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Enhancing Soil Strength Using Sisal Fibers And Cement: An Experimental Approach

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Abstract:
The improvement of soil strength is a critical aspect of geotechnical engineering, especially for weak or problematic soils. This study investigates the potential of natural fiber reinforcement—specifically sisal fibers—in enhancing the strength characteristics of cement-stabilized soil. An experimental program was conducted wherein unconfined compressive strength (UCS) tests were performed on soil specimens reinforced with varying sisal fiber contents (0.4% and 0.8% by weight), fiber lengths (2.5 mm, 5 mm, and 10 mm), and cement contents (4%). The specimens were tested under three distinct conditions: natural, moist, and soaked, to simulate field moisture variations. The UCS results demonstrated a significant improvement with fiber reinforcement. At 4% cement and 0.8% fiber content, the highest UCS value recorded was 31.04 kg/cm² under soaked conditions using 10 mm fibers—compared to 9.16 kg/cm² in the unreinforced case. Similarly, with 8% cement and the same fiber configuration, UCS increased to a maximum of 54.68 kg/cm² under soaked conditions, from a baseline of 34.87 kg/cm². Optimum strength was achieved with 5 mm and 10 mm fiber lengths, especially under moist and soaked conditions. The study concludes that the integration of sisal fibers with cement stabilization significantly enhances soil strength. The approach offers a cost-effective and sustainable solution for improving subgrade and foundation performance in geotechnical applications.
Key Words: *Soil stabilization, Cement, Sisal Fiber, Unconfined Compression Strength (UCS), fiber reinforced cement stabilized soil.*

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I. Introduction

Soil stabilization is a key practice in geotechnical engineering, particularly for improving the performance of weak or problematic soils that exhibit low shear strength, high compressibility, and excessive settlement. The engineering behavior of subgrade soils directly influences the safety and durability of overlying structures. Consequently, enhancing the strength and resilience of such soils through reinforcement and chemical treatment has become a focal area of research.

Fiber reinforcement has emerged as a practical and environmentally favorable solution to enhance soil performance, particularly in terms of shear strength, tensile resistance, and ductility. Traditionally, natural fibers such as straw were used in earthen construction. Modern approaches have expanded to include both natural and synthetic fibers, which are now widely incorporated into soil composites to improve load-bearing behavior and resistance to cracking and deformation.

Among natural fibers, sisal fiber, derived from the Agave sisalana plant, has gained significant attention due to its high tensile strength (468–700 MPa) and Young's modulus (9.4–22 GPa), attributes largely attributed to its cellulose-rich structure. With an annual global production of approximately 4.5 million tons, sisal is both abundant and renewable. Similarly, flax fiber offers high tensile strength and biodegradability, while Recron 3S (a synthetic polyester-based fiber) represents the class of synthetic reinforcements widely adopted in construction due to their uniformity and strength. Polyester alone constitutes nearly 60% of global synthetic fiber production.

Numerous studies have explored the influence of sisal and other fibers on soil mechanical behavior. Ghavami et al. (1999) reported that the inclusion of 4% volume of natural fibers such as sisal and coir enhanced ductility and marginally increased the compressive strength of soils. Prabakar and Sridhar (2002) found that increasing fiber length and content reduced dry density due to fiber interlocking effects, with 20 mm fiber length and 0.75% content yielding optimal shear strength gains. However, excessive fiber addition may lead to clumping and reduced compaction efficiency, especially in natural fibers.

The integration of polymers with fiber-reinforced soils has also produced promising results. Wei et al. (2018) demonstrated that polyurethane polymers improved cohesion and mechanical integrity in sisal-reinforced sandy soils. Wu et al. (2014) confirmed through unconfined compression testing that a 10 mm fiber length at 1% content notably enhanced the bearing capacity of silty clays. However, fiber durability remains a concern. Santhi Krishna and Sayida (2009) reported that sisal fibers degrade more quickly in clayey soils, emphasizing the need for chemical treatment to improve longevity.

Failure modes in sisal-reinforced soils include crack failure, drum failure, shear surface failure, and ends leaning failure—each influenced by factors such as fiber type, length, content, confining pressure, and strain rate (Wu et al., 2014). Despite these complexities, sisal fibers have also been shown to improve soil workability and reduce brittleness. Enhanced California Bearing Ratio (CBR) values and delayed failure mechanisms have been observed with appropriate fiber integration.

On the other hand, cement stabilization remains a traditional and widely practiced method to improve soil properties by increasing strength and reducing plasticity (Ingles and Metcalf, 1972). However, cement-treated soils often exhibit brittle behavior and limited post-peak ductility under cyclic or dynamic loads (Chegenizadeh and Nikraz, 2012). To mitigate these limitations, the use of fibers in cement-treated soils has been proposed to enhance residual strength, ductility, and crack resistance.

