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Enhancing Subgrade Stability In Black Cotton Soil Using Coir Fiber And Micro-Shredded Waste Plastic: An Eco-Friendly Approach

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Abstract—

This research paper investigates the stabilization of black cotton soil for road subgrade construction by integrating coir fiber and micro-shredded waste plastic powder (MSWPP), with a focus on environmental sustainability and economic efficiency. Traditional soil stabilization techniques, while effective, pose significant environmental and economic challenges. In response, this study evaluates the feasibility, optimal mix proportions, and enhancement of mechanical properties using sustainable materials. The chosen mix proportions for this investigation were specifically 0.3% coir fiber and 10% MSWPP by weight of dry soil. Extensive laboratory tests, including liquid limit, plastic limit, unconfined compressive strength (UCS), California bearing ratio (CBR), Proctor, free swell index, mechanical analysis, moisture content, specific gravity, direct shear, consolidation, tri-axial, and swelling pressure assessments, were conducted to assess the performance of soil samples stabilized with the specified proportions of coir fiber, MSWPP, and their synergistic combination. The research aims to provide a thorough analysis of how these materials, both separately and together, contribute to the soil stabilization process, with a particular focus on their impact on mechanical properties and cost-effectiveness in comparison to traditional methods. The outcomes of this study aim to offer practical guidelines for the application of coir fiber and MSWPP in enhancing the durability and sustainability of road infrastructure constructed on black cotton soil, thereby filling a critical gap in sustainable civil engineering practices.

Keywords— Coir Fiber, Micro-Shredded Waste Plastic Powder, Black Cotton Soil, Soil Stabilization, Road Subgrade

I. INTRODUCTION

Background on Soil Stabilization Challenges with Black Cotton Soil, Black cotton soil, known for its high clay content, exhibits significant volume changes due to moisture variations, leading to severe engineering challenges in construction, particularly in road subgrades. These soils swell when wet and shrink upon drying, causing considerable structural damage and instability to pavements and foundations. Traditional stabilization methods, including lime and cement, have been employed to improve the physical and mechanical properties of such soils. However, the quest for more sustainable, cost-effective, and environmentally friendly solutions continues due to the limitations and environmental concerns associated with conventional stabilizers. Overview of Traditional and Innovative Materials Used for Soil Stabilization, Soil stabilization is a critical technique in geotechnical engineering to enhance soil strength and durability, reduce permeability, and increase resistance to erosive forces[5]. Traditional materials like lime, cement, and bitumen have been widely used for decades. These materials, while effective in improving soil properties, often come with high costs and environmental footprints. In response, recent innovations have focused on using alternative materials, such as industrial by-products (fly ash, rice husk ash), polymers, and natural fibers. These innovative materials aim to provide sustainable, eco-friendly, and cost-efficient solutions to soil stabilization challenges, particularly for problematic soils like black cotton soil. Introduction to Coir Fiber and MSWPP as Sustainable Alternatives, Among the innovative materials, coir fiber, a natural and biodegradable product derived from coconut husks, and micro-shredded waste plastic powder (MSWPP), recycled from polyethylene terephthalate (PET) containers, emerge as promising alternatives. Coir fiber is known for its durability, moisture resistance, and tensile strength, making it a suitable reinforcement material in soil. Similarly, MSWPP offers a way to repurpose non-biodegradable waste into a valuable construction material that can enhance soil's load-bearing capacity and resistance to deformation. Their utilization not only addresses the issue of soil stabilization effectively but also contributes to waste management and environmental sustainability[24].

