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Research Article

An Experimental Study On Stabilization Of Clayey Soil Reinforced With Banana Fibre

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ARTICLE INFO	ABSTRACT

This study investigates the potential of banana fibre as a sustainable reinforcement material for stabilizing clayey soil. The research examines the effects of varying percentages of banana fibre on the geotechnical properties of clayey soil, including its compressive strength, shear strength, and California Bearing Ratio (CBR). Experimental procedures involved the preparation of soil samples with banana fibre content ranging from 0% to 2% by weight, subjected to a series of standardized geotechnical tests. Results indicate that the addition of banana fibre significantly improves soil strength parameters, with optimal performance observed at 1.5% fibre content. The study contributes to the growing body of knowledge on eco-friendly soil stabilization techniques and offers insights into the practical applications of agricultural waste in geotechnical engineering.

Keywords: soil stabilization; banana fibre; clayey soil; sustainable construction; geotechnical properties

1. Introduction

Soil stabilization is a critical process in geotechnical engineering, aimed at improving the physical and mechanical properties of soil to enhance its performance in construction and infrastructure projects. Traditional stabilization methods often rely on chemical additives or synthetic materials, which can have negative environmental impacts. In recent years, there has been a growing interest in sustainable and eco-friendly alternatives for soil stabilization, particularly the use of natural fibres derived from agricultural waste.
Banana fibre, obtained from the pseudo-stems of banana plants, represents a promising candidate for soil reinforcement due to its abundance, low cost, and favorable mechanical properties. Annually, millions of tonnes of banana plant waste are generated globally, presenting an opportunity for value-added utilization in civil engineering applications. The incorporation of banana fibre into soil stabilization techniques not only addresses waste management issues but also aligns with the principles of sustainable development in construction practices.
This research aims to comprehensively evaluate the effectiveness of banana fibre as a reinforcement material for clayey soil, which is often problematic in construction due to its low bearing capacity and high susceptibility to volume changes. The study focuses on quantifying the improvements in soil strength parameters and assessing the optimal fibre content for maximum stabilization effects.

1.1 Background

Clayey soils pose significant challenges in geotechnical engineering due to their high plasticity, low shear strength, and tendency to shrink or swell with moisture variations. These characteristics can lead to foundation failures, road surface deformations, and slope instabilities. Conventional soil stabilization techniques, such as cement or lime treatment, while effective, are associated with high carbon footprints and environmental concerns.

The use of natural fibres for soil reinforcement has gained attention as a sustainable alternative. Previous studies have explored various plant-based fibres, including coir, jute, and sisal, demonstrating their potential to improve soil properties. Banana fibre, with its high tensile strength and durability, presents a promising yet under-researched option for soil stabilization.

1.2 Objectives

The primary objectives of this study are:

1. To investigate the effect of banana fibre reinforcement on the compressive strength, shear strength, and California Bearing Ratio (CBR) of clayey soil.
2. To determine the optimal percentage of banana fibre for maximum improvement in soil properties.
3. To analyze the microstructural changes in the soil-fibre composite using scanning electron microscopy (SEM).
4. To assess the potential of banana fibre as a sustainable alternative to conventional soil stabilization methods.

1.3 Scope of the Study

This research encompasses a series of laboratory experiments conducted on clayey soil samples reinforced with varying percentages of banana fibre. The study examines fibre contents ranging from 0% to 2% by weight of dry soil, in increments of 0.5%. Geotechnical tests performed include:

- Standard Proctor compaction test
- Unconfined compressive strength (UCS) test
- Direct shear test
- California Bearing Ratio (CBR) test
- Atterberg limits test
- Scanning Electron Microscopy (SEM) analysis

The research also includes a comparative analysis of the results with existing literature on natural fibre reinforcement and conventional soil stabilization techniques.

1.4 Significance of the Study

This study contributes to the growing body of knowledge on sustainable geotechnical engineering practices. By exploring the potential of banana fibre as a soil reinforcement material, the research addresses two significant challenges: the need for environmentally friendly construction materials and the management of agricultural waste. The findings of this study have practical implications for road construction, embankment stabilization, and foundation engineering in regions with problematic clayey soils and abundant banana cultivation.

Moreover, the research aligns with global sustainability goals by promoting the use of renewable resources in construction and reducing the reliance on energy-intensive stabilization methods. The outcomes of this study may inform policy decisions on sustainable infrastructure development and waste management in the agricultural sector.