While synthetic fibers like polypropylene have shown efficacy in this regard, natural fibers are gaining traction due to their sustainability, biodegradability, and local availability (Akbulut et al., 2007; Tang et al., 2007). Sisal, in particular, stands out for its surface roughness and strong interaction with soil particles, which enhances bonding and load transfer. Maher and Ho (1994) and Ramesh et al. (2010) emphasized the role of sisal in improving structural performance and delaying failure onset, thereby contributing to more resilient and sustainable soil systems.

This study aims to evaluate the effect of sisal fiber reinforcement on the unconfined compressive strength (UCS) of cement-stabilized sandy soil. The experimental investigation considers two fiber contents (0.4% and 0.8%), three fiber lengths (2.5 mm, 5 mm, and 10 mm), at 4% cement content. To simulate realistic field conditions, the specimens were subjected to different curing environments, including natural (no curing), moisture curing, and spray curing. The results are intended to contribute toward developing cost-effective, sustainable, and high-performance soil stabilization techniques for infrastructure and foundation engineering applications.

II. Materials And Methods

Materials

Soil: The soil used in this study was locally sourced from Bhogapuram village, West Godavari District, Andhra Pradesh and classified based on its grain size distribution and Atterberg limits. Laboratory tests indicated that the soil falls under the category of Poorly Graded Reddish Sandy Soil as the Indian Standard Soil Classification System. The natural soil exhibited poor strength characteristics, making it suitable for stabilization studies.

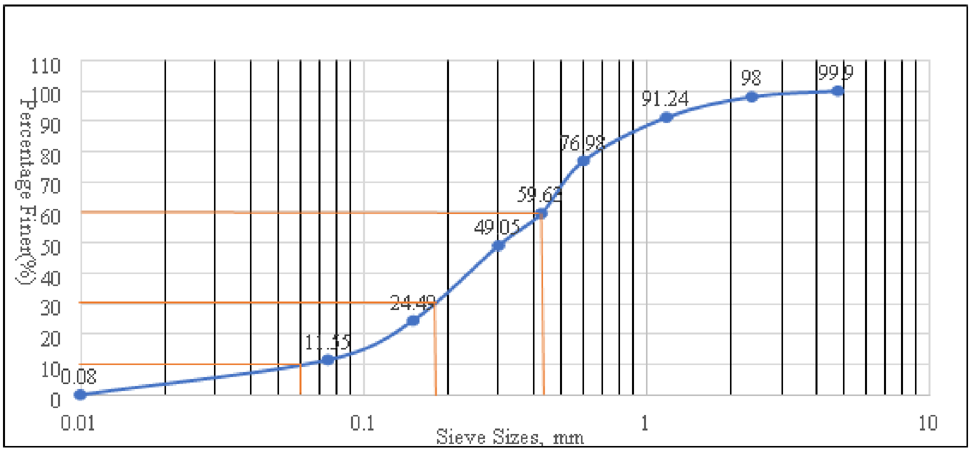

Fig.1 Particle Size Distribution

Table.1 Properties of Soil

S.No.	Engineering Properties	Result
1	IS classification	Poorly Graded Sandy Soil (SP)
2	Specific gravity	2.49
3	Plastic limit	57.%

4	Liquid limit	48%
5	Optimum Moisture Content	7.5%
6	Maximum Dry Density	2.02g/cc
7	Caulifornia Bearing Ratio	3.443%
8	Cohesion	c_u=2.22 kg/cm²
9	Friction Angle	ϕ=22°
10	UCS test	q_u=4.45kg/cm²

Cement: Ordinary Portland Cement (OPC) of 43 Grade was used as the primary stabilizing agent. It was added to the soil 4% by dry weight of soil, to evaluate its impact on strength improvement.

Table.2 Cement properties

S.No.	Properties	Observations
1	Fineness of Cement test	6.5%
2	Consistency of Cement test	31%
3	Initial setting	30 min

Sisal Fiber: Sisal fibers, a natural and biodegradable reinforcement material, were used in chopped form. The fibers were manually cut into lengths of 2.5 mm, 5 mm, and 10 mm. Two different fiber contents, 0.4% and 0.8% by weight of dry soil, were selected to investigate the optimal dosage for strength enhancement. The fibers were clean, untreated, and free from any impurities.

