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Original Article

Exploring the Potential of Cement-Stabilized Fiber Reinforced Soil in Slope Stability

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Abstract - *Landslides pose a significant challenge in the northeastern states of India, particularly in Arunachal Pradesh, due to the region's steep topography and heavy monsoon rainfall. This study explores the stabilization of soils of a slope at Bage Tinali, Itanagar of Arunachal Pradesh, using cement as an additive and Polypropylene fiber as reinforcement to enhance the strength and stability. The research emphasizes replacing traditional sand and coarse aggregates with locally available silty soil of a slope to enhance its strength, which proves to be an innovative and cost-effective solution for stabilising the natural soils of a slope. Comprehensive laboratory experiments were performed to evaluate critical parameters, including Maximum Dry Density (MDD), Optimum Moisture Content (OMC), Unconfined Compressive Strength (UCS) and water absorption of the stabilised soil. The results show that incorporating 20% cement and 1.25% polypropylene fiber increases UCS by approximately 1829.48% compared to untreated soil. Additionally, the proposed mixture exhibited notable improvements in MDD and OMC, confirming its effectiveness for slope stabilization in hilly terrains. Economic analysis highlights the cost-efficiency of this method compared to conventional shotcrete techniques. This study offers a sustainable and economical solution for mitigating landslides, contributing to the resilience of critical infrastructure in the region.*

Keywords - *Slope stabilization, Compressive strength, Soil improvement, Polypropylene fibers, Soil stabilization.*

1. Introduction

Landslides or slope failures are significant natural disasters that cause extensive damage to engineering projects and structures, such as roads, earth dams, buildings, embankments, and retaining walls. The northeastern states of India, located near the Himalayan range, are particularly vulnerable due to the region's topography and heavy monsoon rainfall. States like Meghalaya, Mizoram, and Arunachal Pradesh experience frequent rainfall-induced landslides in their hilly terrain, especially during the monsoon season. This research focuses on the soil of a slope at Bage Tinali, Nirjuli, Arunachal Pradesh, an area prone to severe landslide hazards, which often lead to considerable economic and environmental impacts.

Rainfall-induced landslides are among the most common types in this region. The occurrence of these types of landslides was generally due to the increase of the wetting front and the decrease in shear strength caused by the decrease in matrix pressure of the unsaturated soil matrix on the surface of the slope [1]. To address this issue, the present study investigates various methods for protecting the top layer of slopes. Soil stabilizations are very effective in changing the properties of soils according to the needs and materials used. Using soil stabilization, the upper layer of the slope can be made water-resistant using different materials such as cement, lime, etc. Hence, the water cannot reach the lower layer of soil, which could cause failure in the slope.

The shotcrete technique is one of the potential methods for improving slope stability at the site. Widely recognized for tunnel lining, shotcrete is an effective global strategy [2]. In the early 1900s, American innovators introduced specialized equipment designed to pneumatically spray a cement mixture blended with fine aggregates-a method now widely known as gunite [3].

Since the introduction of the first cement gun, significant advancements have been made in the equipment, techniques, and materials used for shotcrete application, including the adoption of robotic spray arms worldwide [3, 4]. Structural shotcrete applications often integrate steel reinforcement elements such as bars and wire mesh, available in uncoated or galvanized forms, to improve structural integrity. This approach parallels reinforcement methods employed in standard concrete construction practices, where embedded steel components strengthen the material's load-bearing capacity and longevity [5].

In architectural applications, shotcrete offers advantages over traditional concrete by enabling the creation of complex shapes [4]. However, shotcrete application results in increased aggregate rebound, necessitating a lower aggregate content compared to cast concrete [6, 7]. While cast concrete typically contains 50-60% coarse aggregate by weight, shotcrete blends include only about 30%, with further reductions due to rebound. Shotcrete mixtures generally have a higher cement content (400-450 kg/m³), and due to aggregate rebound during application, the in-situ cement content can reach 600-700 kg/m³ in dry-process shotcrete [8-10]. It is noteworthy that shotcrete involves large quantities of cement, sand, and other expansive admixtures, making it costly, particularly in low-population zones.

Additionally, the high cost of steel fibers can be prohibitive in hilly, sparsely populated areas. Furthermore, the study area is in Arunachal Pradesh, a low population density area, and these expensive slope stability techniques cannot be utilized. It was also discovered that the road just near the study area in the vicinity of Karsingsa, Arunachal Pradesh, had to be relocated because of the problems caused by the rainfall-induced slope failures, and that is why research needed to be conducted in this region to tackle similar future problems.

