till 2% fibre inclusion. Fibre also bridges the gap preventing the formation of wider and longer cracks.

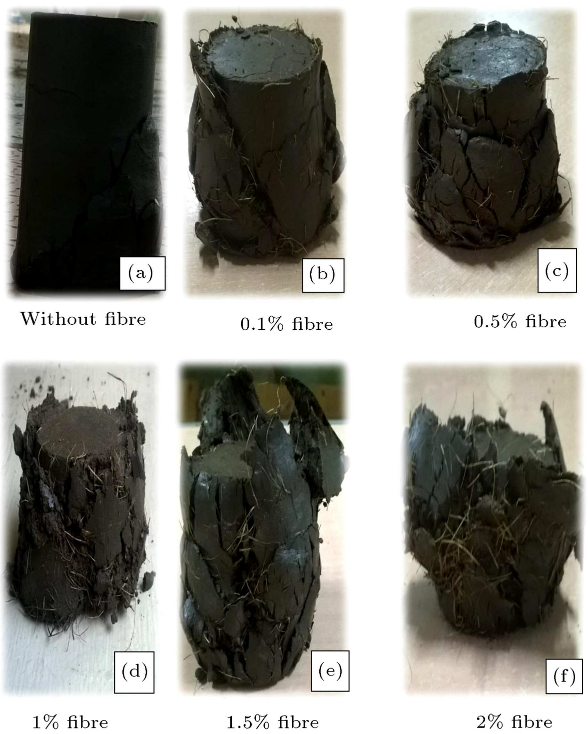

Figure 7. Failure pattern observed in the unreinforced and reinforced soil samples.

5. Conclusions

The results of comprehensive experimental study illustrate the unconfined compressive strength and stiffness response of highly compressible clay reinforced with sisal fibre. The following concluding remarks can be drawn from the study.

Random inclusion of sisal fibres controls the compaction behavior of the reinforced soil. A distinct shift to the right side of optima of the compaction curve is observed, indicating a more parallel orientation of soil-fibre matrix because of the influence of fibre. Fibre content increase also causes an increase in optimum moisture content and a decrease in maximum dry density. Fibre inclusion is observed to increase the unconfined strength of the soil. The maximum increase in strength is observed at 2% fibre addition. The results of the study indicate that the optimum percentage of sisal fibre reinforcement is 2% at which an increase in strength of nearly 50% is observed. The addition of fibres also induces a more ductile behavior of the treated soil, which is evident from the stress-strain response of the soil. The post-peak strength of the soil also shows an improvement with fibre reinforcement, implying that toughness of clay is improved with the addition of fibres. Failure of the sisal fibre reinforced soil occurs at higher strain rate, indicating that fibre reinforced soil has a higher capacity to absorb energy. The failure pattern observed in the fibre-reinforced soil underlines this fact. Failure pattern of reinforced soil gradually transforms to plastic bulging with a network of small cracks and no apparent shear plane at failure. The mode of failure of the reinforced soil indicates that fibres resist the formation of tension cracks. Fibres bridge the crack, thereby arresting the propagation of cracks. In addition to the improvement in strength and behavior of soil, use of natural fibres, such as the sisal fibres, for improving soil can also aid sustainable development and minimize ground contamination and pollution.