Table.3 Sisal Fiber properties

S.No.	Properties	Values
1	Density(g/cm³)	1.33-1.45
2	Tensile strength	510-700
3	Young's modulus (GPa)	9-38
4	Moisture absorption %	11
5	Elongation at break (%)	2.2-2.9

Fig.2 Sisal fibre

Methodology

The soil was oven-dried, pulverized, and passed through a 4.75 mm sieve. The required quantities of cement and sisal fibers were measured based on the mix proportions. Dry mixing of soil, cement, and fibers was done thoroughly to ensure uniform distribution. Water was then added to achieve the Optimum Moisture Content (OMC), and the mixture was compacted in cylindrical molds (38 mm diameter × 76 mm height) using static compaction. Each mix was prepared in triplicate for reproducibility. After compaction, the specimens were demolded and cured for 7 days under moist conditions in a humidity-controlled environment, simulating field-like curing. The Unconfined Compression Strength (UCS) test was performed for all three fiber lengths in accordance with IS: 2720 (Part 10) – 1991. Specimens were tested under three curing conditions: No Curing Condition (NC): Specimens tested immediately after curing, Moist Curing Condition (MC): Specimens are placed in a container and covered with wet cloth for 7 days before testing and Spray Curing Condition (SC): Specimens are placed in a container and sprayed with water daily before testing.

The axial load was applied at a constant strain rate of 1 mm/min using a UCS loading frame, and the peak compressive strength was recorded. The influence of fiber length, fiber content, and cement dosage on UCS was studied across all three testing conditions.

III. Results And Discussions

The results of the Unconfined Compression Strength (UCS) tests for soil samples stabilized with varying combinations of sisal fiber length, fiber content, and cement dosage under different moisture conditions are presented and discussed in this section.

Test results on 0.4% sisal fiber and 4% cement treated Soil

No curing: The unconfined compressive strength (UCS) of soil samples treated with 0.4% sisal fiber and 4% cement, without any curing process, showed modest improvements. Among the tested fiber lengths, the 5 mm length resulted in the highest UCS of 9.37 kg/cm², followed by 10 mm (9.16 kg/cm²), while the lowest strength was recorded for 2.5 mm (6.16 kg/cm²). These results indicate that sisal fibers do contribute to enhancing soil strength, although the improvements are not as significant as those observed with flax or synthetic fibers. The performance trend suggests that medium-length fibers are more effective in resisting crack propagation and distributing tensile stresses, but the lack of curing significantly limits cement hydration and bonding, thereby reducing the overall strength development.

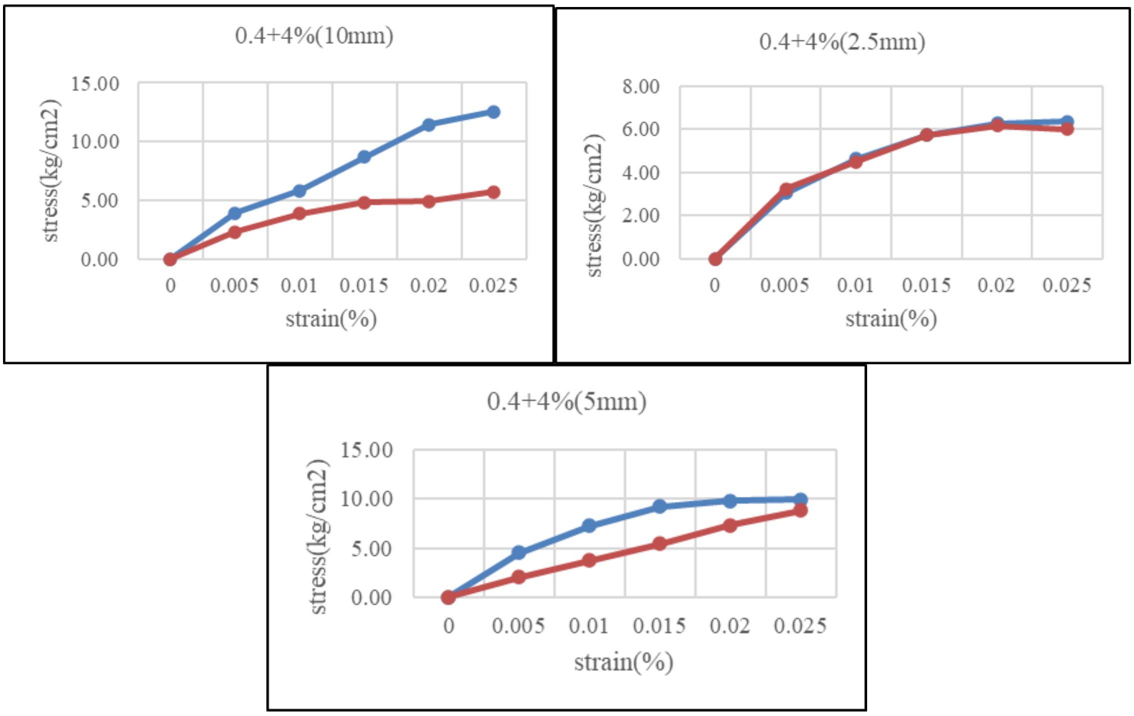

Plate 1. Stress-Strain curves of 0.4% sisal fiber and 4% cement treated Soil with varying fiber lengths, No Curing condition.