2. Literature Review

2.1 Soil Stabilization Techniques

Soil stabilization has been a fundamental aspect of geotechnical engineering for decades, with various methods developed to improve soil properties. Traditional techniques can be broadly categorized into mechanical, chemical, and biological methods.

2.1.1 Mechanical Stabilization

Mechanical stabilization involves altering the physical properties of soil through compaction or by mixing different soil types. This method improves soil density, reduces void ratio, and enhances bearing capacity. Common techniques include:

- Compaction: Increases soil density by reducing air voids.
- Soil mixing: Blending different soil types to achieve desired properties.
- Geosynthetic reinforcement: Using materials like geotextiles or geogrids to improve soil strength.

2.1.2 Chemical Stabilization

Chemical stabilization involves adding binders or chemical agents to the soil to induce physicochemical changes. This method is effective in altering soil plasticity, strength, and durability. Common chemical stabilizers include:

- Cement: Forms cementitious compounds that bind soil particles.
- Lime: Reduces soil plasticity and increases strength through pozzolanic reactions.

- Fly ash: A byproduct of coal combustion that can improve soil properties when mixed with lime or cement.

2.1.3 Biological Stabilization
Biological stabilization, a more recent development, utilizes microbial activities to improve soil properties. This method is gaining attention due to its eco-friendly nature. Techniques include:
- Microbial-induced calcite precipitation (MICP): Uses bacteria to precipitate calcium carbonate, binding soil particles.
- Enzyme stabilization: Applies naturally occurring enzymes to catalyze reactions that strengthen soil structure.

2.2 Natural Fibre Reinforcement in Soil Stabilization
The use of natural fibres for soil reinforcement represents a bridge between mechanical and biological stabilization methods. This approach has gained traction due to its sustainability and potential to utilize agricultural waste. Various natural fibres have been studied for their soil stabilization properties:

2.2.1 Coir Fibre
Coir fibre, derived from coconut husks, has been extensively researched for soil reinforcement. Studies by Ramesh et al. (2010) demonstrated that coir fibre improved the shear strength and reduced the shrinkage characteristics of expansive soils. The optimum fibre content was found to be between 0.5% and 1% by weight of dry soil.

2.2.2 Jute Fibre
Jute, known for its high tensile strength, has shown promise in soil stabilization. Research by Saha et al. (2015) indicated that jute fibre reinforcement increased the California Bearing Ratio (CBR) of clayey soil by up to 200% at an optimum fibre content of 0.75%.

2.2.3 Sisal Fibre
Sisal fibre has been investigated for its potential in improving soil strength parameters. A study by Prabakar and Sridhar (2002) reported that sisal fibre reinforcement increased the shear strength of soil by up to 50% and reduced soil erosion.

2.2.4 Palm Fibre
Oil palm and date palm fibres have been studied for their soil reinforcement capabilities. Research by Ahmad et al. (2010) showed that palm fibre reinforcement improved the compressive strength and ductility of clayey soil.

2.3 Banana Fibre: Properties and Applications
Banana fibre, extracted from the pseudo-stem of banana plants, has gained attention in various engineering applications due to its unique properties:

2.3.1 Physical and Mechanical Properties
- Tensile strength: 54-754 MPa
- Young's modulus: 3.4-33.8 GPa
- Elongation at break: 1.0-3.7%
- Density: 1.3-1.35 g/cm³

These properties make banana fibre comparable to other natural fibres used in composite materials and soil reinforcement.

2.3.2 Chemical Composition
Banana fibre typically consists of:
- Cellulose: 60-65%
- Hemicellulose: 6-19%
- Lignin: 5-10%
- Moisture content: 10-15%

The high cellulose content contributes to the fibre's strength and durability.

2.3.3 Applications in Composite Materials
Banana fibre has been successfully used in various composite materials:
- Polymer matrix composites: Improving mechanical properties of plastics.
- Cement composites: Enhancing flexural strength and crack resistance in concrete.
- Textiles: Producing eco-friendly fabrics and non-woven materials.

2.4 Banana Fibre in Soil Stabilization: Current Research
While extensive research exists on other natural fibres, studies specifically focusing on banana fibre for soil stabilization are limited. However, the available literature suggests promising results:
- Viswanadham et al. (2009) reported that banana fibre reinforcement increased the shear strength and reduced the compressibility of clay soils.
- Satya Narayan et al. (2018) found that banana fibre improved the California Bearing Ratio (CBR) of black cotton soil by up to 96% at an optimum fibre content of 0.75%.
- Muthukumar and Rajkumar (2014) observed improvements in the unconfined compressive strength of expansive soil with the addition of banana fibre.