After conducting literature reviews, it can be observed that soil stabilization techniques are used to protect unsealed road pavements in Australia which is noteworthy [11-17]. Moreover, it is also observed that some researchers have also utilized fiber reinforced concrete to protect the backfill [18-20]. The idea behind the present study is inspired by observations obtained from these studies.

Soil stabilization emerges as a more economical alternative for slope surface stabilization. By using cement and synthetic polypropylene, this method leverages locally available materials, making it cost-effective. Literature reviews indicate soil stabilization increases unconfined compressive strength, maximum dry density, and optimum moisture content [21, 22]. Stabilized soil enhances water resistance, draining excess rainfall without compromising slope stability. The study's primary objective is to consider the economic aspects of soil stabilization and study the improvements in the strength of slope soil to utilize it as an effective and affordable approach to improving slope stability.

2. Materials and Methodology

2.1. Soil

The soil used in this study was collected from a slope at Bage Tinali, Itanagar, Arunachal Pradesh. It was stabilized with various cement and polypropylene fiber combinations to enhance its index and engineering properties. This slope soil was used as a replacement for sand in shotcrete mixtures, potentially providing a more homogeneous mixture while reducing the costs associated with sand. Moreover, the soil from slopes in Arunachal Pradesh contains abundant gravel particles, which can fulfil the coarse aggregate requirements in a shotcrete mixture. This composition may improve strength through enhanced cohesion in the fiber-reinforced soil-cement mixture. Additionally, the slope soil is silty in nature, with low optimum moisture content and low liquid and plastic limits. The properties of the soil used in the study are presented in Table 1.

Table 1. Physical properties of soil

Properties	Slope Soil
Plastic Limit (%)	18.15
Liquid Limit (%)	22.5
Specific Gravity	2.46
Maximum Dry Density (gm/cc)	1.72
Optimum Moisture Content (%)	14.14
Soil Classification	ML or OL
Unconfined Compressive Strength (Kg/cm2)	3.46

2.2. Cement

The cement used in this study is Ordinary Portland Cement (OPC) of grade 43 as per IS 269-2015. The properties of the OPC are presented in Table 2.

Table 2. Physical properties of OPC cement (Grade 43) (According to IS-269-2015)

Parameter	Value
Fineness (m^2/kg)	225
Soundness (Maximum)	10
Setting Time	
Initial (minutes)	30
Final (minutes)	600
Compressive Strength (N/mm^2)	
7 days	33
28 days	43

2.3. Fiber

In this study, Polypropylene Fiber (PPF) is used to reinforce the soil-cement mixture. Polypropylene fiber was chosen because it is synthetic, making it more durable and resistant to decay. Moreover, it has high tensile strength. The properties of the PPF are presented in Table 3.

Table 3. Physical properties of polypropylene fiber

Parameter	Value
Diameter (mm)	0.01-0.015
Density (g/cm^3)	0.9-0.91
Length (mm)	15
Young’s Modulus (GPa)	2-40
Tensile Strength (MPa/g.cm^{-3})	550-700
Breaking Tensile Strength (MPa)	525

2.4. Mixed Design

To achieve consistent material dispersion, soil from the site was first collected and oven-dried for 24 hours at 105°C. It was then hand-mixed with Portland cement as uniformly as possible. Subsequently, polypropylene fibers were added to the mixture. Water was then blended into the mixture in the proportions shown in Table 4, based on the respective Optimum Moisture Content (OMC) obtained from the Standard Proctor test for each combination. The overall mixtures were incrementally introduced over 15 minutes at a temperature of 20°C. The samples for Unconfined Compressive strength tests were prepared at Maximum Dry Density (MDD) of a corresponding combination. These combinations were selected based on observations noted from literature reviews in which various researchers conducted experimental studies on similar soil stabilization techniques [23-31].