Spray Curing: Spray curing had a pronounced impact on the UCS values of sisal fiber-reinforced soil. The highest UCS was recorded at 5 mm fiber length (31.94 kg/cm²), marking a more than threefold increase compared to the uncured sample. The 2.5 mm and 10 mm fibers yielded 27.57 and 25.13 kg/cm², respectively. This improvement can be attributed to enhanced hydration of the cement matrix, which promotes better interfacial bonding between the fibers and soil particles. The optimal performance at 5 mm suggests this length facilitates an effective distribution of reinforcing elements without causing entanglement or fiber pull-out. Spray curing appears to support the structural integration of sisal fibers within the cemented soil matrix by maintaining a controlled moisture environment, which is crucial for the hydration process.

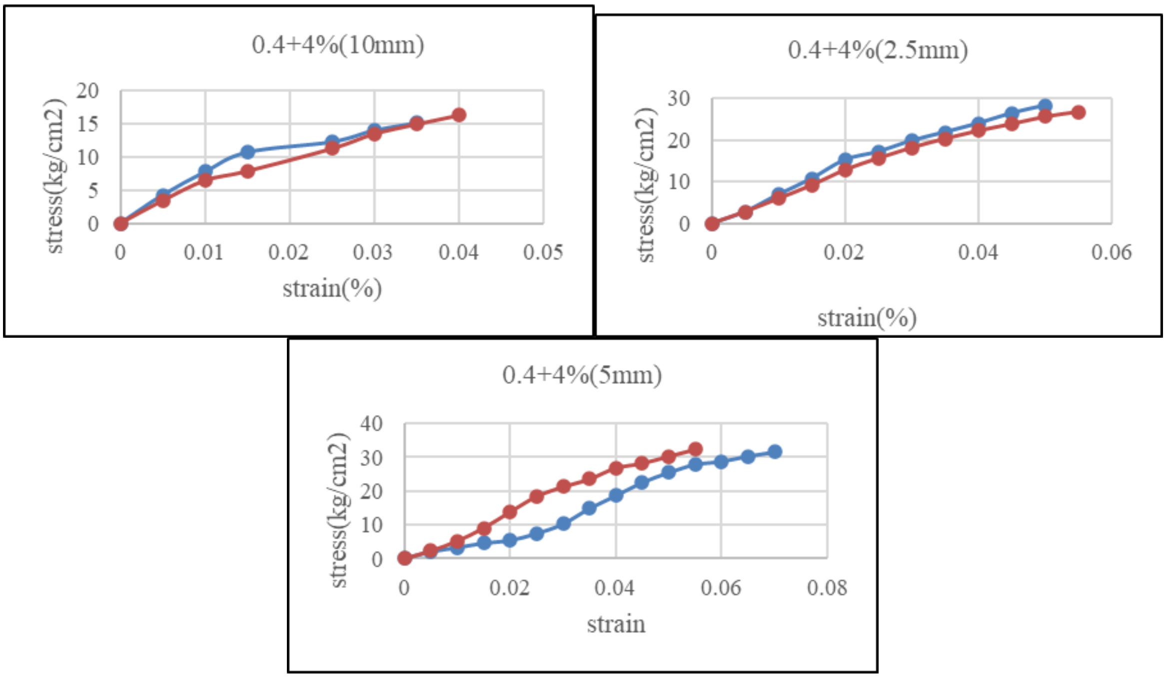

Plate 2. Stress-Strain curves of 0.4% sisal fiber and 4% cement treated Soil with varying fiber lengths, Spray Curing condition.

Moisture Curing: Moisture curing further supported the strength development of the fiber-reinforced soil, albeit to a slightly lesser extent than spray curing. The 5 mm fiber length again emerged as the most effective, yielding a UCS of 25.65 kg/cm², followed by 2.5 mm (18.19 kg/cm²) and 10 mm (15.17 kg/cm²). The 10 mm fibers, while offering increased surface area, may have contributed to fiber clustering or bridging, which could inhibit uniform stress transfer and reduce strength gains. Moisture curing facilitated deeper hydration compared to dry air exposure, leading to improved fiber-cement interaction and overall soil matrix stabilization.