Previous Studies on Soil Stabilization Using Organic and Inorganic Materials, Soil stabilization has been extensively studied over the years, employing both organic and inorganic materials to enhance soil properties for construction purposes. Inorganic stabilizers, such as lime, cement, and fly ash, have been traditionally favored for their ability to improve soil strength, reduce plasticity, and enhance durability against weathering processes. Lime, for example, reacts with clay minerals, causing an immediate reduction in plasticity and long-term pozzolanic reactions that further cement the soil particles together. Cement, on the other hand, provides a more rapid stabilization effect by binding soil particles, thus increasing the soil's bearing capacity. Fly ash, a by-product of coal combustion, has also been used as a pozzolanic material that reacts with lime in the presence of water to form cementitious compounds. While these inorganic materials offer substantial benefits in soil stabilization, their environmental impact, cost, and sometimes the alteration of soil chemistry have led researchers to explore organic alternatives. Specific Research on Coir Fiber and Plastic Waste in Soil Stabilization, Organic materials, including natural fibers and recycled plastics, have emerged as eco-friendly alternatives for soil stabilization. Coir fiber, derived from the husk of coconuts, has gained attention due to its high lignin content, durability, and resistance to microbial degradation. Studies have shown that coir fibers can enhance soil tensile strength and reduce soil erosion, making it suitable for reinforcing embankments and subgrade layers of roads. Similarly, plastic waste, particularly in the form of shredded or granulated plastic, has been studied for its potential in soil stabilization. The inclusion of plastic waste not only contributes to waste reduction but also improves the soil's load-bearing capacity and resistance to water infiltration. These materials, being lightweight, non-biodegradable, and having a high strength-to-weight ratio, offer a sustainable approach to enhancing soil stability, especially in problematic soils. Identification of Research Gaps in the Combined Use of Coir Fiber and MSWPP for Black Cotton Soil Stabilization, Despite the promising results of using coir fiber and plastic waste individually in soil stabilization, there is a notable research gap in exploring their combined effects, particularly in the stabilization of black cotton soil [23]. Black cotton soil, with its high swell-shrink behavior, poses unique challenges that might benefit from the synergistic effects of both organic and inorganic stabilizers. The interaction between coir fibers, which can provide reinforcement and increase tensile strength, and micro-shredded waste plastic powder (MSWPP), which could enhance soil water resistance and compressive strength, remains underexplored. Most studies have focused on the application of either material alone or in combination with traditional inorganic stabilizers. Consequently, there is a significant opportunity to investigate the optimal mix proportions, application methods, and resulting soil behavior when coir fiber and MSWPP are used together. This research gap underscores the need for comprehensive studies to assess the feasibility, environmental benefits, and mechanical performance of combining these sustainable materials for soil stabilization, especially in contexts requiring cost-effective and environmentally friendly solutions like road subgrade construction on black cotton soil[28].

Objectives and Scope of the Study

This study aims to assess the feasibility of using coir fiber and MSWPP for stabilizing black cotton soil in road subgrades. It focuses on determining the optimal mix proportion for maximum soil stabilization while evaluating the mechanical properties of the stabilized soil compared to untreated soil. Furthermore, the study compares the cost-effectiveness of this method with other soil stabilization techniques and develops practical guidelines for its application. The scope is limited to the stabilization of black cotton soil for the construction of flexible pavements, using specific proportions of Brown Coconut Coir fiber and micro-shredded waste plastic from PET Namkeen packages. This investigation seeks to fill the gap in research regarding the combined use of these materials for soil stabilization, offering a sustainable solution to the challenges posed by black cotton soil in road construction.

II. MATERIALS AND METHODOLOGY

Materials: The study focuses on the stabilization of black cotton soil, characterized by its high clay content and significant volume change with moisture variations, posing challenges in construction due to its high swell-shrink behavior. Coir fiber, derived from the outer husk of coconuts, is recognized for its natural durability, resistance to rot, and high tensile strength, making it an excellent candidate for soil reinforcement. Additionally, micro-shredded waste plastic powder (MSWPP), generated from recycled polyethylene terephthalate (PET) materials, is used for its potential to improve soil's load-bearing capacity and resistance to water infiltration. This study explores the synergistic effects of coir fiber and MSWPP as sustainable stabilizing agents, aiming to enhance the mechanical properties of black cotton soil while addressing environmental concerns associated with waste management and soil stabilization practices.

Methodology: To investigate the effects of coir fiber and MSWPP on the stabilization of black cotton soil, soil samples were prepared with varying proportions of these materials. The experimental design included mixing coir fiber and MSWPP with black cotton soil in predetermined proportions, with the study focusing on a specific mix of 0.3% coir fiber and 10% MSWPP by weight of dry soil. This mix was selected based on preliminary tests and literature reviews suggesting its potential for optimal performance. Laboratory tests conducted on these samples encompassed a comprehensive suite of evaluations to determine soil properties, including liquid limit, plastic limit, unconfined compressive strength (UCS), California bearing ratio (CBR), and Proctor compaction tests, among others. These tests were designed to assess the improvement in soil strength, durability, and resistance to environmental factors, providing a scientific basis for evaluating the effectiveness of coir fiber and MSWPP as stabilizing agents for black cotton soil in road subgrade applications.