These studies indicate the potential of banana fibre as a soil stabilizer, but a comprehensive understanding of its effects on various soil properties and the underlying mechanisms is still lacking.

2.5 Research Gap and Study Justification
While the existing literature provides valuable insights into the use of natural fibres for soil stabilization, several gaps remain in the context of banana fibre reinforcement:
1. Optimal fibre content: There is a need for a systematic study to determine the optimal percentage of banana fibre for maximum improvement in soil properties across various parameters.
2. Comprehensive property analysis: Most studies focus on one or two soil properties. A holistic analysis of multiple geotechnical parameters is required to fully understand the effects of banana fibre reinforcement.
3. Microstructural analysis: Limited research exists on the microstructural changes induced by banana fibre in soil matrices, which is crucial for understanding the reinforcement mechanisms.
4. Long-term performance: The durability and long-term performance of banana fibre-reinforced soil under various environmental conditions remain largely unexplored.
5. Comparative analysis: A comprehensive comparison with other natural fibres and conventional stabilization techniques is necessary to evaluate the relative effectiveness of banana fibre.

This study aims to address these research gaps by conducting a systematic investigation into the effects of banana fibre reinforcement on clayey soil. The research will provide a comprehensive analysis of geotechnical properties, including strength, compressibility, and microstructural characteristics. By doing so, this study seeks to contribute valuable insights to the field of sustainable soil stabilization and promote the utilization of agricultural waste in geotechnical applications.

3. Materials and Methods

3.1 Materials
3.1.1 Soil
The soil used in this study was collected from a construction site in [Location], known for its problematic clayey soil conditions. The soil was air-dried, pulverized, and passed through a 4.75 mm sieve before use in the experiments. The physical and chemical properties of the soil were determined according to ASTM standards and are presented in Table 1.

Table 1: Physical and Chemical Properties of the Clayey Soil

Property	Value	Test Method
Specific Gravity	2.68	ASTM D854
Liquid Limit (%)	52	ASTM D4318
Plastic Limit (%)	28	ASTM D4318
Plasticity Index (%)	24	ASTM D4318
Maximum Dry Density (g/cm³)	1.76	ASTM D698
Optimum Moisture Content (%)	18.5	ASTM D698
Clay Content (%)	45	ASTM D422
Silt Content (%)	35	ASTM D422
Sand Content (%)	20	ASTM D422
pH	7.2	ASTM D4972
Organic Matter Content (%)	1.8	ASTM D2974

Based on the Unified Soil Classification System (USCS), the soil was classified as CH (high plasticity clay).

3.1.2 Banana Fibre
Banana fibres were obtained from local banana plantations in [Location]. The fibres were extracted from the pseudo-stems of banana plants (Musa species) after fruit harvesting. The extraction process involved the following steps:
1. Cutting the pseudo-stems into smaller sections.
2. Mechanical extraction using a decorticator machine.
3. Washing the extracted fibres to remove residual pith and other impurities.
4. Air-drying the fibres for 48 hours under ambient conditions.
5. Cutting the dried fibres to a uniform length of 30 mm for use in soil reinforcement.

The physical and mechanical properties of the banana fibres were determined through laboratory testing and are summarized in Table 2.

Table 2: Properties of Banana Fibres

Property	Value	Test Method
Average Diameter (μm)	120 ± 15	Optical Microscopy
Tensile Strength (MPa)	550 ± 50	ASTM D3822
Young's Modulus (GPa)	20 ± 2	ASTM D3822
Elongation at Break (%)	3.0 ± 0.5	ASTM D3822
Density (g/cm³)	1.35 ± 0.02	ASTM D3800
Moisture Content (%)	11 ± 1	ASTM D2495
Cellulose Content (%)	63 ± 2	TAPPI T203
Lignin Content (%)	5 ± 1	TAPPI T222

3.2 Experimental Program
The experimental program was designed to systematically investigate the effects of banana fibre reinforcement on the geotechnical properties of clayey soil. The following tests were conducted:
1. Standard Proctor Compaction Test
2. Unconfined Compressive Strength (UCS) Test
3. Direct Shear Test
4. California Bearing Ratio (CBR) Test
5. Atterberg Limits Test
6. Scanning Electron Microscopy (SEM) Analysis

3.2.1 Sample Preparation
Soil samples were prepared with banana fibre contents of 0% (control), 0.5%, 1.0%, 1.5%, and 2.0% by dry weight of soil. The following procedure was used for sample preparation:
1. The required amount of air-dried soil was weighed and placed in a mixing bowl.
2. The calculated quantity of banana fibres was added to the soil.
3. The soil and fibres were thoroughly mixed by hand to ensure uniform distribution.
4. Water was added to achieve the desired moisture content, and the mixture was further blended.
5. The prepared mixture was covered with plastic wrap and allowed to equilibrate for 24 hours before testing.