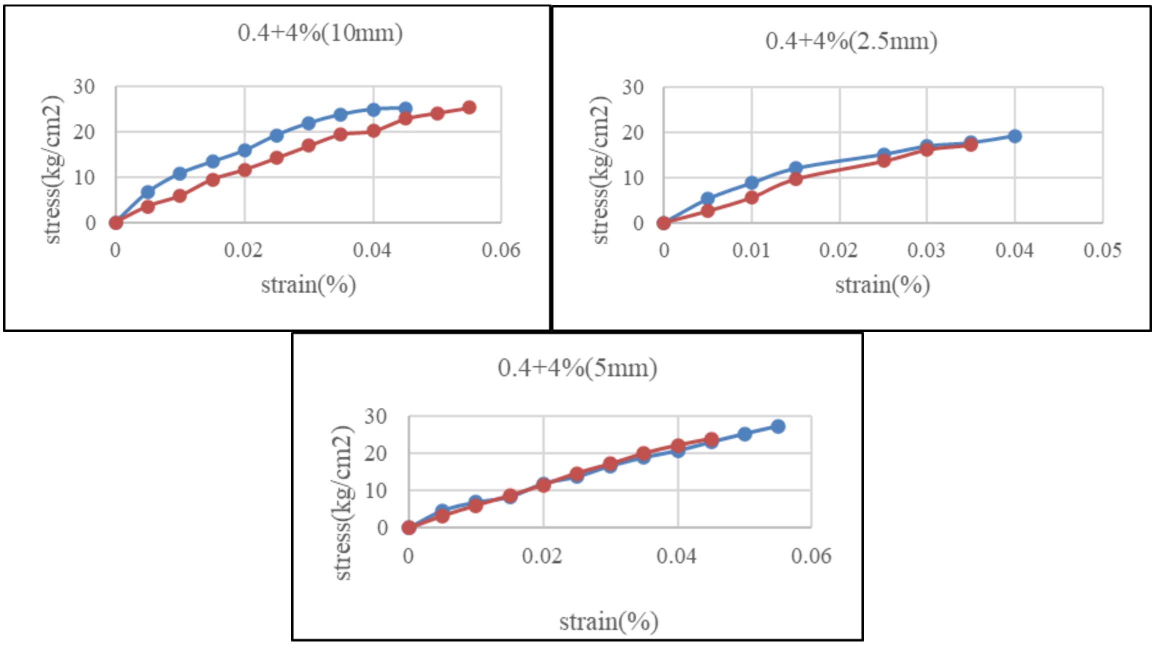

Plate 3. Stress-Strain curves of 0.4% sisal fiber and 4% cement treated Soil with varying fiber lengths, Moisture Curing condition.

In conclusion, the incorporation of sisal fiber at 0.4% in combination with 4% cement shows a clear dependency on both curing method and fiber length. Spray curing consistently yielded the highest UCS values, especially for the 5 mm fiber length. Moisture curing also resulted in a considerable increase in strength, reinforcing the idea that adequate moisture retention is key for optimal performance of natural fibers in cement-stabilized soil. Sisal fibers, due to their natural roughness and biodegradability, offer a promising eco-friendly option, especially when paired with effective curing practices. However, their mechanical contribution is relatively modest compared to flax or synthetic fibers, necessitating precise control over length and curing conditions for best results.

Sisal Fiber	Content	0.40%		
	Length	N C	M C	S C
Cement 4%	10mm	9.16	15.17	25.13
	5mm	9.37	25.65	31.94
	2.5mm	6.16	18.19	27.57

Table 4 UCS Values for Sisal Fiber (0.4+4%)

Test results on 0.8% sisal fiber and 4% cement treated Soil

No Curing: The unconfined compressive strength (UCS) of soil samples treated with 0.8% sisal fiber and 4% cement, without any curing process, showed modest improvements. Among the tested fiber lengths, the 5 mm length resulted in the highest UCS of 30.36 kg/cm², followed by 2.5 mm (26.57kg/cm²), while the lowest strength was recorded for 10 mm (18.23 kg/cm²). These results indicate that sisal fibers do contribute to enhancing soil strength, although the improvements are not as significant as those observed with flax or synthetic fibers. The performance trend suggests that medium-length fibers are more effective in resisting crack propagation and distributing tensile stresses, but the lack of curing significantly limits cement hydration and bonding, thereby reducing the overall strength development.