Table 4. Combination of cement and fiber was used for the research

Mix Code	Cement Content (%)	Polypropylene Fiber (%)
C-0-P-0	7.5	0
C-7.5-P-0.5	7.5	0.5
C-7.5-P-0.75	7.5	0.75
C-7.5-P-1	7.5	1
C-7.5-P-1.25	7.5	1.25
C-7.5-P-1.5	7.5	1.5
C-10-P-0	10	0
C-10-P-0.5	10	0.5
C-10-P-0.75	10	0.75
C-10-P-1	10	1
C-10-P-1.25	10	1.25
C-10-P-1.5	10	1.5
C-12.5-P-0	12.5	0
C-12.5-P-0.5	12.5	0.5
C-12.5-P-0.75	12.5	0.75
C-12.5-P-1	12.5	1
C-12.5-P-1.25	12.5	1.25
C-12.5-P-1.5	12.5	1.5
C-15-P-0	15	0
C-15-P-0.5	15	0.5
C-15-P-0.75	15	0.75
C-15-P-1	15	1
C-15-P-1.25	15	1.25
C-15-P-1.5	15	1.5
C-17.5-P-0	17.5	0
C-17.5-P-0.5	17.5	0.5
C-17.5-P-0.75	17.5	0.75
C-17.5-P-1	17.5	1
C-17.5-P-1.25	17.5	1.25
C-17.5-P-1.5	17.5	1.5
C-20-P-0	20	0
C-20-P-0.5	20	0.5
C-20-P-0.75	20	0.75
C-20-P-1	20	1
C-20-P-1.25	**20**	**1.25**
C-20-P-1.5	20	1.5

C - Cement, P-Polypropylene Fiber

2.5. Objectives of the Study

This study explores critical aspects of various materials used in prior research, focusing on cost analysis, maximum dry density, optimum moisture content, and unconfined compressive strength. The parameters listed below are analyzed across various materials and then compared to different mixtures proposed in this study.

2.5.1. Maximum Dry Density

This parameter reveals how tightly a material can be compacted in its dry form, offering critical insight into its compaction behavior. It plays a pivotal role in projects like road building, embankment construction, and foundation work.

2.5.2. Optimum Moisture Content

This is the precise amount of water needed for a material to reach its highest possible density. Since moisture affects a material's stability, strength, and compactness, our research examines how various substances perform under different moisture conditions.

2.5.3. Unconfined Compressive Strength

It can be defined as a key property that measures a material's ability to endure vertical loads without lateral support. It is essential to assess whether a material is suitable for geotechnical and structural engineering. The present study investigates how different materials and their mixtures perform in this regard.

2.5.4. Evaluation Against Proposed Mixtures

One of the main goals of the research is to compare the properties-namely, maximum dry density, optimum moisture content, and unconfined compressive strength-of the materials tested with those of the mixtures formulated.

This comparison aims to evaluate the performance of our proposed mixtures against similar materials found in other studies.

2.5.5. Economic Feasibility

Besides technical properties, our analysis includes a cost assessment to determine the economic viability of using these materials in construction projects.

This financial perspective is crucial for making well-informed decisions in the planning and executing such projects.

3. Results and Analysis

The following laboratory tests are conducted to determine key parameters:

1. Unconfined Compressive Strength tests
2. Laboratory Light Compaction tests
3. Water Absorption Tests
4. Cost Analysis

3.1. Unconfined Compressive Strength (UCS)

Laboratory unconfined compression strength tests were conducted after 28 days of curing each sample of all combinations to find the values of UCS, and the results were recorded and represented in Table 5.

Table 5. Unconfined compressive strength (kg/cm2) for various combinations of mixes

Cement Content (%)	**PPF Content (%)**					
	0	**0.5**	**0.75**	**1**	**1.25**	**1.5**
0	3.46	7.02	7.70	8.48	9.25	8.76
5	20.62	28.99	33.91	36.87	44.84	39.65
7.5	23.95	30.76	35.73	40.54	46.5	41.6
10	26.72	32.54	38.18	43.86	48.64	44.86
12.5	30.34	34.65	42.58	47.72	52.34	48.75
15	35.67	37.82	45.92	53.16	56.5	54.12
17.5	39.36	41.38	50.75	58.145	61.42	60.25
20	46.12	48.76	56.15	63.48	66.76	64.25

The recorded data indicate that compressive strength increases with fiber content up to 1.25 %, after which a slight decrease is observed at 1.5 % fiber content. This reduction occurs due to excessive fiber content, which reduces the mixture's compatibility with the soil. Additionally, the increased fiber content introduces heterogeneity, diminishing the cohesive properties of the mixture.