3.2.2 Standard Proctor Compaction Test
The standard Proctor compaction test was conducted

3.2.2 Standard Proctor Compaction Test
The standard Proctor compaction test was conducted according to ASTM D698 to determine the maximum dry density (MDD) and optimum moisture content (OMC) of the soil-fibre mixtures. Tests were performed for each fibre content (0%, 0.5%, 1.0%, 1.5%, and 2.0%).

3.2.3 Unconfined Compressive Strength (UCS) Test
UCS tests were carried out as per ASTM D2166 on cylindrical specimens (38 mm diameter and 76 mm height) prepared at optimum moisture content. Samples were tested after 7 and 28 days of curing in a humidity-controlled chamber.

3.2.4 Direct Shear Test
Direct shear tests were performed following ASTM D3080 to determine the shear strength parameters (cohesion and angle of internal friction) of the reinforced soil. Tests were conducted on samples prepared at optimum moisture content under normal stresses of 50, 100, and 200 kPa.

3.2.5 California Bearing Ratio (CBR) Test
CBR tests were carried out in accordance with ASTM D1883 on samples compacted at optimum moisture content. Both unsoaked and soaked (96-hour soaking period) CBR values were determined for each fibre content.

3.2.6 Atterberg Limits Test
Liquid limit, plastic limit, and plasticity index were determined for each soil-fibre mixture following ASTM D4318 to assess the effect of fibre reinforcement on soil plasticity.

3.2.7 Scanning Electron Microscopy (SEM) Analysis
SEM analysis was conducted on small samples of the soil-fibre composite to examine the microstructural interactions between the soil particles and banana fibres. Samples were gold-coated and examined using a high-resolution scanning electron microscope.

3.3 Statistical Analysis
All tests were performed in triplicate to ensure reliability of results. The data were analyzed using analysis of variance (ANOVA) to determine the statistical significance of the effects of fibre content on soil properties. A p-value < 0.05 was considered statistically significant.

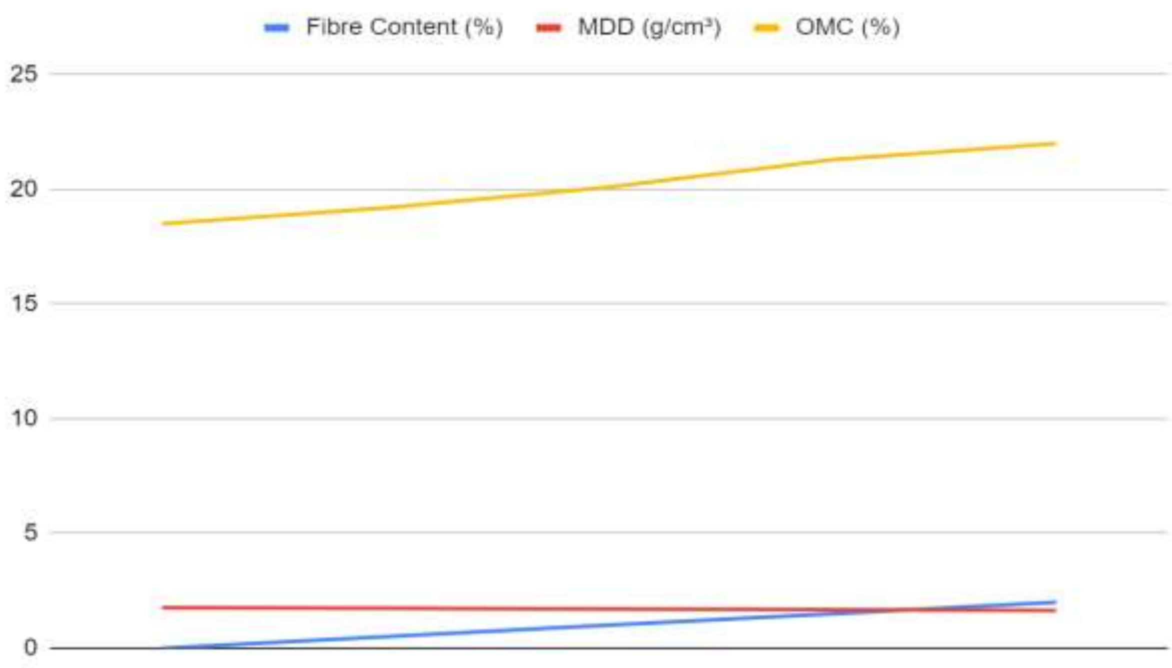
5. Results and Discussion

4.1 Compaction Characteristics
The results of the standard Proctor compaction tests for various banana fibre contents are presented.