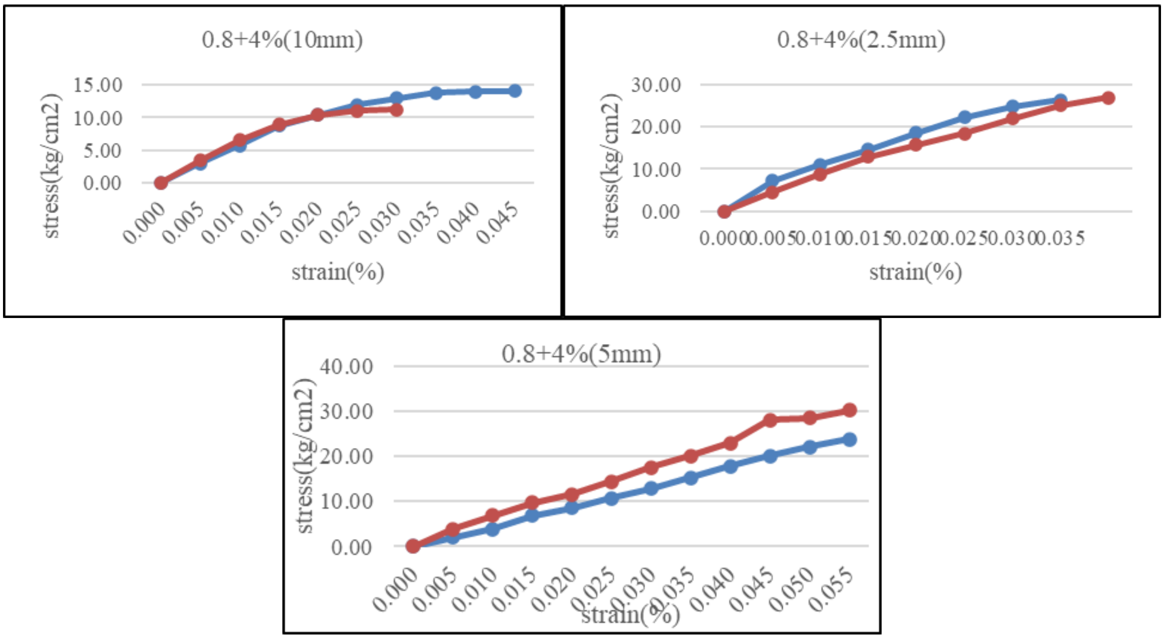

Plate 4. Stress-Strain curves of 0.8% sisal fiber and 4% cement treated Soil with varying fiber lengths, No Curing condition.

Spray Curing: Spray curing had a pronounced impact on the UCS values of sisal fiber-reinforced soil. The highest UCS was recorded at 5 mm fiber length (49.43 kg/cm²), marking a more than threefold increase compared to the uncured sample. The 2.5 mm and 10 mm fibers yielded 38.93 and 31.04 kg/cm², respectively. This improvement can be attributed to enhanced hydration of the cement matrix, which promotes better interfacial bonding between the fibers and soil particles. The optimal performance at 5 mm suggests this length facilitates an effective distribution of reinforcing elements without causing entanglement or fiber pull-out. Spray curing appears to support the structural integration of sisal fibers within the cemented soil matrix by maintaining a controlled moisture environment, which is crucial for the hydration process.