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References

1. Mandal, J.N. and Murti, M.V.R. "Potential for use of natural fibres in geotextile engineering", *Proc. of the International Workshop on Geotextiles*, pp. 251-254 (1989).
2. Aqeel Al Adili, Rafig Azzam, Giovanni Spagnoli, and Joerg Schrader "Strength of soil reinforced with fiber materials (papyrus)", *Soil Mech. Found Eng.*, **48**(6), pp. 241-247 (2012).
3. Chakraborty, T.K. and Dasgupta, S.P. "Randomly reinforced fly ash as foundation material", *Proc. of the Indian Geotechnical Conf.*, Madras, India, pp. 231-235 (1996).
4. Prabakar, J. and Sridhar, R.S. "Effect of random inclusion of sisal fiber on strength behaviour of soil", *Constr Build Mater.*, **16**, pp. 23-131 (2002).
5. Gray, D.H. and Ohashi, H. "Mechanics of fiber reinforcement in sand", *J. Geotech. Eng. ASCE*, **109**(3), pp. 335-353 (1983).
6. Lekha, K.R. "Field instrumentation and monitoring of soil erosion in coir geotextiles stabilized slopes a case study", *Geotext. Geomembr.*, **22**(5), pp. 399-413 (2004).
7. Vishnudas, S., Savenije, H.H.G., Zaag, P.V.D., Anil, K.R., and Balan, K. "The protective and attractive covering of a vegetated embankment using coir geotextiles", *Hydrol. Earth Syst. Sci.*, **10**, pp. 565-574 (2006).
8. Patel, S.K. and Singh, B. "Unconfined compressive strength behaviour of fibre-reinforced lateritic soil", *J. Civil Eng. Environ. Tech.*, **1**(4), pp. 93-98 (2014).
9. Kumar, A., Walia, B.S., and Mohan, J. "Compressive strength of fibre reinforced highly compressible clay", *Constr Build Mater.*, **20**, pp. 1063-1068 (2006).
10. Mirzababaei, M., Miraftab, M., Mohamed, M., and MacMohan, P. "Unconfined compression strength of reinforced clays with carpet waste fibres", *J. Geotech. Geoenviron.*, **139**(2), pp. 483-493 (2013).
11. Maher, M.H. and Gray, D.H. "Static response of sands reinforced with randomly distributed fibers", *J. Geotech. Eng. ASCE*, **116**(11), pp. 1661-1667 (1990).
12. Casagrande, M.D.T., Coop, M.R., and Nilo Cesar Consoli, N.C. "Behaviour of a fibre reinforced bentonite at large shear displacement", *J. Geotech. Geoenviron.*, **132**(11), pp. 1505-1508 (2006).
13. Al-Wahab, R.M. and El-Kedrah, M.M. "Using fibres to reduce tension cracks and shrink/swell in compacted clays", In: *Geoenvironment 2000, Geotechnical Special Publication No. 46*, Y. B. Acar and D. E. Daniel, Eds., ASCE, Reston, **1**, pp. 791-805 (1995).
14. Malekzedah, M. and Bilsel, B. "Effect of polypropylene fiber on mechanical behaviour of expansive soils", *EJGE*, **17**(A), pp. 55-63 (2012).
15. IS: 2720, *Compendium of Soil Testing*, Bureau of Indian Standards, New Delhi (2006).
16. Joseph, K., Filho, R.D.T., James, B., Thomas, S., and De Carvalho, L.H. "A review on sisal fibre reinforced polymer composites", *Rev. Bras. Eng. Agríc. Ambient*, **3**(3), pp. 367-379 (1999).
17. Jiesheng, L., Juan, Z., and Lin, X. "Deformation and strength characteristics of sisal fibrous soil", *EJGE*, **19**, pp. 1585-1594 (2014).
18. Anggraini, V., Asadi, A., Farzadnia, N., Jahangirian, H., and Bujang B.K. Huat. "Reinforcement benefits of nanomodified coir fiber in lime-treated marine clay", *J. Mater. Civ. Eng.*, **28**(6), p. 06016005 (2016).
19. Michalowski, R.L. and Zhao, A. "Failure of fiber-reinforced granular soils", *J. Geotech. Eng. ASCE*, **122**(3), pp. 226-234 (1996).
20. Zornberg, J.G. "Discrete framework for limit equilibrium analysis of fibre-reinforced soil", *Geotechnique*, **52**(8), pp. 593-604 (2002).
21. Wu, Y., Li, Y., and Niu, B. "Assessment of the mechanical properties of sisal fiber-reinforced silty clay using triaxial shear tests", *Scientific World J.*, 2014, Article ID 436231, 9 pages (2014).
22. Tang, C., Shi, B., Gao, W., Chen, F., and Cai, Y. "Strength and mechanical behavior of short polypropylene fiber reinforced and cement stabilized clayey soil", *Geotext. Geomembr.*, **25**, pp. 194-202 (2007).
23. Gao, L., Hu, G., Xu, N., Fu, J., Xiang, C., and Yang, C. "Experimental study on unconfined compressive strength of basalt fiber reinforced clay soil," *Adv. Mater. Sci. Eng.*, 2015, Article ID 561293, 8 pages (2015).

Biographies

Evangelin Ramani Sujatha is an Associate Professor in the School of Civil Engineering, SASTRA

University, Thanjavur. She has completed her BE in Civil Engineering in Madras University in 1997, ME in Soil Mechanics and Foundation Engineering in College of Engineering, Guindy, Anna University in 1999, and PhD in SASTRA University in 2008. She has worked extensively on the suitability of unconventional fibres and ashes for improving soil properties. She has also extensively worked on landslides, susceptibility mapping and GIS.

Elangovan Lakshmi Priya completed her BTech Civil Engineering in SASTRA University in 2015. She has a keen interest in geotechnical engineering, particularly soil improvement techniques, particularly the use of unconventional materials for stabilizing soil.

Raghavan Sangavi completed her BTech Civil Engineering in SASTRA University in 2015. Her area of interest encompasses geotechnical engineering and pavement design.

Vijayakumar Poonkuzhali completed her BTech Civil Engineering in SAS in SASTRA University in 2015. Her area of interest encompasses geotechnical engineering and applications of engineering in software development.