The data also show that compressive strength increases with cement content, regardless of the amount used. However, the high cost of cement makes using large quantities financially challenging, especially for applications like shotcrete. To address this, the study limits cement usage to 20 % and replaces sand with soil from the slope. This approach reduces costs and promotes a more homogeneous mixture, enhancing slope stability.

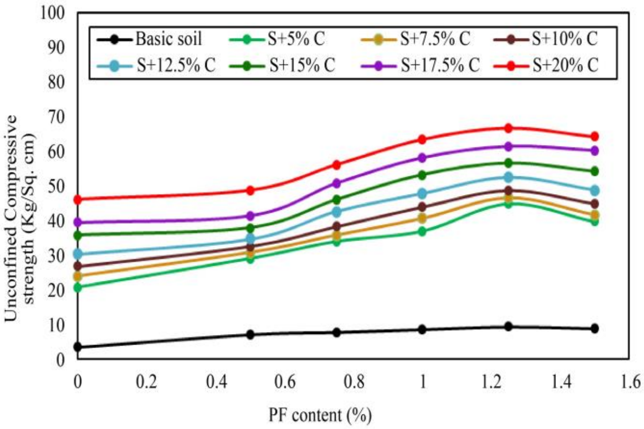

Fig. 1 Unconfined Compressive Strength (UCS) for various combinations

Considering both factors, the proposed mixture emerges as a suitable, cost-effective alternative to shotcrete. The compressive strength of each combination corresponding to different cement content is plotted for comparison and analysis. Figure 1 represents the variation of Unconfined Compressive Strength (UCS) for different combinations used in the study. The results show that unconfined compressive strength increases with higher cement content, reaching a maximum when the soil is mixed with 20 % cement and 1.25 % Polypropylene Fiber (PPF). Beyond 1.5 % PPF content, unconfined compressive strength starts decreasing. Notably, the mixture with the composition coded as S+20% C + 1.25 %PPF exhibits an unconfined compressive strength increase of approximately 1829.48% compared to the basic slope soil.

3.2. Laboratory Light Compaction Tests

The study examines the maximum dry density of the mixes, a key parameter for understanding their compaction characteristics. Maximum dry density provides insight into how densely a material can be packed in its moist state, which is essential for applications such as road construction, embankments, and foundations.

Table 6. MDD for various combinations mentioned earlier

Cement Content (%)	**PPF Content (%)**					
	0	**0.5**	**0.75**	**1**	**1.25**	**1.5**
0	1.72	1.74	1.752	1.76	1.8	1.69
5	1.75	1.86	1.88	1.915	1.944	1.84
7.5	1.765	1.88	1.899	1.93	1.963	1.86
10	1.784	1.90	1.926	1.95	1.978	1.88
12.5	1.815	1.93	1.95	1.97	1.997	1.91
15	1.837	1.96	1.973	1.988	2.02	1.93
17.5	1.859	1.98	1.999	2.016	2.04	1.95
20	1.892	2.01	2.0195	2.034	2.058	1.97

After plotting the compaction-tested data for different combinations of fiber-reinforced cement-soil mixes (described in Table 6), as shown in Figure 2, it can be observed that for the soil-polypropylene fiber mix, the Maximum Dry Density (MDD) initially decreases when the fiber content reaches 0.5 %. This may occur because the introduction of the fiber reduces the overall weight of the mixture, leading to a decrease in MDD. However, as fiber content increases to 1%, the MDD rises, likely due to the fibers absorbing water, increasing the weight and MDD. Beyond this point, further increases in fiber content led to a decrease in MDD.

In the case of the cement-soil-polypropylene fiber mix, the MDD also initially decreases when the cement content reaches 0.5% for all combinations of the soil-fiber mix. However, with subsequent increases in cement content, the MDD continues to rise. This trend may result from the initial increase in cement content, causing the mixture to lose weight. In contrast, the additional water absorbed by the mixture with increased cement content leads to an overall increase in weight, thus raising the MDD.