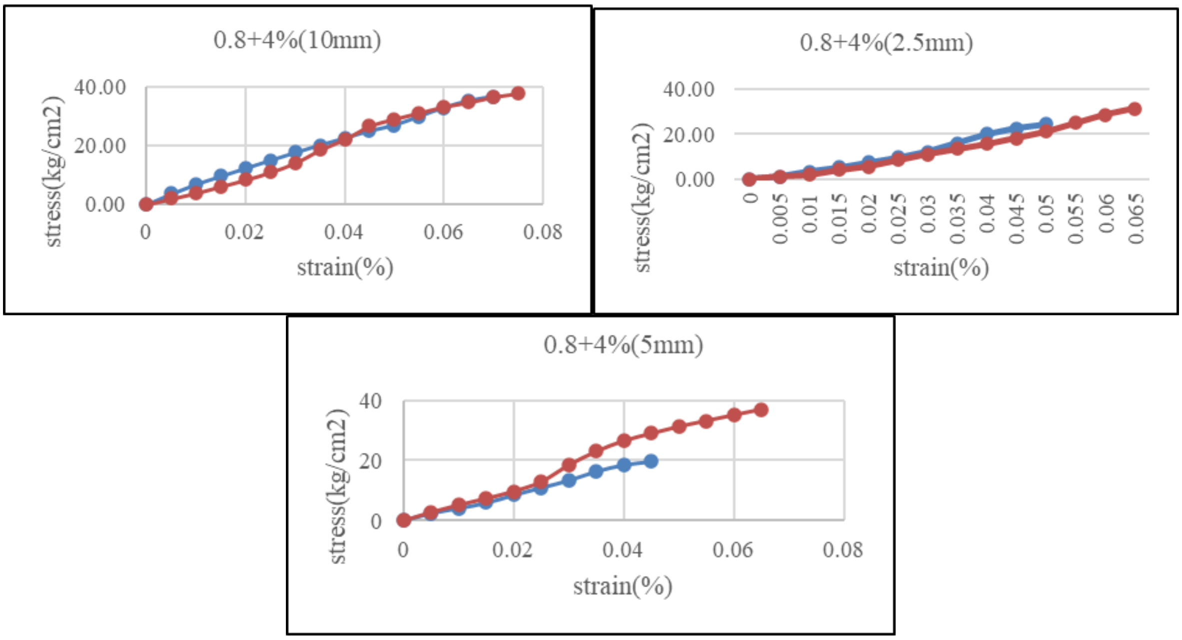

Plate 5. Stress-Strain curves of 0.8% sisal fiber and 4% cement treated Soil with varying fiber lengths, Spray Curing condition.

Moisture Curing: Moisture curing further supported the strength development of the fiber-reinforced soil, albeit to a slightly lesser extent than spray curing. The 5 mm fiber length again emerged as the most effective, yielding a UCS of 37.33kg/cm², followed by 2.5 mm (37.29kg/cm²) and 10 mm (28.33 kg/cm²). The 10 mm fibers, while offering increased surface area, may have contributed to fiber clustering or bridging, which could inhibit uniform stress transfer and reduce strength gains. Moisture curing facilitated deeper hydration compared to dry air exposure, leading to improved fiber-cement interaction and overall soil matrix stabilization.

In conclusion, the incorporation of sisal fiber at 0.8% in combination with 4% cement shows a clear dependency on both curing method and fiber length. Spray curing consistently yielded the highest UCS values, especially for the 5 mm fiber length. Moisture curing also resulted in a considerable increase in strength, reinforcing the idea that adequate moisture retention is key for optimal performance of natural fibers in cement-stabilized soil. Sisal fibers, due to their natural roughness and biodegradability, offer a promising eco-friendly option, especially when paired with effective curing practices. However, their mechanical contribution is relatively modest compared to flax or synthetic fibers, necessitating precise control over length and curing conditions for best results.

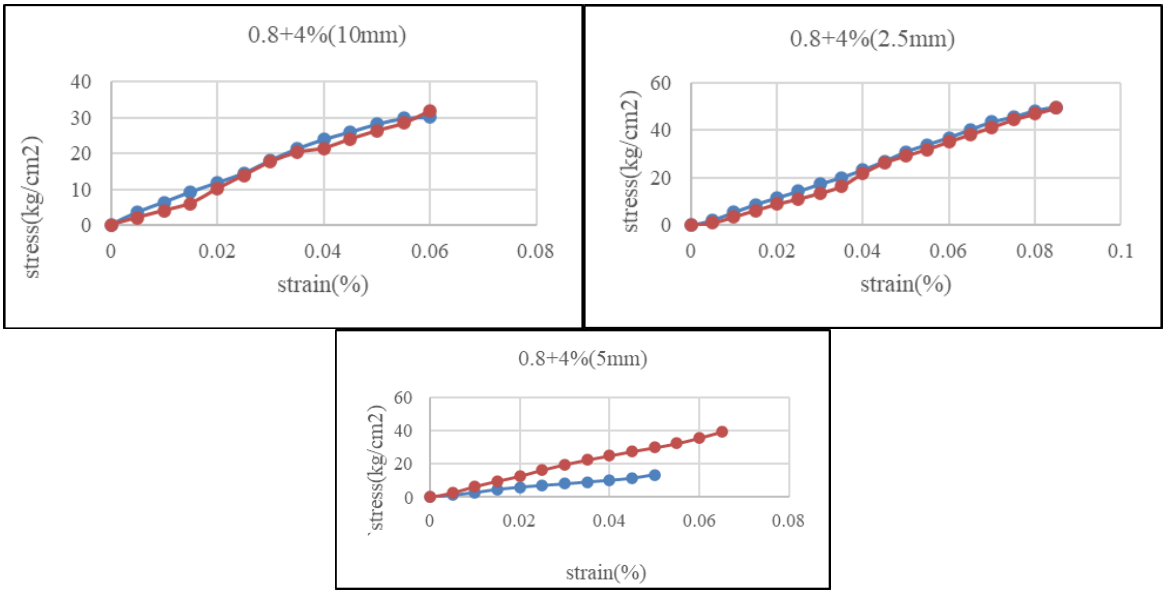

Plate 5. Stress-Strain curves of 0.8% sisal fiber and 4% cement treated Soil with varying fiber lengths, Spray Curing condition.