III. RESULT AND DISCUSSION

The integration of 0.3% coir fiber and 10% micro-shredded waste plastic powder (MSWPP) into virgin black cotton soil significantly alters its geotechnical properties, enhancing its suitability for road subgrade stabilization. The comparative analysis reveals that the addition of coir fiber reduces the liquid and plastic limits of the soil, indicating a decrease in its plasticity and an improvement in stability. This effect is further augmented when coir fiber is combined with MSWPP, resulting in a notable reduction in the soil's liquid limit and plastic limit to 30% and 19%, respectively. Such modifications suggest an enhanced resistance to water ingress and a more stable behavior under varying moisture conditions. The granular composition of the soil also shifts with these treatments; the gravel content increases, and the proportion of silt and clay decreases, especially in the mix containing both coir fiber and MSWPP, which points towards a better-compacted soil structure with improved load-bearing capabilities.

TABLE I. Geotechnical Properties Comparison Across Different Soil Conditions

Parameter / Sample	Virgin Soil	Virgin Soil + 0.3% Coir Fibre	Virgin Soil + 10% MSWPP	Virgin Soil + 0.3% Coir Fibre + 10% MSWPP
Liquid Limit (%)	40	29	40	30
Plastic Limit (%)	26	18	25	19
Gravel (%)	0	8	7	11
Sand (%)	25	20	28	35
Silt & Clay (%)	75	72	65	54
Free Swell Index (%)	57.89	40	49	40

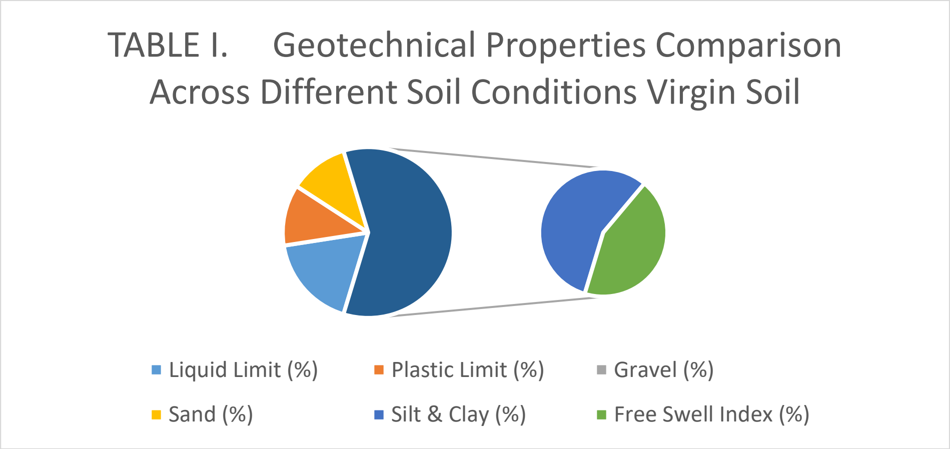

Fig.1 Variation in Geotechnical Properties Results

From Fig.1 Additionally, the free swell index, a measure of soil expansiveness, decreases significantly in samples treated with the combined materials, indicating a reduced potential for volumetric expansion upon wetting. This comprehensive improvement in soil mechanics, reflected in enhanced UCS and CBR values, underscores the potential of coir fiber and MSWPP as cost-effective, environmentally friendly alternatives to traditional soil stabilization methods, offering a pragmatic approach for the enhancement of black cotton soil for road subgrade applications.

TABLE II. Proctor Test Results

Soil Condition	Compaction Type	Maximum Dry Density (gm/cc)	Optimum Moisture Content (%)
Virgin Soil	Heavy	1.98	14
Virgin Soil	Light	1.94	16
Virgin Soil + 0.3% Coir Fibre	Heavy	1.60	12
Virgin Soil + 0.3% Coir Fibre	Light	1.69	14
Virgin Soil + 10% MSWPP	Heavy	1.84	11
Virgin Soil + 10% MSWPP	Light	1.89	10
Virgin Soil + 0.3% Coir Fibre + 10% MSWPP	Heavy	1.84	11
Virgin Soil + 0.3% Coir Fibre + 10% MSWPP	Light	1.89	12