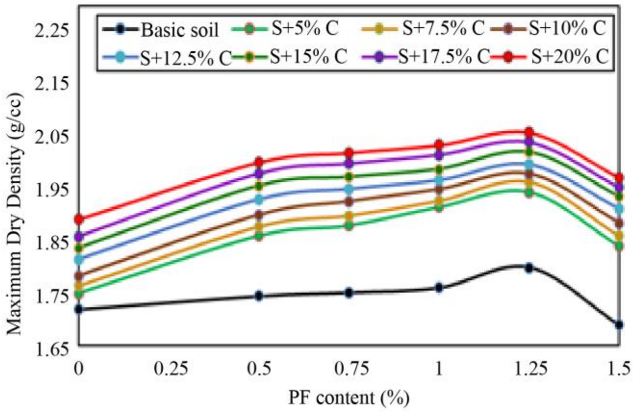

Fig. 2 Maximum dry density for various combinations

The increase in Maximum Dry Density (MDD) is also observed with higher fiber content. As the amount of fiber increases, it absorbs excess water along with the soil and cement mixture, resulting in an increase in the weight of the fiber-reinforced cement-soil mix. Consequently, it can be concluded that the maximum MDD of the mixture with the code S + 20 % C +1.5 % PPF shows an increase of approximately 15.91 % compared to the basic slope soil. The moisture level at which a material achieves its maximum density is referred to as Optimum Moisture Content (OMC). This is one of the crucial factors essential for the compaction of materials and can considerably influence the stability and strength of numerous structures. The present study explores how different materials respond to varying moisture content and its effect on compaction.

Table 7. OMC for various combinations of cement and PPF

Cement Content (%)	PPF Content (%)					
	0	0.5	0.75	1	1.25	1.5
0	14.14	14.48	15.025	15.8	16.28	17.12
5	16.32	16.67	16.87	17.01	17.2	17.57
7.5	16.48	16.96	17.16	17.28	17.38	17.81
10	16.59	17.06	17.27	17.45	17.57	18.05
12.5	16.76	17.18	17.315	17.56	17.68	18.18
15	16.92	17.3	17.56	17.71	17.8	18.32
17.5	17.2	17.58	17.78	17.99	18.2	18.76
20	17.62	18.08	18.3	18.41	18.53	18.92

After plotting the tested data for different combinations of fiber-reinforced cement-soil mixes (described in Table 7), as shown in Figure 3, it can be observed that the Optimum Moisture Content (OMC) increases with higher cement content. This trend occurs because an increase in cement content enhances the water absorption tendency of the soil, leading to a rise in MDD.

The rise in Optimum Moisture Content (OMC) is also observed with higher fiber content. As the amount of fiber increases, the soil mix's tendency to absorb excess water also rises, which, in turn, contributes to an increase in the MDD of the fiber-reinforced cement-soil mix.

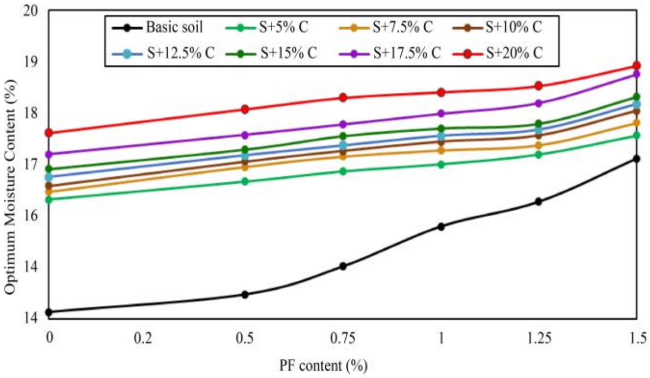

Fig. 3 Optimum Moisture Content for various combinations

Hence, from the observations, it can be concluded that the maximum Optimum Moisture Content (OMC) of the mixture with the code S+20%C+1.5%PPF shows an increase of approximately 33.81% compared to the basic slope soil. Additionally, to better understand the improvement of the UCS and MDD values and find the optimum combination of fiber reinforcement, a Bar Chart is prepared for these parameters corresponding to 20 percentage of cement content, which is shown in Figure 4. It is clear from the figure that optimum values of UCS and MDD are achieved for the mixed code S+20%C+1.25%PPF (in the Figure, Bar Chart corresponding to C-20-P-1.25) with 20% cement content.