Sisal Fiber	Content	0.80%		
	Length	N C	M C	S C
Cement 4%	10mm	18.23	28.33	31.04
	5mm	30.36	37.33	49.43
	2.5mm	26.57	37.29	38.93

Table 5 UCS Values for Sisal Fiber (0.8+4%)

IV. Conclusion

This study investigated the enhancement of soil strength through the combined use of sisal fibers and cement, focusing on parameters such as fiber length, fiber content, cement dosage, and moisture exposure. Based on extensive Unconfined Compressive Strength (UCS) testing under varied conditions, the following key conclusions were drawn:

1. 4% cement content substantially improved the UCS of the treated soil. For instance, UCS values rose from 31.04 kg/cm² to 49.43 kg/cm² for samples with 0.8% fiber and 10 mm length under soaked conditions. The higher cement dosage enhanced the formation of cementitious bonds and improved the soil matrix's load-carrying capacity.
2. Fiber length was a critical factor, with 10 mm fibers yielding the highest UCS among tested lengths. Longer fibers provided better interfacial bonding and crack-bridging ability, resulting in improved strength and ductility of the soil matrix.
3. Increasing fiber content from 0.4% to 0.8% improved UCS by 15.6%, with 0.8% emerging as the most effective dosage. This improvement is attributed to a denser fiber network that enhanced tensile resistance and reduced brittleness.
4. Surprisingly, the soaked condition produced the highest UCS (49.43 kg/cm²), indicating that the combination of cement hydration and fiber reinforcement yielded a resilient and water-tolerant system. This suggests the suitability of the treated soil for water-prone environments.

In conclusion, the integration of natural sisal fibers with cement stabilization provides an eco-friendly, cost-effective, and technically sound method for improving the strength and durability of soil. Future work may include durability testing under cyclic loading, freeze-thaw cycles, and field-scale validation to confirm the laboratory findings and expand applicability in real-world infrastructure projects.

References

[1]. Ingles, O.G., & Metcalf, J.B. (1972). Soil Stabilization: Principles And Practice. Butterworths.
[2]. Chegenizadeh, A., & Nikraz, H. (2012). Mechanical Behavior Of Fiber Reinforced Clay. Advances In Materials Science And Engineering.
[3]. Akbulut, S., Arasan, S., & Kalkan, E. (2007). Modification Of Clayey Soils Using Scrap Tire Rubber And Synthetic Fibers. Applied Clay Science.
[4]. Tang, C., Shi, B., Gao, W., Chen, F., & Cai, Y. (2007). Strength And Mechanical Behavior Of Short Polypropylene Fiber Reinforced And Cement Stabilized Clayey Soil. Geotextiles And Geomembranes.
[5]. Maher, M.H., & Ho, Y.C. (1994). Mechanical Properties Of Kaolinite/Fiber Soil Composites. Journal Of Geotechnical Engineering, ASCE.
[6]. Ramesh, H.N., Manoj Krishna, K.V., & Mamatha, H.V. (2010). Compaction And Strength Behavior Of Lime-Coir Fiber Treated Black Cotton Soil. Geomechanics And Engineering.
[7]. Al-Refeai, T.O., & Al-Suhaibani, A.S. (1999). The Effect Of Fiber Reinforcement On The Unconfined Compressive Strength Of Cohesive Soils. Geotextiles And Geomembranes.
[8]. Ghavami, K., Toledo Filho, R. D., & Barbosa, N. P. (1999). Behaviour Of Composite Soil Reinforced With Natural Fibers. Cement And Concrete Composites, 21(1), 39–48.
[9]. Prabakar, J., & Sridhar, R. S. (2002). Effect Of Random Inclusion Of Sisal Fibre On Strength Behaviour Of Soil. Construction And Building Materials, 16(2), 123–131.
[10]. Santhi Krishna, K., & Sayida, M. K. (2009, November). Behaviour Of Black Cotton Soil Reinforced With Sisal Fibre. 10th National Conference On Technological Trends (NCTT09).
[11]. Wei, L., Zhou, A., Wang, H., & Zhang, Q. (2018). Study On Properties Of Polyurethane-Sisal Fiber Reinforced Sand. [Study Reference Within Shared Document].
[12]. Wu, Y. K., Li, Y. B., & Niu, B. (2014). Investigation Of Mechanical Properties Of Randomly Distributed Sisal Fibre Reinforced Soil. Materials Research Innovations. Https://Doi.Org/10.1179/1432891714Z.000000000511