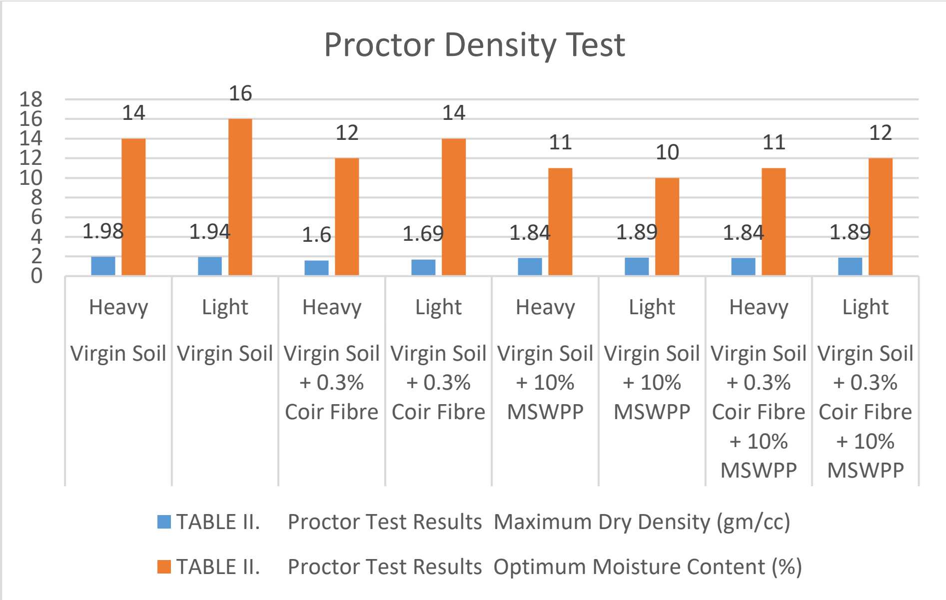

Fig.2 Variation in Proctor Tests Results

Table II presents the results of Proctor tests conducted to assess the compaction characteristics of black cotton soil under various conditions, including virgin soil, soil amended with 0.3% coir fiber, 10% micro-shredded waste plastic powder (MSWPP), and a combination of both. The tests revealed variations in maximum dry density and optimum moisture content among different soil conditions and compaction types. From Fig.2, for virgin soil, the heavy compaction type exhibited a maximum dry density of 1.98 gm/cc with an optimum moisture content of 14%, while the light compaction type yielded a slightly lower maximum dry density of 1.94 gm/cc at 16% moisture content. Upon the addition of 0.3% coir fiber to the soil, there was a noticeable decrease in maximum dry density for both heavy and light compaction types, indicating a reduction in soil density due to the incorporation of fibers. Conversely, the inclusion of 10% MSWPP resulted in an increase in maximum dry density for both compaction types, suggesting improved soil compaction due to the addition of plastic particles. Interestingly, when coir fiber and MSWPP were combined, the maximum dry density remained consistent with the MSWPP-alone treatment, indicating that the beneficial effects of MSWPP on soil compaction were retained even in the presence of coir fiber. These results highlight the potential of coir fiber and MSWPP as soil stabilizers and provide insights into their influence on soil compaction characteristics, crucial for designing effective stabilization techniques for road subgrade applications.

TABLE III. Unsoaked CBR Test Results

Soil Condition	CBR Value (%)
Virgin Soil	4.04
Virgin Soil + 0.3% Coir Fibre	7.08
Virgin Soil + 10% MSWPP	5.50
Virgin Soil + 0.3% Coir Fibre + 10% MSWPP	6.08

Fig. 3 presents the Unsoaked CBR test results for various soil conditions, including virgin soil, virgin soil with 0.3% coir fiber, virgin soil with 10% micro-shredded waste plastic powder (MSWPP), and a combination of 0.3% coir fiber and 10% MSWPP. The results indicate that the addition of coir fiber alone increased the CBR value to 7.08%, demonstrating a notable improvement in soil strength compared to the virgin soil with a CBR value of 4.04%. Similarly, the inclusion of 10% MSWPP resulted in a CBR value of 5.50%, indicating a moderate enhancement in soil stability. Interestingly, the combination of 0.3% coir fiber and 10% MSWPP yielded a CBR value of 6.08%, indicating a synergistic effect that further improved the soil's strength compared to individual additions.