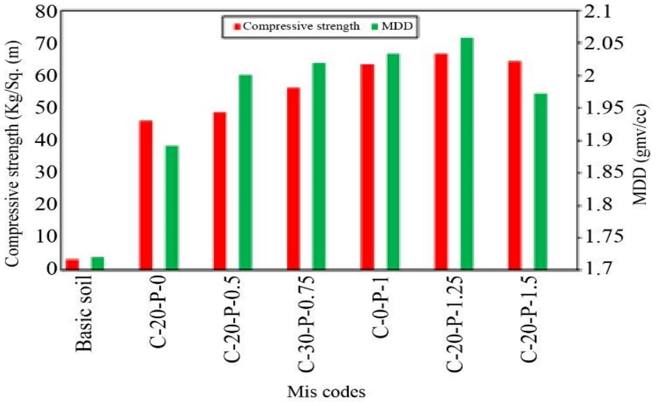

Fig. 4 Bar chart showing the improvements of UCS and MDD at 20% cement content

3.3. Water Absorption Tests

A water absorption test is a common procedure to assess a material's absorption ability. This test is crucial in various industries, including construction, engineering, and materials science, as it provides valuable insights into a material's porosity, permeability, and durability. It is typically conducted on concrete, bricks, ceramics, and other porous substances. All samples observed an increase of approximately 12% to 18% in water absorption. While water absorption above 10% is generally considered high, it is not significantly greater than the soil's Optimum Moisture Content (OMC). As a result, the soil beneath the stabilized layer can absorb water without experiencing a substantial loss in strength. Furthermore, stabilizing the top layer of the slope improves drainage during rainfall, reducing water absorption by preventing stagnant water.

3.4. Cost Analysis

To investigate the economic aspects of the study, the cost of materials, starting with common components such as cement, coarse aggregates, and fine aggregates, are analyzed. The amount of cement used in this study ranges from 5% to 20%, which is significantly lower than that typically used in shotcrete, where cement content often exceeds 50%. In this study, the fine aggregates are made of free soil from the slope, while the sand used in shotcrete can be costly depending on where it is utilized. Sand can be utilized as a replacement for slope soil if it is freely accessible. Coarse aggregates are excluded from this study, as the focus is on evaluating the compressive strength of fiber-reinforced cement-stabilized soil, which requires sieving out gravel particles from the soil sample. However, in field applications, soil stabilization involves using a larger sieve, allowing coarse aggregates like gravel to remain in the mixture at no additional cost. In contrast, coarse aggregates used in shotcrete, such as stone dust, stone particles, and crushed bricks, are typically more expensive.

In this study, the amount of fiber used is minimal and lightweight, ensuring it does not compromise slope stability. Additionally, the synthetic fiber selected offers excellent durability. In comparison, fibers commonly used in shotcrete, such as steel fibers, are heavier, and more expensive, and their weight can negatively impact slope stability. Moreover, steel fibers were excluded from this study due to their susceptibility to rust. Other additives, such as accelerators, superplasticizers, water reducers, air-entraining agents, and blended aggregates, are often expensive and not easily accessible. In conclusion, fiber-reinforced cement-stabilized soil is much more economical compared to shotcrete.

4. Conclusion

This study highlights the feasibility of using fiber-reinforced soil-cement mixtures as an innovative and effective solution for slope stabilization in landslide-prone areas. The proposed method addresses the economic, logistical, and environmental challenges associated with traditional shotcrete applications by utilising locally available silty soil and incorporating cost-efficient polypropylene fibres. Laboratory tests reveal that a mixture containing 20% cement and 1.25% polypropylene fiber optimally enhances unconfined compressive strength, maximum dry density, and moisture retention, significantly improving slope stability. Furthermore, the approach minimizes material costs and environmental impact by reducing dependency on conventional sand and coarse aggregates. The findings support using this approach as a practical, low-cost alternative for slope stabilization in hilly terrains, offering significant implications for infrastructure development and disaster risk reduction in northeastern India.

4.1. Recommendations

It is recommended that practitioners consider using larger amounts of cement to enhance compressive strength and maximum dry density if needed, for problematic slope soils, such as expansive or organic soils, sand or other suitable materials from external sources can be used as alternatives, as demonstrated in this study.