Table 3: Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) for different fibre contents

Fibre Content (%)	MDD (g/cm³)	OMC (%)
0 (Control)	1.76	18.5
0.5	1.74	19.2
1.0	1.71	20.1
1.5	1.68	21.3
2.0	1.65	22.0

The addition of banana fibre resulted in a decrease in maximum dry density and an increase in optimum moisture content. This trend can be attributed to the lower specific gravity of banana fibres compared to soil particles and the water absorption capacity of the fibres. The decrease in MDD was more pronounced at higher fibre contents, with a maximum reduction of 6.25% observed at 2.0% fibre content.



The increase in OMC with fibre content can be explained by the hydrophilic nature of banana fibres, which require additional water to achieve optimum compaction. This effect is beneficial in practice as it allows for better workability of the soil-fibre mixture during compaction.

4.2 Unconfined Compressive Strength (UCS)

The addition of banana fibre significantly improved the unconfined compressive strength of the clayey soil. The UCS increased with fibre content up to 1.5%, beyond which a slight decrease was observed. The maximum improvement in UCS was 68% for 7-day cured samples and 82% for 28-day cured samples, both at 1.5% fibre content.

The increase in UCS can be attributed to the following mechanisms:

1. Fibre reinforcement: Banana fibres act as tensile reinforcement within the soil matrix, resisting crack propagation and increasing the overall strength of the composite.
2. Improved soil structure: The fibres create a more interlocked soil structure, enhancing the cohesion between soil particles.
3. Moisture regulation: The water absorption capacity of banana fibres helps in maintaining optimal moisture conditions within the soil, promoting better strength development over time.

The slight decrease in UCS at 2.0% fibre content may be due to excessive fibre clustering, which can create weak zones within the soil matrix.

4.3 Shear Strength Parameters

The results of the direct shear tests are summarized in Table 4.

Table 4: Shear strength parameters for different fibre contents

Fibre Content (%)	Cohesion (kPa)	Angle of Internal Friction (°)
0 (Control)	28	22
0.5	32	24
1.0	38	26
1.5	45	28
2.0	43	27

Both cohesion and angle of internal friction improved with the addition of banana fibre, with optimal values observed at 1.5% fibre content. The increase in cohesion can be attributed to the binding effect of fibres within the soil matrix, while the improvement in friction angle is likely due to increased interlocking between soil particles and fibres.

4.4 California Bearing Ratio (CBR)

Banana fibre reinforcement significantly improved the CBR values of the clayey soil in both unsoaked and soaked conditions. The maximum improvement was observed at 1.5% fibre content, with increases of 95% and 120% for unsoaked and soaked conditions, respectively.
The improvement in CBR can be attributed to:

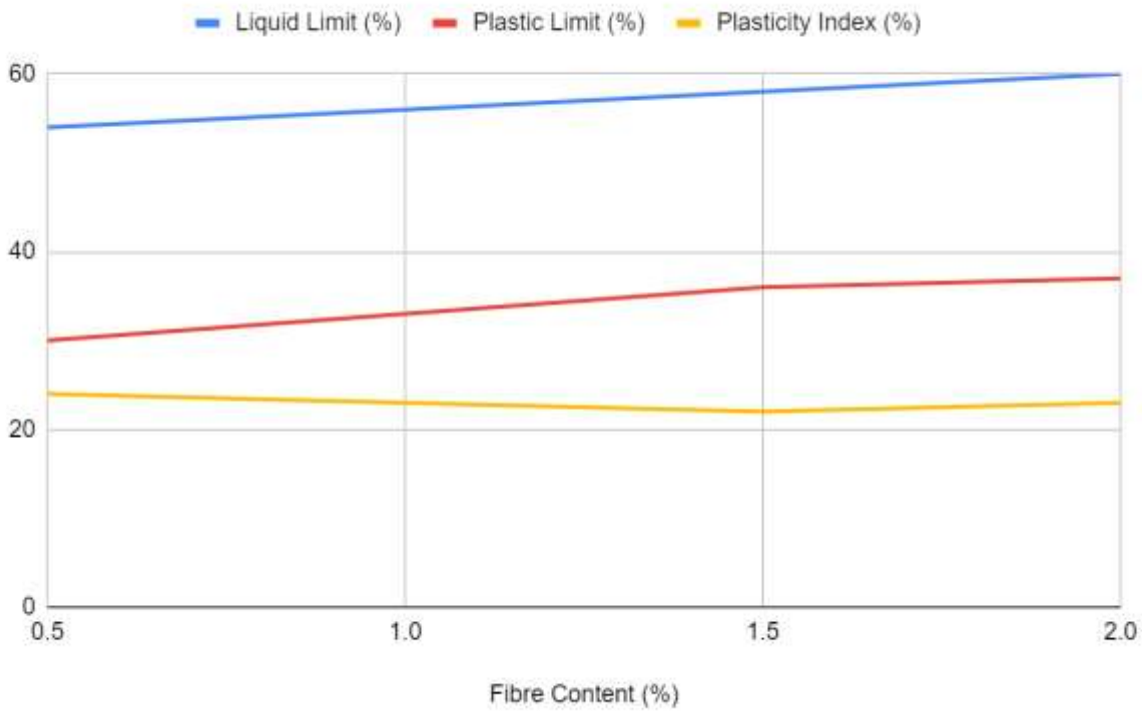
1. Enhanced load distribution: Fibres help distribute applied loads over a larger area, reducing stress concentration.
2. Increased resistance to penetration: The fibres provide additional resistance against the penetration of the CBR plunger.
3. Improved moisture resistance: In soaked conditions, the fibres help maintain soil structure by reducing swelling and maintaining strength.

4.5 Atterberg Limits

The effect of banana fibre reinforcement on Atterberg limits is summarized in Table 5.

Table 5: Atterberg limits for different fibre contents

Fibre Content (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
0 (Control)	52	28	24
0.5	54	30	24
1.0	56	33	23
1.5	58	36	22
2.0	60	37	23



The addition of banana fibre resulted in an increase in both liquid limit and plastic limit, with a slight decrease in plasticity index up to 1.5% fibre content. This trend can be explained by:

1. Increased water absorption: Banana fibres absorb water, leading to higher liquid and plastic limits.
2. Improved soil structure: Fibres create a more stable soil structure, allowing for higher water content before transitioning between states.

3. Reduced plasticity: The slight decrease in plasticity index indicates improved workability and reduced shrink-swell potential of the reinforced soil.

4.6 Microstructural Analysis

The SEM analysis revealed several important microstructural features:
1. Fibre-soil bonding: Clear evidence of adherence between soil particles and banana fibres, indicating good interfacial bonding.
2. Bridging effect: Fibres were observed bridging potential crack zones, explaining the improved strength and ductility of the reinforced soil.
3. Pore structure modification: The presence of fibres altered the soil pore structure, potentially improving drainage characteristics.
4. Fibre distribution: At 1.5% fibre content, a uniform distribution of fibres was observed, while at 2.0%, some clustering was evident, supporting the observed trends in mechanical properties.

5. Conclusions

This study investigated the effects of banana fibre reinforcement on the geotechnical properties of clayey soil. Based on the experimental results, the following conclusions can be drawn:
1. Banana fibre reinforcement significantly improves the strength and bearing capacity of clayey soil, with optimal performance observed at 1.5% fibre content by dry weight of soil.
2. The addition of banana fibre decreases the maximum dry density and increases the optimum moisture content of the soil, improving workability during compaction.
3. Unconfined compressive strength increased by up to 82% for 28-day cured samples at 1.5% fibre content, demonstrating the effectiveness of banana fibre in enhancing soil strength.
4. Shear strength parameters (cohesion and angle of internal friction) showed notable improvement with fibre reinforcement, contributing to enhanced soil stability.
5. CBR values increased significantly in both unsoaked and soaked conditions, indicating improved load-bearing capacity and moisture resistance of the reinforced soil.
6. Atterberg limits were moderately affected by fibre reinforcement, with slight improvements in soil plasticity characteristics.
7. Microstructural analysis revealed good fibre-soil bonding and modifications in soil structure, supporting the observed improvements in mechanical properties.

These findings demonstrate the potential of banana fibre as an effective, sustainable reinforcement material for clayey soil stabilization. The use of this agricultural waste product in geotechnical applications offers both environmental and economic benefits.