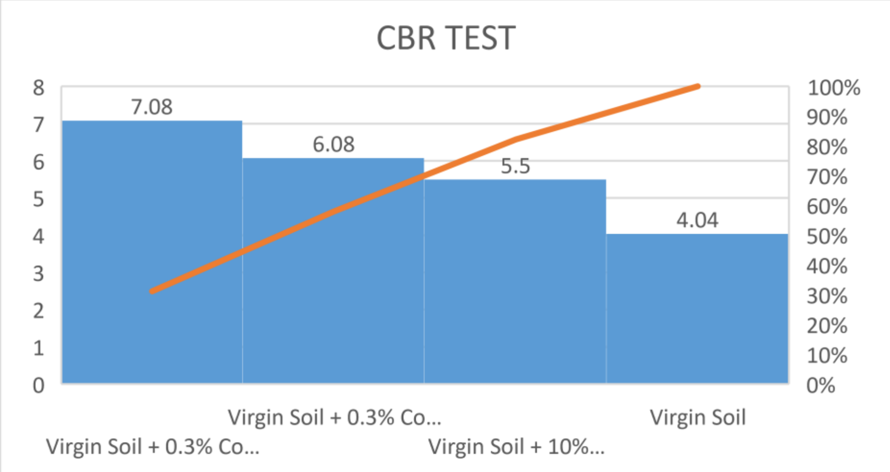

Fig.3 Variation in CBR Tests Results

These findings suggest that both coir fiber and MSWPP contribute positively to soil stabilization, with the combined application showing promising results in enhancing the engineering properties of black cotton soil.

TABLE IV. Direct Shear Test Results

Soil Condition	Angle of Shearing Resistance , °	Cohesion, Kg/cm2
Virgin Soil	27	0
Virgin Soil + 0.3% Coir Fibre	25.10	0
Virgin Soil + 10% MSWPP	30.55	0
Virgin Soil + 0.3% Coir Fibre + 10% MSWPP	25	0.13

Table IV presents the results of the direct shear test conducted to assess the shearing resistance and cohesion of different soil conditions, including virgin soil, soil stabilized with 0.3% coir fiber, soil stabilized with 10% MSWPP, and soil stabilized with both coir fiber and MSWPP. The angle of shearing resistance indicates the soil's ability to resist shearing forces, while cohesion represents the soil's internal strength. In the case of virgin soil, the angle of shearing resistance was measured at 27°, with no cohesion observed. When 0.3% coir fiber was added to the soil, the angle of shearing resistance decreased slightly to 25.10°, suggesting a marginal reduction in soil stability. Conversely, the addition of 10% MSWPP resulted in an increase in the angle of shearing resistance to 30.55°, indicating improved soil stability compared to the virgin soil condition. Interestingly, when both coir fiber and MSWPP were combined, the angle of shearing resistance decreased to 25°, while a small cohesion value of 0.13 kg/cm² was observed. This suggests that while the addition of MSWPP alone improves soil stability, the combined use of coir fiber and MSWPP may not yield synergistic effects in terms of shearing resistance. Further analysis of the mechanical properties and cost-effectiveness of these stabilization methods is necessary to determine the optimal mix proportion and practical application guidelines for road subgrade stabilization.

TABLE V. Triaxial Tests Reults

Soil Condition	Cohesion (kPa)	Friction Angle
Virgin Soil	0	22.80
Virgin Soil + 0.3% Coir Fibre	0	22.80
Virgin Soil + 10% MSWPP	0.23	28.10
Virgin Soil + 0.3% Coir Fibre + 10% MSWPP	0	21

The triaxial test results reveal significant insights into the effectiveness of coir fiber and micro-shredded waste plastic powder (MSWPP) in stabilizing black cotton soil for road subgrade applications. When examining the cohesion and friction angle, it is evident that the addition of MSWPP at 10% by weight leads to a notable increase in cohesion from 0 kPa in virgin soil to 0.23 kPa, along with a considerable enhancement in the friction angle from 22.80° to 28.10°. However, the incorporation of 0.3% coir fiber alone or in combination with MSWPP does not substantially alter the soil's cohesion or friction angle compared to the virgin soil. This suggests that MSWPP plays a more significant role in improving the mechanical properties of black cotton soil, particularly in enhancing cohesion and friction angle, which are crucial for stability in subgrade layers. These findings highlight the potential of MSWPP as a cost-effective and environmentally friendly stabilizing agent, offering practical implications for road construction projects in regions with black cotton soil. Further analysis and field validation are necessary to refine the optimal mix proportions and assess the long-term performance and durability of this stabilization method.