4.2. Future Scope

The future of the use of soil stabilization techniques in shotcrete technology holds immense potential for advancements in construction and infrastructure development. One key area of focus is improving material properties by incorporating advanced admixtures and fiber reinforcements to enhance durability, strength, and resistance to cracking. Additionally, sustainability efforts can drive innovation by integrating recycled materials and alternative cementitious components to reduce the environmental footprint. Optimizing application techniques can also minimize material waste and energy consumption, making shotcrete an eco-friendly solution. Automation and robotics are set to play a crucial role in refining shotcrete application processes and improving precision, efficiency, and safety, especially in complex environments like heavy rainfall-prone areas, earthquake-prone areas, etc. Incorporating artificial intelligence and machine learning can facilitate real-time monitoring and predictive maintenance, further ensuring quality control. Additionally, exploring shotcrete’s potential in emerging construction techniques, such as 3D printing, can lead to faster and more cost-effective building solutions. Expanding its use in unconventional environments, such as underwater structures or even extraterrestrial habitats, could open up new possibilities for its application. Advancements in testing and quality assurance methods, such as Non-Destructive Testing (NDT) and digital twin simulations, can help evaluate soil stabilization techniques for slope stability and enhance long-term reliability. Furthermore, establishing updated global standards and industry-specific guidelines can ensure consistency and reliability. With ongoing research and collaboration, the use of soil stabilization techniques as an economical replacement for shotcrete is poised to evolve, offering new solutions for sustainable and high-performance construction.

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References

[1] H. Rahardjo et al., *The Effect of Antecedent Rainfall on Slope Stability*, Unsaturated Soil Concepts and Their Application in Geotechnical Practice, Springer Netherlands, pp. 371-399, 2001. [CrossRef] [Google Scholar] [Publisher Link]

[2] E. Stefan Bernard, "Design of Fibre Reinforced Shotcrete Linings with Macro-Synthetic Fibres," *Proceedings Shotcrete for Underground Support XI*, Davos, Switzerland, pp. 1-10, 2009. [Google Scholar] [Publisher Link]

[3] George D. Yoggy, "The History of Shotcrete," *Shotcrete (American Shotcrete Association)*, pp. 26-32, 2005. [Google Scholar] [Publisher Link]

[4] Lihe (John) Zhang, Is Shotcrete Sustainable?," *Shotcrete*, pp. 20-26, 2010. [Google Scholar] [Publisher Link]

[5] J. Warner, "History of Shotcrete in Seismic Retrofit in California," *Shotcrete*, vol. 11, no. 4, pp. 14-17, 2004. [Google Scholar]

[6] Gang Pan et al., "A Study of the Effect of Rheological Properties of Fresh Concrete on Shotcrete-Rebound based on Different Additive Components," *Construction and Building Materials*, vol. 224, pp. 1069-1080, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[7] D.R. Morgan, N. McAskill, and J. Neill, "Evaluation of Shotcretes," *Proceedings of CANMET/ACI Workshop on Condensed Silica Fume in Concretes*, Montreal, Canada, 1987. [Google Scholar]

[8] Hugo Sogayar Armelin, "*Rebound and Toughening Mechanisms in Steel Fiber Reinforced Dry-Mix Shotcrete*," Thesis, The University of British Columbia, pp. 1-262, 1997. [Google Scholar] [Publisher Link]

[9] V. Bindiganavile, and N. Banthia, "Rebound in Dry-Mix Shotcrete: Influence of Type of Mineral Admixture," *ACI Materials Journal*, vol. 97, no. 2, pp. 115-119, 2000. [CrossRef] [Google Scholar] [Publisher Link]

[10] N. Banthia, *4 - Sprayed concrete (Shotcrete)*, Developments in the Formulation and Reinforcement of Concrete, Woodhead Publishing, pp. 98-113, 2008. [CrossRef] [Google Scholar] [Publisher Link]

[11] Jermy C. Ashlock et al., "Construction of Chemically and Mechanically Stabilized Test Sections to Reduce Freeze-Thaw Damage of Granular Roads," *12th International Conference on Low-Volume Road*, Kalispell Montana, United States, pp. 58-63, 2019. [Google Scholar] [Publisher Link]

[12] Anusree Bhowmik, Brundaban Beriha, and Umesh Chandra Sahoo, "Cement-Stabilized Fly Ash for Application in Structural Layers of Low-Volume Road Pavements," *12th International Conference on Low-Volume Roads*, Kalispell Montana, United States, pp. 390-403, 2019. [Google Scholar] [Publisher Link]

[13] Romel N. Georgees et al., "Resilient Response Characterization of Pavement Foundation Materials Using a Polyacrylamide-Based Stabilizer," *Journal of Materials in Civil Engineering*, vol. 30, no. 1, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[14] D. Jones, "*Guidelines for the Selection, Specification and Application of Chemical Dust Control and Stabilization Treatments on Unpaved Roads*," Technical Report, University of California Pavement Research Center, pp. 1-146, 2017. [Google Scholar] [Publisher Link]