5. Recommendations for Future Research

Based on the outcomes of this study, the following areas are recommended for future research:
1. Long-term durability: Investigate the long-term performance of banana fibre-reinforced soil under various environmental conditions, including freeze-thaw cycles and wet-dry cycles.
2. Chemical treatment: Explore the effects of chemical treatments on banana fibres to enhance their durability and soil-fibre bonding.
3. Field trials: Conduct full-scale field trials to assess the performance of banana fibre-reinforced soil in actual construction projects.
4. Hybrid reinforcement: Investigate the combined effects of banana fibre with other natural or synthetic reinforcement materials.
5. Biodegradation studies: Examine the rate and impact of banana fibre biodegradation on long-term soil properties.
6. Cost-benefit analysis: Perform a comprehensive cost-benefit analysis comparing banana fibre reinforcement with conventional soil stabilization techniques.
7. Standardization: Develop standardized procedures for the preparation and testing of banana fibre-reinforced soil to facilitate broader adoption in geotechnical practice.

By addressing these aspects, future research can further establish the viability and optimize the use of banana fibre reinforcement in sustainable geotechnical engineering practices.

References

1. Ahmad, F.; Bateni, F.; Azmi, M. Performance evaluation of silty sand reinforced with fibres. Geotext. Geomembr. 2010, 28, 93-99.
2. Anggraini, V.; Asadi, A.; Huat, B.B.; Nahazanan, H. Effects of coir fibers on tensile and compressive strength of lime treated soft soil. Measurement 2015, 59, 372-381.