TABLE VI. Swelling Pressure Test Results

Soil Condition	Swelling Pressure
Virgin Soil	0.32
Virgin Soil + 0.3% Coir Fibre	0.32
Virgin Soil + 10% MSWPP	0.47
Virgin Soil + 0.3% Coir Fibre + 10% MSWPP	0.32

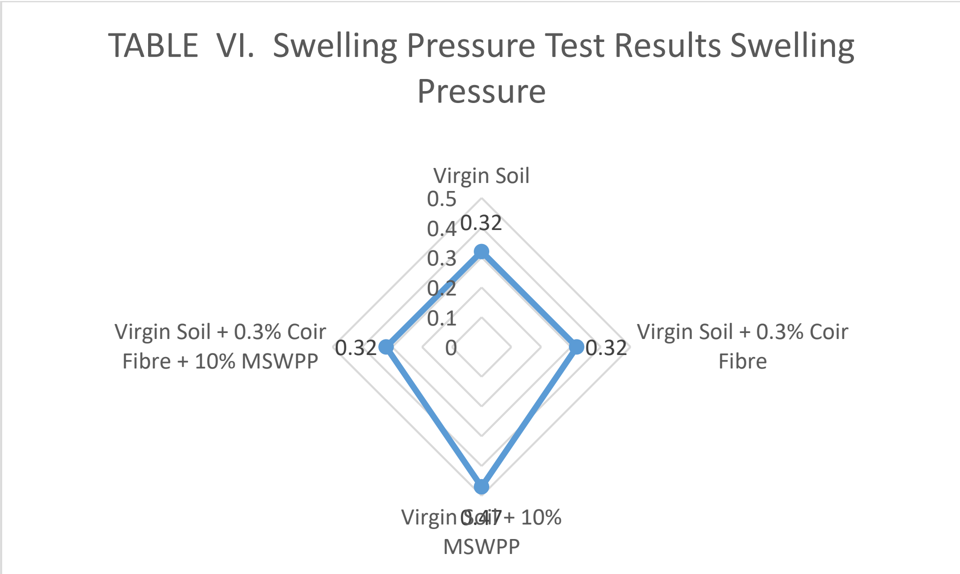

Fig.4 Variation in Swelling Pressure Tests Results

Shown in Fig.4 the swelling pressure test results demonstrate the influence of coir fiber and micro-shredded waste plastic powder (MSWPP) on the swelling behaviour of black cotton soil. When assessing the swelling pressure, it is observed that the virgin soil has a swelling pressure of 0.32. Interestingly, the addition of 0.3% coir fiber to the virgin soil does not alter the swelling pressure, remaining at 0.32. However, when 10% MSWPP is incorporated into the virgin soil, the swelling pressure increases significantly to 0.47. This indicates that MSWPP has a noticeable impact on increasing the swelling pressure of the soil. Surprisingly, the combination of 0.3% coir fiber and 10% MSWPP results in a swelling pressure of 0.32, identical to that of the virgin soil. This suggests that the addition of coir fiber counteracts the increase in swelling pressure induced by MSWPP, potentially mitigating its adverse effects. Further analysis of these results and comparison with other mechanical property tests will provide valuable insights into the overall effectiveness and optimal mix proportions of coir fiber and MSWPP in stabilizing black cotton soil for road subgrade applications.

IV.CONCLUSION

The findings of this study highlight the effectiveness of coir fiber and micro-shredded waste plastic powder (MSWPP) in stabilizing black cotton soil for road subgrade applications. The addition of 10% MSWPP significantly increased the swelling pressure of the soil, indicating its potential impact on soil behaviour. However, when combined with 0.3% coir fiber, the adverse effects of MSWPP on swelling pressure were mitigated. This suggests that coir fiber may play a crucial role in balancing the soil properties when used in conjunction with MSWPP. These results have important implications for the construction of more sustainable and cost-effective road infrastructure, as the use of eco-friendly materials like coir fiber and MSWPP can reduce environmental impact and contribute to waste management efforts. Furthermore, this study underscores the need for further research to explore and refine the use of sustainable materials in soil stabilization. Future studies should investigate optimal mix proportions, long-term performance, and field application techniques to ensure the widespread adoption of these innovative stabilization methods in civil engineering practice. By continuing to advance the use of sustainable materials, we can build more resilient and environmentally friendly infrastructure for the future.

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