[15] C. Kiran, N.K. Nabeel Muhamed, and R.S. Jaya, "Mechanical Stabilization of Black Cotton Soil using Recycled Concrete Aggregates," *12th International Conference on Low-Volume Roads*, Kalispell Montana, United States, pp. 372-383, 2019. [Google Scholar] [Publisher Link]

[16] Mark L. Russell, "Stabilizing Sand Roads Using Pulp and Paper Mill Boiler Ash," *12th International Conference on Low-Volume Roads*," Kalispell Montana, United States, pp. 358-371, 2019. [Google Scholar] [Publisher Link]

[17] J. Pooni et al., "A Review on Soil Stabilisation of Unsealed Road Pavements from an Australian Perspective," *Road Materials and Pavement Design*, vol. 24, no. 4, pp. 1005-1049, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[18] Tohid Asheghi Mehmandari et al., "Flexural Properties of Fiber-Reinforced Concrete using Hybrid Recycled Steel Fibers and Manufactured Steel Fibers," *Journal of Building Engineering*, vol. 98, pp. 1-26, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[19] Yafei Hu et al., "Strength Investigation and Prediction of Superfine Tailings Cemented Paste Backfill Based on Experiments and Intelligent Methods," *Materials*, vol. 16, no. 11, pp. 1-23, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[20] Yafei Hu et al., "Development of Cemented Paste Backfill with Superfine Tailings: Fluidity, Mechanical Properties, and Microstructure Characteristics," *Materials*, vol. 16, no. 5, pp. 1-16, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[21] Talha Zafar, Mohd Asif Ansari, and Atif Husain, "Soil Stabilization by Reinforcing Natural and Synthetic Fibers - A State of the Art Review," *Materials Today: Proceedings*, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[22] Yixian Wang et al., "Behavior of Fiber-Reinforced and Lime-Stabilized Clayey Soil in Triaxial Tests," *Applied Sciences*, vol. 9, no. 5, pp. 1-15, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[23] Jitendra Singh Yadav, and Suresh Kumar Tiwari, "Effect of Inclusion of Crumb Rubber on the Unconfined Compressive Strength and Wet-Dry Durability of Cement Stabilized Clayey Soil," *Journal of Building Materials and Structures*, vol. 3, no. 2, pp. 68-84, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[24] B.V.S. Viswanadham, B.R. Phanikumar, and R.V. Mukherjee, "Effect of Polypropylene Tape Fibre Reinforcement on Swelling Behaviour of an Expansive Soil," *Geosynthetics International*, vol. 16, no. 5, pp. 393-401, 2009. [CrossRef] [Google Scholar] [Publisher Link]

[25] Chaosheng Tang et al., "Strength and Mechanical Behavior of Short Polypropylene Fiber Reinforced and Cement Stabilized Clayey Soil," *Geotextiles and Geomembranes*, vol. 25, no. 3, pp. 194-202, 2007. [CrossRef] [Google Scholar] [Publisher Link]

[26] S.P. Guleria, and R.K. Dutta, "Unconfined Compressive Strength of Fly Ash–Lime–Gypsum Composite Mixed with Treated Tire Chips," *Journal of Materials in Civil Engineering*, vol. 23, no. 8, pp. 1255-1263, 2011. [CrossRef] [Google Scholar] [Publisher Link]

[27] IS: 4332, "Methods of Test for Stabilized Soils," *Bureau of Indian Standards*, pp. 1-17, 1969. [Publisher Link]

[28] IRC: SP 89, 2010, "Guidelines for Soil and Granular Material Stabilization using Cement, Lime & Fly Ash," *Indian Roads Congress*, pp. 1-46, 2010. [Google Scholar] [Publisher Link]

[29] IS: 1498-1970, "Classification and Identification of Soils for General Engineering Purposes," *Bureau of Indian Standards*, pp. 1-28, 1970. [Google Scholar] [Publisher Link]

[30] IS: 2720 (Part 8)-1983, "Methods of Test for Soils: Determination of Water Content-Dry Density Relation using Heavy Compaction," *Bureau of Indian Standards*, pp. 1-14, 1983. [Google Scholar] [Publisher Link]

[31] IS: 2720 (Part 10): 199, "Methods of Test for Soils: Determination of Unconfined Compression Stregth," *Bureau of Indian Standards*, pp. 1-11, 1991. [Publisher Link]