3. ASTM D2166 / D2166M-16, Standard Test Method for Unconfined Compressive Strength of Cohesive Soil, ASTM International, West Conshohocken, PA, 2016.
4. ASTM D3080 / D3080M-11, Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions, ASTM International, West Conshohocken, PA, 2011.
5. ASTM D4318-17e1, Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils, ASTM International, West Conshohocken, PA, 2017.
6. ASTM D698-12e2, Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort, ASTM International, West Conshohocken, PA, 2012.
7. Babu, G.L.S.; Vasudevan, A.K. Strength and Stiffness Response of Coir Fiber-Reinforced Tropical Soil. J. Mater. Civ. Eng. 2008, 20, 571-577.
8. Cai, Y.; Shi, B.; Ng, C.W.W.; Tang, C. Effect of polypropylene fibre and lime admixture on engineering properties of clayey soil. Eng. Geol. 2006, 87, 230-240.
9. Chauhan, M.S.; Mittal, S.; Mohanty, B. Performance evaluation of silty sand subgrade reinforced with fly ash and fibre. Geotext. Geomembr. 2008, 26, 429-435.
10. Chegenizadeh, A.; Nikraz, H. Investigation on compaction characteristics of reinforced soil. Adv. Mater. Sci. Eng. 2012, 2012, 1-7.
11. Consoli, N.C.; Montardo, J.P.; Prietto, P.D.M.; Pasa, G.S. Engineering behavior of a sand reinforced with plastic waste. J. Geotech. Geoenviron. Eng. 2002, 128, 462-472.
12. Diambra, A.; Ibraim, E.; Wood, D.M.; Russell, A.R. Fibre reinforced sands: Experiments and modelling. Geotext. Geomembr. 2010, 28, 238-250.
13. Estabragh, A.R.; Bordbar, A.T.; Javadi, A.A. Mechanical behavior of a clay soil reinforced with nylon fibers. Geotech. Geol. Eng. 2011, 29, 899-908.
14. Freitag, D.R. Soil randomly reinforced with fibers. J. Geotech. Eng. 1986, 112, 823-826.
15. Ghavami, K.; Toledo Filho, R.D.; Barbosa, N.P. Behaviour of composite soil reinforced with natural fibres. Cem. Concr. Compos. 1999, 21, 39-48.
16. Hejazi, S.M.; Sheikhzadeh, M.; Abtahi, S.M.; Zadhoush, A. A simple review of soil reinforcement by using natural and synthetic fibers. Constr. Build. Mater. 2012, 30, 100-116.
17. Kumar, A.; Walia, B.S.; Bajaj, A. Influence of fly ash, lime, and polyester fibers on compaction and strength properties of expansive soil. J. Mater. Civ. Eng. 2007, 19, 242-248.
18. Li, C.; Zornberg, J.G. Mobilization of reinforcement forces in fiber-reinforced soil. J. Geotech. Geoenviron. Eng. 2013, 139, 107-115.
19. Lekha, K.R.; Kavitha, V. Coir geotextile reinforced clay dykes for drainage of low-lying areas. Geotext. Geomembr. 2006, 24, 38-51.
20. Maliakal, T.; Thiyyakkandi, S. Influence of randomly distributed coir fibers on shear strength of clay. Geotech. Geol. Eng. 2013, 31, 425-433.
21. Marandi, S.M.; Bagheripour, M.H.; Rahgozar, R.; Zare, H. Strength and ductility of randomly distributed palm fibers reinforced silty-sand soils. Am. J. Appl. Sci. 2008, 5, 209-220.
22. Mirzababaei, M.; Miraftab, M.; Mohamed, M.; McMahon, P. Impact of carpet waste fibre addition on swelling properties of compacted clays. Geotech. Geol. Eng. 2013, 31, 173-182.
23. Moghal, A.A.B.; Vyasa, V.K.; Dhatrak, A.I. Improvement in CBR Value of Soil Reinforced with Jute Fiber. Int. J. Innov. Res. Sci. Eng. Technol. 2016, 5, 3-6.
24. Muntohar, A.S.; Widianti, A.; Hartono, E.; Diana, W. Engineering properties of silty soil stabilized with lime and rice husk ash and reinforced with waste plastic fiber. J. Mater. Civ. Eng. 2013, 25, 1260-1270.
25. Muthukumar, M.; Rajkumar, R. Influence of random inclusion of sisal fibres on strength behaviour of soil. Int. J. Eng. Res. Dev. 2014, 10, 38-44.
26. Prabakar, J.; Sridhar, R.S. Effect of random inclusion of sisal fibre on strength behaviour of soil. Constr. Build. Mater. 2002, 16, 123-131.
27. Qu, J.; Li, C.; Liu, B. Mechanical properties of soil reinforced with hybrid fibers. Constr. Build. Mater. 2019, 203, 13-21.
28. Ramesh, H.N.; Krishna, K.V.; Mamatha, H.V. Compaction and strength behavior of lime-coir fiber treated Black Cotton soil. Geomech. Eng. 2010, 2, 19-28.
29. Rao, G.V.; Dutta, R.K.; Damarashetty, U. Strength characteristics of sand reinforced with coir fibers and coir geotextiles. Electron. J. Geotech. Eng. 2005, 10, 1-12.
30. Sadek, S.; Najjar, S.S.; Freiha, F. Shear strength of fiber-reinforced sands. J. Geotech. Geoenviron. Eng. 2010, 136, 490-499.
31. Saha, P.; Roy, D.K.; Manna, S.; Adhikari, B.; Sen, R.; Roy, S. Durability of transesterified jute geotextiles. Geotext. Geomembr. 2015, 43, 425-433.
32. Santoni, R.L.; Tingle, J.S.; Webster, S.L. Engineering properties of sand-fiber mixtures for road construction. J. Geotech. Geoenviron. Eng. 2001, 127, 258-268.
33. Satya Narayan, P.V.; Kumar, P.M.; Dutta, R.K. Improvement in tensile strength of sandy soil through waste fiber reinforcement. J. Inst. Eng. India Ser. A 2018, 99, 93-97.
34. Shahnazari, H.; Ghiassian, H.; Noorzad, A. Shear strength characteristics of sand-geotextile reinforced with natural and synthetic fibers. Geotext. Geomembr. 2009, 27, 256-262.

35. Singh, H.P.; Bagra, M. Improvement in CBR value of soil reinforced with jute fiber. Int. J. Innov. Res. Sci. Eng. Technol. 2013, 2, 3447-3452.
36. Tang, C.; Shi, B.; Gao, W.; Chen, F.; Cai, Y. Strength and mechanical behavior of short polypropylene fiber reinforced and cement stabilized clayey soil. Geotext. Geomembr. 2007, 25, 194-202.
37. Tingle, J.S.; Santoni, R.L.; Webster, S.L. Full-scale field tests of discrete fiber-reinforced sand. J. Transp. Eng. 2002, 128, 9-16.
38. Viswanadham, B.V.S.; Phanikumar, B.R.; Mukherjee, R.V. Swelling behaviour of a geofiber-reinforced expansive soil. Geotext. Geomembr. 2009, 27, 73-76.
39. Yetimoglu, T.; Salbas, O. A study on shear strength of sands reinforced with randomly distributed discrete fibers. Geotext. Geomembr. 2003, 21, 103-110.
40. Zornberg, J.G. Discrete framework for limit equilibrium analysis of fibre-reinforced soil. Géotechnique 2002, 52, 593-604.